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INVESTIGATING THE CAUSES OF STORMWATER DRAINS FAILURE: THE CASE OF AKAKI KALITY SUBCITY,

By

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Investigating the Causes of Stormwater Drain Failure: The Case of Akaki Kality Subcity,

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Declaration

I, under signed, declare that this thesis is my original work and that it has not been submitted partially; or in full, by any other person for an award of degree in any other university/institution.

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Approval

As a member of the Examiners board of the final Master's thesis, we have read and evaluated the thesis prepared entitled “INVESTIGATING THE MAIN CAUSES OF STORM WATER DRAINS FAILURE: THE CASE OF AKAKI KALITY, ADDIS ABABA” and recommended to the Ethiopian Institute of Architecture, Building Construction and City Development, Addis Ababa University to accept the Thesis for the Fulfillment of Requirements for the award of Degree of Masters of Science in Urban Planning.

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Abstract

Ditch, channel, river, stream, pond, and lake drainages are essentially constructions that gather, transport, and discharge runoff from the surface of road pavements and other catchment areas to artificial or natural waterways. Drainage issues might be the result of improper design, use, or construction and poor waste disposal practices. Storm runoff overflows drainage channels, spews debris, floods pavements, obstructs traffic, and causes accidents, as seen in the majority of Addis Abeba city roads. Water on the road can cause traffic jams, impair traction, raise the risk of hydroplaning, diminish vision owing to splash and spray, and make it harder to drive a car when the front wheels hit puddles. The objective of this study is to examine the reasons for and effects of drainage failure in the Akaki Kality. Drainage systems are essential for managing rainwater runoff and avoiding flooding. However, Akaki Kality has recently been plagued by substantial drainage issues, leading to flooding, property destruction, and public health problems. Thus, to address this issue, a comprehensive study conducted to recognize the primary causes of drainage failure in the area. Data was gathered using a variety of methods, including surveys, site visits, interviews, observation, and photography, and is then assembled and shaped using the SPSS analysis. Residents who live close to the research area's corridor and offices that deal directly with drainage were called and given the questionnaire. The data indicated that sedimentation, litter, and debris buildup are the main causes of drainage system failure in the study area. Residents' waste dumping into the channels, inadequate channel size, and shoddy construction work are the culprits. In order to control, direct, and monitor the design and construction of storm runoff drainages, to regularly inventory drainage assets & furniture, to draft drainage master plans, to raise awareness of solid waste disposal, to routinely clean the channels, and to upgrade existing structures, municipalities must establish a legally required and dedicated drainage department. The study's findings help us comprehend the difficulties and complexity of drainage failure in Ethiopia, with an emphasis on the Akaki Kality sub-city. The findings will give urban planners, decision-makers, and local authorities useful information for creating sustainable drainage systems that can survive the effects of climate change and increased urbanization.

Keywords: Debris, Drainage, Drainage failure, Flooding, Runoff, Waste disposal

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List of Abbreviations

AACRA	**Addis Ababa city road authority**
AHP	**Analytic hierarchy process**
GDP	**Gross domestic product**
GPS	**Global positioning system**
IHDP	**Integrated housing development program**
LID	**Low Impact Development**
NURP	**National urban runoff program**
SPSS	**Statistical package for the social science**

Chapter one: Introduction

1.1 Background of the study

The drainage system is a technique for managing excess stormwater in right-of-ways and for draining it. Drainage systems have a big impact on a pavement's ability to withstand the effects of traffic and the environment (Leta, 2020).

Stormwater is the liquid that results from precipitation events like rain and snowmelt as well as human activities like car washes, pool draining, and grass watering. By lessening the impact of urban development, stormwater management aims to preserve environmental quality and create opportunities for human usage (Aziz, 2012).

Stormwater management refers to the understanding and control of water movement during different stages of the hydrologic cycle. It involves designing effective systems to handle precipitation events and is applicable to various fields such as water supply, agriculture drainage, lake management, and flood control. The application of stormwater management techniques has successfully integrated water into urban landscapes (Aziz, 2012).

Contemporary stormwater management systems are engineered to not only prevent flooding, but also to eliminate contaminants, safeguard aquatic bodies, collect rainwater to replenish underground water sources, and prevent harm to property and wildlife habitats (Stormwater Management).

Storm water management in Addis Ababa is purely traditional, with no additional purpose than collecting and conveying storm water from source to rivers. In terms of storm water drains coverage, the system is inadequate to manage storm water within the boundary of the city (AdugnaDagnachew, 2011).

In Addis Abeba, sewage is illegally connected to local rivers and storm drainage systems as well as dumped in an open, uncontrolled manner. Public health and the appearance of the city are being impacted by the situation (Fikadu, 2018).This situation has become one of the major challenges for the city administration.

The stormwater drainage system in Addis Ababa is inadequate. Although the bulk of the city's population use on-site sanitation systems, a substantial proportion still resorts to using open areas for waste disposal. As a result of inadequate design and regular maintenance, the majority of existing sanitation facilities fail to fulfill their intended function and instead pose health hazards. The unsanitary conditions resulting from poor management and inadequate waste disposal facilities are observed to contribute to public health issues and environmental deterioration (Adam, 1999).

Over the past 20 years, Addis Abeba has undergone significant infrastructure improvements; yet, the city's drainage system has long been criticized for being inadequate and obsolete. As rainy season approaches, it's not uncommon to see the city's streets completely submerged in rainwater. The lack of properly planned drainage and sewage infrastructure is the problem's obvious symptom.

Climate change and increasing urbanization present serious issues for Akaki Kality, an Addis Ababa subcity, when it comes to stormwater management. The region currently faces problems with inadequate water quality management and infrastructure. Numerous locations where wastewater is discharged flow straight into rivers, seriously contaminating them. The absence of a thorough stormwater management system makes this problem worse, resulting in regular floods and deterioration of the water quality (Guyasa)

The current conditions of storm water management in Akaki Kality Sub City in Addis Ababa, Ethiopia, are a growing concern due to rapid urbanization and inadequate infrastructure. The area faces challenges such as flooding, erosion, and water pollution during the rainy season. Efforts are being made to improve drainage systems, implement sustainable water management practices, and raise awareness about the importance of proper storm water management.

In Akaki Kality, both structural and non-structural methods are used to manage stormwater. Enhancing the current wastewater treatment infrastructure is one of the main tactics for lowering the amounts of pollutants that enter the river. This entails modernizing and enlarging treatment facilities to accommodate the growing amount of wastewater brought on by urbanization (Angello, 2021).

Overall, Akaki Kality's stormwater management and water quality are intended to be improved by further efforts to upgrade infrastructure, adopt green solutions, and employ cutting-edge modeling techniques even though there are still many substantial hurdles to overcome. Both sustainable development and the welfare of the local community depend on effective management.

1.2 Statement of the problem

Akaki Kality's stormwater drainage infrastructure has not kept up with the city's fast urbanization, which has resulted in frequent flooding and waterlogging. The increased volume of runoff overwhelms the existing drainage systems, seriously damaging infrastructure and property. The lack of comprehensive urban planning and poor maintenance aggravate this inadequacy of infrastructure, underscoring the pressing need for efficient stormwater management systems.

The demise of Akaki Kality's stormwater drainage systems has serious consequences for the environment and public health. Local water bodies are contaminated by contaminated stormwater runoff that is full of household and industrial garbage, which lowers water quality and kills aquatic life. Furthermore, standing floodwaters serve as breeding grounds for disease-carrying vectors, raising the prevalence of waterborne illnesses in the general public. Immediate action is needed to address these problems in order to enhance drainage infrastructure and put sustainable water management techniques into place.

Significant financial costs are placed on the village of Akaki Kality by the insufficient stormwater drainage system. Homes, companies, and vital infrastructure are harmed by frequent flooding, which results in expensive repairs and financial losses. In addition, the disruption of daily routines and displacement of residents cause disarray in the community's social fabric. This circumstance calls for an integrated strategy to stormwater management that takes into account the socioeconomic effects on the impacted people in addition to the physical infrastructure.

The ways that Akaki Kality now manages its stormwater are insufficient to meet the demands of growing urbanization and climate change. Regular flooding and declining water quality are caused by improper maintenance, the inadequacy of the current drainage systems, and lax enforcement of the law. To improve resilience and sustainability, a thorough revision of the stormwater management strategy is required, encompassing both grey and green infrastructure options.

Akaki Kality's ongoing problems with rainwater drainage highlight the need for comprehensive and long-term fixes. The intricate relationships that exist between hydrological processes, climate variability, and urban development cannot be adequately addressed by traditional engineering methods alone. To create a strong and flexible stormwater management framework, non-structural strategies like green infrastructure and community involvement must be combined with structural ones like enhanced drainage networks and retention basins.

1.3 Objective of the research

1.3.1 General objective

The general objective of the study is to assess the effectiveness of current stormwater drainage failures in Akaki Kality, Addis Ababa, with the aim of developing sustainable and integrated stormwater management strategies that mitigate flooding, improve water quality, and enhance the resilience of the urban infrastructure.

1.3.2 Specific objective

I. To evaluate the state of the current drainage infrastructure.

II. To investigate the causes of stormwater failure.

III. To develop strategies to sustain stormwater drains.

1.4 Research questions

I. What is the condition of the existing storm water drainage structures in Akaki Kality sub-city?

II. What are the main reasons behind the failure of storm water drainage structures in Akaki Kality sub-city?

III. What sustainable practices can be implemented to improve the maintenance and efficiency of stormwater drainage systems?

1.5 Significance of the study

In general, this study provides the following benefits.

It will be a different approach to finding a solution for assuring sustainable growth and boosting the socio-economic and environmental functions of road and urban storm water drainage facilities. Researchers who carry out comparable studies on other road drainage structures could find it useful.

The study aims to distinguish between road pavement runoff drainage and storm runoff drainage and promotes awareness raising and proper solid waste disposal techniques. Additionally, a sizable portion of the money that would have been spent on unneeded maintenance, rework, and indemnification payments will now be diverted to new projects instead.

1.6 Scope of the study

Geographically, this study is only focused on the Akaki Kality sub city, Addis Ababa. Even though drainage issues are widespread, it is challenging to inspect every road across the entire city. As a result, the main highways that are highly affected in Akaki Kaliti Sub City are selected, and analysis of the sub-city's various drainage infrastructure is being done. The study's focus will be on issues relating to drainage systems and how they fit into the provision of roads.

1.7 Organization of the thesis

The broad and general study goals, the research question, the importance of the study, and its scope the following details were presented in the study's first chapter, which acts as an introduction.

A review of the literature was included in the second chapter, and the methodology which includes data collecting, methodologies and tools, processes, and the study area was covered in the third chapter. The fourth chapter was devoted to the analysis of the information gathered during the survey and its results, along with a discussion of the results. The study's conclusion and suggestions are covered in the fifth and final chapter. These are based on the findings of the research and a broad evaluation of the literature.

At the conclusion of the paper, appendices, references, and other pertinent writings are attached.

Chapter Two: Literature review

2.1 Introduction

Because of the interaction between human activities and the natural water cycle, drainage systems are necessary in urbanized regions. In order to provide water for human life, water must be removed from its natural cycle. This interaction also happens when land is covered in impermeable surfaces, which divert precipitation from the area's natural drainage system. Due to these two distinct interactions, two distinct types of water need to be drained (John, 2004).

These two forms of water are managed by urban drainage systems with the goal of minimizing the detrimental impacts on both the environment and human life. As a result, there are two primary places where urban drainage interacts with the environment. Urban drainage services are typically transmitted by the public rather than received by them (a practice known as "flush and forget"), which may help to explain why this essential urban utility is not well known or valued by the general public (John, 2004).

Generally speaking, an urban drainage system is a runoff collecting and transportation system that is in charge of swiftly removing storm water runoff from only metropolitan areas in order to prevent any floods (Yazdanfar, 2015). Because of the non-stationary climate and rapid urbanization, urban drainage systems typically operate poorly. As these systems deteriorate, issues such as increased urban flooding and sewer overflows, which increase the pollutant loads in receiving water bodies, are swiftly spreading (Yazdanfar, 2015).

A detailed investigation is necessary to fully comprehend these variables, which alter through time and space, become more complex when they are interwoven, and affect urban drainage. Every local area needs to create an integrated, cost-effective, and functional planning and design framework (Yazdanfar, 2015).

Urbanization and climate change problems must be addressed together, so sustainable drainage systems must be installed using well-considered adaptive methods. Urban drainage is used to preserve an environment that doesn't generally have an impact on public health. There won't be a significant epidemic disease outbreak as a result of the construction of such living conditions. Controlling environmental pollution and enhancing environmental quality is necessary for a robust ecosystem and a comfortable human habitat. It serves as a preventive measure to safeguard both the general and individual health of the community. Sewer systems should be built, operated, maintained, and repaired in a sustainable manner that uses the least amount of resources possible (Yazdanfar, 2015).

Sewers, pipes, and structures that collect and dispose of water, are the foundation of the drainage system in many urban areas. Communities without a primary drainage system are often those that are isolated or have low incomes. Storm water is naturally discharged into the earth while sewage is treated locally (or not at all). These arrangements have typically been in place when urbanization has not been as extensive (John, 2004).

Overall, urban drainage presents a typical combination of contemporary environmental concerns, including the need for technical advancements that are both economically viable and socially acceptable, the evaluation of the effects of such advancements, and the pursuit of long-term solutions. These difficulties cannot be viewed as the sole responsibility of one profession, as in all other environmental concerns. All citizens, including decision-makers in politics, engineers, and environmentalists, have a part to play. These roles must also be performed collaboratively. Both engineers and anyone attempting to influence policy need to have some awareness of the bigger picture challenges (John, 2004).

2.2 Historical development of sormwater management system

Considering how specialized and advanced in technology current engineering is, it is challenging to understand how it compares to ancient engineering. The engineering tools we take for granted today, such as design guidelines, empirical equations, physics, numerical approaches, and computer simulators, were not available to ancient engineers (Steven, 2002).

Even though contemporary engineers have a technological advantage over their forebears, incredible engineering feats on par with today's have been accomplished throughout history. For instance, many ancient civilizations built magnificent cities from stone, brick, and wood and also equipped them with modern infrastructure including roads, water supply and distribution systems, wastewater collection systems, and storm-water drainage. In addition, there have been instances where infrastructure systems have been linked, as was usually the case with wastewater collection and storm-water drainage (Steven, 2002).

People in cities and towns created drainage systems from the very beginning to get surface water out of their homes and streets. Typically, these systems consisted of an open drain in the street into which rainwater runoff from the nearby surfaces flowed (Orman, 2013).

