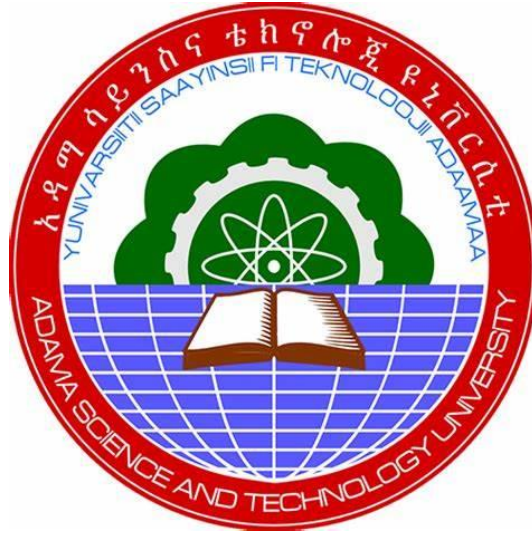


ASSESSMENT OF IMPACT OF POOR URBAN DRAINAGE SYSTEM ON ROADS IN FLOOD PRONE AREAS: THE CASE OF ADAMA CITY



Getu Assefa Mulatu

A Thesis Submitted to the Department of Architecture
School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Urban
Planning and Desing

Office of Graduate Studies
Adama Science and Technology University

Adama, Ethiopia

May, 2024

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Declaration

I declare that this Master Thesis entitled “Impact of poor urban drainage system on roads in flood prone areas: The Case of Adama City” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

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Recommendation

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “Impact of poor urban drainage system on roads in flood prone areas: The Case of Adama City” prepared under my guidance by Getu Assefa submitted in partial fulfillment of the requirements for the degree of Master’s of Science in Urban Planning and Design. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

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We, the undersigned, members of the Board of Reviewers of the thesis by Getu Assefa have read and evaluated the thesis entitled “Impact of poor urban drainage system on roads in flood prone areas: The Case of Adama City” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Urban Planning and Design.

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LIST OF ACRONYMS

ADB	Asian Development bank
DDM	Drainage Design Manual
DEM	Digital Elevation Model
DFT	Department for Transport
ERA	Ethiopian Road Authority
EU	European Union
GIS	Geographic Information System
GPS	Global Positioning System
UN	United Nation
WB	World Bank

ABSTRACT

Urban areas, particularly in developing countries, are often plagued by poor drainage systems, leading to frequent flooding and disruption of transportation. This research focused on Adama City, a flood-prone area in Ethiopia, and investigated the impact of its urban drainage system on roads. Despite being among the largest urban infrastructures urban drainage systems do not always function flawlessly. Failures in urban drainage system occur regularly in practice, resulting in malfunctioning systems, and high costs. To anticipate their malfunctioning, and thus to improve their performance, a better understanding of failures occurring in urban drainage system and their underlying causes was needed. Using a mixed-methods approach, the study employed questionnaires, site visits and semi-structured interviews with urban professionals, engineers and authorities. This study presented an inventory of causes of poor urban drainage system, an analysis of their root causes and their impact on roads then recommending mitigation strategies. For identification of flood prone areas GIS-based hydrological modeling, quantitative analysis, and qualitative surveys were implemented. This research implemented both probability and non-probability sampling techniques; thus, purposive sampling and random sampling were used to decide locations to be studied and passengers to be asked respectively. Both primary and secondary data collection methods were implemented in order to acquire the appropriate data. The results showed that the interfaces between drainages and other urban systems are prominent failure locations. In addition, the study found that failures originate from the entire development process of urban drainage system, i.e., from the design, construction and user/maintenance phase. With respect to the causes underlying these failures, the results showed that these are mainly socio-institutional in nature. The study also concluded road blockage by waste and surface flood, reduced load bearing and roadside surface erosion as the major impacts of poor drainage on roads. The study at the end set out list of mitigating strategies for the identified root causes and for the impacts that poor drainage causes on roads.

Key Words: *Urban Drainage, Flood Prone Areas, Road*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Drainage system is a process of removing & controlling excess surface water with in right of way. Drainage is an important feature in determining the ability of given pavement to withstand the effects of traffic and environment. (Adequate drainage is very essential in the planning of roads since it affects the highway's serviceability and usable life. If ponding on the traveled way occurs, hydroplaning becomes an important safety concern. Drainage design involves providing facilities that collect, transport and remove storm water from the highway (O'Flaherty, C.A. (2002).

The objective of drainage system is to prevent onsite water standing on the surface and convey the offsite storm runoff from one side of the roadway to the other. To carry out the offsite drainage. Culverts are closed conduits in which the top of the structure is covered by embankment. Transportation systems are vital component to the smooth functioning of daily life and to society's standard of living (Pant et al., 2018). Events like floods and extreme snowfalls can have adverse impacts on infrastructure function in the form of economic disruption and loss to social systems (Bil et al., 2015; Dong et al., 2020; Wisniewski et al., 2020). Nearly all transportation modes (e.g., roads, transit, aviation, etc.) are highly dependent on the supporting network of infrastructure, and are vulnerable to extreme events such as large floods (He et al., 2020). During these types of events, structural integrity and the safety of the infrastructure can be compromised, which can lead to serious consequences (Esposito et al., 2018). These flood events effect the transportation and its connectivity by reducing, deviating, or canceling travel for passengers, goods, and services due to roads being submerged, closed, or unsafe to travel (Douglas et al., 2017; Diakakis et al., 2020; He et al., 2020).

According to Esposito (2018), an effective transportation system is significantly important in sustaining economic growth in contemporary economies since it provides linkages between different parts of the country and the global world. It links to work, deliver products to market, underpins logistics and supply chain, and support local and international trade.

A good-established transportation system is not only key to national growth but also serves as catalyst for economic development of a country. Thus, there is a relationship between transportation and productivity (Lu et al. 2009). As the flooding can cause a serious impact on both the road access and its strength, an efficient drainage system is the most important part of road construction and maintenance works. Good drainage needs to be taken into consideration at the early planning stages in order to secure a long life for the road. Accidents may occur as a result of hydroplaning and loss of visibility from squish and sprig. The importance of enough drainage is recognized in the amount of highway construction dollars allocated to drainage facilities. About 25 percent of highway construction dollars are spent for erosion control and drainage structures, such as culverts, bridges, channels, and ditches (Wyatt et al, (2000).

Floods have direct effects on transportation through physical damage to infrastructure, and indirect effects that are the result of a cascade of adverse effects that can severely impact critical infrastructure (e.g., energy related infrastructure). They can lead to the failure of a city's infrastructure and economy (Pant et al., 2018; Serre and Heinzlef, 2018; Wang et al., 2020). Critical infrastructure like transportation systems, power grids, etc., are generally interdependent in cities. Within interdependent networks, failure of one element or node may result in failure of multiple nodes that are interconnected (Saidi et al., 2018; Wang et al., 2019). In light of climate change, cities are to expected to face an increase in devastating floods in the coming years, which are in turn compounded by increases in population size, urbanization, and impermeable surfaces (Pregnoiato et al., 2017a).

Surface drainage encompasses all means by which surface water is removed from the pavement and right of way of the street. A properly planned roadway surface drainage system should effectively intercept all surface and watershed runoff and direct this water into adequately designed channels and gutters for eventual discharge into the natural waterways. Water seeping through cracks in the roadway riding surface and shoulder areas into underlying layers of the pavement may result in serious damage to the pavement. The major source of water for this type of intrusion is surface runoff. An adequately designed surface drainage system will therefore minimize this type of damage.

1.2.Statement of the Problem

The transport system is an element of urban infrastructure which is important for daily life, enabling the movement of people, goods and services for social activities and community development at all levels (DeSousa and Franery, 2013; Xenidis and Tamvakis, 2012; Wang, 2015), and also plays a crucial role in the urban resilience to extreme flood incidents seen in some developing cities (Cigler, 2007; WB, 2012).

As the world's growing population is particularly concentrated in urban areas, developing cities have inherently become more vulnerable. Low-lying land areas only accounts for two percent of the world's land, but now houses 13% of the global urban population (McGranahan et al., 2007). Along with the general trend of 75% of the global population expected to be living in urban areas by 2050 (UN Habitat, 2009), the pressure of rapid development is resulting in larger (existing or new) infrastructures facing flood hazards.

Poor urban drainage system is affecting the road based on, inadequate drainage sections, conventional drainage system with low capacity and poor slope surface of the road of existing drainage system, and over and above disposal of solid waste into the drains and drainage paths are accounted for the prime causes of water logging. Urban drainage constitutes a vital part of water infrastructure systems in cities by limiting interruption of transportation services, protecting property, and inhibiting flood-related health issues (Fryd, O., 2012). As a result, poorly constructed storm water systems persist as an issue in developing communities. These ineffective systems often fail to cope with the storm water runoff volumes generated in growing urban landscapes during rainfall events, which exacerbates even small-scale floods.

Due to the combined effects of climate change and poor or inadequate drainage facilities, observing frequent surface floods during rainy seasons has become a common tragedy in most rapidly sprawling urban environments. The submergence of road surfaces due to flood inundation as a result of the inappropriate and poor performance of drainage facilities will significantly affect the subgrade soil or road foundations, which may lead to the deterioration of pavement structures (Schmocker, L, 2011). In addition, surface flooding has several destructive characteristics that adversely impact road performance, drainage structures' failure, and traffic-related accidents and transport disruptions.

The inadequacy of drainage system during the rainy season to pass the flood, poor quality construction and improper maintenance of some drainage systems with respect to the road alignment. This is the main reason why this study wants to analyze impact of poor urban drainage system on roads during the flood scenario and provide mitigating approaches.

According to Wikipedia, Adama, also known as Nazareth, is the fourth-most populous city in Ethiopia. Due to its rapid urbanization, high population density, and low elevation, Adama is highly prone to flooding, especially during the rainy season from June to September. Two studies by Leta B. and his colleagues have revealed that most of the city is at moderate to very high risk of flooding, which poses a serious threat to the lives, properties, and infrastructure of the residents (Leta B. *et al.*, 2024).

Adama City is grappling with a complex interplay of challenges that exacerbate its vulnerability to flooding. The city's flood-prone areas are further compromised by the presence of poorly designed drainage systems, which are ill-equipped to manage the water flow effectively. This issue is particularly pronounced during periods of heavy rainfall, a phenomenon that has become increasingly common in recent times due to noticeable shifts in the city's climate. The convergence of these factors – flood-prone topography, inadequate drainage infrastructure, and changing weather patterns – underscores the urgency of addressing this problem. The need for comprehensive research to rather give solutions and strong recommendations to alleviate the problems in sustainable urban planning and infrastructure development strategies in Adama City is therefore both timely and critical.

Inadequate drainage systems can lead to frequent and severe surface flooding, especially during periods of heavy rainfall. This flooding can disrupt transportation by causing road closures, traffic delays, and damage to infrastructure. It can also make certain routes impassable, forcing detours that increase travel times and disrupt the efficiency of the transportation.

Moreover, these issues can have a cascading effect on other aspects of urban life, including emergency response times, access to services, and overall quality of life for residents. Therefore, addressing these interconnected challenges is crucial for improving transportation efficiency and resilience in Adama City.

Certainly, the collective impact of flood-prone areas, poorly designed drainage systems, and changing weather patterns in Adama City has significant implications for the city's transportation.

1.3.Objective of the Study

1.3.1. General Objective

To analyze the impact of poor urban drainage system on roads in flood prone areas in Adama.

1.3.2. Specific Objective

1. To identify the major cause of poor urban drainage systems.
2. To analyze the major impacts of surface flood on the roads.
3. To suggest possible remedial measures in order to mitigate the urban drainage problem.

1.4.Research Question

This research attempts to answer the following questions:

1. What are the major causes of poor urban drainage systems in Adama City in flood prone locations?
2. How does surface flooding impact the road and pavements in Adama City?
3. What are the possible remedial measures that could be implemented to mitigate the urban drainage problem in Adama City?

1.5.Significance of the Study

By investigating the interplay between poor drainage systems, surface flooding, and transportation, this study could provide valuable insights that inform urban planning and infrastructure development strategies. The findings could guide the design of more effective drainage systems, thereby reducing surface flooding and improving transportation efficiency in flood-prone areas. This, in turn, could enhance the city's resilience to changing weather patterns, improve emergency response times, ensure better access to services, and ultimately, improve the quality of life for residents. Therefore, this research holds substantial practical implications for urban sustainability and resilience in Adama City and potentially other cities facing similar challenges.

1.6.Scope of the Study

The scope of this study is strategically delineated both spatially and thematically. Spatially, it is confined to areas within Adama City that are both flood-prone and burdened by poor urban drainage systems. Three locations were identified fit to these criteria from the flood history of the city; namely indicated as site A, site B and site C in chapter 4. Thematically, the study hones in on the impact of these inadequate drainage systems, particularly their role in exacerbating flooding during periods of heavy rainfall, and the subsequent effects on the city's transportation system. While the broader context of flooding is acknowledged, it is not the primary focus of the study. Instead, the research concentrates on the specific intersection of poor drainage, flooding, and transportation in these vulnerable areas.

1.7.Limitation of the Study

The study is confined to Adama City, and the findings may not be applicable or generalizable to other cities or regions with different geographical, climatic, or urban planning characteristics. The study primarily focuses on the intersection of poor drainage, flooding, and transportation. Other potential impacts of inadequate drainage systems, such as health risks or environmental damage, are not explored in this study. The study's conclusions are dependent on the availability and accuracy of data regarding flood-prone areas, urban drainage systems, and transportation networks within Adama City. The study may not account for future changes in climate patterns, urban development, or improvements in drainage systems and infrastructure, which could alter the dynamics of flooding and its impact on roads.

1.8.Definition of Key Terms

a. Urban Drainage

Urban drainage refers to the system responsible for draining surface water runoff from built-up areas to prevent flooding. It involves the use of gullies and underground pipe systems designed to convey the water away as quickly as possible.

b. Transportation

Transportation is a framework of routes linking locations. It describes an infrastructure that permits and constrains movement or flow.

c. Road Performance

Road performance can be evaluated using various metrics such as the condition, use, and operating characteristics of the road.

d. Flooding

Flooding is an overflowing of water onto land that is normally dry. It can happen during heavy rains, when ocean waves come on shore, when snow melts quickly, or when dams or levees break.

1.9.Organization of the Research

The thesis is structured into five comprehensive chapters, each meticulously examining the study's data and content. The foundational chapter of the thesis is further elaborated as follows:

Chapter One: Introduction: This chapter sets the stage for the thesis by illuminating the primary topic of the study, research problems, objectives, questions, significance, scope, operational definitions, and organization.

Chapter Two: Literature Review: This chapter delves into key definitions of urban drainage, transportation, resilient approaches, and trends. It encompasses both empirical and theoretical frameworks.

Chapter Three: Research Methodology: This chapter explicates the research methodology. It provides a detailed account of the methods employed in the study and the process of data collection and analysis.

Chapter Four: Results and Discussion: This chapter presents and discusses the findings from both qualitative and quantitative data. The quantitative data are derived from physical measurements, while the qualitative data are analyzed based on a questionnaire survey, field observation notes, and printed documents.

Chapter Five: Conclusion and Recommendations: This final chapter concludes the research. It draws conclusions based on the findings from the measurements and their comparison with the standard, and it also provides recommendations.

CHAPTER TWO

2. LITERATURE REVIEW

2.1.Introduction

As rapid and uncontrolled development has resulted in increasing flood vulnerability in several developing cities, resilience has emerged as a conceptual theory to help such cities deal with adverse events. This chapter reviews the contemporary literature on flood vulnerability in relation to resilience to flooding. As part of a vision for transport planning, this will lead to opportunities for theoretical flood resilience development, relying on the properties of a resilient system with a focus on application at a city level within a planning framework.

2.2.Theoretical Review

2.2.1. Trends in developing countries

Urban growth can be traced back to the 19th century, when economic drivers provided an impulse for territorial expansion as a direct impact of industrialization (Hall and Jones, 2011). This trend has continued to the present day. Often adjacent to main water bodies (which also serve as a major transport mode), old towns were normally founded on land which provided suitable conditions for urban settlement, such as sources of pure water, high elevations against flooding risk, and easy connections to new urban areas. These lands would be planned for development but would be limited to certain population levels and territorial areas, while the surrounding areas were normally left unused, due to their disadvantages in relevance to low terrain subject to flood risk. As rising urban populations produce higher demand for accommodation, the availability and lower cost of such lands can be seen as a dominant driver for property development. Thus, urbanization in these areas can therefore lead to a decline in permeable surfaces (green land or water areas) and water storage capacity, resulting in a higher risk of flooding. Cigler (2007) stated that a growing imbalance between the natural and human environment has led to a higher risk of urban flooding.

In line with global trends, the cities of developing countries have also experienced much more rapid urbanization tendencies. In an investigation of global urban expansion in 90 cities worldwide, Angel et al. (2005) projected that built-up areas would expand from 200,000 km² in 2010 to 600,000 km² by 2030, with a doubling of the population in developing countries.

However, these cities are more vulnerable to the impacts of climate change, as they do not have enough financial power to prepare for urban adversity, nor experience of urban planning and management to control (WB, 2010). As a result, these cities are predicted to continuously see populations and assets being concentrated in vulnerable areas. Indeed, the results from the research of Hanson et al. (2008) show a large number of cities in developing countries in Asia with highly exposed populations and assets at risk from climate change impacts (WB, 2010; ADB, 2010; Storch and Downes, 2012; Phi, 2013).

2.2.2. Transport development and flooding

Associated with the urbanization process, the appearance of new suburbs has become a significant driver for transport development, with an expansion of the network from the old centers to surrounding areas.

Dominating the 20th century, the growing trend of urbanization will also importantly affect the remainder of the 21st century, particularly in developing countries. This not only reflects the trend of increasing concentration of people and assets over specific areas, but also refers to mobility problems linked to urban activities particularly in major cities where residents have different demands, lifestyles and levels of consumption (Rodrigue et al., 2006). Wang (2015) states that the change in land use, in terms of demand and planning of places for people to work and live, has an inextricable link with the transport system, as a direct result of various decisions by inhabitants and policymakers. “Transportation is the spatial linking of a derived demand” (Rodrigue et al., 2006), and its network is normally upgraded in relation to expansion of physical infrastructure in practice (ibid).

Thus, key infrastructure investments, mainly in transport structures such as highways, elevated roads, bridges and metro lines, have been recently used by local governments to ensure the connections between existing city centers and new development areas as emerging-cities continue the expansion of urban territory. Land-routes can be extended to meet the requirements of the growth of built-up areas providing connections to existing urban areas, such as city centers (Rodrigue et al., 2006). In fact, faced with the challenge of financial investments, the effectiveness of planning for transport investments in these cities is really concerned, not only to meet the increasing demand of transport capacity, e.g. reduce congestion, but also to help deal with other environmental effects, such as flooding.