Urban settlements have been drained for more than 5,000 years, but it has only been in the last few decades that the environmental effects of drainage and the need to mitigate those impacts have come to light. By preventing water from pooling, flooding, and draining marshes for new construction, urban drainage systems were initially constructed to enhance living conditions in metropolitan areas (Marsalek, 2005).

An ancient settlement called Mohenjo-Daro was situated on the west bank of the Indus River in the southern part of what is now Pakistan. It was constructed between 4,000 and 5,000 years ago and stood until about 1,700 BC. Archaeological digs have indicated that the city had at least 35,000 inhabitants and that the streets had baked brick drains in addition to the majority of homes having modest bathrooms (Evance, 2013).

The palace at Knossos was constructed by the Minoan civilization in Crete in the same period (1,700 BC), and it was discovered to include an elaborate water supply and drainage system, including a flushing toilet, to handle wastewater and storm water in addition to providing fresh water (Evance, 2013).

In certain British towns and cities as well as throughout the former Roman Empire, portions of Roman drainage pipelines are still in use. The 2,000+ year-old ceramic drain pipes were discovered in Ephesus, a Greco-Roman city with 500,000 inhabitants in 100 AD. It was the second-largest city in the Roman Empire and the most significant metropolis in the Eastern Mediterranean (Evance, 2013).

This brief review of the early development of urban drainage must include the city of Rome, where a sewer, the Cloaca Maxima, constructed around 600 BC, is still in use as a component of the sewer system of the modern metropolis (Evance, 2013).

Climate change and growing urbanization have made managing urban stormwater an urgent global concern, increasing the frequency and severity of flooding occurrences. This is a survey of the literature on different approaches and solutions for managing urban stormwater, with an emphasis on both novel nature-based solutions and conventional techniques.

- **Traditional Urban Stormwater Management Systems**

Conventional urban drainage systems are mainly made to collect and transport wastewater and stormwater out of cities, with the goal of controlling the amount of water present. However, because of their limited capacity and inability to adjust to the growing frequency and intensity of urban flooding brought on by urbanization and climate change, these systems frequently fail (Zhou, 2014).

- **Sustainable Urban Drainage Systems (SUDS)**

The use of Sustainable Urban Drainage Systems (SUDS) has increased in response to the drawbacks of traditional systems. With the use of SUDS, stormwater may be managed sustainably by imitating natural hydrological processes. Rain gardens, permeable pavements, and green roofs are important elements that assist lower surface runoff and enhance water quality. Moreover, SUDS improve biodiversity and urban green spaces, among other advantages (Zhou, 2014).

- **Nature-Based Solutions**

Urban stormwater management has found a potential partner in nature-based solutions. Stormwater is managed by integrating green roofs and artificial wetlands with natural processes and green infrastructure. These methods provide ecological benefits like habitat building, carbon sequestration, and recreational areas in addition to managing runoff (Su, 2023).

- **Integrated Urban Stormwater Management Systems**

In order to address stormwater management holistically, the integrated approach combines different techniques and technologies at the building and district scales. This includes integrating NBS and SUDS with conventional drainage infrastructure to create a more resilient urban environment, with the main goals being to improve water quality, enhance the urban ecosystem, and reduce rainwater runoff at the source (Su, 2023)

2.2.1 Development of modern stormwater drainage

The first contemporary urban drainage techniques appeared in nineteenth-century European communities. The Paris sewer system was created by the engineer Pierre-Emmanuel Bruneseau's initial efforts. To document the condition of the sewers, Bruneseau oversaw investigations into the underground maze. The political upheaval had a disastrous influence on the condition of the sewers, according to Bruneseau's reports to the Emperor. Attempts to clean the sewers, in his opinion, would demonstrate how superior the Empire was to both the former monarchy and the revolutionary republic (Steven, 2002).

When engineer Pierre-Emmanuel Bruneseau improved the Paris sewer system in the nineteenth century, it marked the beginning of contemporary urban drainage methods in European cities. In order to show the Empire's supremacy over earlier monarchies and revolutionary administrations, Bruneseau chronicled the state of the sewers and urged efforts to clean them. However, his work was far from finished when he passed away in 1819. The sewers were improved by H.C. Emmery, who oversaw the Paris sewer system from 1832 to 1839. He added inlets and replaced open channels with gutters. During the first half of the nineteenth century, the sewers had a reputation for being a haven for undesirables and criminals (Steven, 2002).

Improvements in pipe materials, construction techniques, maintenance routines, the decision to use water-carriage waste removal, comprehensive sewer system design, combined-versus separate-sewer systems, the discovery of waterborne diseases, the introduction of wastewater treatment, advances in urban hydrology, computer advancements, and environmental awareness were the nine categories into which the main urban drainage developments in the United States during the nineteenth and twentieth centuries were divided (Steven, 2002).

In the middle of the nineteenth century, most sewers were only intended for storm-water drainage, therefore sanitary wastes were usually dumped from buildings into cesspools and privy vaults. Sanitary connections to sewers were made lawful and new sewers were built to drain storm water and sanitary wastewater as a result of the integration of water-carriage sanitary waste collection into urban drainage systems (Steven, 2002).

Due to scientific data connecting sanitary wastes and the spread of illness, urban drainage went from being an afterthought to being seen as an essential public works system. The success of the Hamburg sewer system led to the creation of sewer systems for other cities in Europe and the United States. Municipal authorities began major initiatives to develop extensive sewer systems in larger cities in Europe and the United States (Steven, 2002).

Urban drainage design was viewed differently in the nineteenth century, shifting from a design approach to considering technical specialists' advice. The design of the Hamburg sewer system uses engineering calculations and empirical data to highlight the significance of effective drainage systems in urban environments (Steven, 2002)**.**

2.2.2. Current urban drainage system

In order to meet the problems presented by urbanization and climate change, sustainable and resilient practices are being incorporated more and more into current urban stormwater drainage systems. Modern drainage systems, which prioritize swiftly eliminating precipitation, are being augmented, and occasionally supplanted, by more comprehensive strategies emphasizing resilience and sustainability.

- **Sustainable Urban Drainage Systems (SUDS)**

The goal of SUDS is to control stormwater by imitating natural hydrological processes. This covers techniques such as rain gardens, detention basins, green roofs, and permeable pavements. In addition to lowering surface runoff and enhancing water quality, these systems also benefit the ecosystem by increasing biodiversity and creating recreational areas (Wang, 2023).

- **Low Impact Development (LID)**

By utilizing decentralized microscale controls that encourage infiltration, evapotranspiration, and the reuse of rainwater, LID aims to manage rainfall at its source. Vegetated swales, infiltration trenches, and bioretention cells are some of the methods. By using these techniques, metropolitan areas' pre-development hydrology is preserved and the strain on conventional drainage infrastructure is lessened (Chen, 2023).

2.3. Stormwater drainage in a developed countries

In developed nations, stormwater drainage systems have undergone tremendous evolution in response to the difficulties presented by urbanization and climate change. Modern technologies and environmentally friendly methods are being integrated into these systems to efficiently manage stormwater, reduce the risk of flooding, and safeguard water quality.

SUDS are intended to control rainfall at its source by imitating natural hydrological processes. They consist of a range of methods like swales, rain gardens, green roofs, and permeable pavements. By filtering contaminants, these techniques aid in lowering surface runoff, encouraging groundwater recharge, and enhancing water quality (Chen, 2023).

The integration of natural and semi-natural systems into urban environments is known as "green infrastructure." This covers the usage of artificial wetlands, urban woods, and green roofs. In addition to managing stormwater, these systems also improve air quality, increase urban biodiversity, and create recreational areas (Chen, 2023).

Developed nations are increasingly embracing integrated strategies that blend ecological practices with age-old drainage systems. The goal of this integration is to use both green (natural) and grey (sewers and pipes) infrastructure to increase the resilience of urban areas to harsh weather occurrences. This all-encompassing strategy reduces the risk of flooding, enhances the quality of the water, and has positive social and environmental effects (Chen, 2023).

To summarize, developed nations are leading the way in the development of novel stormwater management strategies that include sustainable and integrated methods to tackle the issues posed by urbanization and climate change. These initiatives enhance urban areas' overall sustainability and livability in addition to increasing stormwater systems' efficiency.

2.4. Stormwater drainage in developing countries

Stormwater drainage systems in emerging nations encounter distinct obstacles and prospects because of the swift urbanization, restricted financial means, and frequently insufficient infrastructure. In spite of these obstacles, a number of cutting-edge strategies and tactics are being used to enhance stormwater management.

Challenges

- Rapid Urbanization: Developing countries are experiencing rapid urban growth, leading to increased impervious surfaces and higher volumes of runoff. This often results in flooding, waterlogging, and strain on existing drainage systems (UN-Habitat, 2020).
- **Inadequate Infrastructure**: Many developing countries lack the necessary infrastructure for effective stormwater management. Existing drainage systems are often outdated, poorly maintained, and unable to cope with increasing runoff volumes (Sonnenberg, 2021).
- **Financial Constraints**: Limited financial resources constrain the ability to invest in new infrastructure or upgrade existing systems. This makes it difficult to implement comprehensive stormwater management strategies (Bank, 2019).
- **Environmental Degradation**: Pollution from untreated stormwater runoff can severely impact water quality and ecosystem health. In developing countries, the lack of effective waste management exacerbates this issue (Ali, 2020).

Because urban development occurs in more difficult socioeconomic, technological, and climatic conditions than in industrialized nations, urban drainage techniques in developing countries face more serious problems than those in developed nations. Developing countries see rapid urbanization due to a lack of infrastructure investment and insufficient public services for water treatment, collecting and treating waste sewage, trash collection, urban drainage, transportation, and health. Urban concentrations have a harmful impact on the environment in a number of ways, including urban flooding and soil, air, and water channel pollution. Settlements are constructed in unsuitable locations, including those that were originally intended for environmental protection, on steep hillsides, and in areas that are prone to flooding (Silveira, 2002).

Urban drainage is the section of the water infrastructure that aims to prevent harm to the environment and public health caused by rainfall in urban areas as well as interruptions to the free flow of vehicles and pedestrians. Urban drainage is the third of three fundamental buildings that cities use to manage their water resources, together with water supply facilities and sewage removal systems. Modern urban drainage in industrialized nations today places a strong emphasis on the environment, primarily with a view to enhancing storm runoff quality. On the other hand, managing the amount of storm runoff in developing nations remains the key challenge in order to prevent human fatalities and property damage (Silveira, 2002).

In developing nations, the urban poor frequently reside on marginal land since it has a lower economic value yet is the only available land that they can afford. This includes real estate that frequently floods as a result of poor drainage or that is situated on a steep hillside where landslides are frequent. The benefits of living near employment centers and urban amenities often exceed the disadvantages of floods, which are typically viewed as a normal and seasonal occurrence (Parkinson, 2002).

Flooding can occasionally have disastrous effects, especially on underprivileged people that lack the money to reconstruct their houses. However, these communities generally accept floods as a fact of life and adapt coping mechanisms to deal with the effects of inundation (Parkinson, 2002).

Urban flooding problems are more common during the rainy season, but poor drainage also has long-term effects that are directly linked to declining sanitary and environmental health conditions. Although the effects of these problems are less evident than runoff flooding, they still have a big influence on urban communities' health and way of life. In areas with poor drainage, urban runoff combines with sewage from overflowing latrines and sewers, causing pollution and a number of problems connected to an increased risk of waterborne diseases (Parkinson, 2002).

Lack of understanding of global variations in urban hydrology and rainfall distribution patterns is one of the fundamental issues with drainage system design in emerging nations. Many developing nations are located in humid tropical regions with a monsoon season that has substantially higher rainfall intensity than locations with temperate climates and concentrates the rain in a few months of the year (Parkinson, 2002).

The distribution of rainfall may be further impacted by global warming, increasing the uncertainty in the planning of drainage systems and flood predictions. Storm-water runoff from urban surfaces is influenced by hydrological elements such as surface depression storage (dips in the ground that can hold water and create puddles) and previous rainfall conditions that affect the catchment's wetness. Urban catchments in developing nations often differ physically from those in industrialized nations in a substantial way, which results in broad variances in the rainfall-runoff response and the volume of runoff and peak flows that occur (Parkinson, 2002).

In emerging nations, stormwater management is changing through a combination of conventional methods and cutting-edge approaches. Improving urban resistance to flooding and guaranteeing sustainable growth require overcoming institutional, technical, and financial obstacles. A comprehensive strategy involving community involvement, environmentally conscious solutions, low-cost technologies, and international collaboration is needed for effective stormwater management.

2.5. Urban drainage in Ethiopia's context

Currently, there is an urgent need for effective storm water management throughout the world, especially in developing nations like Ethiopia. The idea of effective storm water management is founded on the need to safeguard public welfare, safety, and welfare, conserve water, and work toward a suitable environment, among other things. Urbanization now has a negative impact on Ethiopia's unplanned cities and towns' urban drainage systems (KokebZena, 2016).

Due to improper drainage infrastructure installation and poor maintenance of existing drains, storm water in Ethiopian cities and towns generally causes floods, especially during the rainy season. The issue is particularly severe in highland cities like Addis Abeba and Adigrat, though it also exists in cities with flat & plain geographies like Assosa, Adama, Bahir Dar Woliso, and others (KokebZena, 2016).

One of the nations where flooding is a major issue is Ethiopia. An inadequate drainage system can drastically limit the service life of infrastructure. Surface water covers the highways during the rainy season, which runs from July through September. This water causes a loss in revenue by quickening the rate of road damage. Inadequate road drainage systems and a lack of connection between the road and the urban storm water drainage network are to blame for the flooding of the highways (Ewnetu, 2013).

Despite a nation's general development, notably in the road sector, the practice of building appropriate integrated drainage systems did not receive the attention it deserved in our nation. In order to take corrective actions for the improved performance of the road infrastructure, it is necessary to examine the issues and successes related to the design, construction, and maintenance of surface road drainage systems. One of the most frequent complaints from Ethiopian inhabitants is that many towns lack adequate urban storm water drainage systems, and this issue is only getting worse given the country's continuous high pace of urbanization, particularly in Addis Abeba (TameneAdugna, 2015).

Along with the pattern of urbanization and industrialization, Ethiopia has seen an expansion in the construction of urban infrastructure. All of these factors combine to intensify the raindrops, which speed up and concentrate runoff. A substantial portion of the study area is subject to flooding hazards as a result of poor management and inadequate integration of the infrastructure for road and urban storm water drainage. As a result, urban storm water drainage resources and management have degraded. The primary causes of flooding were determined to be obstructions in urban storm water drainage systems and a lack of interaction between road and urban storm water drainage infrastructures (AdugnaDagnachew, 2011).