Potential integration between these objectives can be seen as an opportunity to improve resilience with appropriate transport plans following spatial planning for urban development.

In addition to the problem of flooding, it appears that transport development also challenges the planning and management process in terms of its interaction with existing drainage system. The expansion of built-up areas normally leads to horizontal development of transport network, such as number of routes or width of road developments, but the efficiency in transport development in the long-term is considerable when the city not only deals with the pressure of increasing demand but also the environmental hazards such as flooding.

In brief, urban growth associated with the expansion of built-up areas has generated demand for the development of transport systems. Along with this, networks will be expanded in terms of spatial scale, particularly from the old urban areas to new development areas. Although such a process can create the risk of flooding due to increasing geographical intersections between new transport structures and drainage networks, it can be seen as a tremendous opportunity for a revision of more effective plans to reduce flood vulnerability. A balance between horizontal and vertical development of urban transport systems can help cities dealing with flood hazards, and improve investment efficiency during implementation. Along with this, the continuity through alternative links and nodes within a network is really important when planning for transport development.

2.2.3. Flood resilience

Vulnerable cities need to be planned to have more resilience to particular events, such as large-scale floods combined with other factors. Planning for evacuation and emergency management can lessen vulnerability (Campanella, 2006). This poses urgent questions to many governments in relation to practical design, stress management and emergency planning (Valdes and Purcell, 2013; Coaffee and Lee, 2016). Cities need to be prepared for worst-case situations; this refers to the threshold of stress that an urban system could withstand, adaptation to unpredicted changes, or to the reorganization of their structure for survival.

2.2.3.1. An integrated approach

Liao (2012) proposed that ‘urban resilience to floods’ is the capability of a city to tolerate flooding and to reorganize itself in order to minimize potential fatalities and injuries, while maintaining its socioeconomic identity. This concept advocates ‘flood ability’ and

reorganization in urban systems, and a reduction in the value of thresholds in order to increase the rate of tolerable socioeconomic fluctuation. However, it is argued that an acceptance of occasional floods within a city will in itself constrain urban development.

To this end, there remain several unanswered questions; for example, what flooding thresholds (in relation to particular flood levels) could be planned and assigned to urban areas and transport structures, or how a resilient model can be integrated into a framework for the planning and management system of a city. It is also argued that the gap between theoretical models and their practical applications is due to a lack of testing to demonstrate their feasibility. The greater the number of applications of a model into particular cases (e.g. cities, towns), the greater their value in practice. This has challenged urban researchers, who need to establish ways to apply their conceptual models to practical plans for specific cities. ‘Enhanced built-in resilience’ is needed in different urban fields, particularly in planning, management and design for cities (White and Howe, 2002; Godschalk, 2003). In practice, wider approaches to the urban context can be used to explain the rising number of resilient models for cities to mitigate hazards, including urban flooding, although some contemporary models of resilience still need more reality in the unevenness of space (Coaffee and Lee, 2016). Thus, further research of resilience into the urban context is still necessary to propose more spatial-temporal models associated with tailor-made solutions to urban flooding, in which the resilience of transport is expected to complement urban flood resilience.

2.2.4. Properties of resilient systems

In the face of potential shock and stress, a resilient city can be seen as a complex adaptive system including sub-urban systems, of which their resilience can contribute to the resilience of a whole system for long-term development. Considered as a physical system, the resilience of urban infrastructure, including transportation, is constituted by the following four properties (Tierny and Bruneau, 2007; Bruneau et al., 2003; Bruneau and Reinhorn, 2006; Liao, 2012):

- i. Robustness: physical strength to withstand a disturbance;
- ii. Redundancy: substitution of system components;
- iii. Resourcefulness: identifying problems and mobilizing resources;
- iv. Rapidity: capacity for timely restoration.

With respect to urban development, rapid urbanization has necessitated a major construction of urban infrastructure (e.g. roads, railways, embankments etc.), which are normally planned and designed to cope with predicted demand with capacity.

With respect to the stability feature of engineering resilience outlined in the previous section, new investments in infrastructure buildings are required to ensure a persistent state as the main function for urban activities. Thus, robustness is considered as the key property, allowing a move from resistance to (engineering) resilience, whilst redundancy can be seen as an equally important to offer different options for critical elements, as a target to adjust system scale in order to ensure the ‘survival’ of the whole system regarding the objective of an ecologically resilient system. For example, in transportation Berdica (2002) believes that the preparedness of various options for transport routes/means between departures and destinations can mitigate the serious impacts on some parts of the system in the case of disturbance.

As secondary factors, resourcefulness and rapidity can be gradually evolved in the longer term, depending on the development conditions of each city. It is difficult to evaluate the sufficiency of urban resources and restoration capacity of a city if it has never experienced a shock.

The true resilience of any city can only be observed and recognized through particular events (Desouza and Flanery, 2013). Otherwise, it could be tested by simulating worse-case scenarios for potential preparation (Coffee and Lee, 2016). For instance, urban areas vulnerable to flooding should retain a higher number of transport modes and means ready to deal with different flood scenarios, but this requires high (even abundant) budgets for investment and maintenance; e.g., a number of spare public transport vehicles and parking facilities for private vehicles. Such costs can be minimized by an effective forecasting ability, employing early warning systems in relation to different modelled scenarios. However, each simulation model also contains uncertainties due to the potential assumptions and data limitations, which are notable barriers. Therefore, it can be envisaged that robustness and redundancy should be prioritized for immediate development planning, whilst resourcefulness and rapidity should be included in longer-term plans following economic development prospects particularly in developing countries.

2.3. Empirical Literature Review

2.3.1. Definition, and perspectives of development

Vision of transport development

Urban transport systems can comprise internal components, such as transport structures (roads, pedestrian crossings, corridors and terminal stations), vehicles and equipment, and external components (government, customers etc.) (Desousa and Franery, 2013); and they consist of several different modes, such as road, rail, sea and air. The transport network “is an indispensable component of the economy and plays a major role in spatial relations between locations”, linking people’s activities between different regions of the world (Rodrigue et al., 2006).

Development of a transport system is relevant to the shares of different transport modes, which can be changed in regard to practical demands. Roads are normally the dominant mode of individual mobility, while rail can satisfy the demand for high-capacity travel (Xenidis and Tamvakis, 2012). Indeed, motorization constituted the largest proportion of urban commuting in the EU due to their convenience; as a result, road and rail were the two types of transport which have rapidly increased in recent decades. For urban commuting, social activities still mainly depend on urban road systems, which serve not only people’s daily mobility needs and the transport of goods, but also act as a lifeline system to rescue people when a city is faced with disruptions or needs repair or recovery (Mattsson and Jenelius, 2015). Cities are still developing; they are not only an agglomeration of people and firms, but also a hub of transport networks for various human activities. There is no evidence of any potential reduction in urban commuting, despite future improvement in information technology. Particularly in developing countries, the demand for urban transport has been rising due to:

- i. The increase in population (the larger number of transport trips);
- ii. The expansion of built-up areas (longer journeys);
- iii. Higher incomes (greater propensity for travel);
- iv. Rising activities of commerce and industry.

As cities continuously expand, changes in the level and distribution of urban populations in terms of spatial and geographic dimensions will inevitably lead to an increase in the complexity

of transport systems, such as the generation of highly intensive routes between old centers and new residential areas. In terms of spatial structure, urban territorial expansion subsequently requires the enlargement of the transport network, and accelerates new investments in transport structures, such as new main roads, bridges or tunnels; in turn, new road development can trigger the development of housing and associated commercial activities. For example, main roads from the old town can be extended with potential connections to new suburbs in surrounding areas, so the resistant approach is often used for new developments in order to ensure the interconnection between the old and the new (e.g. elevation of road surfaces to accumulated flood levels). Reviewing the historical evolution of transportation, Rodrigue et al. (2006) states that such a process is complex and is “related to the spatial evolution of economic systems”, but many contemporary networks are either unchanged or only slightly modified, even after a long period of urban development, sometimes more than a hundred years. For example, the highway network in France has been established from the pattern of national roads, which were built in the early 20th century, but originated from roads built by the Romans (Rodrigue, 2006). “The development of a location reflects the cumulative relationships between transport infrastructure, economic activities and the built-environment” (Rodrigue, 2006).

Flood impacts to transportation

As a result of the impacts of climate change, the transport systems of many cities have suffered many unpredicted effects. Extreme weather has affected transport modes, particularly road and rail, which can be susceptible to flooding (West and Gawith, 2005; Hooper and Chapman, in Ryley and Chapman, 2012). For instance, floods caused by heavy rain can result in physical damage and operational obstructions to certain segments, or to a whole network of roads or railways (Hooper and Chapman, 2012). The impacts can increase the direct costs of repair and maintenance, or lead to indirect economic losses due to closures of important transport links. For example, flooding resulting in road closures costs at least £100,000 per hour due to delays at peak times in London (Arkell and Darch, in Ryley and Chapman, 2012), an example being the floods of July 2007 (Standley et al., 2009).

Flooding, which can be seen a kind of “external threat” related to “natural phenomena including various degrees of adverse weather and natural disasters”, can cause disruption to urban infrastructures, including the transport system (Mattsson and Jenelius, 2015). Any disruption to

urban transportation may not only potentially damage physical structures, but will also result in widespread disruption to urban operations. Based on the two dimensions of frequency and degree of damage, Wang (2015) classifies disruptions to urban transport systems into three categories: “disasters, day-to-day variations and ongoing long-term changes”. Normal incidents can occur more regularly (Campanella et al., 2006). For example, three hours of heavy rain in August 2008 overwhelmed the capacity of the urban drainage system (assembled under the road network) of Mexico City, with the resultant flood causing “a chaos of collisions” (Lankao, 2010). Despite their rarity, it can take a long time for urban areas to recover from the effects of disasters (Wang, 2015). They can even create lasting memories in people over many generations.

Hence, it can be stated that urban transportation has become more susceptible to floods related to climatic uncertainties, although Divall (2012) argues that “the threat of climate change does not mean that we must trade or travel less”. This implies that the intensity and complexity of urban transportation are expected to continue to grow, despite the increasing threats from environmental changes. This requires governments, particularly of cities in developing countries, to pay more attention to planning urban transport systems which are more resilient to adversity, and resilient development is required to coordinate with the existing resistant systems to maintain the operation of a whole system

2.3.2. Developing flood resilience in transport planning

As previously mentioned, it is well established that the resilience of the transport system represents a key component of the overall resilience of the urban system, particularly as cities are becoming vulnerable to flooding. The transport system is a sub-system of physical and critical urban infrastructure systems and needs to be considered in resilience improvement, thus consisted by four properties (Tierny and Bruneau, 2007). “A certain minimum operational level must be ensured in any case of sudden disturbances that have various and adverse impacts to the systems; moreover, a quicker recovery of the system is imperative to avoid long-term effects” (Xenidis and Tamvakis, 2012).

This highlights the need for early-stage planning in the transport sector to develop resilience to precarious conditions, during which cities are still able to maintain certain levels of urban commuting.

In the UK, the resilience in transportation is defined by DFT (2014) as “the ability of the transport network to withstand the impacts of extreme weather, to operate in the face of such weather and to recover promptly from its effects”, in order to ensure:

- Continued transportation of people and goods;
- Quick restoration of services and routes to normality;
- Sufficient and thorough communication to transport users.

These three objectives of a resilient transport system are suggested in the context of UK conditions with a transport system and infrastructure developed over a long period of time. They can be targeted differently under a developing countries context which have more recently planned for their infrastructure developments as a driver for economic development. During a flood event, resilient transportation would be expected to minimize potential widespread disruptions from some critical routes to the whole network as the capability to maintain its vital connection between different areas. Thus, the continuation of its function therefore should be a priority while the time for restoration and communication can be considered as the less important features which could be developed in longer term as cities can obtain stronger finance to achieve.

2.4.Literature Review Gaps

Along with historical urban expansion driven by economic growth, transport systems have developed in terms of spatial and geographical dimensions, such as larger horizontal networks, and also more geographic links to new suburbs surrounding their old center in order to meet the higher transportation demand. Moderate floods can break the continuity and cohesion, and affect the transport connections between different urban areas, while extreme floods can cause constraints on evacuation, consequently leading to high losses and damages to isolated areas. Case studies from other cities are therefore necessary to draw useful lessons related to uncontrolled settlement on low-lying lands vulnerable to flooding, and potential losses and damages due to inaccessibility of transport in emergency. Therefore, the development of transport systems in developing cities are required not only to meet the increasing demand of urban commuting, but also to deal with potential flood effects. Closely linked with the urbanization process and the expansion of urban areas facing flood hazards, a balance between horizontal and vertical development of the physical transport system is necessary, referred to

efficiency in long-term development particularly in developing countries. While previous studies have looked at the impact of poor drainage in general, there is a gap in understanding how specific issues within the drainage system (like blockages, inadequate capacity, poor maintenance, etc.) contribute to surface flooding and affect transportation efficiency. There is also a lack of comparative studies analyzing the impact of poor drainage on transportation efficiency in different types of areas (residential, commercial, industrial, etc.) within Adama City. There is lack of researches on effective mitigation strategies that can be implemented to improve the urban drainage system and thereby enhance the transportation in flood-prone areas. Additionally, a gap arose in research considering future climate change scenarios and their potential impact on urban drainage and transportation efficiency in flood-prone areas.

Despite these research findings, there are still some knowledge gaps and potential future research directions that need to be addressed. Firstly, there is a need for more research on the specific socio-economic impacts of poor urban stormwater on transportation in flood-prone areas. Understanding the social and economic consequences of these events is crucial for developing effective mitigation and adaptation strategies.

Furthermore, there is a need for further research on the effectiveness of different stormwater management strategies in urban areas. This includes exploring the potential of green infrastructure, such as permeable pavements and green roofs, in mitigating the impact of poor urban stormwater on transportation in flood-prone areas. Lastly, future research should focus on evaluating the long-term resilience of urban communities to stormwater impact on transportation. This includes assessing the effectiveness of urban planning and infrastructure development in creating resilient communities that can withstand the challenges posed by poor urban stormwater in flood-prone areas.

In conclusion, poor urban stormwater impact on transportation in flood-prone areas is a complex issue influenced by various factors such as uncontrolled urban development, land subsidence, and annual flood occurrences. Addressing these challenges requires a comprehensive understanding of the socio-economic impacts, effective stormwater management strategies, and long-term resilience of urban communities.

2.5. Conceptual Framework

The diagram presented delineates a theoretical structure that encapsulates the interconnections between the urban drainage system and transportation. This is an abstract depiction of the concepts and their interrelationships, expressed symbolically.

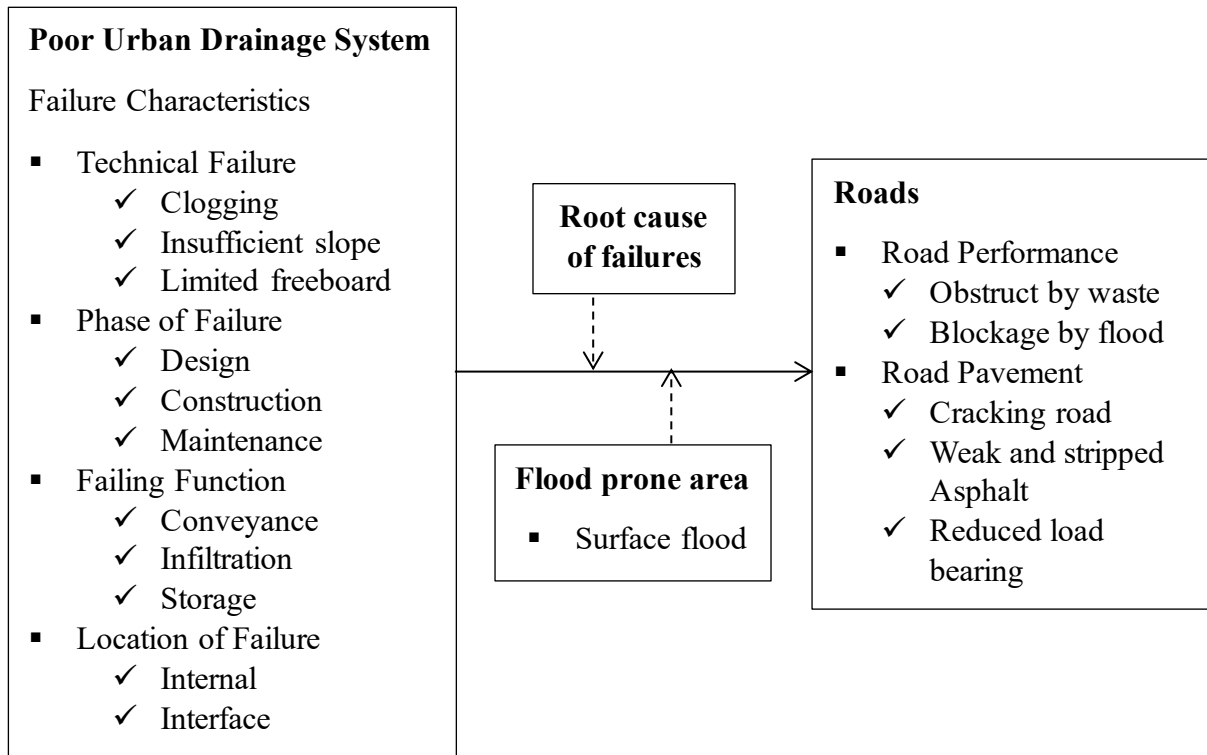


FIGURE 1: CONCEPTUAL FRAMEWORK DEVELOPED

CHAPTER THREE

3. MATERIALS AND METHODS

3.1.Introduction

The research examined the impact of poor urban drainage system on roads and also identified the major causes of road sections totally affected due to drainage system. Typically, the deductive research approach was used with highly-structured data and the support of measurement. This chapter describes the methodological framework used in attaining the stated aim and objectives of the study. It shows how the research questionnaires or hypothesis postulate empirically determine and examine relevant methodological approaches adopted in the study. The research design, type and sources of data are examined along with the procedure employed in testing the questionnaires and accomplishing the study objectives. In particular, focus is one the study populations/sample frame and its characteristics, sampling technique chosen, and a description of the choice of data collection instruments, questionnaire design and methods of data measurement, in this chapter.

3.2.Description of the Study Area

Adama city is one of the districts in the Oromia regional state of Ethiopia. It is totally ordered by East Showa woredas specifically bordered in the East by Wolenchiti, in the West by Modjo, on the South by Sodare. Adama city is located in the Great East African Rift Valley system which runs from Syria in the Middle East to Mozambique in the Southern Africa approximately stretching along 6,000km. Astronomically, the city is positioned between 8°033'11" to 8°036'11" North latitudes and 39 011'57" to 39 021'15" East longitudes.

Topography of the city is characterized by flat terrain that is surrounded by ridges. The plain land is covered by lacustrine sediments and reworked volcanic, while the ridges are made of volcanic rocks. The nature of topography has created three drainage sub-catchments; one that drain to Awash River and the others two closed basins, absence of appropriate drainage network, lack of natural out let and unplanned human interventions that have made the city vulnerable to natural and human-induced disasters. The track of the Addis Ababa Djibouti railway crosses the southern part of this district. Adama city was built on flat and undulating fertile ground that ranges from a completely low-lying center to hilly peaks overlooking the city, each with its unique landscape sceneries.

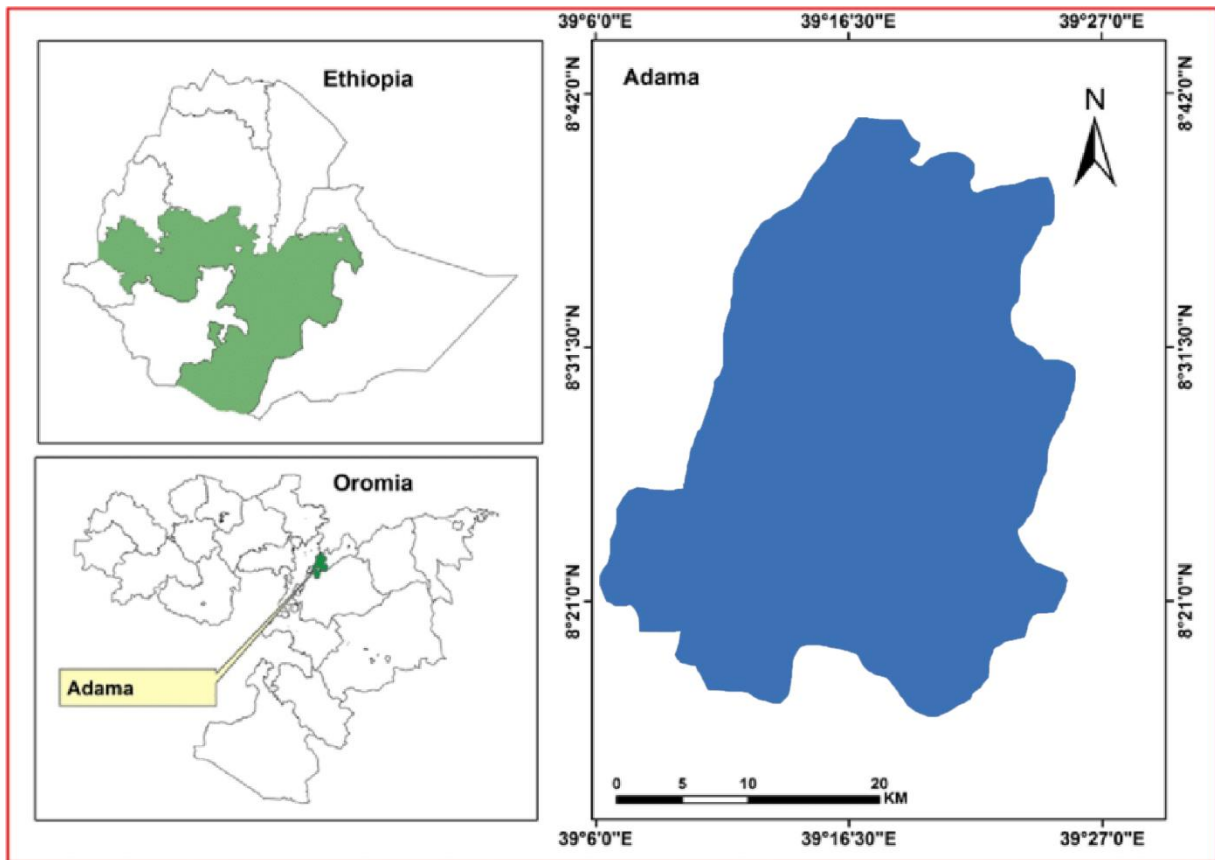


FIGURE 2: LOCATION MAP OF THE STUDY AREA

The altitude steadily drops/declines from all of the city's outskirts to the city's core, where the slopes become mild in the heart of the city, which contains significant swaths of the city. According to the city's current master plan, the city is located between 1500 and 1900 meters above mean sea level with an average elevation/altitude of 1700 meters above sea level. The climate is tropical, with plenty of rain in the summer and relatively little in the winter. The average annual temperature of Adama is 20.50°C, with an annual rainfall of 808 mm. There are six sub-cities and 18 administrative kebeles in the city (the lowest administrative level) (“Socio-Economic Profile of Adama”, 2019). Geographically Adama city is surrounded by plateaus, mountainous and ridged topography. These surrounding mountains are the source of flooding and made gullies from which surface moves downstream to Adama city. As a result, Flood has been the manifestation of Adama city since long past. The city’s history of flooding shows that the problem is cyclic and routine which has a long history as equal as the age of the city.

3.3. Research Design

This study adhered to a descriptive and explanatory research methodology, utilizing both qualitative and quantitative data derived from a physical assessment conducted in select areas of Adama Town. The data collection process relied primarily on firsthand sources. Three distinct locations within the city, identified as being susceptible to flooding due to inadequate urban drainage, were specifically chosen for this study.

The collected data underwent a process of classification and interpretation, segregating it into primary and secondary sources. Primary data was amassed through site visits, questionnaires aimed at the study area, and field surveys. Secondary data, in contrast, was procured from a review of documents such as topographic maps, hydrographic maps, Google Earth imagery, and hydrological maps. These documents were instrumental in identifying potential mitigation measures.

Upon completion of the data collection, an analysis of the existing drainage system was undertaken. The findings from this analysis were then discussed in depth. The study culminated with a set of recommendations, which were based on the results of the analysis. These recommendations were designed to address the identified issues and propose viable solutions for improvement.

3.4. Study Approach

A mixed-methods approach was selected suitable for this research. This approach combines both qualitative and quantitative research methods, allowing for a more comprehensive understanding of the research problem. Quantitatively the research involved the use of GIS-based hydrological modeling to simulate the impact of various flooding scenarios on the roads. Qualitatively it comprised conducting interviews or surveys with local residents, road users, urban planners, and transportation officials to understand their experiences and perspectives on the impact of poor urban drainage on roads during flood events. Additionally, Case study analysis was done and that involved conducting a case study analysis of a specific flood event in Adama City. This has provided a detailed, context-specific understanding of the research problem.

3.5.Data Type and Source

To attain the objectives of this research, different types of quantitative and qualitative data were needed. The quantitative data were derived from field measurement data and questionnaires. Both primary and secondary data source was used and descriptive statistics approaches was adapted. Records of road traffic accident situations which occurred during flooding and heavy flooding on public, recent experiences were retrieved from secondary data and interview with municipality officials.

3.6.Study Population

Utilizing both simple random and judgmental purposive sampling techniques, samples were meticulously selected from designated sample groups. An exhaustive review of secondary data pertaining to historical flood events was conducted, supplemented by personal experiences, leading to the identification of three locations as potential flood-prone areas. The reasoning behind the selection of these specific areas will be comprehensively detailed in Chapter 4.

Following the identification of these three locations with recurrent flood events, an observational study was carried out to categorize the types of roads within these areas and their respective characteristics. This was done with the primary objective of identifying major roads that are plagued by inadequate drainage infrastructure.

Upon the identification of major roads with deficient drainage systems, a spatial threshold of a 100-meter radius within the flood-prone areas was established. This decision was informed by both random face-to-face conversations and a thorough study of secondary data on the extent of flood accidents in the area. This spatial threshold was instrumental in determining the size of the population adversely affected by these substandard urban drainage infrastructures.

- Approx. total household in Adama = 60,174
- Area of Adama = 29.86 Sq. Km
 - Approx. household per Sq. Km = 2015 household / Sq. Km
- Using Average of 5 family per household
 - Approx. population per sq. km. = 10,075 popn. per Sq. Km
- Using an area of 100m radius threshold
 - Approx. population size is established at 300 (3*300) per site.

By utilizing parameters such as the number of households per square kilometer and the number of families per household, the total population size for this research was established at 900. This figure was then used to calculate the sample size for the study.

3.7.Sampling Technique

In accordance with the relevance of the study, both probability and non-probability sampling methods were employed. Non-probability sampling is characterized by the selection of participants based on non-random criteria, such as convenience or their pertinence to the research question. Consequently, typical case sampling, a type of purposive sampling, was utilized. This method recruits subjects who are representative or average, enabling researchers to understand the most common members or elements. The objective of this process is to depict an image of the average case, outcome, or beliefs. In the context of our study, this method was used to identify specific areas that are known to be susceptible to flooding or possess inadequate urban drainage systems.

Probability sampling involves selecting participants based on their statistical probability of being chosen. It ensures that every member of the population has an equal chance of being selected, which can help to eliminate bias. Thus, random sampling was used to select different passengers and residents within the study area. A total of 68 residents and road users were identified.

Random sampling, involves the selection of subjects from a population in an unpredictable manner. In its most basic form, each subject has an equal probability of being chosen from the population under study. Following the randomization of the population frame, the subsequent step is to determine the sampling interval. The sample size is determined with a confidence level set at 95% for the target population. The response is assumed to be within a range of plus or minus 5% ($\pm 5\%$) of the population. Subsequently, questionnaires are prepared to gather information from engineers, residents and the road users as well about the current state of the drainage system and its impact on the roads.

The sample size for the population was computed using the following formula. This approach ensures a comprehensive and statistically sound method of data collection, contributing to the reliability and validity of the research findings.

$$n = \frac{pqNz^2}{e^2(N-1) + z^2pq}$$

Where;

N – Size of the population

P – Sample proportion

n – Size of sample

q – 1-P

e – Accepted error (e = 0.05, this is because estimate should be within 5% of the true value)

Z – The value of the standard deviation at a given confidence level.

$$n = \frac{0.95 * 0.05 * 1.96^2 * 900}{0.05^2(900 - 1) + (1.96^2 * 0.95 * 0.05)} = 68$$

3.8.Data Collection Process

The primary data was obtained through questionnaires, systematic observations and face-to-face interviews in the study. The secondary data was obtained through published documents and office document.

3.8.1. Primary data collection

The research used primary data including various forms of recordings, systematic observations, face-to-face interviews, and questionnaire surveys. Using GPS and distance measurement applications. The data collected from different target groups at locations was triangulated and analyzed.

Questionnaire: A questionnaire serves as a methodical research tool, encompassing an array of queries and additional prompts designed to amass information from respondents. Data pertaining to the study area was diligently collected from local residents and road users.

Simple questionnaire was conducted on the identified locations. This facilitated in making comparisons between the flood risk a community is exposed to and the effectiveness of corresponding drainage system provided for that specific part of the city.

A meticulously designed questionnaire was developed for completion by local residents and frequent road users and government officials and professionals. This group encompassed public transport providers, private vehicle operators, and pedestrians who regularly traverse the area. The primary objective was to gain insights into the impact of inadequate drainage on their daily routines and any consequent alterations in their activities. This approach has facilitated a comprehensive understanding of the implications of the substandard drainage system on the roadway and elicit their perspectives on potential solutions.

Interview: Qualitative data was amassed through the utilization of key informants. This approach was specifically designed to procure reliable data on the prevailing conditions, sourced directly from professionals and government officials. This method provided unique insights that could not be gleaned through other techniques such as questionnaires. For the interviews, the researcher employed semi-structured questions, which facilitated the collection of data to substantiate the research findings.

An interview framework was devised for completion by representatives of the local construction bureau and consulting professionals. The primary aim of this questionnaire was to ascertain the responsibilities and challenges encountered by the entities tasked with the construction and upkeep of the road. Furthermore, it aimed to comprehend the consultant's role in the provision of the drainage system for the road. This approach has facilitated a comprehensive understanding of the dynamics involved in road maintenance and drainage system implementation.

Site Observation: This method allowed the researcher to gather information through direct observation to supplement and strengthen the collected data through questionnaires and interviews.

A comprehensive site inspection was conducted to evaluate the prevailing conditions of the inadequate drainage systems within the designated areas, juxtaposed against acceptable industry standards. The investigative approach incorporated the utilization of a meticulously designed physical observation checklist, which was populated based on direct observations. Additionally, a digital camera served as an instrumental tool in capturing visual evidence of the existing state of both the roadway and the drainage infrastructure.

3.8.2. Secondary data collection

The research commences with the identification of the root causes of urban drainage issues, accomplished through a comprehensive review of relevant literature and a focused desk study on selected urban drainage problems within the designated study area. This methodical approach ensures a thorough understanding of the issues at hand, paving the way for effective problem-solving strategies.

Published Documents: Reviewing books, journals, reports, magazines, and other published documents related to the topic. There are many journals, reports related to the thesis topic; reading this document and using it for the research as secondary data.

Office document: Reviewing the Adama city guideline, and standard documents of other countries.

3.9.Data Analysis and Interpretation

The process of data analysis aimed at determining whether the questionnaires support the research questions that are formulated before going into the field to collect the information. With regards to this study, the data collected was checked for accuracy and completeness before they are subjected to analysis. Descriptive statistics was described by frequency tables, average, and charts to summarize the data for better analysis. The questionnaires were analyzed using Microsoft Excel 2019. ArcGIS tool was then used to create flood hazard map of Adama to correlate it with the secondary data on flood history. In analyzing the data, based on answers from different respondents, field's measurement and information obtained from documents are thoroughly checked and compared to establish their validity. Analysis of data is basically based on the number of sample size using scaling methods.

3.10. Ethical Considerations and Data Quality Assurance

This study is executed in strict adherence to the ethical considerations requisite for conducting a thesis. Correspondingly, a formal letter was dispatched from the Department of Architecture at Adama Science and Technology University to the relevant entities. Consequently, the majority of individuals approached by the researcher for interviews were receptive and cooperated with the thesis research. Furthermore, the researcher ensured to obtain prior consent from all participants before initiating the interview process.

Prior to the data collection phase, a thorough assessment of the availability of all source populations was conducted, and the daily work schedules of respondents were duly respected. The questions were formulated in a simple and clear manner to facilitate comprehension and encourage participation. The willingness of respondents to engage with the study was evaluated, and all necessary schedules required for the administration of questionnaires, conduction of observations, interviews, and measurements were meticulously planned and executed. This comprehensive approach ensured a smooth and efficient data collection process.

3.11. Reliability and Validity of Data

Content validity of the data collection instrument in providing adequate coverage of the topic under study was confirmed. By using a universally accepted sampling method a representative sample of the population was drawn. Besides that, due emphasis was given to make the questions objective type and understandable so that the respondents can answer the questions properly based on what they know. Vague and confusing wordings were avoided not to mislead on the time of filling the questionnaires. The questionnaire was organized and finalized with a close consultation of my advisor and expertise of the subject area. The questioners distributed for the respondents were fully collected. Response's completeness and accuracy was reviewed carefully. Each response was coded and categorized and carefully fed in to frequency table using Microsoft excel sheet.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Identification of Flood Prone Areas

4.1.1. Based on historical flood events

The study area, Adama Town, is situated at an altitude ranging from 1489 m to 1976 m above sea level. The city experiences an average annual rainfall of approximately 866.25 mm, with the majority of precipitation occurring during the rainy season, which spans from June to September. Flooding poses a significant natural hazard in Adama City, a phenomenon primarily attributed to its geographical location within the flat-lying rift and the urban impervious surfaces (Seid, 2005).

A comprehensive study of the town's flood history has led to the identification of three locations that are frequently at risk of flooding. Field surveys have been conducted in these areas to further understand and assess the situation.

Site-A is strategically positioned in the southern sector of the city, in close proximity to the renowned "Tikur Abay" Hotel. The locale is distinguished by its relatively low-lying topography, which is further characterized by a sparse drainage network and unauthorized residential constructions. The confluence of these elements culminates in a heightened susceptibility to flooding within this region. This provides a cogent explanation for the recurrent flood incidents that are annually observed in this area.

Site-B is strategically situated in the heart of the city, extending from Derartu Square or the Post Office to Kebele 09, in the vicinity of the "Eftah" Hotel. This region is recognized as a densely populated residential area, nestled within a low-lying elevation range and equipped with a limited drainage infrastructure. Moreover, the existing stormwater drainage lines are frequently obstructed by various urban wastes and constructions intended for utility crossings. This scenario elucidates the annual occurrence of potential flood events in the area. In the previous year, a significant flood event transpired in this region, resulting in substantial damage. This was primarily attributed to the insufficient capacity of the existing drainage systems and blockages caused by tree roots planted on the road divider.