A good drainage system is a crucial element that must be given top priority when designing highways because it considerably affects their usability and serviceability. Urban drainage issues include water logging, road deterioration, soil degradation, sedimentation, flooding of residential areas, and blockage of drainage facilities. In this regard, the essential job of diverting or removing surface water off the highway is carried out by highway hydraulic structures (Meraf, 2015).

This is particularly true in Ethiopia, where a large proportion of urban areas' watersheds receive a significant amount of annual precipitation, and where rainfall intensity is often high. Maintaining the serviceability of the highway depends on preventing flooding, managing runoff at the source, and safely removing extra water through suitable drainage infrastructure (Meraf, 2015).

The number of impermeable surfaces, such as those on homes and businesses, also rises with urbanization, and drainage patterns inevitably lead to an increase in environmental issues including land degradation. This is a serious issue for the nation's current and future transportation infrastructure (Meraf, 2015).

Ethiopian urban centers typically have fewer drainage facilities despite these real concerns. A significant number of recently constructed roadways are flooded and ruined as a result of the lack of planning and design in the construction and operation of such facilities. Due to the often severe negative impacts of poorly designed road construction and lack of integration with the master plan on the environment and socioeconomic activities, it is difficult to obtain the necessary service from a given infrastructure (Meraf, 2015).

There was no organized working organization in the field of urban storm-water drainage systems prior to the founding of the National Urban Planning Institute. Even today, attention to urban storm-water systems is still in its infancy, which is why the majority of urban storm-water drainage structures become clogged with solid waste of all kinds even after significant sums of money have been invested in them (AdugnaDagnachew, 2011).

Because urban areas were sometimes the root of the environmental problem, urban storm-water drainage systems in metropolitan regions were largely created to safely discharge storm runoff outside of urban areas. Due to the technologies employed to address flooding issues brought on by inadequate urban storm-water drainage systems, it has never been possible in Ethiopia to use flood or runoff for other purposes, such as treating or sedimenting runoff water or building detention ponds and other perforated structures to allow the water to seep into the soil (AdugnaDagnachew, 2011).

Along with the pattern of urbanization and industrialization, Ethiopia has seen an expansion in the construction of urban infrastructure. All of these factors combine to intensify the raindrops, which speeds up and concentrate runoff. A substantial portion of the study area is subject to flooding hazards as a result of poor management and inadequate integration of the infrastructure for road and urban storm water drainage. As a result, urban storm water drainage resources and management have degraded. The primary causes of flooding were determined to be obstructions in urban storm water drainage systems and a lack of interaction between road and urban storm water drainage infrastructures (AdugnaDagnachew, 2011).

In the Akakai Kality sub-city, there aren't enough drainage systems that were correctly built, and the ones that are there are blocked by various kinds of solid waste. As a result, there was a flood during the rainy season, which resulted in casualties and property damage. Additionally, the incorrect management of solid and liquid wastes has caused environmental harm (the Akaki River, for example, is highly polluted by solid and liquid wastes). Additionally, this should be fixed by developing and implementing a successful waste management system (EmebetHailemichael, 2018).

2.6. Types of drainage structures

Channels or ditches are used in surface drainage systems to remove surplus water from the ground's surface. In some cases, grading or contouring the ground surface produces a slope toward the channels. Surface drainage systems come in a variety of shapes and sizes, including open drains, levees, humps and hollows, and grassy streams (Chris, 2021).

Below the soil's surface, subsurface drainage systems are installed. They occasionally go by the name "French drains," and they work at the root level to remove extra water (Chris, 2021).

Slope drainage systems allow water to exit a building in a downward direction. To assist, pipes that go through the slope are employed. The pipe that has been installed is connected to an inclination, which guides the water through it and quickly takes it from the building.

The downspout and gutter systems of a structure serve as the first line of defense against oversaturation by storm water. Frequently, they are emptied into a rain barrel, an aluminum extension, a covert drainpipe, or some other container. Water will be rerouted to other street or sidewalk drainage systems in order to achieve the desired result. To connect them to an underground sewer system, gutter drains or "underground drains" may occasionally be employed (Chris, 2021).

Let's discuss the three types of drainage which are surface drainage, subsurface drainage, and storm water management.

Surface drainage-Surface drainage is the most common type of drainage. Water is directed away from homes and other structures using gutters, downspouts, and drains. Surface drains are frequently located around bodies of water or at the base of hills. They collect snowmelt runoff and rains and redirect it away from the land (Ashworth drainage, 2022).

Subsurface Drainage- Subsurface drainage is used to gather and remove water that has already seeped into the ground. This drainage technique is typically employed in areas with high groundwater tables or subpar soils. It can also be used to prevent excessive moisture from harming a foundation. Subsurface drains are frequently found around a property's perimeter as a component of a drainage system that transports water away from it (Ashworth drainage, 2022).

Storm water management-Storm water management is a type of drainage system used to control storm runoff. It requires employing techniques like detention ponds and infiltration basins to hold water and allow it to slowly percolate into the ground. Storm water management is typically employed in areas where there is a significant risk of flooding or rainfall (Ashworth drainage, 2022).

2.7. Causes of stormwater drainage structures failure

Systems for drainage of organic and inorganic solid wastes frequently fail transversely and longitudinally. Semi-urban (less developed urban) areas and highly urbanized areas do not share the same failure modes.

Debris comprised mostly of plastic waste, food, and vegetable wastes, especially chat wastes, is a major cause of failure in highly urbanized and business areas. Natural solid wastes including plants, tree branches (drifts), and silts with stones are the primary causes of failure in less-developed semi-urban areas (Mengistu, 2023).

In densely inhabited areas, topography has no appreciable impact in contrast to less developed regions. In developing and semi-urban areas, however, silts, tree branches, and plants greatly contribute to the failure of drainage systems. The results of our study show that the failure of drainage infrastructures will significantly affect road paving by resulting in enduring potholes, surface fractures, and other asphalt distresses. Surface flooding brought on by poor drainage also affects transportation and results in accidents (Mengistu, 2023).

It seems that the traditional sanitary solutions to urban drainage have run their course in the major cities of developing countries. Canalizing waterways has cost a lot of money, yet the issues have not been resolved. The current era is one of transition, during which the hygienic paradigm of the 19th century is being replaced with the environmental model (Silveira, 2002).

Urbanization is one of the key causes of drainage systems performing poorly. Metropolitan growth is one of the main causes of floods in metropolitan areas. This has an effect on the runoff coefficients, one of the key elements affecting how storm water drainage systems are designed. The drainage network's design criteria, such as outfall discharge, velocity, lag time, and construction costs, will be impacted by changes in the runoff coefficient (Hany F., 2020).

Both natural and man-made factors can contribute to water blockages. The natural causes also include poor drainage of the subsoil under favorable geological conditions of hard pan below the surface, sub-emergence of land under floods, and deep percolation from rainfall in addition to excessive seepage from unlined ditches and distributaries, hydraulic pressure from upper saturated areas located at higher elevations, poor maintenance of natural drainage or blocking of natural drainage by roads, and these factors are not to mention the lack of maintenance of natural drainage systems (Bezabih, 2020).

One of the man-made causes is the improper usage of drainage systems during construction. By using poor design and construction, water may be prevented from draining away or may be redirected onto the road. Another element contributing to the pavement's collapse and inadequate drainage is a lack of routine maintenance. Routine maintenance is always required, regardless of a road's engineering features or traffic numbers. Inadequate drainage is a major cause of pavement distress because it forces costly repairs before the pavement reaches its intended life. If water can be drained immediately, service life can be increased by 50% (Bezabih, 2020).

Stormwater drainage systems can fail for a variety of reasons, ranging from inadequate design and construction to environmental and human factors. Understanding these causes is crucial for improving the resilience and effectiveness of urban drainage infrastructure.

2.7.1. Inadequate Design and Planning

Insufficient Capacity: Many stormwater drainage systems are designed based on historical rainfall data, which may not account for the increasing frequency and intensity of storms due to climate change. This results in systems that are unable to handle peak runoff volumes during extreme weather events (Watson, 2020).

Poor Site Selection: Incorrect placement of drainage infrastructure can lead to ineffective water management. For example, placing stormwater inlets at high points rather than low points in the landscape can prevent proper water collection (Ashley, 2005).

Lack of Redundancy: Drainage systems without sufficient redundancy or backup systems are more likely to fail when individual components are overwhelmed or blocked. Redundancy ensures that if one part of the system fails, others can compensate (Butler, 2011).

2.7.2. Poor Maintenance and Blockages

Sediment and Debris Accumulation: Over time, sediment, trash, and organic debris can accumulate in drainage systems, reducing their capacity and effectiveness. Regular maintenance is essential to prevent blockages that can lead to localized flooding (Novotny, 2003).

Vegetative Growth: Infiltration and bio retention systems can become clogged with excessive vegetation growth, which can impede water flow and lead to overflow issues (Barbosa, 2012)

2.8. Impacts of drainage structures failure

The drainage quality has a big impact on how effective the road pavement is. Before they reach the end of their planned life, roads with poor drainage need several costly repairs or replacements (Tiza, 2016).

Poor drainage on highway structures has a number of detrimental effects on the economy of users, as both functional and structural failures as a result of poor drainage lead to an increase in travel time, reduce productivity of a community or nation, it cause illnesses like malaria fever due to mosquito breeding in stagnant water around poorly drained pavements in residential areas, there is an increased number of accidents, thus leading to the death of many (Tiza, 2016).

Roads are severely harmed by poor drainage. It does it in a number of ways that result in the collapse of roads. When an effective drainage system is put in place, roads last longer. However, the road's early edge breakdown was caused by a subpar drainage system. Therefore, appropriate road drainage should be considered when developing roadways (Tiza, 2016).

To keep roadways drained, suitable design, building, and maintenance techniques should be used (Tiza, 2016).

The usability, safety, and comfort of the road are significantly impacted by pavement damage. Roads must be maintained to ensure that the requirements for safety, effectiveness, and durability are met because they deteriorate over time due to use after being built. Newly paved roads normally deteriorate very slowly over the first ten to fifteen years of their existence before deteriorating much more swiftly if timely maintenance is not carried out (Bezabih, 2020).

It is well known that as the water content of granular material increases, the rate at which roads degrade quickens. The shear strength of unbound materials is reduced, expansive subgrade soils experience differential swelling, unbound fines move through the base and sub-base layers of flexible pavements, rigid pavements experience pumping of fines and durability cracking, and flexible pavements experience stripping of asphalt. These are just six of the negative effects of excess water (Bezabih, 2020).

Travel time is lost due to road damage. Some approaching vehicles share lanes when necessary to avoid potholes, pavement gullies, and other hazardous sections of the road.

During rainy seasons, it becomes riskier for water to seep into the pavement from the sides and top surface, and the top layer can separate from the bottom layers.

2.9. Drainage Failure Mitigation

2.9.1 In the case of Addis Ababa city

The management and routine maintenance of infrastructure assets, which accounts for 36.3% of the solutions to improve urban drainage problems, was found to be the top priority according to the findings of the AHP qualitative survey. The bulk of drainage infrastructure failures brought on by solid wastes may be handled with suitable asset and solid waste management strategies, routine maintenance, and protection. By making up 15.6% of all mitigation measures, good drainage system construction oversight considerably lowers drainage failures (Mengistu, 2023).

According to the AHP multi-criteria decision support tool, asset management and maintenance are given top priority when it comes to drainage failure mitigation strategies. Other crucial mitigating measures for the durability of drainage facilities include upstream catchment management, good construction monitoring, and public awareness campaigns. When longitudinal grades are higher than cross-fall slopes, implementing adequate gutters and local depressions at inlets is a design mitigation strategy that can reduce surface flooding by increasing the trapping efficacy of longitudinal drain systems (Mengistu, 2023).

The study's conclusions vehemently recommend that drainage infrastructures be given high priority throughout the development, implementation, and management phases. Drainage infrastructure stakeholders should have a clear strategy, policy, and guideline as well as seasonal inventories, condition surveys, and maintenance plans in order to manage the assets and use them appropriately. The paper recommends further research on the effects of drainage problems on society and the environment (Mengistu, 2023).

2.9.2. Mitigation of urban drainage failure in the case of Taiwan

Taiwan's Tuku lowlands have seen an increase in runoff discharge as a result of land expansion. In recent years, frequent floods brought on by severe weather have caused considerable economic and social damage. In lowland areas that are vulnerable to flooding, many infrastructures have already been constructed; the strategies and tactics for flood mitigation are primarily technical. Stakeholders and engineers have benefited from public involvement in the formulation of guidelines for future flood management (Hsiang-Kuan, 2013).

An integrated drainage-inundation model, which includes a drainage flow model and a two-dimensional overland-flow inundation model, is used to evaluate flood control measures with damage loss estimation. Some of the suggested remedies include expanding drainage capacity, using fishponds as retention ponds, setting up pumping stations, and building flood diversion culverts. In order to examine the effects on the drainage system of anticipated increases in rainfall due to climate change, simulations were run for each method to determine the probable inundation extent and depth in terms of damage losses. The results show how important it is to assess climate change effects in order to establish efficient flood management techniques (Hsiang-Kuan, 2013).

2.9.3. Mitigation of urban drainage failure in the case of Argentina

Buenos Aires and the adjacent areas on the Pampa Humeda have long struggled with surface water drainage during periods of unusually high rainfall due to the general terrain (complicated by the effects of engineering architecture and bad maintenance). However, drainage problems have become significantly more prevalent and chronic in many areas of the conurbation in recent years due to a considerable and persistent rise in groundwater levels in the underlying aquifer, which has pushed them quite close to the land surface in some regions (Garduño, 2002).

Groundwater levels have risen as a result of the progressive withdrawal of neighborhood water wells from the urban water supply network, an increase in water imports from the Ro de la Plata, and, to a smaller extent, a drop in pumping from industrial water wells as a result of the economic crisis. The rise in groundwater has a variety of repercussions, including basement flooding, rising damp in residential structures, issues with in-situ sewage systems, overloading and overflowing of sewers, and disruption of the urban infrastructure. The impacted areas, mostly inner suburbs with a total population of over 3.5 million, continue to face rising social misery, health risks, and financial costs, yet despite noble intentions, efforts to solve the problem have so far been dispersed (Garduño, 2002).

The potential efficacy of mitigation strategies to solve the drainage problem is strongly influenced by the hydrogeological conditions:

- Due to the surface's typically low permeability, surface drains, and even shallow wells or well points will be ineffective.
- Restoring under-drainage through the continued operation of some former municipal and industrial water wells would be the most practical solution (Garduño, 2002).

2.9.4. Sustainable drainage system

Drainage systems may assist sustainable development and improve the areas and places where we live, work, and play by balancing the different opportunities and challenges that affect urban planning and the expansion of communities. Sustainable Drainage Systems (SuDS) are surface water management techniques that consider water quantity (flooding), water quality (pollution), biodiversity (wild life and plants), and amenity (Susdrain.org, 2023)**.**

Because they either little or never impact the environment, SUDS drainage systems are regarded as being environmentally benign. They are generally viewed as a collection of management methods, directives, and tactics designed to efficiently and sustainably drain surface water while minimizing pollution and managing the impact on the water quality of neighboring bodies of water (Susdrain.org, 2023).

SuDS are an organic technique to control urban drainage, especially close to houses. The majority of surfaces in urban contexts have been paved, which makes it much more difficult for water to naturally soak in. As a result, when it rains, practically all of our rainwater flows away. Many people don't know what happens to rain when it drains away, as we've found (Thames21, 2023).

In London, there are two distinct drainage systems. Both are separate and combined systems. In another setup, rainwater is dumped into a nearby canal after entering a conduit together with any road pollution when it rains. In a combined system, rainwater is directed to a sewage treatment plant, where it may overflow and send untreated sewage into our rivers. In London, sewage is discharged about once every week (Thames21, 2023).

2.10. Properties of an effective stormwater drainage system

Effective stormwater drainage systems are crucial for managing urban runoff, preventing flooding, and protecting water quality. Here are the key properties of effective stormwater drainage systems.

Capacity and Efficiency

- **Adequate Sizing**: Effective systems are designed to handle peak runoff volumes from extreme weather events without being overwhelmed. Proper sizing is based on hydrological data, including rainfall intensity and frequency (Butler, 2011).

- **Flow Efficiency**: Systems should minimize obstructions and maximize flow efficiency to ensure quick and effective drainage of stormwater. This includes smooth channel surfaces and appropriate slopes to facilitate gravity-driven flow (Novotny, 2003).

Reliability and Redundancy

- **Redundancy**: Incorporating multiple pathways for water to flow ensures that if one part of the system is blocked or overwhelmed, alternative routes are available. This increases the overall reliability of the system (Fletcher, 2013)
- **Durability**: Materials and construction techniques used should be durable and resistant to wear and environmental damage to reduce the frequency of maintenance and repair (Watson, 2020).

Adaptability and Resilience

- **Climate Adaptation**: Effective systems are adaptable to changing climate conditions, including increased rainfall intensity and frequency. This involves using flexible design standards that can be updated as climate projections evolve (Ashley, 2005).
- **Modularity**: Systems should be designed in a modular fashion, allowing for easy upgrades and expansions as urban areas grow and demands on the system increase (Butler, 2011)

Environmental Integration

- **Green Infrastructure**: Incorporating green infrastructure elements such as rain gardens, green roofs, and permeable pavements helps manage runoff at the source, enhance infiltration, and improve water quality (Barbosa, 2012).
- **Pollution Control**: Systems should include features that filter and treat stormwater to remove pollutants before it enters natural water bodies. This can include sedimentation basins, constructed wetlands, and vegetative filters (Novotny, 2003).

Maintenance and Accessibility

- **Ease of Maintenance**: Systems should be designed to allow easy access for inspection, cleaning, and repairs. Regular maintenance is crucial to prevent blockages and ensure optimal performance (Shuster, 2005)**.**
- **Community Involvement**: Engaging local communities in maintenance activities can help ensure systems are well-maintained and functioning correctly. This includes education on the importance of keeping drains clear of debris (Fletcher, 2013).

2.11. Criteria for good stormwater drainage

Road drainage and, ultimately, road stability are impacted by slope morphology. The slope shape (uniform, convex, concave) slope gradient, slope length, stream drainage characteristics (braided, dendritic) depth to bedrock, bedrock characteristics (fractured, hardness, bedding) soil texture, and permeability are all significant variables. The form of a slope might indicate the concentration or dispersion of surface and subsurface water. Convex slopes, such as broad ridges, will usually cause water to scatter as it descends. Hydrostatic pressure accumulates on straight slopes because it concentrates water on the lower slopes. Swales and draws are frequently present on concave slopes. These locations represent the least ideal place for a road since water is concentrated at the lowest point on the slope (Nations, 1998).

If a road drainage system is to be functional for the duration of its design life, it must meet two key requirements:

It must drain surface and subsurface water away from the roadway and dissipate it in a way that minimizes excessive accumulation of water in unstable regions and consequent downstream erosion. It must allow for the least amount of disruption of the natural drainage pattern (Nations, 1998).

In order to successfully manage water and avoid problems associated with it, there must be good drainage. The following items are necessary for good drainage in Ethiopia:

Slope: To allow for natural water flow, the land should have a proper slope. To avoid erosion and guarantee optimum water flow, a gradual slope is preferred (Ethiorobo, 2023).

Drainage channels need to be correctly planned to hold the anticipated amount of water. They must to have a smooth surface and enough width to handle the flow without becoming obstructed.

Maintenance: To guarantee that drainage systems are operating efficiently, routine maintenance is essential. Debris, sediment, and vegetation that can obstruct water flow must be removed as part of this process (Ethiorobo, 2023).

Building the right infrastructure, such as culverts, bridges, and subsurface drainage systems, can assist in controlling water flow during torrential downpours or flash floods. Proper land use planning is essential to avoiding the obstructing of natural drainage pathways. Buildings or roads must not be constructed on wetlands or flood-prone areas. Engagement of the Community: Long-term success depends on educating communities about the value of proper drainage and motivating their active participation in drainage system maintenance (Ethiorobo, 2023).

2.12. Evaluation of Stormwater drain systems

In order to control runoff and avoid flooding, stormwater drainage systems are crucial for metropolitan areas; nevertheless, because to urbanization and climate change, these systems confront numerous difficulties. A number of important methods and strategies are used in the evaluation and improvement of these systems in order to increase their resilience and sustainability.

Sustainability Indices: Evaluating stormwater systems often involves using sustainability indices. A study on six Indian cities used indices like the Natural Drainage System Index (NDSI), Permeability Index (PI), and Stormwater Discharge Quality Index (SWDQI) to assess the effectiveness and sustainability of urban drainage systems. These indices help in understanding various aspects of drainage performance, including natural drainage capabilities, permeability of surfaces, and the quality of discharged water (Vishwakarma, 2023).

Climate Change Impact Assessment: Stormwater systems must be evaluated for their capacity to handle increased precipitation and extreme weather events. This includes examining the shape and spatial distribution of design storm events, to ensure they reflect current and future climate conditions (Duin, 2021).

Analytical Hierarchy Process (AHP): This method helps in ranking different sustainability indices by deriving weights for each index and aggregating them into an overall sustainability score. This comprehensive approach allows cities to prioritize areas for improvement based on their specific needs and conditions (Vishwakarma, 2023).

2.13. Research gap

Like many other fast urbanizing areas, Akaki Kality has serious problems managing its stormwater. Inadequate infrastructure, increased urbanization, and increasing rainfall intensity linked to climate change have resulted in regular flooding and drainage failures in the area. Research on broad urban stormwater management strategies and the effects of climate change on urban infrastructure has been conducted, but localized studies that combine community-specific sustainable drainage systems with climate adaptation measures are scarce.

The research that is currently available frequently discusses the effects of climate change in general terms without paying particular attention to regional climate conditions and how they affect stormwater systems. Comprehensive climate models that forecast extreme weather events unique to the Akaki Kality region and how they will affect the demands for stormwater management are necessary.

Although sustainable urban drainage systems (SuDS) and low impact development (LID) have received a lot of attention, not enough has been done to tailor these approaches to the unique urban structure, socioeconomic circumstances, and infrastructure constraints of Akaki Kality. It is essential to look at how these sustainable solutions might be adapted to the local environment.

Research that integrates contemporary sustainable drainage solutions with traditional drainage practice which may be more environmentally and culturally appropriate for the area is lacking. Assessing the potential for integrating indigenous knowledge and practices with modern technical solutions could lead to more efficient and long-lasting results.

Chapter Three: Methodology of the study

3.1. Description of study area

3.1.1. Topography

Addis Abeba is roughly in the middle of the country between latitudes 8o50' and 9o5' N and 38o38' and 38o54' E, close to the western escarpment of the rift valley. Its area is approximately 520 km2. The city's elevation declines from the northern hilly region to the south, with the highest and lowest places falling between 3040 m and 2050 m above sea level (Tadesse, 2021).

The two main rivers that cross the city are the Tinishu Akaki, also known as the Little Akaki, and the Tiliku Akaki, also known as the Great Akaki. These rivers originate in the Entoto Mountains, which are located north of Addis Abeba, and flow to Aba Samuel Lake (43 km to the south). The entire city is located within the Awash River Basin, one of the nation's twelve river basins. The ridge between the Awash and Abay basins, which is upstream of the Awash River Basin, borders the city on the north (Tadesse, 2021).

Akaki Kality is located in Addis Ababa, Ethiopia, at 8.895831 latitude and 38.789162 longitude. The GPS coordinates for Akaki Kality, Addis Abeba, Ethiopia are 8° 53' 44.9916" N and 38° 47' 20.9832" E. It is a place in the Districts place category in the country of Ethiopia. Additionally, it is 2,140 meters above sea level (EmebetHailemichael, 2018).

This sub-city has both mild and messy topography. The Akaki River flows through this subcity. During the rainy season, this river poses a significant concern because it frequently results in the loss of life and property. For instance, during the summer of 2009 E.C., a river overflow had serious repercussions for those living nearby, causing a small number of fatalities and a large number of property losses. Risks will always exist unless appropriate and long-lasting safeguards are adopted (EmebetHailemichael, 2018)

3.1.2. Location

One of Addis Abeba's ten sub-cities, Akaki-Kality serves as both the city's and the nation's industrial hub. It is situated in the city's southern region. The distance to the city's center is 20 kilometers (Emmanuel, 2007) . Akaki Kality is located in Addis Ababa, Ethiopia, at 8.895831 latitude and 38.789162 longitude. The GPS coordinates for Akaki Kality, Addis Abeba, Ethiopia are 8° 53' 44.9916" N and 38° 47' 20.9832" E. It is a place in the Districts place category in the country of Ethiopia. Additionally, it is 2,140 meters above sea level (LatLong.net, 2017).

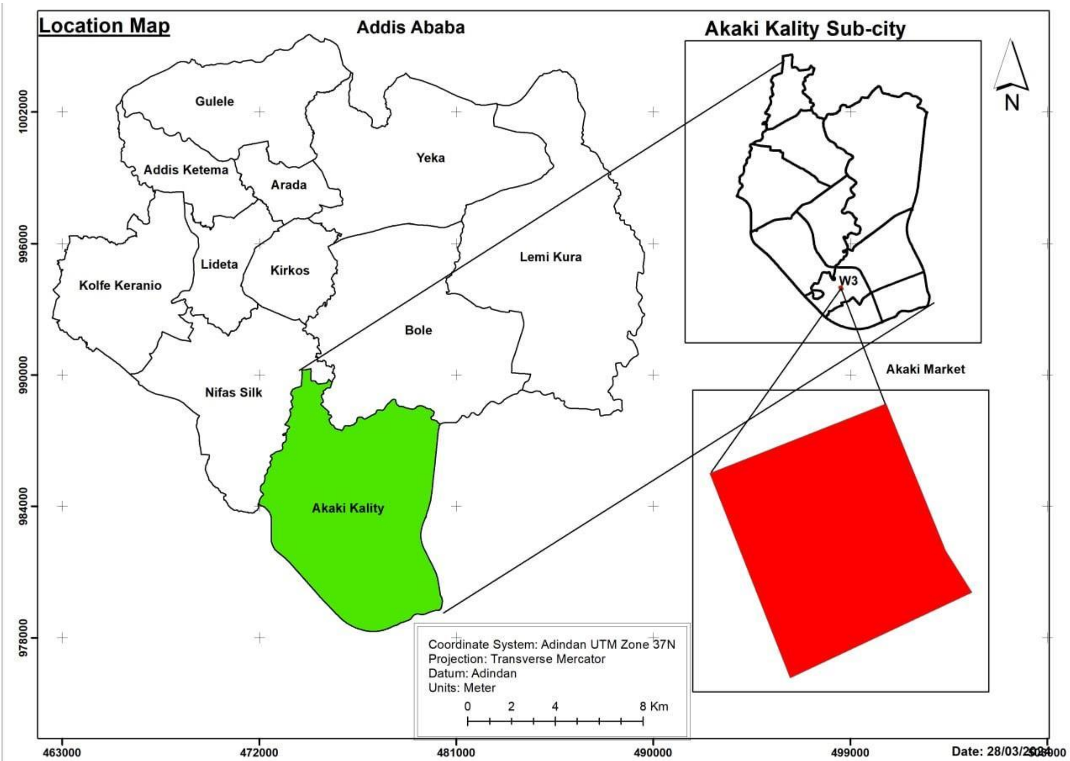

Figure 3.1: Akaki Kaliti with in Addis Ababa

3.2. Research Approach

An approach to study known as mixed methods research involves gathering both quantitative and qualitative data, integrating the two types of data, and employing unique designs that may include philosophical presumptions and theoretical frameworks. The fundamental premise of this type of study is that using both qualitative and quantitative methods together yields a more comprehensive grasp of a research problem than each method by itself (Creswell, 2009).

3.3. Source of data

I conducted research using both primary and secondary data in order to completely understand a certain set of data. Information that the researcher directly obtained from sources like surveys, interviews, or observations is referred to as primary data. It makes it possible for us to obtain specialized and individualized information straight from the source.

Contrarily, secondary data refers to information that already exists and was obtained for a different purpose. It is possible to employ information from publications like books, journals, official papers, or online databases. Secondary data allows us to compare and contrast information from numerous sources and offers our conclusions a more thorough context.

By merging primary and secondary data, we can increase the reliability and validity of our conclusions. Using primary sources ensures that information is accurate and up to date.

3.3.1. Primary Data Sources

Field Surveys: Information gathered directly from the site through fieldwork, including measurements, visual inspections, and observations of Akaki Kality's stormwater drain infrastructure.

Interviews: I had direct discussions with relevant parties, such as locals, government representatives, engineers, and environmental specialists, to learn about their opinions, experiences, and knowledge regarding drain failures.