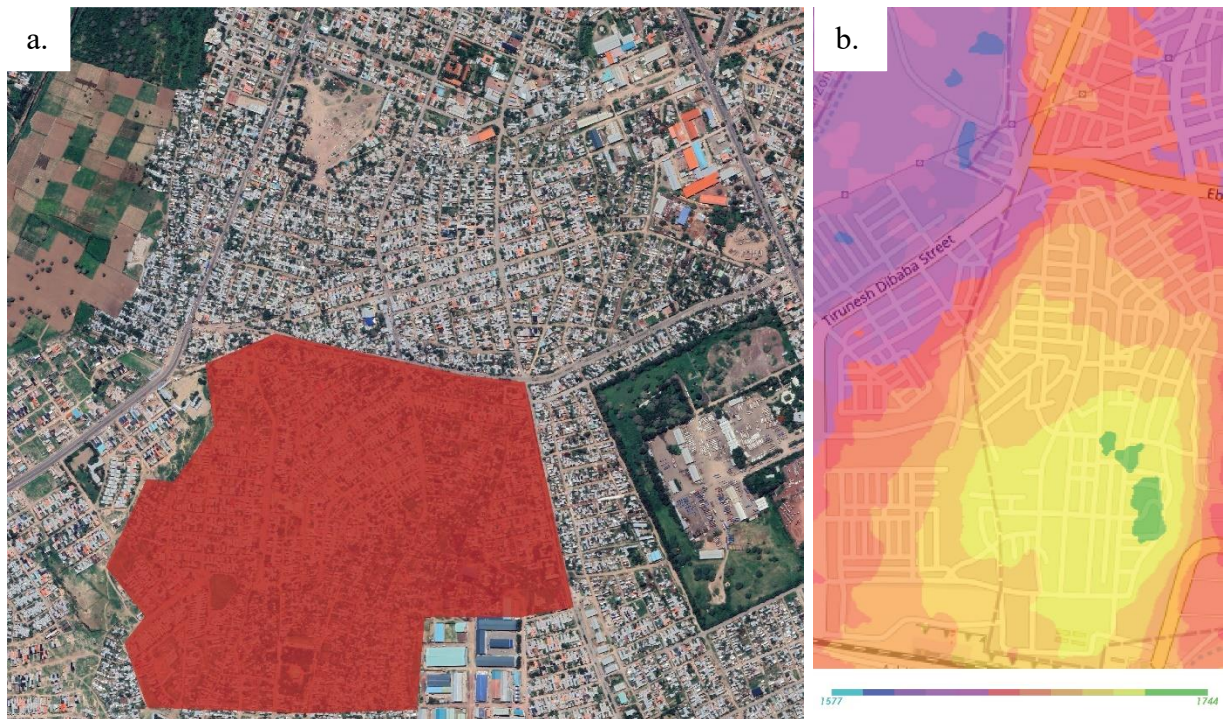


FIGURE 3: (a) SITE A (b) ELEVATION MAP FOR SITE A

Site A (a) a flood prone location with 0.84 km² area. (b) Elevation map for Site A with elevation ranging between 1577m and 1744m

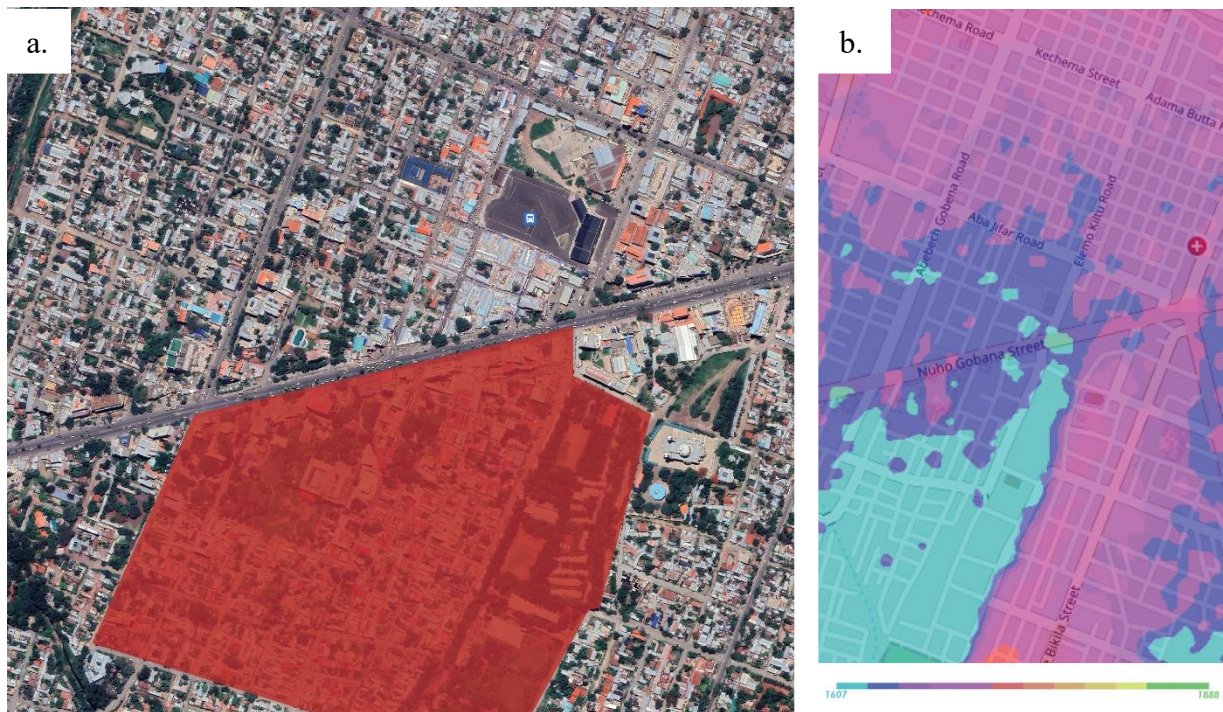


FIGURE 4: (a) SITE B (b) ELEVATION MAP FOR SITE B

Site B (a) a flood prone location with 0.37 km² area. (b) Elevation map for Site B with elevation ranging between 1607m and 1888m

Site-C is strategically positioned in the vicinity of the “Migira Bus Station” within Kebele 02. The area is distinguished by its low-lying topography and a sparse drainage network. These characteristics significantly contribute to the area’s susceptibility to flooding, as runoff from all surrounding areas converges towards the lower elevation zones. This provides a comprehensive explanation for the frequent flood events observed in this region.

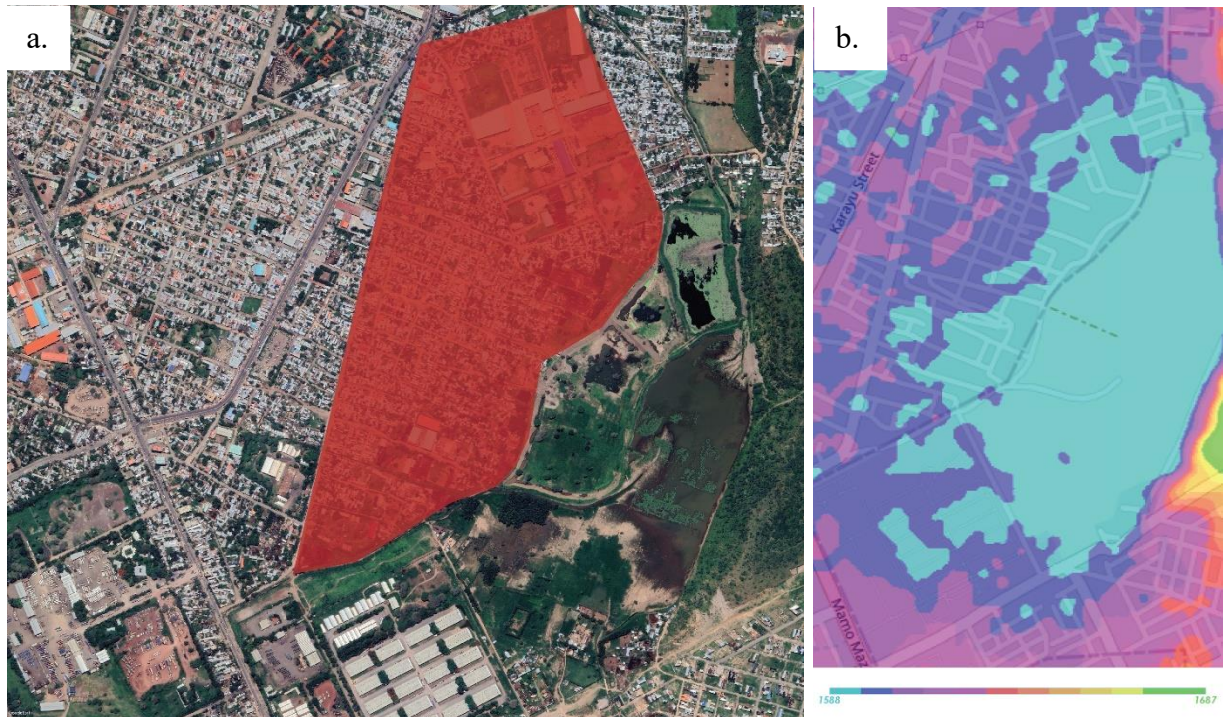


FIGURE 5: (a) SITE C (b) ELEVATION MAP FOR SITE C

Site C (a) a flood prone location with 0.82 km² area. (b) Elevation map for Site C with elevation ranging between 1588m and 1687m

4.1.2. GIS based mapping

The study involves identification and mapping of flood hazard zones, flood risk mapping by superimposing considered hazard zone in Geographical Information Systems (GIS) environment. The general procedure used for the case is the following:

- i. According to the examined literature (Kubal et al., 2009; and Morita M. 2014), and based on the current conditions of the research region, the five most significant flood causing components were selected: land use land cover, drainage density, slope, elevation, and geology.

- ii. Thematic layers for each factor were created and standardized by assigning new pixel values. The reclassification was done based on a factor's anticipated relevance in flood generation.
- iii. The relative relevance (weight) of all factors contributing to flooding was assessed using pairwise comparison approaches.
- iv. The target map was created using weighted spatial overlay analysis in a GIS context.
- v. Pixels on the target map were classified based on their cumulative pixel value, and flood hazard zones were determined at various levels.
- vi. The result was field verified with places that had already undergone flood events.

4.1.2.1. Selection of factors and standardization

A. Drainage Density

Drainage is a crucial habitat for managing flood dangers. A location with higher drainage density is less prone to floods than one with lower drainage density. Drainage density was calculated using the spatial analyst's line density module and the drainage feature class. This module determines the density of drainage features in the vicinity of each output raster cell. Density was determined in terms of length per unit area. It is further divided into 5 sub-classes. Pixels in lower drainage density class intervals were allocated the maximum value, whereas pixels in higher drainage density class intervals were assigned the minimum value.

B. Land-use

The land-use and land-cover statistics of the study region are the most essential factors for flood hazard zoning because they indicate the current use of the land pattern, the kind of usage, and the area's soil stability and infiltration capacity. For example, land-covering vegetation in soils, whether permanent grassland or crop cover, has a significant influence on the soil's ability to operate as a water storage. Rainwater runoff is far more likely to occur in barren fields than in agricultural areas. Impermeable surfaces in metropolitan areas, on the other hand, are termed resistant covers because they increase peak flow of water, which exacerbates floods.

However, urban land use zones such as commercial and residential sectors would not reduce soil penetration capacity and increase water runoff in the same proportion. As a result, land use and land cover play an essential role in influencing the frequency of flooding in metropolitan areas.

In this research, a land use land cover map was created using digital orthophotography and ground surveying techniques. New pixel values were assigned using their anticipated relative infiltration capacity. The most impermeable land use category (commercial land use) received the highest value, while agricultural land with an anticipated high infiltration potential received the lowest value.

C. Elevation Factor

Local depressions in pluvial floods, i.e., DEM cells with lower elevation than the surrounding ones, are vulnerable to flooding because water always gathers in cells with lower height. This layer's pixels were divided into five interval subclasses based on elevation data. New pixel values have been assigned. Pixels in lower elevation ranges were allocated greater values, whereas pixels in higher elevation ranges were assigned lower values.

D. Slope Factor

The slope determines the direction and volume of surface runoff or subsurface drainage that reaches a place. Surface runoff is more likely to occur on steeper slopes, whereas waterlogging occurs on flat terrains. As a result, a region with a low gradient is more vulnerable to floods than an area with a high gradient slope because extra water constantly accumulates in areas with a low gradient. As a result, the slope factor was calculated using the contour feature class of the research region, which had a contour interval of 3m. First, it was converted to a raster format utilizing the elevation property as a source. Using ArcGIS' 3D analyst tools, a Digital Elevation Model (DEM) of the area was constructed, and the rate of change between each pixel and its neighbors was determined using the spatial analyst module. The slope raster layer was categorized into five sub-classes. New values were allocated using inverse weighting, which meant that the maximum value was assigned to pixels in the subclass with the lowest slope values, while the minimum value was applied to pixels in the region with steep slopes.

4.1.2.2. Weighting causative factors

Every causative element has a varied amount of relevance in relation to the other factors that cause floods. For example, if we examine drainage density and elevation considerations, a location with low drainage density may be flooded more than an area with dense drainage since lower areas are less sensitive. According to this, the drainage density factor is more essential than the elevation element in determining flood danger rating. As a result, the likelihood of

flooding was calculated taking into account all causal elements. Their relevance was determined by weighing and pairwise comparison on a nine-point continuous rating scale.

Table 1. Scale for pairwise comparison (Saaty and Vaargas, 1991)

Intensity of Importance	Definition	Explanation
1	Equal importance	Equal importance or indifference
3	Weak importance of one over another	Experience and judgement slightly favor one activity over another
5	Essential or strong importance	Experience and judgement strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between adjacent scale values	
Reciprocals	For inverse comparison	

Next, relative weights were calculated using the weight module of the IDRISI 3.2 software package. The pairwise comparison matrix file was loaded into the Analysis menu Decision Support system, and the best suited set of weights was generated. Pairwise comparison calculates the weight of each causal factor and uses a consistency ratio to reflect the amount of subjectivity in component comparisons. Poor comparisons across components will result in values larger than 0.1, and vice versa. The derived eigenvector serves as a coefficient for the corresponding causal component.

Table 2. Pairwise comparison matrix

	Elevation	Slope	Land use	Drainage Density
Elevation	1			
Slope	1/3	1		
Land use	1/3	3	1	
Drainage Density	2	5	2	1

The numbers are allocated based on the relative importance or preference of one option over another.

4.1.2.3. Relative relevance of causative factors

The relative significance of each causative factor was computed through a method of pairwise comparison. The degree of subjectivity in the comparison of these factors was found to be 0.05. The consistency ratio was significantly lower than the threshold value of 0.1, indicating a high degree of consistency in the pairwise comparison judgments. Therefore, the weights determined through this process are deemed acceptable. Upon analysis of the causative factors, drainage density emerged as the most significant contributor to flooding in the study area, followed by elevation and land use factors.

Table 3. Weight of each causative factor determined from pairwise comparison matrix

Factor	Weight (%)
Drainage Density	39.99
Elevation	30.94
Land use	19.85
Slope	9.22
Computed consistency ratio = 0.05	

4.1.2.4. Flood hazard zoning

Flood hazard zoning is a sophisticated procedure employed to ascertain the susceptibility of a specific geographical location to flood events, as represented by the corresponding pixel values. In the context of this research, the cumulative probability of flood occurrence at each individual pixel was derived from the weighted aggregation of pixel values across the causative factors under consideration. The final pixel value, which serves as the determinant for estimating the likelihood of flooding at a specific pixel, is computed as the summation of the product of the pixel value in each causative factor (v_i) and the assigned weight of that causative factor (ω_i).

$$\text{Resultant value of } i^{\text{th}} \text{ cell} = \sum_{i=1}^n v_i \omega_i$$

The flood hazard map was generated through a weighted spatial overlay of thematic layers utilizing the spatial analysis module in ArcGIS. The resultant raster map displays the value of each pixel, with a higher value indicating a greater susceptibility of the pixel to flooding. The output layer was subsequently reclassified into five distinct classes using a natural break interval. Relative flood hazard levels were then qualitatively assigned to each class, ranging from 1 to 4. Specifically, a class with high resultant pixel values was assigned a level of 4,

indicating high flood risk, while a class with the lowest resultant pixel values was assigned a level of 1, indicating low flood risk.

4.1.2.5. Flood susceptible zones classification

The weighted spatial overlay technique synthesizes a singular map derived from the amalgamation of all analyzed causative factors. This map delineates various flood hazard zones at distinct levels. The map produced as a result of this process is referred to as the flood hazard map.

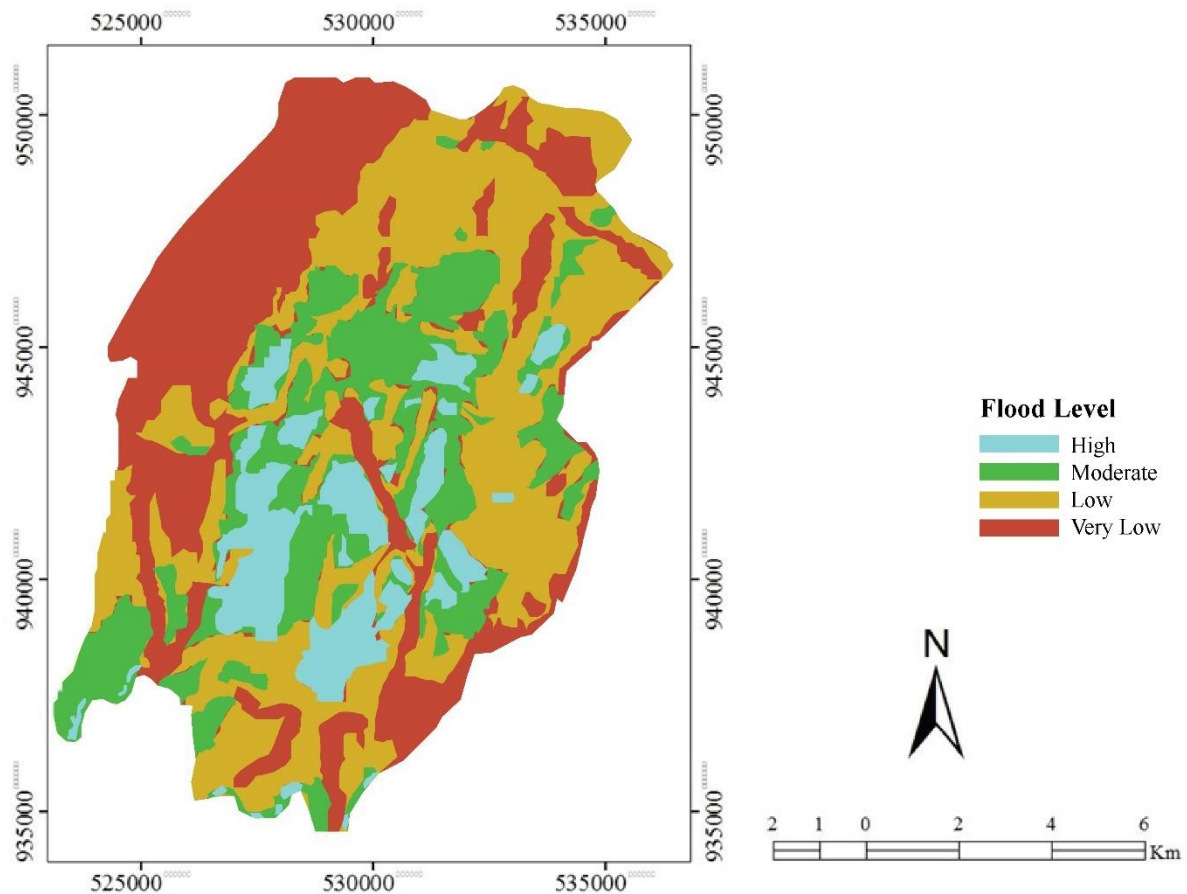


FIGURE 6: FLOOD PRONE MAPPING CLASSIFICATION IN ADAMA CITY FROM HIGH TO VERY LOW

Field verification of the result of flood hazard zoning revealed that sites frequently experienced past flood events, are spatially located in high flood hazard zone identified in this study.

4.2.Results from Questionnaires and Interviews

Questionnaires and interviews were meticulously organized for engineers, officials of the construction bureau, and consultants from specific sub-cities. A questionnaire was distributed to residents residing in proximity to the identified flood-prone areas, as well as individuals who frequently utilize the road, collectively referred to as “road users”. The questionnaire encompassed a blend of open-ended and structured queries, focusing on issues pertinent to the study. This comprehensive approach ensured a thorough exploration of the subject matter.

Table 4. Primary data collection response rate

Data Collection Tools	Respondents	Planned Respondents	Actual Responded	Response Rate
Questionnaire	Residents	68	34	82.35%
	Road Users		22	
Interview	Gov’t. Authority	5	4	80.00%
	Engineers	6	4	66.67%
Total		79	64	81.01%

A response rate of 50% is deemed acceptable for data analysis and reporting, a rate of 60% is considered good, and a rate exceeding 70% is classified as very good. For this particular study, a commendable response rate of 81.01% was achieved, thereby rendering the data highly suitable for analysis.

4.2.1. Major causes of poor urban drainage system

In each delineated flood-prone region, instances of malfunctions were meticulously documented in the urban drainage system through comprehensive site inspections. Furthermore, semi-structured dialogues were orchestrated with urban professionals who have been instrumental in the execution and operation of the urban drainage infrastructure.

The malfunctions were chronicled based on the professional’s identification of a dysfunctional urban drainage system, that is, instances where the system failed to fulfill its designated function as per the urban drainage experts. Each distinct location where a professional pinpointed a failure in the urban drainage system was treated as an individual case. These instances were captured photographically, and a concise description of the scenario was appended, drawing upon the insights provided by the professionals.

To ensure a focused approach in this exploratory study and to foster consistency among the cases analyzed, it was resolved to conduct interviews with urban drainage professionals and representatives from construction bureau authorities. The interview inquiries were centered around three primary themes: the professionals' overall experiences with drainage systems, the failures of the urban drainage system in the specific study sites, and their perspective on the root causes of these failures comprehending additional questionnaire to be filled by them.

4.2.1.1. Urban drainage system failure characteristics

A comprehensive analysis was conducted on all failures, utilizing four distinct characteristics of urban drainage system failures as the basis: technical malfunction, compromised functionality, location of failure, and the stage at which the failure occurred. The subsequent table delineates these characteristics along with their respective categories. Throughout the course of site inspections, these categories underwent iterative refinement to enhance their accuracy and relevance. To ascertain the validity and appropriateness of these categories in accurately representing the data set, a subsequent verification process was undertaken during the interview phase. This rigorous approach ensures a robust and comprehensive understanding of urban drainage system failures.

Table 5. Overview of the four case characteristics and their initial categories

Failure Characteristics	Description	Categories
Technical Failure	The technical issue that causes malfunctioning	Clogging; poor maintainability; insufficient slope; illicit connections
Failing Function	The main hydraulic function of the system	Conveyance; infiltration; storage
Failure Location	The location of the failure	Internal locations: roof; house; private plot; street; public open space; water body Interface locations: between roof and house; between house and private plot; between private plot and street; between street and public open space; between public open space and surface water body
Phase of Failure	The project phase where the failure originated from	Design phase; construction phase; user/maintenance phase

The classification of technical failures was primarily predicated on extant research. The most frequently cited technical failures in scholarly literature encompass: clogging (Abbott & Comino-Mateos 2001; Boogaard & Wentink 2007), diminished maintainability of urban drainage systems (Boogaard & Rombout 2008; McDonald 2018), inadequate slope for effective water conveyance (Pötz 2016), and unauthorized connections in subsurface infiltration systems (Boogaard & Rombout 2008; Heppenhuys 2020). In instances where these categories were insufficient in accurately characterizing the failure, additional technical failures were incorporated post consultation with industry professionals.

The remaining case characteristics, which are inherently descriptive, were documented in accordance with the categories delineated in the preceding table. The categories for the case characteristic ‘failure location’ were bifurcated into internal and interface locations. ‘Internal’ pertains to failures transpiring within a singular urban system, while ‘interface’ denotes failures occurring at the physical juncture between two systems. This meticulous categorization facilitates a more nuanced understanding of urban drainage system failures.

4.2.1.2. Root causes for failures

In order to ascertain the fundamental reasons for these failures within each urban drainage system, comprehensive interviews were conducted with professionals in the field of urban drainage. These interviews facilitated the identification of one or more causes for each failure. In order to distill a coherent list of root causes, duplicate causes were eliminated and overlapping ones were rephrased for clarity. A socio-technical systems perspective was employed to cultivate a balanced assortment of causes, encompassing both technical factors and those related to the behavior of actors and their respective institutions. In instances where root causes were isolated to one or two cases, a broader description of the root cause was sought. This ensured that it could be applicable to at least three cases, while still allowing each case to be accurately represented by one of the root causes. This rigorous methodology ensures a comprehensive understanding of the root causes of failures in urban drainage systems.

4.2.1.3. Analysis of the failures and root causes

Technical Failures

The analysis identified ten technical failures within urban drainage systems. Three of these failures have been previously documented in academic literature, while the remaining seven emerged from empirical data.

The bar chart provides a clear representation of the frequency of each failure, with “Clogging” and “Poor Maintainability” being the most prevalent, each recorded six times. These failures suggest design or operational shortcomings that result in blockages and maintenance difficulties. Consequently, issues in maintenance execution due to design constraints or accessibility, coupled with the accumulation of debris, are contributing to subpar urban drainage performance.

Other significant issues include “Insufficient Slope” and “Limited Freeboard,” each reported six times. These problems indicate challenges with water flow and overflow capacity, respectively. An inadequate gradient for water movement and a lack of sufficient capacity to manage excess water during peak flows are as significant as clogging and poor maintainability.

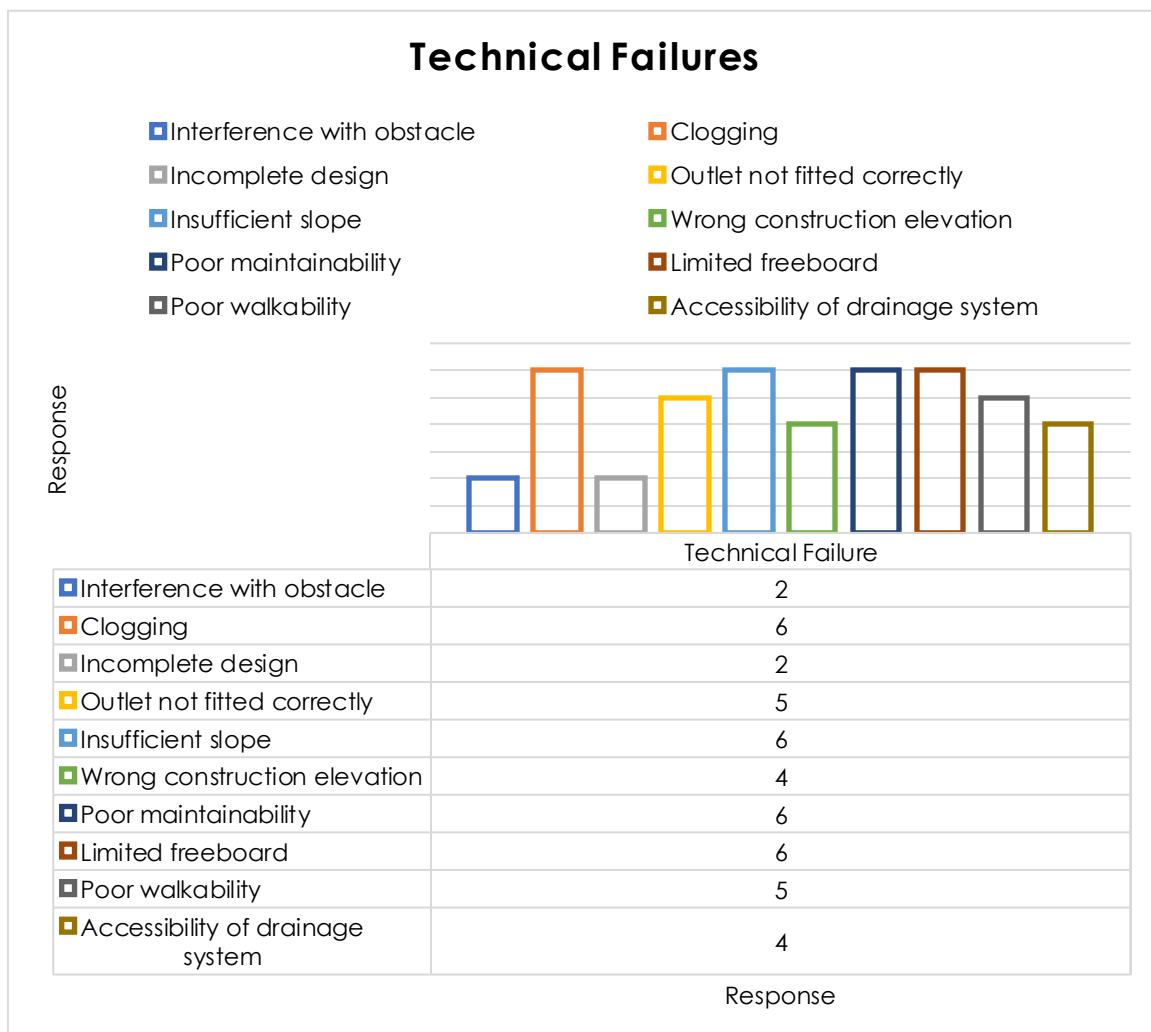


FIGURE 7: A CHART ILLUSTRATING OVERVIEW OF EACH TECHNICAL FAILURE

Furthermore, design-induced poor walkability, incorrectly fitted outlets (i.e., improper installation leading to drainage inefficiency), challenging accessibility of the drainage system for maintenance, and incorrect construction elevation leading to functional issues are also central to the major causes of drainage system inefficiency. In some areas, incomplete design lacking essential elements for optimal function and physical obstructions causing blockages have been observed. These factors further contributed to the inefficiency of the drainage systems.

Failing Function

The analysis revealed the most frequently observed technical failures for each of the three functions (infiltration, conveyance, and storage) of urban drainage systems:

1. **Infiltration Systems:** The predominant technical failure identified was “Clogging”. This aligns with prior research, which has consistently linked clogging to the malfunction of swales, permeable pavements, and infiltration crates (Scholz & Grabowiecki, 2007; Hatt et al., 2009; Bergman et al., 2011).
2. **Conveyance Systems:** The most frequently observed technical failure was “Insufficient Slope”. This issue has been previously highlighted by Boogaard et al. (2006). The second most common failure, “Outlet Not Fitted Correctly”, also corroborates with earlier studies (Boogaard et al., 2006; Pötz, 2016).
3. **Storage Systems:** The most common technical failures were “Limited Freeboard” and “Interference with Obstacle”. However, there appears to be a lack of relevant literature addressing these specific failures.

Failure Locations

The chart delineates the distribution of failure locations within the urban areas, distinguishing between internal and interface locations. The term “internal” refers to failures that occur within a single urban system, while “interface” pertains to failures that transpire at the physical junction between two systems. Approximately 45% of the failures are observed at the physical interfaces of urban systems, i.e., the points where the physical infrastructures of two urban systems intersect. These failures are not associated with the internal processes of the urban drainage systems, such as their hydraulic performance.

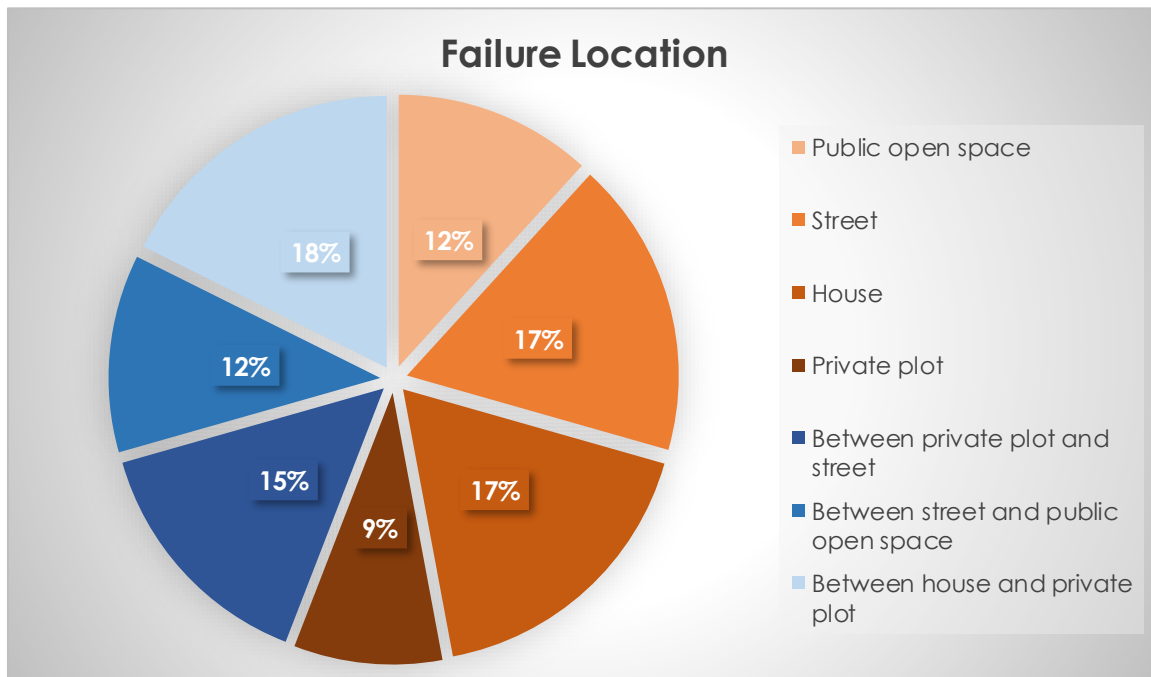


FIGURE 8: OVERVIEW OF FAILURE LOCATION

Interfaces are typically characterized by physical alterations in surfaces (e.g., transition from a paved surface to vegetation), height disparities (e.g., a sidewalk), and structures (e.g., a fence), suggesting their susceptibility to failure. Moreover, physical interfaces often reflect the demarcations of ownership and/or responsibility (e.g., private versus public ownership, or between two different public domains). The ambiguity regarding maintenance responsibility at these interfaces could potentially be the cause of these drainage facilities' malfunction.

This observation, that interfaces significantly contribute to the malfunctioning of urban drainage systems, is corroborated by prior research. Nieuwenhuis et al. (2021) examined integrated urban water solutions and discovered that interfaces, which materialize at locations where previously disconnected systems become interconnected, are a significant source of uncertainty. These interfaces complicate the understanding of the overall system behavior, thereby escalating the risk of failure. They elucidated that such interfaces encompass numerous potential mismatches, which could be both technical (related to physical changes in surfaces) and socio-institutional (related to the boundaries of responsibility and ownership).

Phase of Failure

The chart presented delineates the distribution of failures across various project phases. It is noteworthy that the construction phase is the origin of a substantial 40% of the total failures. The remaining 60% of the failures are split between the design and maintenance phases, contributing 33% and 27% respectively. This data underscores the fact that each phase of the project harbors a significant percentage of the total failures.

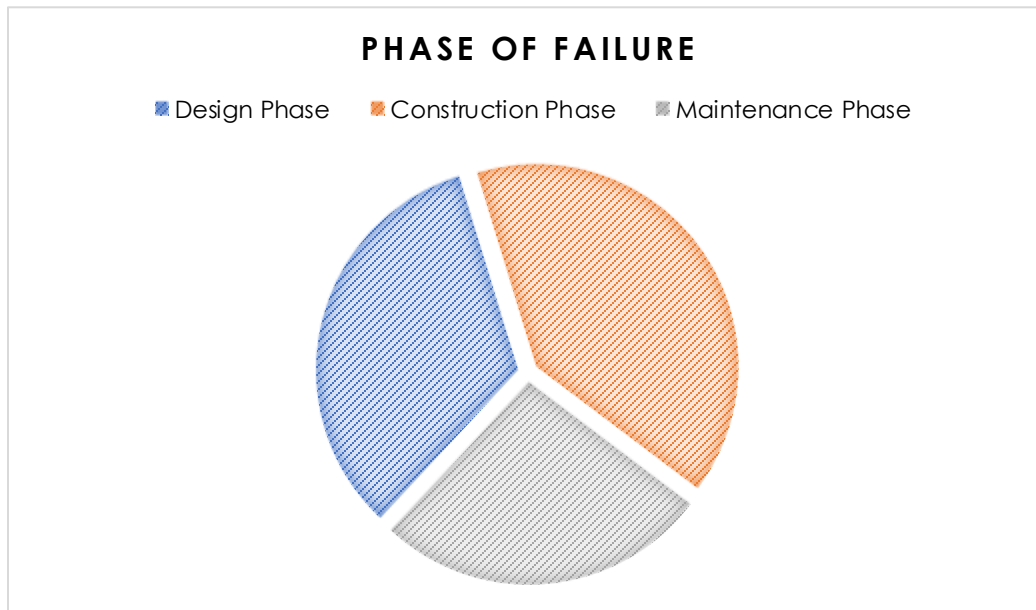


FIGURE 9: OVERVIEW OF PHASE OF FAILURE

Therefore, it is imperative that each phase receives meticulous attention to ensure the development of a robust urban drainage system. This assertion is corroborated by the study conducted by Rijke et al. (2008), which concluded that the successful implementation of innovative water systems hinges on the careful execution of all phases of the development process.

Root Causes

This section elucidates the primary causes contributing to the failure of drainage systems in the identified flood-prone regions. Insights were gleaned from interviews with urban professionals, culminating in the identification of 10 distinct root causes. It is noteworthy that some failures were attributed to two root causes, while others were linked to a single cause. The subsequent table enumerates these root causes. Those highlighted in gray represent the most prevalent causes and are discussed in greater detail.

Brief descriptions are provided for the remaining causes. Finally, a comprehensive discussion on the nature of these root causes as a collective set is presented.

Table 6. Overview of the root causes

Root Causes	Response
Entrenched practices among participating actors	6
Inadequacy of existing drainage systems	6
Inadequate communication among various stakeholders	6
Insufficient understanding of the interplay between the drainage system and other urban systems	5
Challenges in adapting the drainage system to unexpected situations	4
Actual utilization of the drainage system by individuals	4
Ineffective communication across different phases of the project	3
Knowledge gap in maintaining the drainage system	3
Subpar maintainability of the drainage system	2
Uncertainty regarding maintenance responsibilities	1

Entrenched practices among participating actors

The root cause of the issue at hand can be traced back to the entrenched beliefs, knowledge, and methodologies employed by professionals across various urban sectors such as water, green spaces, or roads. These factors contribute to the improper design, construction, or maintenance of urban drainage systems, culminating in their dysfunction. Occasionally, these ingrained practices are based on guidelines, but they can also be habitual routines. As highlighted by six interviewees, certain work methods or traditional measures can be so deeply rooted in practices that they become challenging to alter. They cited the construction of raised edges around roads and the creation of convex-shaped roads as examples. Both these practices hinder the above-ground management of stormwater, thereby restricting the functionality of urban drainage systems as shown in figure below.