Surveys: Data on certain aspects of stormwater drain failure, maintenance procedures, or environmental conditions were gathered through the administration of questionnaires and organized interviews to persons.

3.3.2. Secondary Data Sources

Secondary data was compared to primary data in order to support the information from primary sources. Therefore, secondary data was employed, such as instructions linked to the drainage program, legal documents, websites, strategy documents, manual report documents, and directives. Additionally, a number of reports and other papers were examined to gather relevant information.

3.4. Sampling design

The sampling design's goal to gather representative information about the causes of stormwater drain failures near the Akaki market place and to comprehend the effects of these failures on the neighborhood's infrastructure and community.

3.4.1. Sample population

The target population includes:

- Residents and business owners around Akaki marketplace.
- Local government officials and urban planners.
- Technical experts involved in stormwater management.

3.4.2. Sample size

First, calculate the initial sample size using the formula:

$n=Z^2 \cdot p \cdot (1-p) / e^2$

where:

- n = initial sample size
- Z = Z-value corresponding to the desired confidence level (1.96 for 95% confidence)
- p = estimated proportion of the population (0.5 for maximum variability)
- e = margin of error (0.05 for 5%)

$n= 1.96^2 * 0.5(1-0.5)/ 0.05^2$

n=384.16

Population size (N) is 96 households, I adjusted the sample size using the finite population correction:

$n_{adj} =$

$n_{adj} = 76.58$

For a population of 96 households, the required sample size with a 95% confidence level and a 5% margin of error is approximately 77 households.

Residents: (50% of total sample size)

Total Sample Size × Proportion

77×0.50=38.577

Adjusted Sample Size: 39 (rounded to the nearest whole number)

Business Owners: (30% of total sample size)

Total Sample Size × Proportion

77×0.30=23.177

Adjusted Sample Size: 23 (rounded to the nearest whole number)

Local Government Officials: Fixed Number: 5

Technical Experts: Fixed Number: 5

Community Leaders: Fixed Number: 5

Summary of sample sizes

- Residents: 39
- Business Owners: 23
- Local Government Officials: 5
- Technical Experts: 5
- Community Leaders: 5
- Total 77

3.4.3. Sampling technique

Sampling techniques for different groups include systematic random sampling for residents, stratified random sampling for business owners, purposeful sampling for local government officials, and purposive sampling for technical experts. Systematic random sampling ensures equal chance selection, reduces selection bias, and was easier to administer. Stratified random sampling categorizes businesses into strata based on type, ensuring representation from all business types. Purposive sampling selects officials from relevant departments, focusing on their roles, expertise, and involvement in stormwater management. Technical experts were identified through professional networks and industry organizations, focusing on their experience and publications. Community leaders were identified through local associations, NGOs, and community groups, capturing the perspectives of well-informed community members and providing holistic insights into the impact of stormwater drain failures.

3.5. Method of data collection

The study involves direct observation of Akaki Kality's stormwater drain system, structured interviews with stakeholders, surveys to gather quantitative data on frequency, severity, and impact of failures, and document analysis to understand the causes and maintenance practices. The research aims to identify potential issues and improve the system's performance.

3.6. Method of data analysis

To analyze stormwater drain failures in Akaki Kality, I used descriptive statistics, regression analysis, qualitative analysis, data visualization, and integration of findings. Descriptive statistics summarize quantitative variables like frequency and maintenance activities. Regression analysis identifies relationships between variables, while qualitative analysis helps identify recurring themes and experiences. Data visualizations help communicate complex patterns and trends. Finally, I integrated findings to develop a comprehensive understanding of Akaki Kality stormwater drain failures, identifying key insights for improving drainage infrastructure resilience and management practices.

3.7. Method of data presentation

This study used summarize methodology, key findings, analysis, and conclusions. Tables were present detailed numerical data, providing context and explanation. A narrative summary that convey the significance of findings, emphasizing implications for stakeholders and potential future research.

3.8. Validation

This thesis underwent rigorous validation procedures to ensure the reliability and accuracy of its findings. Data validation involved cross-referencing data from various sources, quality control measures, peer review, and pilot testing. Methodological validation assessed the methodologies' suitability and reliability in addressing research objectives. Pilot testing identified operational challenges, expert consultation sought input from civil engineering, hydrology, and environmental science, and sensitivity analyses evaluated modeling results' robustness. These validation procedures provided confidence in the reliability and validity of the data and methodologies, enhancing the overall quality and integrity of the thesis.

Chapter Four: Result and Discussion

4.1. Socioeconomic description and response rate of respondents

4.1.1. Socioeconomic description

The residents come from various socio-economic backgrounds, ranging from low-income households living in informal settlements to middle-class families in modern housing complexes. Many residents work in nearby industries, such as manufacturing and textiles, while others are employed in the service sector or run small businesses. Overall, Akaki Kality is a vibrant community with a rich cultural heritage and a strong sense of community spirit.

Analysis of economic status:

The bulk of responders (85%) are classified as low- to middle-income, suggesting that maintaining and repairing drainage systems may be financially difficult. Because of their working conditions, a sizable fraction (30%) of blue-collar workers may have firsthand knowledge of the state and shortcomings of the drainage system.

Analysis of social characteristics:

Fifty percent of long-term inhabitants have probably seen many stormwater events, which offers important historical context for understanding the system's functionality. The high percentage of participation (20%) in community events can be used to support neighborhood-based projects aimed at improving stormwater management.

4.1.2. Response rate of respondents

Reporting the survey's response rate is crucial for assessing the validity and representativeness of the data gathered. The percentage of responses offers information on the degree of participation and the degree to which the survey results may be applied to the study area.

Details of the survey:

120 surveys were distributed overall.

77 responses in all were received.

Calculating Response Rate:

Response Rate is equal to (Total Surveys Distributed /Total Responses Received) × 100.

Response Rate = (Distributed Total Surveys /Received Total Responses)×100

Answer Rate = (77/ 120) × 100 = 64%

In survey research, a response rate of 64% is seen as relatively high, suggesting that the community is actively involved and interested. This increases the data's dependability and raises the possibility that the conclusions are broadly reflective of the population.

The demographic profile includes gender, age, how long they lived in the area, and status of the respondents. Out of 77 respondents 31 of them were males and 46 females. According to their age includes from 18 up to 40 years old. And most of the respondents lived more than ten years in the area.

Table 4.1: Demographic profile of respondents

Description		Frequency	Percent
Gender	Male	31	40.3
	Female	46	59.7
Age	18-25	13	16.9
	26-30	35	45.5
	31-40	29	37.7
How long they live in the area?	Less than 10 years	1	1.3
	10-20 years	19	24.7
	More than 20 years	27	35.1
Status	Professionals	37	48.1
	Resident	40	51.9

4.2. The state of current drainage infrastructure

Akaki Kality, an Addis Ababa sub-city that is fast urbanizing, has serious drainage infrastructure issues. Protecting property, preserving public health, and preventing flooding all depend on the current stormwater management system. This section presents an evaluation of Akaki Kality's drainage system as it stands today, based on stakeholder interviews, municipal records, and field assessments.

An overview of the drainage system

Types of drainage structures: drainage system is made up of natural streams, subterranean stormwater pipelines, culverts, and open ditches.

Coverage: The drainage system's coverage varies, with certain parts being well-served by contemporary infrastructure and others depending on antiquated or primitive systems.

State of the Infrastructure

Structural Integrity: Culverts and pipes, among other drainage systems, are prone to deterioration. Common problems include material deterioration, obstructions, and fissures.

Open Ditches: Frequently obstructed by silt and debris, which lessens their ability to transport precipitation.

Waste buildup and poor maintenance cause clogs in pipes and culverts on a regular basis.

Upkeep: Inconsistent upkeep results in sporadic breakdowns during intense downpours. These problems are made worse by a lack of planned maintenance schedules and scarce resources.

Views in the Community

Feedback from Residents: Surveys and interviews show that there is a general lack of contentment with the drainage system as it stands.

Frequent blockages, insufficient capacity, and delayed municipal service response times during flooding situations are among the common complaints.

Effects on day-to-day living: Flooding ruins property, interferes with transportation, and puts people's health at danger, especially the elderly and young.

Performance during rainfall events

Flooding Incidents: Especially in the rainy season, the place frequently floods. The neighborhoods closest to poorly maintained drains and low-lying areas are the most affected.

Current Projects and Initiatives

Projects in Progress: There are a number of current initiatives aimed at enhancing drainage infrastructure. Among them are:

Growth of drainage systems: expanding the network of subterranean stormwater pipelines to neglected regions.

Restoration of pre-existing structures: restoring and modernizing aged ditches and culverts to increase their functioning and capacity.

Notwithstanding these endeavors, obstacles like restricted financial resources, fast urbanization, and insufficient community engagement impede the efficacy of these programs.

4.3. Causes of stormwater failure

In urban area such as Addis Ababa's Akaki Kality sub-city, a complex interplay of circumstances can lead to stormwater management problems. It is essential to comprehend these reasons in order to create mitigation methods that work. These are some important factors that causes stormwater failure in the study area.

Inadequate Infrastructure

- **Undersized Drainage Systems**: Many stormwater systems in this area are not designed to handle the volume of runoff generated by current levels.
- **Aging Infrastructure**: Existing stormwater systems are old and deteriorating, reducing their effectiveness in managing runoff.

Poor Maintenance and Management

- **Blocked Drains and Channels**: Accumulation of debris, sediment, and waste in drainage systems can block water flow, leading to localized flooding.
- **Lack of Regular Maintenance**: Inconsistent or insufficient maintenance can exacerbate system failures.

Socio-Economic Factors

- **Rapid Urban Growth**: Rapid population growth and urban expansion can outpace the development and upgrading of infrastructure.
- **Informal Settlements**: Unplanned settlements often lack proper drainage systems, increasing the risk of flooding and waterlogging.

From the data that I got from the respondents the following causes are the major for stormwater drains failure in the study area.

Residents' disposal of solid waste is the main cause of drainage system failure. Pipes that solidify in external pipes are one of the most frequent reasons for blocked drainage systems. They frequently put their waste down in drainages, which clogs them and prevents the water from flowing normally, leading to overflows. After a brief period of rainfall, it's usual to see flooded streets with trash floating everywhere. The accumulation of domestic substances like soap, hair, food, and fat in the Accumulation of debris, such as leaves and dirt, which rain and storms push into gutters and drains. Not all particles cause blockages in drains. For example, suspended particles quickly flow to drainage basin's major water bodies, however, larger particles are occasionally left in these drains where they accumulate and cause obstructions

Table 4.2: Improper disposal of waste

Rate	Frequency	Percent
Disagree	3	3.9
Neutral	22	28.6
Agree	33	42.9
Strongly Agree	19	24.7
Total	77	100.0

The above table shows that only 3 respondents (3.9%) disagree that there is improper disposal of waste. This indicates a very small proportion of the surveyed population does not see improper disposal of waste as an issue.

22 respondents (28.6%) are neutral about the issue. This suggests that nearly a third of the respondents neither agree nor disagree, possibly indicating ambivalence or a lack of strong opinion on the matter.

A significant portion, 33 respondents (42.9%), agree that there is improper disposal of waste. This is the largest category, indicating that a substantial number of respondents perceive improper waste disposal as a problem.

19 respondents (24.7%) strongly agree that improper disposal of waste is an issue. This shows that a considerable number of respondents feel very strongly about the presence of improper waste disposal.

So, the majority of respondents (67.6% when combining 'Agree' and 'Strongly Agree') acknowledge that improper disposal of waste is an issue. This majority highlights a significant concern among the surveyed population regarding waste management practices.

The neutral stance taken by 28.6% of respondents might suggest a lack of awareness or indifference towards the issue.

A very small minority (3.9%) do not see improper disposal of waste as a problem, indicating almost universal recognition of the issue among the rest.

This data implies that there is a widespread recognition of improper waste disposal issues among the respondents, suggesting a need for better waste management practices and increased awareness efforts in the community.

Silt caused by flooding

By obstructing pipes or by filling soak-away and attenuation systems, silt can hinder a drainage system's ability to remove surface water and reduce its capacity to hold water. As silt accumulates, there is a greater chance that water will not drain away, resulting in flooding on the surface and eventually necessitating the replacement of the drainage system.

The majority of respondents (62.4% when combining 'Agree' and 'Strongly Agree') acknowledge that flooding causes silt. This majority highlights a significant concern among the surveyed population regarding the impact of flooding on siltation.

The neutral stance taken by 28.6% of respondents suggests a notable portion of the population is either undecided or lacks sufficient information on the issue.

A small minority (9.1% combining 'Disagree' and 'Strongly Disagree') do not see flooding as a significant cause of silt, indicating a recognition of other potential factors contributing to siltation.

This data implies that there is a widespread acknowledgment among respondents of the relationship between flooding and silt issues, suggesting a need for targeted interventions to manage both flooding and siltation effectively.

Table4.1: silt caused by flooding

Rate	Frequency	Percent
Strongly Disagree	1	1.3
Disagree	6	7.8
Neutral	22	28.6
Agree	37	48.1
Strongly Agree	11	14.3
Total	77	100.0

Blockage or obstruction

Rather than residents' poor waste disposal activity it is common to see improper disposal of leftover materials during construction because of this unnecessary waste the drainages were blocked. After the completion of any construction it can be road or any other construction near the road should be cleaned to keep the drainage safe.

The respondents are divided in their opinions on the issue of blockages or obstructions in stormwater drainage systems. While a significant proportion of respondents (44.2% when combining 'Agree' and 'Strongly Agree') acknowledge blockages as a problem, an almost equal proportion are neutral (28.6%) or disagree (27.3% when combining 'Disagree' and 'Strongly Disagree') with this view.

The significant percentage of neutral responses suggests a considerable degree of uncertainty or lack of strong opinion on the matter among respondents.

This data indicates that while many respondents recognize blockages as an issue, a substantial number are either indifferent or do not see it as a major problem, highlighting the need for more awareness and investigation into the causes and impacts of blockages in the stormwater drainage systems.

Table 4.4: blockage or obstruction

Rate	Frequency	Percent
Strongly Disagree	4	5.2
Disagree	17	22.1
Neutral	22	28.6
Agree	22	28.6
Strongly Agree	12	15.6
Total	77	100.0

Lack of community participation in cleaning and maintenance

The storm-water conveyance system collects and moves urban runoff that might include specific contaminants as a result of its role. Regular maintenance of catch basins, storm-water inlets, and other storm-water conveyance structures removes pollutants, prevents clogging of the downstream conveyance system, restores the capacity of catch basins to trap sediment, and makes sure the system is hydraulically sound to prevent flooding. A neighborhood drainage committee can at least keep an eye on the operation of the system and notify the appropriate officials of any flaws or inadequacies. Many times, the community can also do the majority of the regular maintenance tasks. Then, there needs to be effective coordination and a distinct separation of duties. However, a lack of community cooperation will result in negligence and a loss of a sense of belonging, which poses serious health, flood, and other threats to the neighborhood.

The majority of respondents (59.7% when combining 'Agree' and 'Strongly Agree') acknowledge that there is a lack of community participation in stormwater management. This majority highlights a significant concern among the surveyed population regarding community engagement.

The neutral stance taken by 29.9% of respondents suggests a notable portion of the population is either undecided or lacks sufficient information on the issue.

A small minority (10.4% combining 'Disagree' and 'Strongly Disagree') do not see a lack of community participation as an issue, indicating a recognition of either adequate participation or differing perceptions of community involvement.

This data implies that there is a widespread recognition of the need for greater community participation in stormwater management among respondents, suggesting that efforts to enhance community engagement and involvement could be beneficial for improving stormwater management practices in Akaki Kality.

Table 4.5: lack of community participation

Responses	Frequency	Percent
Strongly Disagree	1	1.3
Disagree	7	9.1
Neutral	23	29.9
Agree	39	50.6
Strongly Agree	7	9.1
Total	77	100.0

4.4. What sustainable practices can be implemented to improve the maintenance and efficiency of stormwater drainage systems?

Descriptive analysis of planning problems contributing to drainage failure

The study reveals that pipe condition and design flaws are the most significant contributors to drainage failure, with aging pipes being the most critical issue. The source of water and the age of the system and construction activities also contribute to failures. Lower mean scores indicate that blockages are less critical, and maintenance and cleaning frequency is important but not as significant as structural problems. Proper installation and construction are crucial but occasionally lapses in construction standards. Poor maintenance practices are less of a concern compared to structural and design issues. The study shows moderate variability in factors such as pipe condition, design flaws, proper installation, source of water, and poor maintenance practices.

Table 4.6: Planning problems according to their contribution to drainage failure

Statement	Mean	Standard Deviation
Age of the drainage System	3.36	1.224
Maintenance and Cleaning Frequency	3.21	1.080
Source of water entering the drainage System	3.40	1.280
Blockage or obstruction	3.27	1.131
Construction activities or infrastructure changes	3.36	1.202
Pipe Condition	3.48	1.046
Proper installation and construction	3.19	1.246
Poor maintenance practices	3.06	1.281
Design Flaws: Inadequate Sizing, improper slop, etc...	3.48	1.231

From the above table the descriptive analysis reveals that structural issues, such as the condition of pipes and design flaws, are perceived as the most significant contributors to drainage failures in the Akaki Kality market place. While maintenance practices are also important, they are seen as less critical compared to these structural problems. This suggests a need for infrastructure improvements, better design standards, and enhanced maintenance routines to address the identified issues effectively.

To improve the condition of drainage systems, several strategies can be implemented. These include infrastructure upgrades, addressing design flaws, redesigning problematic areas, adopting green infrastructure, managing the source of water entering the system, mitigating blockages or obstructions, enhancing maintenance and cleaning frequency, adjusting to construction activities or infrastructure changes, improving proper installation and construction practices, and addressing poor maintenance practices.

Infrastructure upgrades can replace or rehabilitate aging pipes with durable materials, while regular inspections and emergency response plans can help identify and address issues before they lead to failures.

Adapting to construction activities or infrastructure changes can be achieved through coordination with the city's drainage management plan and temporary mitigation measures. Training and certification programs for construction workers and engineers can also improve installation and maintenance practices.

Cause of drainage blockages on their contribution to drainage failure

The study reveals that improper waste disposal, lack of proper cleaning of the drainage system, flooding-induced silt, rainfall intensity, poor maintenance practices, system age, maintenance and cleaning frequency, and pipe condition all contribute to drainage failure, with some variability in responses. These factors have a moderate impact on drainage failure, with varying responses and severity.

Table 4.7: Cause of drainage blockages on their contribution to drainage failure

Cause of drainage blockages	Mean	Std. Deviation
Improper waste disposal practice	2.99	.866
Lack of proper cleaning of the drainage system	3.47	1.021
Silt caused by flooding	3.66	.868
Rainfall intensity or flooding events	3.48	.837
Poor maintenance practices	3.21	1.017
Age of the drainage System	3.19	.918
Maintenance and Cleaning Frequency	3.73	.821
Pipe Condition	3.48	.771

From the data, it can be seen that the frequency of maintenance and cleaning has the highest mean score, indicating it is perceived as the most significant cause of drainage failure. Improper waste disposal has the lowest mean score, suggesting it is considered a less significant cause. The standard deviations indicate that there is some variability in the perceptions of each cause's impact, with the age of the drainage system and poor maintenance practices showing more variability in responses compared to other factors.

To prevent drainage blockages, several strategies can be implemented. These include public awareness campaigns, strict regulations, increased accessibility of waste disposal facilities, regular cleaning schedules, use of advanced cleaning technology, sediment control measures, improved drainage design, green infrastructure, poor maintenance practices, infrastructure upgrades, rehabilitation programs, optimal scheduling, resource allocation, regular assessments of pipe conditions, preventive maintenance, and replacement of damaged pipes. By addressing these causes, the effectiveness and reliability of drainage systems can be significantly improved, reducing the incidence of blockages and failures. Additionally, improving drainage design, implementing green infrastructure solutions, providing training and capacity building for maintenance staff, planning infrastructure upgrades, and ensuring adequate resources are also crucial.

4.6. Regression analysis

The link between a dependent variable and a group of independent variables is examined or estimated using regression analysis. The results of a regression analysis show the relative magnitude of the effects of various independent variables on a dependent variable. This demonstrates how dependent variables alter in response to changes in the independent variable.

4.6.1. Testing regression

Regression model fitness checks were run before beginning a regression analysis. To explain the correlations between dependent and independent variables, the regression model must first be tested. The normality test and linearity are the two main presumptions.

4.6.2. Normality test

The underlying presumption of multiple linear regressions and Pearson correlation is that the data being tested must be regularly distributed. A normality test is run to see if the data are normally distributed and meet the normality assumptions before moving on to other tests. The p-value is also used to assess if the normalcy assumptions are met by a data distribution. Typically, a confidence level of 0.95 or 95% would be indicated with an alpha risk of 0.05. (P-Value.html, https://www.six-sigma-material.com, 2023) The p-value in this table was greater than 0.05, indicating that the data were not anomalous in any way (Razali, 2011)

Table 4.8: Tests of normality

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	df	Sig.
DF	.091	77	.183	.987	77	.638
DB	.097	77	.072	.983	77	.399
CPPI	.110	77	.021	.979	77	.229
a. Lilliefors Significance Correction						

4.6.3. Linearity

Table 4.9: Model summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.789[a]	.622	.617	3.93265
a. Predictors: (Constant), DBCPPI				

The outcome of regression analysis for independent variables (drainage blockages and lack of community participation) and dependent variables (drainage failure). R is equal to 0.789, and the regression model's coefficient of determination (R squared) value is equal to 0.622. This demonstrates the idea that drainage blockage and lack of community participation have a 61.7% influence on drainage failure, with the remaining 38.3% (100% - 61.7% = 38.3%) being explained by other factors not taken into account in this study.

4.6.4. Regression coefficient

Table 4.10: Regression coefficient result

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	11.947	4.589		2.604	.011
	DBCPPI	.918	.083	.789	11.105	.000
a. Dependent Variable: DF						

Table 4.12 shows a significant financial incentive value of 0.000 < 0.05, so the appropriate basis for decision-making in the regression analysis is that the blockage and lack of community participation have a significant effect on drainage failure. Furthermore, the average expected increase in blockage and lack of community participation for drainage failure factors is 0.789.
The P-value for financial incentives is 0.000. This implies that predictors (blockage and lack of community participation) make highly significant contributions to drainage failure.

4.7. Correlation analysis

Correlation analysis was employed to demonstrate the variables' "Interdependence." The relationship between waste-related blockages, a lack of community involvement, and the dependent variable, drainage failure, has been examined in this section. The degree and direction of the association between the dependent and independent variables are both examined using the correlation matrix. Correlation coefficients below 0.28 indicate little effect, those between 0.28 and 0.49 indicate moderate impacts, and those over 0.49 indicate significant impacts according to effect size standards (Cohen, 1988). As a result, both instances' outcomes fell somewhere in the middle of the spectrum. A statistical method known as a correlation matrix is used to assess the relationship between two variables in a data collection. The matrix is a table with correlation coefficients in each cell, where 1 indicates a strong association between variables, 0 indicates a neutral relationship, and -1 indicates a weak relationship. Regression model construction is where it is most frequently employed. Within this context, this correlation coefficient lies between -1 and +1.

Table 4.11: Correlation result

Correlations			
		DF	DBCPPI
DF	Pearson Correlation	1	.789**
	Sig. (2-tailed)		.000
	N	77	77
DBCPPI	Pearson Correlation	.789**	1
	Sig. (2-tailed)	.000	
	N	77	77
**. Correlation is significant at the 0.01 level (2-tailed).			

Chapter Five: Conclusion and recommendation

5.1. Conclusion

The drainage system in Akaki Kality comprises natural streams, subterranean stormwater pipelines, culverts, and open ditches. Coverage varies significantly, with some areas well-served by modern infrastructure and others relying on outdated or primitive systems.

Key findings include:

Improper Waste Disposal: This is a significant issue, as confirmed by 67.6% of respondents who agree or strongly agree that improper waste disposal is a major cause of drainage blockages. Public awareness campaigns and strict waste disposal regulations are essential to mitigate this problem.

Maintenance and Cleaning Frequency: The most significant factor contributing to drainage failure, with a mean score of 3.73. Establishing regular cleaning schedules and using advanced cleaning technology can help address this issue.

Silt Caused by Flooding: Recognized by 62.4% of respondents as a major contributor to drainage blockages. Implementing sediment control measures and regular desilting of drainage channels can reduce this risk.

Structural Integrity: The aging drainage infrastructure, including deteriorating culverts and pipes, significantly impacts the system's effectiveness. Upgrading and rehabilitating these structures are crucial for long-term improvement.

Community Involvement: A significant portion (59.7%) of respondents indicated a lack of community participation in maintenance activities. Enhancing community engagement through education and organized local maintenance committees can foster better upkeep practices.

Evaluation of the state of the current drainage infrastructure

- **Structural Integrity:** Many drainage structures, including culverts and pipes, are deteriorating due to age and inadequate materials. This has led to frequent obstructions and fissures.
- **Open Ditches:** These are often obstructed by silt and debris, reducing their capacity to handle precipitation.
- **Inconsistent Upkeep:** The lack of regular and planned maintenance schedules exacerbates the issues, leading to sporadic failures during heavy rainfall.

Investigation of the causes of stormwater failure

The primary causes of stormwater failure in Akaki Kality are multifaceted, involving both structural and management issues:

- **Improper Waste Disposal:** Identified as a major cause, improper disposal of solid waste by residents leads to frequent blockages.
- **Maintenance and Cleaning Frequency:** Infrequent and inadequate maintenance exacerbates drainage failures, highlighting the need for regular cleaning and upkeep.
- **Silt from Flooding:** Flood-induced siltation obstructs pipes and reduces the capacity of the drainage system, leading to surface flooding.
- **Rapid Urban Growth and Informal Settlements:** The swift pace of urbanization and the presence of informal settlements without proper drainage infrastructure contribute to the system's inability to manage runoff effectively.
- **Structural Issues:** Aging infrastructure and design flaws, such as inadequate sizing and improper slopes, significantly impair the system's functionality.

Development of strategies to sustain stormwater drains

Based on the identified issues, the following strategies are recommended to sustain and improve the stormwater drainage system in Akaki Kality:

Infrastructure Upgrades:

- Replace and rehabilitate aging pipes and culverts with durable materials.
- Expand the network of subterranean stormwater pipelines to underserved areas.

Regular Maintenance and Cleaning:

- Establish and adhere to consistent maintenance schedules.
- Utilize advanced cleaning technologies, such as high-pressure water jets and vacuum trucks.

Public Awareness and Community Engagement:

- Conduct public awareness campaigns to educate residents on the importance of proper waste disposal.
- Form local maintenance committees to monitor and report issues and engage the community in regular upkeep activities.

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5.2. Recommendation

The foundation of a successful urban storm water management program is public awareness and education. Public engagement and education have been a high priority for the program since its start, and this should continue throughout its development and delivery. Focused public awareness campaigns and ongoing "baseline" public information programs and activities are the two main methods by which public awareness and education are to be carried out in storm water management initiatives. A campaign has a start and an end, but a continuous program changes but does not have a planned finish. This is where these two attributes diverge. However, there are some things to consider and tactics to use in every circumstance.

- ❖ The neighborhood should be made aware of the risks associated with the disposal of household trash, together with other contaminants and dangerous chemicals, near open drains. As well, proper disposal techniques must be taught. The community's education alone, however, is insufficient to solve this issue.
- ❖ To control, direct, and oversee the design and construction of storm runoff drainages, and create a legally required and dedicated drainage department in the Ministry of Works and the Municipalities of Addis Abeba. This agency should also regularly undertake inventories of drainage assets and furnishings.
- ❖ To identify the precise areas of failure and the reasons behind them, do a detailed study of the drainage system that is currently in place in Akaki Kality. This will facilitate the creation of focused solutions.
- ❖ Remove obstructions: Remove any dirt, trash, or plants that may be clogging the drainage channels. Drains that are regularly maintained and cleaned can provide uninterrupted water flow and prevent future obstructions.
- ❖ Infrastructure upgrade: If the drainage system is obsolete or insufficient, take this into consideration. To efficiently handle the volume of water, this may entail expanding the drainage channels, adding more pipes, or building new drainage structures.
- ❖ Encourage good garbage disposal habits within the community by implementing proper waste management. It is essential to educate locals on the value of responsible trash management because improper waste disposal can cause sewer clogs.

- ❖ Encourage community involvement by including the neighborhood in drainage system upkeep. To keep the drains clear, remind locals to report any drainage problems right away and involve them in routine cleaning programs.
- ❖ Create a monitoring system: Install a monitoring system to check the drainage system frequently and spot possible problems before they get worse. This will facilitate preventative upkeep and prompt fixes.
- ❖ Consult with civil engineers or regional agencies with expertise in drainage systems to acquire professional advice and direction on the most effective strategies to handle the unique drainage problems in Akaki Kality.