This observation is corroborated by the research conducted by Roy et al. (2008), who discovered that standards and engineering guides occasionally inhibit the utilization of urban drainage systems in a manner that fully exploits their benefits. Urban drainage systems place new demands on those responsible for their design, construction, and maintenance. Consequently, practitioners need to acquire new knowledge and skills, potentially through training.



FIGURE 10: ILLUSTRATION OF ROAD EDGE RAISE DOWNSIDE

Furthermore, there is a need for changes in policies, guidelines, and standards to ensure they support the appropriate design, implementation, and use of urban drainage systems. Kiparsky et al. (2013) term this as ‘institutional innovation’ and argue that it holds equal importance to technological innovation.

Moreover, the multifunctionality of urban drainage systems implies that these systems impose different requirements on other urban systems, which were not initially designed with drainage functions in mind (Hoang & Fenner 2016). In addition to the municipal urban drainage department, numerous other actors are involved. Each of these actors operates according to their own rules and practices, while simultaneously influencing the performance of urban drainage systems. Therefore, it is not only the physical interfaces that emerge with the transition to urban drainage systems that need to be managed, but the urban drainage sector should also address the socio-institutional interfaces. These interfaces encompass the other actors in the urban environment and the institutions that guide these actors.

Inadequacy of existing drainage systems

Engineers and consultants have expressed concerns regarding the inadequacy of the drainage systems in the aforementioned flood-prone areas. They highlighted that the potential scale of flooding in areas where transportation roads are located was not adequately considered during the design phase.

Furthermore, they indicated that preliminary studies conducted prior to the design of these roads did not sufficiently determine the potential extent of surface flooding during the rainy season. As a result, the design lacked the necessary capacity to effectively manage runoff during periods of rainfall. Additionally, substandard workmanship during the construction phase and inadequate maintenance have also been identified as contributing factors to the ongoing drainage issues on these roads.

As articulated by the engineers and consultants, a comprehensive study has been conducted to assess the impact of the substandard drainage system on the surrounding environment. They unanimously concurred that while there is a pressing need for the redesign and reconstruction of the drainage system, it is equally imperative to perform maintenance on the existing drainage facilities to enhance their efficiency and effectiveness. They reported that redesigns and reconstruction efforts are currently underway in certain parts of the city.

Inadequate communication among various stakeholders

The root cause under discussion pertains to both intra-group communication, such as that within the municipal sewer department, and inter-group communication, for instance, between different departments at the municipality or between the municipality and external stakeholders like project developers, civil engineering consultants, and architects. The multifunctionality of urban drainage systems necessitates that decision-making regarding their design, implementation, and maintenance involves actors from diverse disciplines. Each of these actors possesses their own responsibilities, interests, and sector-specific terminology.

Consequently, they may not inherently comprehend the water function of drainages or possess the requisite 'urban water vocabulary'. This complexity in communication heightens the risk of failure.

One interviewee elucidated that architects typically aim to minimize the distance between the ground-floor level of a house and the water level (in this case, 0.15 m), striving for a closer connection with the water.

Conversely, municipalities generally design water systems with a substantial freeboard (in this case, 0.70 m) to augment the water storage capacity, which could mitigate urban flooding following heavy rainfall and prevent water shortage during droughts. However, these requirements were not clearly communicated during the decision-making process, leading to the construction of houses with minimal freeboard. As a result, the storage capacity had to be accommodated elsewhere in the urban water system, incurring significant costs.

Insufficient understanding of the interplay between the drainage system and other urban systems

This root cause pertains to the deficiency in understanding among urban practitioners regarding the interplay between urban drainage systems and other urban systems within public spaces. A number of interviewees have indicated that predicting the interactions of urban drainage systems with other systems beforehand is a complex task. They elaborated that there exists a multitude of urban drainage types, and their functionality is heavily contingent on local conditions. This makes the prediction of interactions at the interfaces with other urban systems a formidable challenge.

Post-implementation, it was observed that vehicular traffic induced friction between the stones, damaging the joint fillings between the cobblestones, leading to their eventual disappearance. Given that the practitioners lacked prior experience with permeable pavement, they failed to anticipate the long-term effects of vehicles on this type of porous pavement construction. Prior research has underscored that the implementation of urban drainage in a complex urban environment can give rise to new system interactions, potentially exerting adverse impacts on the functioning of both the drainage system and other urban systems (Hoang & Fenner 2016).

Such interactions that emerge at the interfaces between previously unconnected systems constitute a significant source of uncertainty: they amplify the complexity, thereby making it more challenging for decision-makers to comprehend the overall system behavior (Nieuwenhuis et al. 2021).

Challenges in adapting the drainage system to unexpected situations

This root cause pertains to the modifications made to the layout or design of drainage systems due to unforeseen circumstances during the design phase. The presence of existing urban infrastructure, both subterranean and above ground (e.g., cables, pipelines, or trees), could pose physical constraints on construction possibilities. This issue is particularly acute in regions lacking detailed geological surveys or systematic infrastructure records. In order to navigate these ‘unanticipated surprises’, workers may opt to make minor alterations to the design, enabling the continuation of the construction process. However, these modifications could significantly impair the functionality of urban drainage systems. This root cause aligns with the findings of previous research conducted by Moglia et al. (2011), who noted that the conditions encountered during the construction phase of drainage systems often deviated from initial expectations. Consequently, contractors, particularly those with experience and tacit knowledge, decided to modify the design.

Actual utilization of the drainage system by individuals

This root cause pertains to the practical utilization of urban drainage systems following their implementation. Individuals may employ these systems in manners not accounted for in their design, such as placing a car tire in the gutter or using it as a waste disposal and burning area. Such actions obstruct the intended flow path of stormwater, causing the water to be transported overland, visibly as opposed to the traditional subsurface lateral house connection, towards the infiltration facility.



FIGURE 11: ILLUSTRATION OF DRAINAGES BEING USED AS CAR TIRE PLACING



FIGURE 12: ILLUSTRATION OF DRAINAGES BEING USED AS BURNING AREA

This issue may originate from the limited awareness among citizens about the concept of drainage systems and their role in the functioning of urban drainages, as suggested by Roy et al. (2008). Furthermore, Zhang & Chui (2018) demonstrated that the willingness of the uninformed public to participate in drainage practices is not a given. They identified a lack of public interest and a lack of public support as two significant impediments to the implementation of effective drainage systems. These factors underscore the need for increased public education and engagement in the planning and maintenance of urban drainage systems.

Ineffective communication across different phases of the project

This root cause pertains to the suboptimal communication between stakeholders involved in distinct stages of the development process, encompassing the design, construction, and user/maintenance phases. An interviewee highlighted instances where, despite the technical drawings illustrating a novel design - for example, a road design that facilitates efficient runoff drainage to an infiltration facility - the construction was still executed using conventional methods.

This issue is linked to the fragmentation inherent in the current urban planning process, leading to a loss of information or knowledge during the transition from one project phase to the subsequent one, as noted by de Graaf & van der Brugge (2010). This underscores the need for improved communication and information continuity across all stages of the development process.

Knowledge gap in maintaining the drainage system

This root cause is attributed to the operators' insufficient understanding of the appropriate maintenance procedures for urban drainage systems. It was noted by three interviewees that operators are often not well-versed with the maintenance demands of new systems. This lack of knowledge could lead to inadequate or incorrect maintenance, ultimately causing the drainage systems to malfunction. This finding is corroborated by the research conducted by Boogaard & Rombout (2008), who concluded that municipalities frequently lack awareness of the maintenance requirements associated with urban drainage systems.

Subpar maintainability of the drainage system

This root cause pertains to the occasional limitations in maintenance opportunities, particularly due to the inaccessibility of certain components of the drainage system.

This observation aligns with prior empirical studies: Boogaard & Rombout (2008) noted that numerous infiltration facilities pose challenges for inspection and cleaning. They posited that the maintainability of drainage systems is integral to their functionality and, as such, should be a key consideration during the design phase. This underscores the need for strategic planning and design that prioritizes ease of maintenance to ensure the long-term effectiveness of urban drainage systems.

Uncertainty regarding maintenance responsibilities

The responsibility for the maintenance of urban drainage systems is frequently ambiguous. This uncertainty often originates from the system interfaces that materialize with the transition towards integrated urban water solutions. Furthermore, the construction of urban drainage systems may result in a redistribution of responsibilities. This suggests that a substantial role in the maintenance of drainage systems could fall to entities whose primary focus is not water-related, such as road authorities in the context of permeable pavement.

4.2.2. Major impacts of surface flooding on roads

4.2.2.1. Government authorities, urban planners, and engineers' response

The lack of proper maintenance of the drainage system is a significant contributor to the degradation of road pavement, thereby reducing its lifespan. The subpar condition of the side drain and its structures persist throughout the rainy season, causing runoff water to flow on the road surface instead of being diverted away from the failed drain.

This critical situation results in severe distress and damage to the pavement. The road edges, in particular, suffer from the detachment of the asphalt layer due to continuous water contact. This leads to the stripping of asphalt from aggregates, resulting in severe pavement distresses such as cracking, potholes, and failure of the road edges.

The adverse impact of poor drainage conditions on road pavement is substantial. It leads to pavement distresses and deterioration, which negatively affect the safety and ride quality of the pavement. The study investigated instances of pavement failures and damages attributable to poor drainage, particularly those experienced during the rainy season.

The major impacts of surface flooding on the road

- Runoff water can obstruct the road by depositing waste material on the surface. Additionally, debris left by water and thawing processes can weaken and strip the asphalt in the pavement.
- The load-bearing capacity of the subgrade, sub-base, asphalt, and shoulder of the road can be reduced due to these conditions.
- The roadside surface can be eroded, washing away the top layer of the road. These factors collectively contribute to the degradation of the road infrastructure.

Based on information obtained from the engineers and the DDM of ERA, it is imperative to consider the topography of the surrounding area when designing and constructing road drainage structures. This consideration is particularly important in relation to the location of settlements along the road, as it can significantly impact both road users and local residents.

The objective is to effectively manage the causes and effects of poor drainage on the road. Additionally, the cost of construction and the current state of the road should be taken into account. Understanding the critical factors considered during the design of a road drainage system is crucial, as it provides insight into the rationale behind each road design.

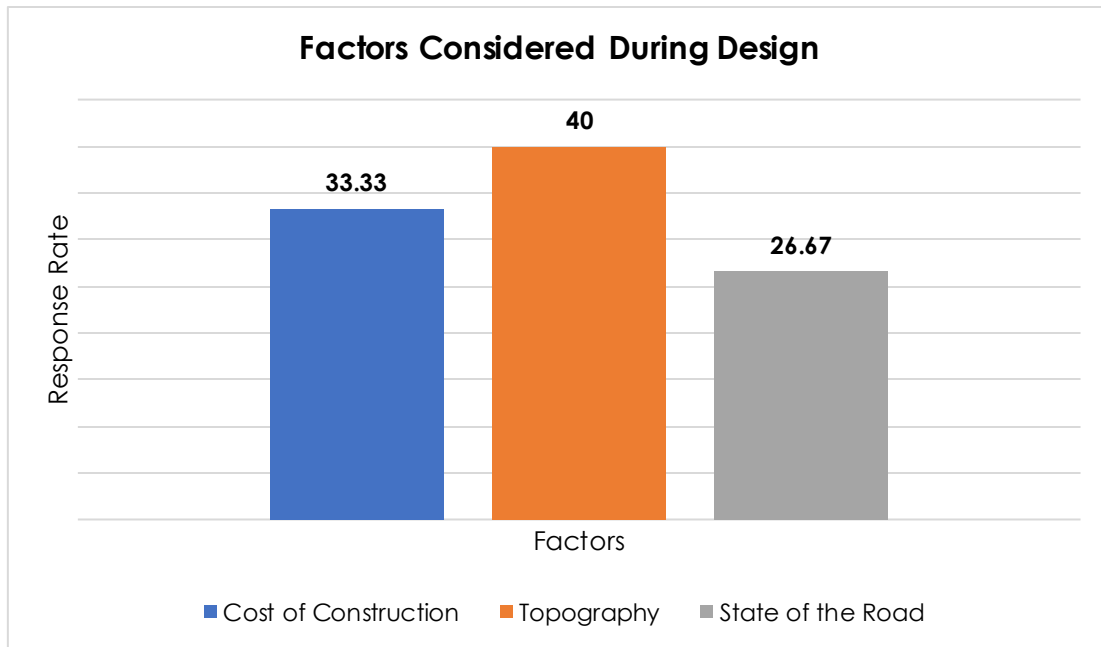


FIGURE 13: FACTORS CONSIDERED WHEN DESIGNING A DRAINAGE

Understanding the key considerations in the design of a road drainage system is of paramount importance. This knowledge provides valuable insights into the underlying rationale for each road's design.

4.2.2.2. Road users' response

A substantial number of respondents reported using the road either daily or twice weekly. The collected data indicates that 80% of the respondents frequently use the road. This information is crucial to the study as it underscores the reliability of the respondents in providing authentic information to fulfill the study's objectives.

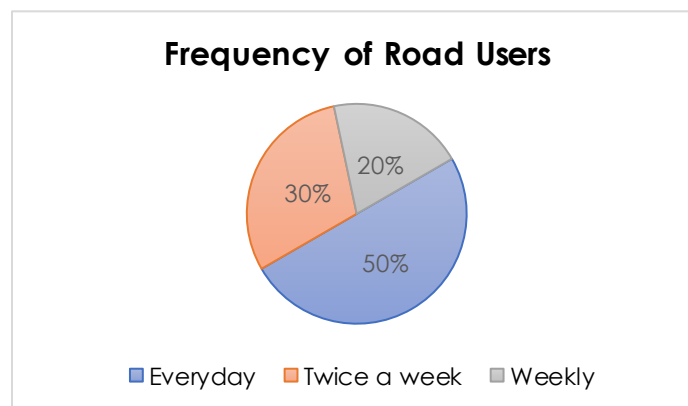


FIGURE 14: FREQUENCY OF ROAD USERS

Road users expressed concerns regarding their safety and the convenience of accessing or residing in these flood-prone locations during rainy periods. The state of the drainage system posed a safety risk. A mere 20% of respondents deemed the provided drainage system to be good, with none rating it as very good. According to road users, which include taxi drivers, pedestrians, and private vehicle owners, the substandard drainage infrastructure in the location has resulted in road damage due to pavement erosion, cracking, washouts from water overflows, waste material deposits on the road, and failure of road edges.

The majority of respondents reported that the primary effects of poor drainage on the road are the debris left by water on the road surface during rainfall, thereby obstructing the free movement of vehicles. The asphalt is also washed away during the rainy season, rendering the road impassable. A significant number of respondents reported that runoff on the road leads to blockages and cracking, leaving debris on the road after the rain. This debris impedes movement along the road, causing inconvenience to travelers and resulting in delays in their business or other engagements.

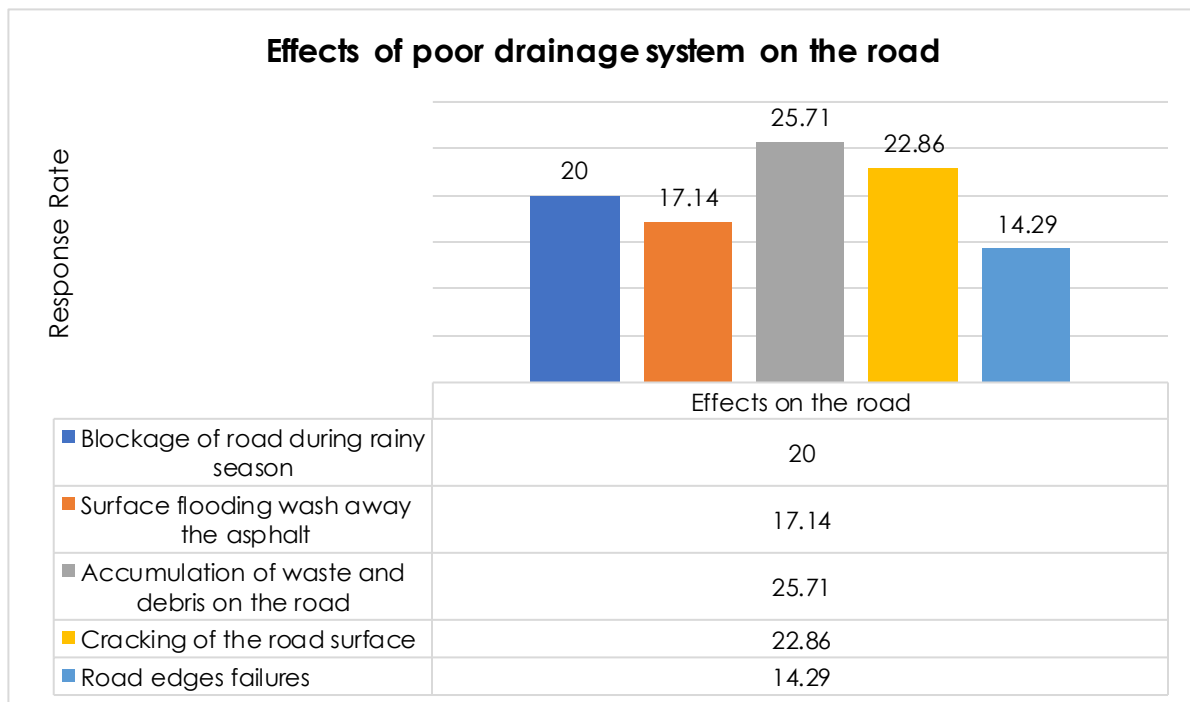


FIGURE 15: RESIDENTS AND ROAD USERS' OPINION ON POOR DRAINAGE EFFECTS

The causes of flooding are multifaceted, with a combination of factors contributing to the occurrence of flooding and its consequences on road drainage systems. According to the responses from the questionnaire, the clogging of drainage pipes, culverts, and ditches by debris flow and fine-grade soil is one of the most critical maintenance issues in current drainage systems. Some respondents indicated that the cleaning of drainage pipes, culverts, and ditches is not scheduled at specific times and is therefore only performed when necessary. This suggests the importance of regular maintenance and cleaning operations to prevent water overflow on the road.

Level of road users' satisfaction

The data provided clearly indicates a prevalent dissatisfaction among road users regarding the current state of the drainage system. Based on the feedback from road users, the drainage systems are in a poor state and adversely affect the road structures. There is a pressing need for improvements to the system to enhance road user satisfaction. The dissatisfaction among road users stems from the impact of the inadequate drainage system on transportation, underscoring the urgent need for remedial measures.