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APPENDIX 1: Manuscript for Publication

Investigating the main causes of stormwater failure in the case of Akaki Kality sub-city

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Abstract

Urban areas, especially rapidly growing ones like Akaki Kality in Addis Ababa, often face significant challenges in managing stormwater drainage effectively. This thesis investigates the state of the current drainage infrastructure, the causes of stormwater failure, and strategies to sustain stormwater drains in Akaki Kality.

The evaluation of the drainage infrastructure reveals a mixed picture, with some areas well-served by modern infrastructure while others rely on outdated systems prone to deterioration. Structural issues such as aging pipes, inadequate maintenance, and silt accumulation from flooding contribute to frequent drainage failures.

Through stakeholder interviews, surveys, and field assessments, the primary causes of stormwater failure are identified, including improper waste disposal, lack of maintenance, siltation from flooding, and urban growth pressures.

Based on these findings, a set of strategies is proposed to enhance the sustainability of stormwater drains in Akaki Kality. These include infrastructure upgrades, regular maintenance and cleaning schedules, public awareness campaigns, green infrastructure solutions, sediment control measures, improved design standards, and policy/regulatory interventions.

Implementing these strategies will improve the resilience of the drainage system, reduce flooding incidents, protect property, and enhance public health and quality of life for residents in Akaki Kality.

Keywords: Drainage failure, Flooding, Public awareness, Stormwater drainage, Sustainability

1. Introduction

The drainage system is a technique for managing excess surface water in right-of-ways and for draining it. Drainage systems have a big impact on a pavement's ability to withstand the effects of traffic and the environment (Leta, 2020). Urban drainage is a component of the water infrastructure that aims to prevent obstructions to pedestrian and vehicle freedom of movement, material damage from torrential flows, and harm to the environment and public health from rainfall in urban areas (Silveira, 2002).

Urban areas require drainage systems because human activity combined with the natural water-cycle produces waste water and storm water (Leta, 2020).Waste water results from water being used to sustain life; it may be polluting and hazardous to human health. It includes dissolved material, fine solids, and bigger solids that come from using the toilet and washing with different kinds of water. Storm water is rain (or any other type of precipitation-related water) that has fallen in a populated area. If storm water is not adequately drained, it could result in annoyances, damages, flooding, health hazards, and some pollutants that come from the catchment surface, air, or rain (David, 2018).

Since it impacts the serviceability and useable life of highways, adequate drainage is crucial for highway design. Hydrology is primarily concerned with the movement of water on the earth's surface, especially that portion that eventually crosses major thoroughfares (such as highway stream crossings). Interior drainage for road ways, median areas, and interchanges is a secondary concern (Meraf, 2015). The drainage plans call for the provision of infrastructure for the collection, transportation, and removal of water from the highway.

Service An inefficient drainage system can significantly shorten the life of infrastructure. Surface water has been seen to cover the highways during the rainy season. This water causes a loss in revenue by quickening the rate of road damage. Inadequate road drainage systems and a lack of connection between the road and the urban storm water drainage network are to blame for the flooding on the highways (Tadele, 2017). Because it influences the serviceability and useable life of the road, as well as the structural strength of the pavement, storm water drainage is a crucial element in the construction of roads (Fikadu, 2018).

Over the past 20 years, Addis Abeba has undergone significant infrastructure improvements; yet, the city's drainage system has long been criticized for being inadequate and obsolete. As summer approaches, it's not uncommon to see the city's streets completely submerged in rainwater. Lack of properly planned drainage and sewage infrastructure is the problem's obvious symptom.

In Addis Abeba, sewage is illegally connected to local rivers and storm drainage systems as well as dumped in an open, uncontrolled manner. Public health and the appearance of the city are being impacted by the situation (Fikadu, 2018).This situation has become one of the major challenges for the city administration.

Flooding, deteriorating roadways, soil degradation, sedimentation, obstruction of drainage facilities, water logging, etc. are examples of drainage issues in metropolitan areas (Fikadu, 2018). People frequently move away from their homes and toward industrial areas in pursuit of economic opportunities and a better standard of living. Rapid urbanization surrounding industries has the side effect of altering the land cover, mostly by turning vegetated areas and arid plains into impermeable pavements and infrastructure (Guptha, 2021).This would have an immediate impact on the hydrology of the system, and as a result, the functioning of the urban area's current drainage system is challenged by a high volume of storm water runoff generation (Guptha, 2021).

Urban flooding has been a common occurrence in many cities across the world since these drainage systems are frequently inadequate to handle the rising urban runoff. Due to urban densification, which primarily changes runoff parameters including volume, peak flow, time to peak, and time of concentration, properly managing urban storm-water has therefore become extremely difficult in recent years (Guptha, 2021). The drainage system in Akaki Kality frequently fails, creating serious problems for the neighborhood. The issue is being exacerbated by excessive rainfall and poor infrastructure, which leads to flooding, waterlogging, and subsequent damage to buildings and roadways. Public health is at risk because stagnant water can serve as a breeding ground for illnesses and pests. It is crucial to address the drainage issues in Akaki Kality right once and put in place practical measures to lessen their negative effects on locals' quality of life and the area's overall growth.

The overall purpose of the study is to assess the effectiveness of the current drainage structures and to identify the main causes of drainage failure and to suggest mitigating actions to lessen the frequency of drainage structure failure in Akaki Kality sub-city. Specifically, it aims to evaluate the state of the current drainage infrastructure, to determine the drainage system's main difficulties, and to investigate how poor drainage performance affects road performance and population

3. Methodology

3.1. Study area

One of Addis Abeba's ten sub-cities, Akaki-Kality serves as both the city's and the nation's industrial hub. It is situated in the city's southern regions. The distance to the city's center is 20 kilometers (Emmanuel, 2007) . Akaki Kality is located in Addis Abeba, Ethiopia, at 8.895831 latitude and 38.789162 longitude. The GPS coordinates for Akaki Kality, Addis Abeba, Ethiopia are 8° 53' 44.9916" N and 38° 47' 20.9832" E. It is a place in the Districts place category in the country of Ethiopia. Additionally, it is 2,140 meters above sea level (LatLong.net, 2017).

3.2. Research approach

An approach to study known as mixed methods research involves gathering both quantitative and qualitative data, integrating the two types of data, and employing unique designs that may include philosophical presumptions and theoretical frameworks. The fundamental premise of this type of study is that using both qualitative and quantitative methods together yields a more comprehensive grasp of a research problem than each method by itself (Creswell, 2009).

3.3. Data collection methods and source of data

I used both primary and secondary data collection strategies when I was performing the study. These methods were used to obtain comprehensive information from citizens and professionals. Data came from both primary and secondary sources. Primary data are the data that were gathered specifically for the aim of analyzing the current study issue. While secondary data are those that were gathered for purposes other than the current study but before it was started.

Both primary and secondary data were used to completely understand a certain set of data. Information that the researcher directly obtained from sources like surveys, interviews, or observations is referred to as primary data. It makes it possible for us to obtain specialized and individualized information straight from the source.

Contrarily, secondary data refers to information that already exists and was obtained for a different purpose. It is possible to employ information from publications like books, journals, official papers, or online databases in this. Secondary data allows us to compare and contrast information from numerous sources and offers our conclusions a more thorough context.

By merging primary and secondary data, we can increase the reliability and validity of our conclusions. Using primary sources ensures that information is accurate and up to date. Primary data was collected through a survey and direct questionnaires obtained from different populations by non-probability purposive sampling techniques involves selecting specific individuals or cases that are most relevant to the research objective by selecting residents how long they stay in the area.

Secondary data was compared to primary data in order to support the information from primary sources. Therefore, secondary data was employed, such as instructions linked to the drainage program, legal documents, websites, strategy documents, manual report documents, and directives. Additionally, a number of reports and other papers were examined to gather relevant information

Combinations of various data gathering tools will be developed and used to collect first-hand information. Beneficiaries were asked to complete a series of surveys that are made up of both open-ended and closed-ended questions in order to provide quantitative data. The questions are direct and I shall answer them on my own. I anticipate that some respondents may not be able to read and write, which is the main reason. Qualitative information will be acquired from the key informants via interview and observation in order to triangulate and supplement responses given through questionnaires as well as to provide an answer for the how component of the research question.

A questionnaire was created and used to gather pertinent information from people of AACRA, Akaki kalti sub-city, including employees, nonemployees, experts, and officials. It was used as the primary data collection tool because it is easy to use and allows for quicker responses from respondents. It helps get relevant data and acquire information from numerous respondents at once. Additionally, it permits respondents to answer questions in confidence and permits me to use representative samples as a source of data to prevent biases from being exposed. Semistructured interview was used as an instrument to collect useful information from experts and officials of AACRA and experts who are working on social participation at sub-city level.

3.4. Sampling design

To determine the sample size I started by identifying the key stakeholders or areas within Akaki Kality that are most affected by drainage failure. This might include residents, local government officials, or experts in the field. Then, I can purposively select a representative sample from these identified groups.

It is important to note that the sample size should be determined based on the research objectives and the resources available. Ideally, the sample size should be large enough to capture the diversity of cases and provide meaningful insights into drainage failure in Akaki Kality. Residents: The individuals living in the area who are directly affected by drainage failure and its consequences.

3.5. Methods of data analysis

The data was gathered using a number of tools, and it was then analyzed using several descriptive statistical tools. It was possible to acquire edited, categorized, and coded replies from self-administered surveys. Statistical software for social science (SPSS) was used to perform descriptive, correlational, and regression analyses on the data that had been gathered. Data in the form of percentages, means, and standard deviations analyzed, described, and interpreted using the descriptive data analysis approach. In order to investigate the strength of the association between the dependent and independent variables, correlation analysis will be used. However, multiple regression analysis is a technique used to investigate the relationship between a dependent variable and a group of independent factors in order to understand the relative degree of each independent variable's influence on the dependent variable and to make predictions. In addition, the qualitative technique will be used in this study to complement the findings and fill in any questionnaire gaps. Individual interviews will be used to perform this part of the study. In-depth explanations are sought from AACRA drainage design professionals during the interview.

4. Results and Discussion

4.1. What are the primary causes of drainage failure?

Residents improper waste disposal activity

Residents' willful or not willful disposal of solid waste is the main cause of drainage system failure. Pipes that solidify in external pipes is one of the most frequent reasons of blocked drainage systems. They frequently put their waste down in drainages, which clogs them and prevents the water from flowing normally, leading to overflows. After a brief period of rainfall, it's usual to see flooded streets with trash floating everywhere. The accumulation of domestic substances like soap, hair, food, and fat in the Accumulation of debris, such as leaves and dirt, which rain and storms push into gutters and drains. Not all particles cause blockages in drains. For example, suspended particles quickly flow to drainage basin's major water bodies, however larger particles are occasionally left in these drains where they accumulate and cause obstructions. In general, the more significant ones or other solid items, like solid household garbage, can contribute to drain blockage. From the total respondents 33(42.9%) were agreed and 19(24.5%) were strongly agreed that residents improper waste disposal activity is highly affecting drainage system.

Table 4.2: Residents improper waste disposal activity

Rate	Frequency	Percent
Disagree	3	3.9
Neutral	22	28.6
Agree	33	42.9
Strongly Agree	19	24.7
Total	77	100.0

Silt caused by flooding

By obstructing pipes or by filling soak away and attenuation systems, silt can hinder a drainage system's ability to remove surface water and reduce its capacity to hold water. As silt accumulates, there is a greater chance that water will not drain away, resulting in flooding on the surface and eventually necessitating the replacement of the drainage system. From the total 77 respondents 37(48.1%) of them agree and 11 (14.3%) of the respondents were strongly agree that silt caused by flooding will affect the drainage system of the study area.

Table 4.3: Silt caused by flooding

Rate	Frequency	Percent	Cumulative Percent
Strongly Disagree	1	1.3	1.3
Disagree	6	7.8	9.1
Neutral	22	28.6	37.7
Agree	37	48.1	85.7
Strongly Agree	11	14.3	100.0
Total	77	100.0	

Poor drainage design

To ensure that the design is accurate, the designer must take into account all load scenarios or load combinations. For instance, it would be appropriate to run the design again to identify the most important load scenario or combination when the drain is full and empty. A drainage plan will offer a safe and efficient approach to handle storm water as well as help to prevent water damage to the road's foundation and structure. From the information I got there is drainage design problem like inadequate pipe size, drainage facilities, kind of drainage and slop of the drainage. From the total respondents 25(32.5%) respondent agree and 18(23.4%) respondents strongly agree that poor drainage design can affect the drainage system.

Table 4.4 : Poor drainage design

Rate	Frequency	Percent	Cumulative Percent
Strongly Disagree	6	7.8	7.8
Disagree	12	15.6	23.4
Neutral	16	20.8	44.2
Agree	25	32.5	76.6
Strongly Agree	18	23.4	100.0
Total	77	100.0	

Blockage or obstruction

Rather than residents poor waste disposal activity it is common to see improper disposal of leftover materials during construction because of this unnecessary wastes the drainages were blocked. And after the completion of any constructions it can be road or any other construction near the road should be cleaned to keep the drainage safe. From the total respondents 22(28.6%) were agree and 12(15.6%) were strongly agree that this reasons of blockage can lead to failures on the drainage.

Table 4.5: Blockage or obstruction

Rate	Frequency	Percent	Cumulative Percent
Strongly Disagree	4	5.2	5.2
Disagree	17	22.1	27.3
Neutral	22	28.6	55.8
Agree	22	28.6	84.4
Strongly Agree	12	15.6	100.0
Total	77	100.0	

Lack of community participation in cleaning and maintenance

The storm-water conveyance system collects and moves urban runoff that might include specific contaminants as a result of its role. Regular maintenance of catch basins, storm-water inlets, and other storm-water conveyance structures removes pollutants, prevents clogging of the downstream conveyance system, restores the capacity of catch basins to trap sediment, and makes sure the system is hydraulically sound to prevent flooding. A neighborhood drainage committee can at least keep an eye on the operation of the system and notify the appropriate officials of any flaws or inadequacies. Many times, the community can also do the majority of the regular maintenance tasks. Then, there needs to be effective coordination and a distinct separation of duties. However, a lack of community cooperation will result in negligence and a loss of a sense of belonging, which pose serious health, flood, and other threats to the neighborhood. From the total respondents 39(50.6%) were agree and 7(9.1%) were strongly agree that lack of community participation is affecting the drainage.