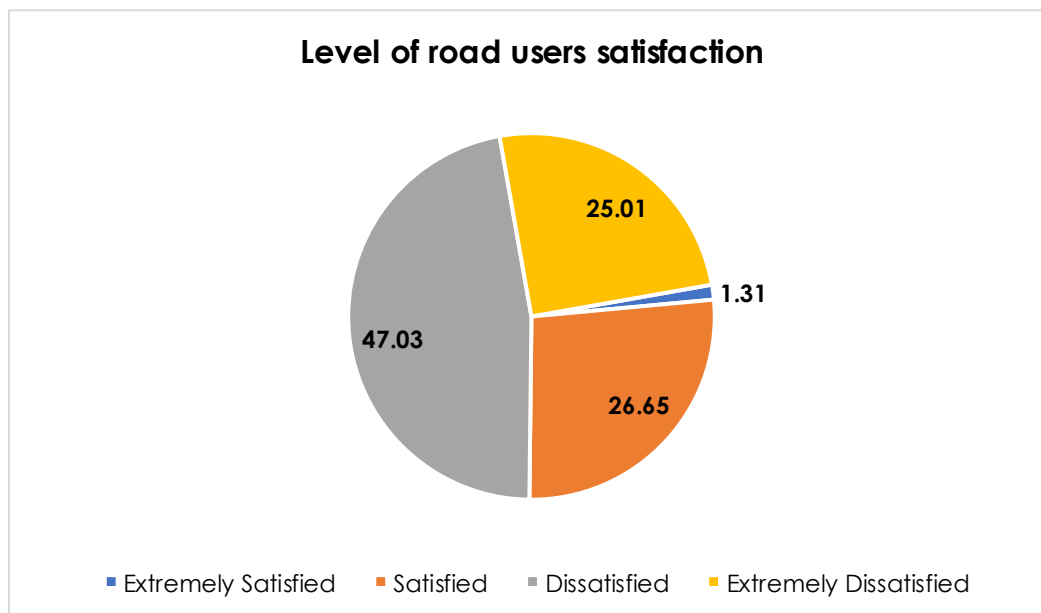


FIGURE 16: ROAD USERS LEVEL OF SATISFACTION BY THE ROAD

4.2.2.3. Residents' response

A significant proportion of questionnaire respondents reside within 100 meters of the road. The collected data indicates that 38.3% of respondents live within a hundred meters from the road, but beyond the 50-meter mark.

This demographic distribution is crucial as it ensures that the respondents are well-positioned to address all the issues pertinent to this study, thereby facilitating the achievement of the study's objectives.

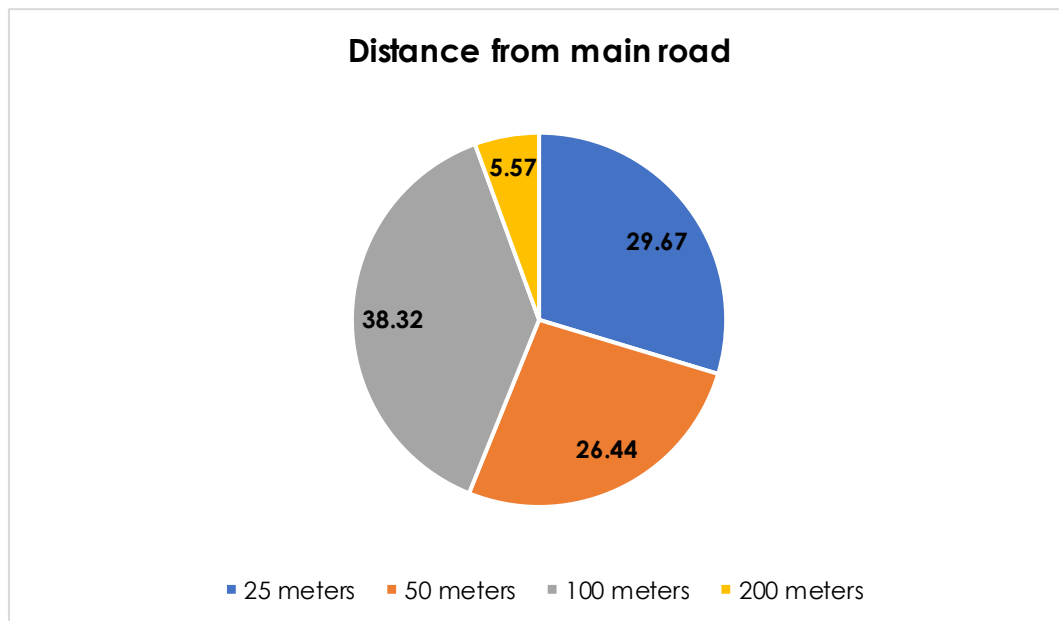


FIGURE 17: RESIDENTS PROXIMITY TO THE ROAD

Regarding the drainage across the road, the inadequacy of the drainage systems often precipitates the onset of deterioration, typically manifesting as cracks or potholes on the road pavements. These defects, which can occur either at the edges or along the driveway, vary in their shapes, configurations, loading amplitudes, traffic movement patterns, and deformation rates.

The figure below illustrates the residents' perceptions of how they have been impacted by the poor drainage in the area. The majority of respondents reported that runoff has had detrimental effects on the road and has resulted in the flooding of their residential homes. They indicated that the runoff erosion originating from the road has created hazardous conditions, particularly during heavy rainfall. They recounted experiencing flooding on several occasions.

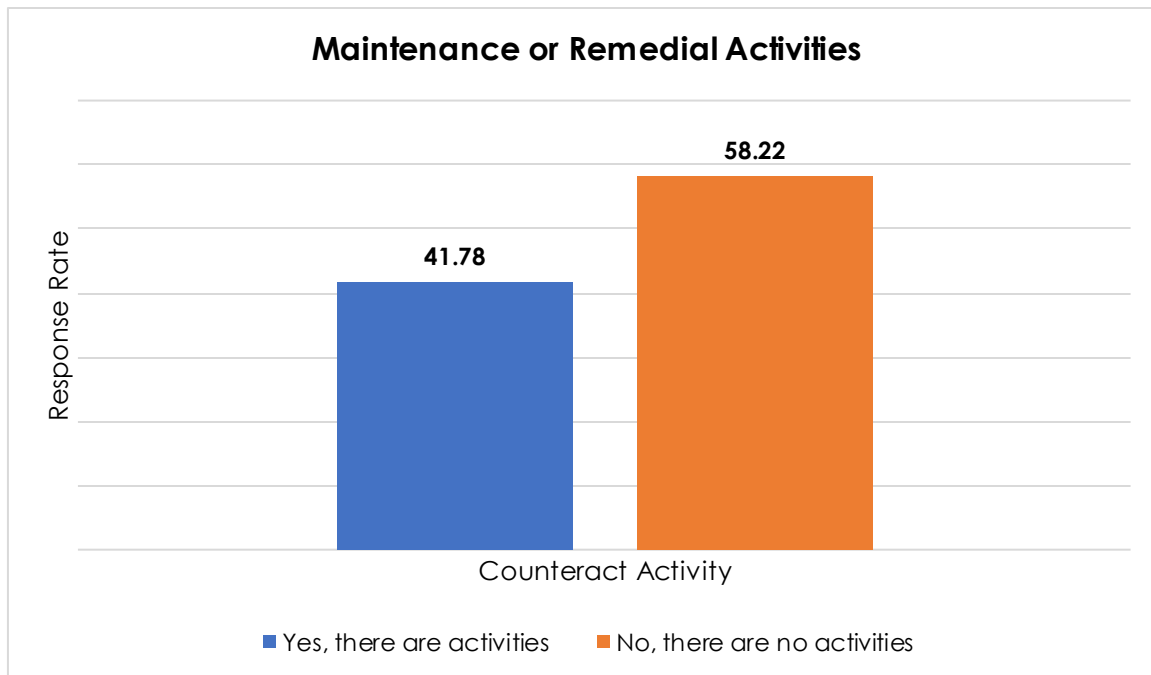


FIGURE 18: RESIDENTS OPINION ON REMEDIAL ACTIVITIES

The data indicates that there have been concerted efforts aimed at enhancing the drainage system. However, a majority of the respondents have not witnessed these improvement activities on the road. Conversely, a notable percentage of respondents have observed these initiatives in progress. This suggests that while strides have been made to ameliorate the drainage system, the efforts have not yet reached a satisfactory level. Consequently, there is a pressing need to elevate the quality of the facilities to meet acceptable standards.

4.3.Results from Observation and Site Visit

The design of a road drainage system should be predicated on the analysis of hydrologic parameters of areas susceptible to flooding. An adequate hydrologic analysis design is crucial for a road drainage system to effectively manage peak discharge without causing disruption, damage to the drainage system, or harm to properties adjacent to the road crossing. Furthermore, following a satisfactory hydrologic analysis design, proper construction is paramount for the road drainage system to function as intended.

Generally, most of the provided drainages are constructed from materials such as bricks, stones, or concrete and are open drains without covers. Some drains are covered with concrete slabs or blocks. Failures of constructed drains, such as the collapse of the bed, side walls, and/or covers, can be attributed to improper design and construction, settlement, or heave. These issues may lead to the development of cracks and subsequent failure. This underscores a situation where preliminary studies that could inform design and construction decisions are not conducted, highlighting the need for such studies in the planning phase to prevent future failures.

4.3.1. Existing drainage system at site A

Upon observation, it is evident that the condition of the drainage system is subpar. Field surveys and corresponding figures have revealed that the road surface has been marred by potholes, cracking, edge damages, and a significant accumulation of soil over a large area. The existing drain, which is situated on both sides of the road, is an open stone ditch with a width of 1 meter and a depth ranging from 0.5 to 1 meter. The condition of this drain is notably poor, with soil accumulation and refuse dumps filling it. The side drain has been blocked by soil, debris, and solid waste, as depicted in the above figure. Given these issues, it is recommended that regular maintenance and cleaning operations be performed to prevent overflowing of water on the road.



FIGURE 19: SITE A CURRENT DRAINAGES STATUS

The longitudinal and cross-sectional slopes of the road are nearly flat, with some deformations. The majority of the damage ranges from moderate to severe edge cracking and raveling. The severe raveling has led to the formation of potholes and depressed areas where the top surface has delaminated from the road pavement, as clearly illustrated in the above photographs.

To address these problems, it is crucial that adequate provisions for drainage systems are made for the road surface to ensure satisfactory performance of the road pavement. Therefore, a drainage system, which includes the pavement and the water handling system, must be properly designed, constructed, and maintained. This comprehensive approach will ensure the effective functioning and longevity of the road infrastructure.

4.3.2. Existing drainage system at site B

Observations indicate that the left carriageway of the road is linked to a side drain, most of which is covered with a concrete slab and damaged manhole covers. The drain, with a small cross-section of 1m width and a depth not exceeding 1m, is in a state of significant disrepair and continues to deteriorate rapidly. The drain suffers from a range of issues including low capacity, soil accumulation, lack of inlets, inadequate maintenance, and the disposal of solid waste into the drain and crossing culverts. To address these issues, it is recommended that regular maintenance and cleaning operations be performed on the drainage structures, and solid waste be removed to prevent further deterioration of the road surface.



FIGURE 20: DRAINAGE BLOCKED BY MUD AT SITE B



FIGURE 21: ILLUSTRATION OF DAMAGED MANHOLE COVER

Unstable side slopes and draining road cuts in areas can easily lead to erosion of pavement structures. It is crucial that surface water flowing from the pavement on paved roads is directed over the road shoulder to the ditch. Allowing water to flow along the pavement edge poses a high risk for erosion.



FIGURE 22: ON ROAD DERBIS AFTER RAIN AT SITE B

Enhancing the road profile with a gentle longitudinal gradient can improve road surface drainage. This slope facilitates the discharge of water from sections of the road surface with limited cross-slope. For roads with an asphalt surface, the camber is typically set at 2% to 3% to ensure easy runoff of water from the asphalt surface. These measures collectively contribute to the effective management of water runoff and the preservation of road infrastructure.

4.3.3. Existing drainage system at site C

The current state of the drainage system and its structures is markedly poor, with conditions deteriorating over time. The drainage system is plagued by a host of issues, including low capacity, natural siltation, lack of inlets, indefinite drainage outlets, and inadequate maintenance. Furthermore, the disposal of solid waste into the crossing culverts exacerbates the problem. The accumulation of silt, sand, and debris, as depicted in the figure below, has led to blockages in the drain. It is evident that the drain and culverts are being transformed into dumping grounds, subsequently obstructing water flow.

The issues associated with the location and construction of slab culverts, as shown in the figure above, can be mitigated through comprehensive site investigation, attention to geomorphic indicators, understanding of road template design requirements, and comprehension of stream and watershed functioning.



FIGURE 23: SITE C CURRENT FAILED CULVERTS

The suboptimal location of the slab culvert on the road renders it prone to failure. The selection of a suitable site for the drainage system necessitates the involvement of multiple disciplines, including preliminary engineering, hydrology and hydraulics, geomorphology, roadway alignment, and environmental and geological considerations. This multidisciplinary approach ensures the sustainability of the structure and its ability to serve road users effectively.

The construction of the drainage system should take into account the required location of the crossing in the watershed, the transportation of water, sediment, and wood at that location, and the configuration of the catchment. Following a proper design, the implementation of correct construction practices is crucial for the drainage system to function as intended for road users. It is important to note that proper design alone does not guarantee the effective functioning of the drainage structure up to its design life. It must be complemented by proper construction practices carried out by qualified personnel in accordance with the design.

4.4. Discussion of the Findings

The study identified ten technical failures, with clogging and poor maintainability being the most common, suggesting design or operational issues leading to blockages and maintenance difficulties. For infiltration systems, clogging was the predominant failure. Conveyance systems often failed due to insufficient slope, while storage systems were affected by limited freeboard and interference with obstacles. About 45% of failures occurred at the physical interfaces between urban systems, highlighting the importance of considering the junctions between different infrastructures. Interviews with professionals revealed a mix of technical and socio-technical root causes for the failures, emphasizing the need for a comprehensive approach to address both design flaws and institutional behaviors.

Physical interfaces, such as transitions between different surfaces or ownership boundaries, are prone to failure and complicate system behavior, increasing the risk of malfunction. Failures are distributed across construction (40%), design (33%), and maintenance (27%) phases, indicating the need for careful execution in each phase.

Interviews with urban professionals identified 10 root causes for drainage system failures, with entrenched practices and inadequacy of existing systems being the most prevalent. Traditional methodologies and practices in urban sectors lead to improper design and functionality of drainage systems, necessitating new knowledge, skills, and institutional innovation.

The existing drainage systems are inadequate for managing runoff, especially in flood-prone areas, highlighting the need for redesign, reconstruction, and maintenance. The study emphasizes the importance of addressing both physical and socio-institutional interfaces, as well as the multifunctionality of urban drainage systems in the overall urban environment.

The study highlights that poor maintenance of drainage systems leads to significant road pavement damage, especially during the rainy season. Continuous water contact causes detachment of the asphalt layer, resulting in cracking, potholes, and failure of road edges. Road users, including taxi drivers, pedestrians, and private vehicle owners, express concerns about safety and accessibility during rainy periods. The inadequate drainage system poses risks and inconveniences, with 80% of respondents frequently using the affected roads.

The clogging of drainage pipes, culverts, and ditches by debris flow and fine-grade soil is identified as a critical maintenance issue. Regular maintenance and cleaning operations are suggested to prevent water overflow and road blockages. Residents living close to the roads report detrimental effects of runoff on the road and flooding of their homes. While some improvement efforts have been observed, the majority of respondents feel that the drainage system's quality has not reached satisfactory levels.

The study emphasizes the importance of hydrologic analysis in designing road drainage systems. Adequate design is essential to manage peak discharge effectively without causing damage or disruption. Most drains are made of bricks, stones, or concrete, with some being covered. Failures often result from improper design, construction, or natural factors like settlement.

Overall, the study underscores the need for effective management of drainage systems to mitigate the adverse impacts on road infrastructure and improve safety and satisfaction among road users and residents. Regular maintenance, consideration of topography in road design, and enforcement of environmental protection protocols are recommended to address these issues.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1.Introduction

This chapter provides a condensed overview of the key findings, conclusions, and recommendations from the study examining the impact of inadequate urban drainage systems on transportation in flood-prone areas of Adama city. It also outlines potential avenues for future research.

The initial section offers a comprehensive summary of the study's primary findings. These findings are derived from a variety of sources, including data analyzed through various software, questionnaires, interviews, secondary data analysis, and site observations conducted in the identified flood-prone areas within Adama city. The focus is on identifying the principal causes of poor urban drainage systems and analyzing their significant impacts on road infrastructure. The subsequent section presents recommendations that are formulated based on the conclusions drawn from the study's findings. The final section of this chapter proposes suggestions for further research in this field, thereby paving the way for continued exploration and understanding of this critical urban issue.

5.2.Conclusion

The findings of this study were derived from the responses provided by participants during the data collection process, site observations, and cross-verification against collected secondary data. These findings were generated in response to the study objectives delineated in Chapter One. The conclusions and recommendations of the study are predicated on these findings and are formulated in consideration of their alignment with the reviewed literature. Following the identification of failure characteristics for the urban drainage system and the recognition of technical failures in the area, this study discerned the primary root causes and potential impacts on the roads. This comprehensive approach ensures a thorough understanding of the issues at hand and provides a solid foundation for the proposed recommendations.

Identification of flood prone areas

This study employed a multicriteria methodology to pinpoint areas in Adama City that are susceptible to flooding. The findings indicate that the primary contributors to flooding in Adama

City are drainage density, elevation, and land use patterns. In contrast, the influence of slope is comparatively less significant. Additionally, the study reveals that 11.24% of the area under investigation, which comprises various urban land uses, is situated within a high flood hazard zone predominantly located in the central and southern parts of the city. This comprehensive approach provides a nuanced understanding of the flood risk landscape in Adama City.

Findings on major causes of poor urban drainage system

Urban drainage systems, which are integral to urban stormwater management, are widely implemented and, like all components of urban water infrastructure, are susceptible to failure. This study has identified specific failure points based on observations, interviews, and prior identifications. The analysis of this failure data reveals the following:

- Failures frequently (in more than one-third of cases) occur at the interfaces of different urban systems. This is where the physical infrastructures of two urban systems intersect, such as the interface between a private plot and a public street.
- Failures impact each of the defined hydraulic functions of drainages: infiltration, conveyance, and storage. The most commonly observed failing functions are clogging, insufficient slope, and limited freeboard, respectively.
- Failures can originate from various phases, including the design phase, construction phase, and maintenance phase.