Table 4.6: Lack of community participation in cleaning and maintenance

	Frequency	Percent	Cumulative Percent
Strongly Disagree	1	1.3	1.3
Disagree	7	9.1	10.4
Neutral	23	29.9	40.3
Agree	39	50.6	90.9
Strongly Agree	7	9.1	100.0
Total	77	100.0	

4.2. How does this failure affect the population and the road?

The impact of poor drainage on the population

Failure of the drainage system may have a big effect on the local population. Particularly during the wet season, inadequate drainage systems might result in frequent floods. People may be forced from their homes, infrastructure may be harmed, and even lives may be lost as a result.

Floods brought on by poor drainage have the potential to contaminate water supplies and spread diseases like cholera and dysentery. Since they act as a home for parasites and other microorganisms that spread disease, open drains provide a health danger to the neighboring population if they are not cleaned. Additionally, once the rainy season arrives, water-borne infections and viruses can spread swiftly through open drains. For instance, in the standing water that open drains provide, agents that act as intermediate hosts for diseases caused by bacteria, protozoa, and viruses generally thrive. The unclean, stagnant water in open drains is rather unpleasant to be around and ugly for people who live near to them. People who live next to open drains find the dirty, stagnant water in them to be quite unpleasant to be around and unsightly. They may also be an annoyance, particularly in areas with a high concentration of youngsters who might jeopardize their health by playing near contaminated water. These diseases can spread quickly, especially in densely populated areas with limited access to clean water and proper sanitation facilities.

Low-lying locations frequently experience flooding and waterlogging due to an inadequate drainage system and clogged open drains. The obstructed water conflicts with the villagers' way of life. A single flood could displace populations and result in fresh health problems.

So the main impacts are:-

Flooding:-Because of its low-lying sections and insufficient drainage systems, Akaki Kality is vulnerable to flooding. Failure of the drainage system can make this problem worse by causing frequent, catastrophic floods during the rainy season. Flooding can result in severe suffering and loss for the impacted population by damaging homes, impeding transportation, and uprooting communities.

Health hazards:-Insufficient drainage can cause stagnant water, which can serve as a breeding ground for mosquitoes and other disease-carrying vectors. This threatens public health by raising the risk of mosquito-borne illnesses including malaria and dengue fever. Additionally, poor drainage can contaminate water sources, causing illnesses like cholera and dysentery that are transmitted through the water.

Economic impact: A number of commercial and industrial operations are located in the Akaki Kality sub-city. Drainage problems can cause financial losses and economic stagnation by upsetting businesses and industries. Additionally, it can harm roads and other infrastructure, which will impact trade and transportation.

Degradation of the environment: Poor drainage systems can cause soil erosion, sedimentation, and water body contamination. The local ecosystem could be harmed, which would have an impact on the biodiversity, aquatic life, and general environmental quality.

The impact of poor drainage on the road

Road deterioration

Road surface water ponding and accumulation can be caused by insufficient drainage systems. This could speed up the deterioration of the road's pavement, resulting in cracks, potholes, and general road degradation. The foundation is weakened as a result of water seeping into the roadbed, which shortens the lifespan of the road infrastructure and causes further damage.

Due to accumulations of silt and other solid objects drained down the drain, open drains typically become clogged over time. Flooding caused by blockages during the rainy season destroys roads. Even worse, as granular moisture concentration increases, so does the pace of road deterioration. Traffic safety is compromised by poor drainage. Water accumulating on the road may cause ponds to form. When there is a buildup of water after rain, aquaplaning is more likely to happen. Longer stopping distances are the effect of decreased friction from a wet surface. Roads with poor drainage require a number of expensive repairs or replacements before they reach the end of their intended life. Early failures and enduring pavement distresses result from water being trapped within the pavement and creating a "bathtub" state. This is because it is unusual for the layer to serve as a reliable drainage layer due to the gradation and quality of the layer's components.

Costlier maintenance actions are needed more frequently because of drainage failure. The stability of the road might be harmed by erosion when water is not properly drained from the road surface. Drainage failure-related road maintenance and repairs can be costly and time-consuming, taking resources away from other crucial infrastructure projects.

Traffic snarls: Water buildup brought on by poor drainage can impede the flow of traffic, causing congestion and delays. Driving conditions might become hazardous due to puddles and standing water, which raises the possibility of accidents. In extreme circumstances, it might even be necessary to close roads, which would put commuters and businesses through further hardship and interruption.

Safety risks: Cyclists and pedestrians may be put in danger if there is a drainage issue. Water puddles on bike lanes or sidewalks can render them unusable, requiring bikers and pedestrians to cross busy streets. Accident risk rises as a result, endangering the safety of hapless road users.

5. Discussion

Planning problems according to their contribution to drainage failure.

Table 4.7: Planning problems according to their contribution to drainage failure

	Mean	Standard Deviation
Age of the drainage System	3.36	1.224
Maintenance and Cleaning Frequency	3.21	1.080
Source of water entering the drainage System	3.40	1.280
Blockage or obstruction	3.27	1.131
Construction activities or infrastructure changes	3.36	1.202
Pipe Condition	3.48	1.046
Proper installation and construction	3.19	1.246
Poor maintenance practices	3.06	1.281
Design Flaws: Inadequate Sizing, improper slop etc...	3.48	1.231

As indicated in the above table the mean values of different planning problems are given. The mean score ranges from 3.06 - 3.48 this implies that the listed causes can strongly contributes drainage failure. According to interview held with the experts they strongly agree that inadequate size, poor maintenance, age of the drainage and the like affects the drainage.

Cause of drainage blockages on their contribution of drainage failure

Table 4.8: Cause of drainage blockages on their contribution of drainage failure

Cause of drainage blockages	Mean	Std. Deviation
Improper waste disposal practice	2.99	.866
Lack of proper cleaning of drainage system	3.47	1.021
Silt caused by flooding	3.66	.868
Rainfall intensity or flooding events	3.48	.837
Poor maintenance practices	3.21	1.017
Age of the drainage System	3.19	.918
Maintenance and Cleaning Frequency	3.73	.821
Pipe Condition	3.48	.771

As listed in the above table the mean values for different causes of drainage blockage are ranged from 2.99 – 3.73. This indicates that maintenance and cleaning frequency (3.73), silt caused by flooding (3.66), lack of proper cleaning (3.47) and others causes listed in the table causes blockage on the drainage.

In what extent did lack of community's participation and poor Infrastructure affect drainage?

As indicated in the table below the mean values for the communities practice and poor infrastructures that causes drainage failure are given. The result which is mean value range from 3.18 – 3.83 indicates that the reasons are strongly affecting drainage failure in the study area. Dumping waste, community carelessness and lack of community cleaning frequency are lack of community participation are highly affecting the drainage. Poor drainage design, low quality pipe and inadequate sizing are poor infrastructure factors that causes failure in drainage.

Table 4.9: In what extent did lack of community's participation and poor Infrastructure affect drainage?

Statement	Mean	Std. Deviation
Poor drainage design	3.31	.950
Dumping waste	3.27	.927
Low quality Pipe	3.18	.884
Improper installation and construction	3.60	1.016
Community Carelessness	3.56	.786
Design improper Flaws: Inadequate Sizing, improper slop etc...	3.83	.785
Lack of Community Cleaning Frequency	3.57	.834

6. Conclusions

The lack of adequate drainage and the area's topography contribute to flooding. Site observations reveal that the existing drainage system is composed of closed ditches on main roads and open ditches on feeder ways, filled with solid waste, leading to out-of-service and causing flooding during rainy seasons.

Residents' improper waste disposal activity is the main cause of drainage system failure, with pipes solidifying in external pipes and clogging them. This leads to overflows and flooded streets. The accumulation of domestic substances, debris, and domestic substances also contributes to drain blockage. The study found that 42.9% of respondents agreed that residents' improper waste disposal activity is highly affecting the drainage system.

Silt caused by flooding can hinder a drainage system's ability to remove surface water and reduce its capacity to hold water. Inadequate drainage design, such as inadequate pipe size, facilities, and slop, can also affect the drainage system. Design flaws include inadequate sizing and improper slop.

Blockage or obstruction is common during construction, as leftover materials during construction can block drainages. After completion, roads and construction near roads should be cleaned to maintain drainage safety.

Lack of community participation in storm-water conveyance system cleaning and maintenance is a significant issue, as it collects and moves urban runoff with contaminants. Regular maintenance removes pollutants, prevents clogging, and ensures the system is hydraulically sound for flooding. A neighborhood drainage committee can monitor the system and notify officials of flaws. However, a lack of community cooperation can lead to negligence, loss of belonging, and health risks.

The study examines the impact of various planning problems on drainage failure, with the mean scores ranging from 3.06 to 3.48. The causes of drainage blockages include inadequate size, poor maintenance, age of the drainage system, improper waste disposal practice, lack of proper cleaning, silt caused by flooding, and lack of proper cleaning. The lack of community participation and poor infrastructure also contribute to drainage failure.

Drainage failure in Akaki Kality has significant impacts on the population and the road. Inadequate drainage systems can lead to frequent flooding, especially during the rainy season, causing displacement, damage to infrastructure, and loss of lives. Floods can also contaminate water sources, leading to waterborne diseases like cholera and dysentery. Open drains, which serve as a haven for parasites and bacteria, also pose health risks to nearby residents. Open drains can transmit water-borne illnesses and diseases, making them unpleasant and annoying for residents.

Flooding and waterlogging occur in low-lying areas due to ineffective drainage systems and blocked open drains, affecting locals' way of life. Flooding alone can uproot populations and cause new health issues. The main impacts include flooding, health hazards, economic impact, and environmental degradation. Inadequate drainage can cause stagnant water, breeding grounds for mosquitoes, and disrupt businesses and industries, affecting economic development and infrastructure. Poor drainage systems can also lead to soil erosion, sedimentation, and pollution, harming the local ecosystem and affecting biodiversity, aquatic life, and overall environmental quality.

Drainage failure can cause road deterioration, causing rapid pavement deterioration, cracks, potholes, and overall degradation. Open drains become clogged, leading to flooding and increased granular moisture content. Poor drainage compromises traffic safety, causing ponds and aquaplaning. Roads with poor drainage require costly repairs or replacements, and trapped water can lead to early failures and persistent pavement distresses.

Maintenance costs increase due to erosion and undermining road stability. Repairing and maintaining roads affected by drainage failure can be expensive and time-consuming, diverting resources from other infrastructure projects. Traffic disruptions occur due to accumulation of water, causing congestion, delays, and hazardous driving conditions. Road closures may also be necessary in extreme cases.

Lastly, drainage failure creates safety hazards for pedestrians and cyclists, making them impassable and increasing the risk of accidents. Addressing drainage issues is crucial for maintaining the safety of road users and ensuring the long-term success of infrastructure projects.

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APPENDIX 2: Data Collection Instrument

Questionnaire

REQUEST TO FILL IN QUESTIONNAIRE

I am a postgraduate student of the Department of urban planning, Ethiopian institute of Architecture and Building construction and city development who is conducting a research on the topic: Investigating the Causes and Impacts of Drainage Failure: in the case of Akaki Kality, Ethiopia in partial fulfillment of the requirements for the award of the Degree of Master in Urban planning.

This questionnaire seeks to collect data related to The Relationship of different causes with their contribution to drainage failure. Hence, your sincere and objective response in filling in the questionnaire will be highly appreciated. Respondents have a liberty to withdraw the consent at any time if you are not comfortable. And also you may choose not to answer any questions that you may find not comfortable with. All responses will be treated with utmost confidentiality and will only be used for the purpose of this study.

Thank you for your anticipated cooperation.

Yours sincerely,

Dear Respondent please read carefully the instructions below before starting to answer the Questionnaire.

1. No need of writing your name
2. Please fill the answer by putting □mark on the appropriate multiple choice and Liker scale questions.
3. Please give your attention and return the completed questionnaire as much as possible.

SECTION A: Demographic Information

Respondents' background information (please tick □ your most right choice as appropriate).

1. **Gender of respondent:**

Male☐ Female☐

2. **Age of respondents:**

18-25 ☐ 26-30☐ 31-4☐ 41-4☐

46 – Above ☐

3. How long have you Lived in the area?

Less than 1 yea ☐ 2-5 yea ☐ More than 5 y ☐

4. Status:

Professionals ☐ Resident ☐

SECTION B: Main Data

Please, read the statements in each part carefully and decide how you feel about them before making a selection by **ticking □ the appropriate box**, which has the following Rating scales:

5. Please rate the following planning problems according to their contribution to drainage failure.

1= Strongly Disagree	**2= Disagree**	**3= Neutral**	**4= Agree**	**5= Strongly Agree**

S/N	**Statements**		**Rating scales**			
		1	**2**	**3**	**4**	**5**
1	Age of the drainage System					
2	Maintenance and Cleaning Frequency					
3	Source of water entering the drainage System					
4	Blockage or obstruction					
5	Construction activities or infrastructure changes					
6	Pipe Condition					

7	Tree root intrusions					
8	Proper installation and construction					
9	Rainfall intensity or flooding events					
10	Poor maintenance practices					
11	Blockage or Obstruction					
12	Design Flaws: Inadequate Sizing, improper slop ETC...					
13	Soil Condition					
14	Improper Drainage Police					
15	Residents Activity(Improper Disposal of Waste)					
16	Climate or Whether Condition					
17	Natural Disaster like Land Slide					
18	Utility Company unplanned work(Ethiotele, EEU, ...)					

Please include any other system adopt in your organization which you feel to be important: ______

____

____

6. Please rate the following cause of drainage blockages on their contribution of drainage failure

1= Strongly Disagree	2= Disagree	3= Neutral	4= Agree	5= Strongly Agree

S/N	Statements		Rating scales

		1	2	3	4	5
1	Improper waste disposal practice					
2	Lack of proper cleaning of drainage system					
3	Silt caused by flooding					
4	Rainfall intensity or flooding events					
5	Poor maintenance practices					
6	Age of the drainage System					
7	Maintenance and Cleaning Frequency					
8	Pipe Condition					
9	Climate or Whether Condition					

Please include any other effects of financial incentives which you feel to be important: __________

____

____

7. In what extent did lack of community's participation and poor Infrastructure affect drainage?

1= Strongly Disagree	2= Disagree	3= Neutral	4= Agree	5= Strongly Agree

S/N	Statements		Rating Scales			
		1	2	3	4	5
1	Poor drainage design					
2	Dumping waste					
3	Low quality Pipe					
4	Improper installation and construction					
5	Community Carelessness					
6	Design improper Flaws: Inadequate Sizing, improper slop etc...					

7	Lack of Community Cleaning Frequency					

Please include any other effects of financial incentives which you feel to be important: ________

____