These findings suggest that a thorough check of urban drainage construction upon completion (which also takes into account the maintenance phase and the transition between phases) has the potential to reduce the number of failures. Special attention should be paid to the interfaces with other urban systems, such as green spaces, roads, and private plots. This could significantly enhance the effectiveness and longevity of urban drainage systems.

Following comprehensive interviews with professionals, engineers, and government authorities, ten fundamental causes contributing to these failures were identified. Each failure was found to be associated with one or two of these root causes. The most frequently observed root causes include:

- Entrenched practices among participating actors
- Inadequacy of existing drainage systems

- Inadequate communication among various stakeholders
- Insufficient understanding of the interplay between the drainage system and other urban systems

Upon comprehensive examination of the root causes, it becomes evident that they are predominantly socio-institutional rather than technical. These root causes typically pertain to the behaviors of actors and the institutions that guide these actors' perceptions and actions, encompassing aspects such as communication, responsibility, knowledge, experience, routines, and guidelines.

This observation could be partially attributed to the phrasing of the root causes. For instance, in the case of two root causes - subpar maintainability of the drainage system and insufficient understanding of the interplay between the drainage system and other urban systems - one could argue that the root causes are primarily associated with the physical infrastructure. However, even for these root causes, a clear relationship with actors and institutions is discernible, suggesting that failures could be mitigated through improved instructions, enhanced communication between actors, or thorough evaluation.

The study demonstrates that the socio-institutional system plays a significant role in the malfunctioning of urban drainages. This implies that the socio-institutional infrastructure may not always be properly aligned with the techniques and technologies employed in the drainage system, and that failures could be prevented if aspects such as communication and guidelines are accorded greater attention. This insight underscores the importance of socio-institutional factors in the effective functioning of urban drainage systems.

Findings on major impacts on the road

The impacts of an inadequate drainage system on the road infrastructure were examined through meticulous site observations and the deployment of questionnaires to residents, road users, and engineers. The capacity and sufficiency of the drainage system were scrutinized through observational studies, secondary data analysis, and the evaluation of questionnaire responses. The analysis of these questionnaires, which were specifically designed for engineers, road users, and residents, facilitated an investigation into the design capacity and the effects of the existing substandard drainage system on the road. This comprehensive approach ensured a thorough understanding of the issue at hand.

The road infrastructure surrounding the drainage system has been compromised due to the overflowing of water on the road. This is primarily caused by runoff water depositing waste material on the road surface, thereby obstructing it. Additionally, the thawing processes and the debris left by water have weakened and stripped the asphalt in the pavement. These conditions have led to a reduction in the load-bearing capacity of the subgrade, sub-base, asphalt, and shoulder of the road. Furthermore, the roadside surface has been eroded, resulting in the washing away of the top layer of the road. Collectively, these factors have significantly contributed to the deterioration of the road infrastructure.

During site observation the most common causes of road drainage problem were found related to insufficient capacity of drainage structures, poor construction, and lack of proper maintenance. There was a general feeling that the type of drainage system is not adequate. Also, the drain suffered from low capacity, soil accumulation, absence of inlets, lack of proper maintenance and disposal of solid waste into the drain and the crossing culverts.

These factors collectively contributed to the inefficiency of the drainage system. The study also found that the existing drainage system is not adequate to handle the volume of storm water runoff. The capacity of the drainage system is not sufficient to handle the volume of water during heavy rainfall. The drainage system is also not well maintained, with debris and waste blocking the flow of water. This leads to flooding and damage to the road infrastructure.

5.3.Recommendations

A hydrologic analysis is prerequisite to identifying flood hazard areas and determining those locations where construction and maintenance would be unusually expensive or hazardous. Since many levels of government plan, design, and construct highway and water resource projects that might affect each other, interagency coordination is desirable and often necessary. In addition, agencies can share data and experiences within project areas to assist in the completion of accurate hydrologic analysis.

Improvement of drainage facilities through maintenance redesign and reconstruction, to improve the role of poor workmanship in the construction of drainage and roads and provision of proper connections or integrations between the road network and drainage network systems is required always when construction of the road.

The designer and contractor should follow the minimum requirement set by ERA regarding to the drainage structure, size, length and alignments of road drainage structure so as to prevent the impact of poor drainage on the road pavement. Therefore, selection of good drainage system site must involve many disciplines that include preliminary engineering, hydrology & hydraulics, geomorphologic concerns, roadway alignment, and environmental & geological concerns in order to make the structure sustainable and a program for cleaning out the surface drainage system is essential.

5.3.1. Mitigating Strategy for root causes

Entrenched practices among participating actors

- ✓ **Promote Cross-Disciplinary Collaboration:** Encourage collaboration between professionals across various urban sectors such as water, green spaces, or roads. This can help break down silos and foster a more holistic approach to urban drainage system design, construction, and maintenance.
- ✓ **Training and Capacity Building:** Provide training and capacity building for practitioners to acquire new knowledge and skills necessary for the design, construction, and maintenance of urban drainage systems. This can help shift entrenched practices and promote the adoption of innovative approaches.
- ✓ **Revise Policies, Guidelines, and Standards:** Review and revise existing policies, guidelines, and standards to ensure they support the appropriate design, implementation, and use of urban drainage systems. This could involve incorporating ‘institutional innovation’ as termed by Kiparsky et al. (2013), which holds equal importance to technological innovation.
- ✓ **Design for Multifunctionality:** Recognize the multifunctionality of urban drainage systems and design other urban systems with drainage functions in mind. This can help ensure that urban systems are designed to work together, rather than in isolation.
- ✓ **Engage All Relevant Actors:** Engage all actors involved in the urban environment, including the municipal urban drainage department and others. This can help ensure that all actors operate according to rules and practices that support the performance of urban drainage systems.

- ✓ **Manage Socio-Institutional Interfaces:** In addition to managing the physical interfaces that emerge with the transition to urban drainage systems, also address the socio-institutional interfaces. This involves managing the relationships between the various actors in the urban environment and the institutions that guide these actors.

By implementing these strategies, it may be possible to overcome the challenges posed by entrenched practices among participating actors and improve the functionality of urban drainage systems.

Inadequacy of existing drainage systems

- ✓ **Comprehensive Drainage Design:** Ensure that the design phase of urban infrastructure projects includes a comprehensive assessment of potential flooding scenarios. This should take into account the scale of potential flooding in areas where transportation roads are located.
- ✓ **Improved Preliminary Studies:** Enhance the preliminary studies conducted prior to the design of roads to better determine the potential extent of surface flooding during the rainy season.
- ✓ **Quality Control:** Implement strict quality control measures during the construction phase to prevent substandard workmanship.
- ✓ **Regular Maintenance:** Establish a regular maintenance schedule for existing drainage facilities to enhance their efficiency and effectiveness.
- ✓ **Redesign and Reconstruction:** Where necessary, redesign and reconstruct inadequate drainage systems. This should be based on comprehensive studies assessing the impact of the substandard drainage system on the surrounding environment.

Inadequate communication among various stakeholders

- ✓ **Cross-Sector Communication:** Foster improved communication between different departments at the municipality and external stakeholders like project developers, civil engineering consultants, and architects. This could involve regular meetings, workshops, or the use of shared digital platforms.

- ✓ **Shared Terminology:** Develop a shared ‘urban water vocabulary’ that can be understood by all actors involved in the design, implementation, and maintenance of urban drainage systems.
- ✓ **Clear Communication of Requirements:** Ensure that the specific requirements of different actors are clearly communicated during the decision-making process. For example, if municipalities require a substantial freeboard to augment water storage capacity, this should be clearly communicated to architects and developers.
- ✓ **Collaborative Decision-Making:** Encourage a more collaborative decision-making process that involves all relevant actors. This can help ensure that the needs and requirements of all actors are taken into account, reducing the risk of costly adjustments later on.

Insufficient understanding of the interplay between the drainage system and other urban systems

- ✓ **Interdisciplinary Training:** Provide training for urban practitioners that emphasizes the interplay between urban drainage systems and other urban systems. This can help practitioners better understand the complex interactions that can occur and how to manage them.
- ✓ **Predictive Modeling:** Develop and use predictive models to anticipate the interactions between urban drainage systems and other urban systems. This can help practitioners design systems that are more resilient and adaptable.
- ✓ **Learning from Experience:** Encourage practitioners to learn from past experiences and case studies. This can help them anticipate potential issues and design systems that are more robust.
- ✓ **Collaborative Design Process:** Foster a collaborative design process that involves practitioners from different disciplines. This can help ensure that all potential interactions are considered during the design phase.

Challenges in adapting the drainage system to unexpected situations

- ✓ **Detailed Preliminary Surveys:** Conduct detailed geological surveys and systematic infrastructure records before the design phase. This can help identify potential obstacles and inform the design process.

- ✓ **Flexible Design Principles:** Adopt flexible design principles that can accommodate unexpected situations. This can help ensure that minor alterations do not significantly impair the functionality of urban drainage systems.
- ✓ **Experienced Contractors:** Engage contractors with experience and tacit knowledge in the construction of urban drainage systems. Their expertise can be invaluable in navigating ‘unanticipated surprises’ and making necessary modifications to the design.
- ✓ **Regular Review and Adaptation:** Implement a process for regular review and adaptation of the drainage system design and layout. This can help ensure that the system remains effective and functional even when unexpected situations arise.

Actual utilization of the drainage system by individuals

- ✓ **Public Education Campaigns:** Implement public education campaigns to raise awareness about the importance of proper utilization of urban drainage systems. This could include information on the negative impacts of improper use and the benefits of proper use.
- ✓ **Community Engagement:** Involve community members in the planning and maintenance of urban drainage systems to foster a sense of ownership and responsibility.

Ineffective communication across different phases of the project

- ✓ **Integrated Project Management:** Adopt an integrated project management approach that ensures effective communication and information continuity across all stages of the development process.
- ✓ **Regular Stakeholder Meetings:** Conduct regular meetings with all stakeholders involved in the project to ensure everyone is on the same page and any issues are addressed promptly.

Knowledge gap in maintaining the drainage system

- ✓ **Training Programs:** Implement training programs for operators to equip them with the necessary knowledge and skills to maintain the drainage systems effectively.
- ✓ **Maintenance Manuals:** Develop comprehensive maintenance manuals that provide clear instructions on how to maintain the drainage systems.

Subpar maintainability of the drainage system

- ✓ **Design for Maintainability:** Incorporate maintainability considerations into the design phase of the drainage systems. This could involve designing systems that are easy to inspect, clean, and repair.
- ✓ **Maintenance Access Points:** Ensure that the drainage systems have sufficient access points for maintenance activities.

Uncertainty regarding maintenance responsibilities

- ✓ **Clear Delineation of Responsibilities:** Clearly delineate the responsibilities for the maintenance of the drainage systems. This could be outlined in a formal agreement or contract.
- ✓ **Cross-Sector Collaboration:** Foster effective cross-sector collaboration in the management of urban drainage systems. This could involve regular meetings and joint training sessions.

5.3.2. Mitigating Strategies for the impacts on roads

Below are some mitigation strategies or policies for the major impacts of surface flooding on roads:

Runoff water obstructing the road

- ✓ **Regular Cleaning:** Implement a regular cleaning schedule to remove waste material and debris from the road surface. This can prevent the weakening and stripping of the asphalt in the pavement.
- ✓ **Drainage Improvement:** Improve the drainage system to ensure that runoff water is effectively diverted away from the road. This can prevent the accumulation of water on the road surface.

Reduced load-bearing capacity

- ✓ **Drainage Maintenance:** Regular maintenance of the drainage system can prevent the saturation of the subgrade, sub-base, asphalt, and shoulder of the road, thereby preserving their load-bearing capacity.
- ✓ **Material Selection:** Use materials that are resistant to water damage for the construction of the road. This can enhance the durability of the road and its ability to withstand the impacts of surface flooding.

Roadside surface erosion

- ✓ **Erosion Control Measures:** Implement erosion control measures such as the use of erosion control blankets, grassing, and the construction of retaining walls. These measures can prevent the washing away of the top layer of the road.
- ✓ **Drainage Design:** Design the drainage system in a way that diverts water away from the roadside surface. This can prevent the erosion of the roadside surface.

These strategies should be tailored to the specific context and needs of the urban area in question. It's also important to monitor and evaluate the effectiveness of these strategies over time and make necessary adjustments.

Furthermore, additional interviews with professionals from other disciplines and sectors, such as landscape architects and urban planners, could provide valuable insights and may lead to other, new, root causes that our approach has not been able to reveal. This study provides valuable insights into the occurrence and root causes of failures in urban drainage and thereby contributes to a renewed socio-technical urban drainage system with more sustainable stormwater management practices.

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APPENDICES

Appendix I: Letter of Transmittal for Data Collection

Adama Science and Technology University,

Adama, Ethiopia

Re: Participation in a Study on Urban Drainage

Dear Respondent,

I am a studying at Adama Science and Technology University pursuing a MSc in Urban Planning and Design. You are being asked to participate in a study I am conducting on impact of poor urban drainage system on transportation in flood prone areas in Adama City, which is part of the requirement for completing my MSc.

Your participation in the research study is voluntary and all information obtained from you during this questionnaire/interview is for academic purposes only. The results will remain strictly confidential.

Please answer the following questions as comprehensively and honestly as possible. Use the space provided to write your answer and if you need more space, feel free to add more lines or enclose an additional sheet.

Thank you for your assistance and your precious time.

Kind regards,

Getu Assefa

Appendix II: Questionnaire One

This questionnaire is being administered for the collection of data to investigate in the study of the impact of poor urban drainage system on transportation in flood prone areas in Adama City. The information collected is confidential and will strictly be used for related data with the study.

Section 1: Practical Perspective and Professional Aspect

1. What is your academic background or field of training?
 - a. Engineer
 - b. Any other (Please specify) _____.
2. What are some of the considerations that are made when coming up with drainage design and appropriate drainage facility in your vicinity?
 - a. State of road
 - b. Cost of construction
 - c. Land Use
 - d. Period of construction
 - e. Topography
3. From your design experience, is the drainage in this vicinity appropriate?
 - a. Yes
 - b. No
4. Do you think there is adequate drainage systems the location?
 - a. Yes
 - b. No
5. If your answer above is yes, why?

6. If your answer is no, in your opinion what percentage of roads are not provided with adequate drainage system?
- a. 0 – 20%
 - b. 20 – 40%
 - c. 40 – 60%
 - d. 60 – 80%
 - e. 80 – 100%
7. From your engineering experience and practice, how can you rate the state of the drainage system in this vicinity?
- a. Excellent
 - b. Very good
 - c. Good
 - d. Poor

Please explain your answer:

8. How often do you carry out inspection to ascertain the state of the drainage system?
- a. Monthly
 - b. Every three months
 - c. Every six months
 - d. Once a year
 - e. Other (Please specify) _____.
9. Have you ever carried out research on the effects of the poor urban drainage system on the surrounding environment?
- a. Yes
 - b. No

10. If yes, what did you find as major effects of poor drainage system on road and their solution?

11. What do you think is the remedy to the solution state of the drainage system in your location?

- a. Maintenance
- b. Redesigning
- c. Reconstruction
- d. Any other (Please specify) _____.

12. What do you think has hindered the above-mentioned measures from being implemented already?

- a. Lack of resources
- b. Lack of awareness
- c. Poor planning
- d. Lack of commitment by the government

13. Which of the following descriptions is the best suitable type to describe the existing drainage system? More than one answer can be selected.

- a. Separate system
- b. Combined system
- c. Open channel drainage
- d. Subsurface drainage
- e. Other (Please specify)

14. In your own opinion based on the professional experience, is the type of drainage facility installed have enough capacity to satisfactorily drain the water from the road during rainy seasons and heavy rainfall?

a. Yes

b. No

15. If your answer is yes, explain how.

16. If your answer is no, set out your reason.

Appendix III: Questionnaire Two

This questionnaire is being administered for the collection of data to investigate in the study of the impact of poor urban drainage system on transportation in flood prone areas in Adama City. The information collected is confidential and will strictly be used for related data with the study.

Section 2: General Perspective.

1. How often do you use the majority of the road in this vicinity?
 - a. Every day
 - b. Twice a week
 - c. Once a week
 - d. Other (Please specify) _____.
2. In your opinion how do you find the condition of the drainage system in this area?
 - a. Very good condition
 - b. Good condition
 - c. Fair condition
 - d. Poor condition
3. What is your view on how poor drainage affect the road? More than one answer can be selected.
 - a. Runoff on the road block the road
 - b. Runoff washes away the asphalt
 - c. Cracking of road surface
 - d. Water leaves debris on the road surface
 - e. Any other (Please specify) _____.
4. What are the main challenges faced when solving flooding hazards in in this area?

5. How does poor drainage system have affected you as the resident/road user?
 - a. Surface flooding resulted during rainy season
 - b. Road blockage due to surface flood
 - c. Waste and debris on the road caused road cracking
 - d. Runoff washes away asphalt road
 - e. Any other (Please specify) _____.
6. Have you observed any improvements on the drainage system?
 - a. Yes
 - b. No
7. In your own view, how satisfied are you as a road user or resident with the state of drainage of the road?
 - a. Extremely satisfied
 - b. Satisfied
 - c. Dissatisfied
 - d. Extremely dissatisfied
8. Which one of the following do you think has responsibility to solve drainage problems?
 - a. Kebele
 - b. Sub-city
 - c. City Administration
 - d. Society or Users
 - e. All
9. In your opinion, what problem should be given the most serious immediate solution?
 - a. Lack of good drainage systems
 - b. Road maintenance
 - c. Both road and drainage maintenance
 - d. Other (Please specify) _____.
10. How do you judge the activities taken to solve the drainage problems?
 - a. Good
 - b. Poor
 - c. No activity at all

Appendix IV: Interview

This interview is being administered for the collection of data to investigate in the study of the impact of poor urban drainage system on transportation in flood prone areas in Adama City. The information collected is confidential and will strictly be used for related data with the study.

Section 1: For municipality officials and Engineers only

1. How long you have been serving the community in this position?
2. How often do you hear cases about the drainage problem in your area?

Probe 1.: What is the mostly issued case?

3. How do you categorize the failures in the location based on their nature?

Probe 1.: Are you familiar with technical, location, phase and function failures?

Probe 1.1.: How do you explain each of these failure characteristics?

4. It is believed that failure can occur at design, construction and maintenance phase as well. Which phase of failure do you believe exist in this vicinity?
5. Failure locations are sub-categorized as ‘internal’ and ‘interfaces’ based on if the failure is located at single urban element or between two urban systems. Based on that would you reflect on this area’s case?
6. Failing function focuses the function that is failing and drainage serves in different types (i.e., conveyance, infiltration and storage). Would you reflect on specific case in this area?
7. These failures raise from different root causes; it can be social, political, economic, professional or intersection of any two. What is your opinion on the root causes?
8. Were there any activities on the case of upgrading the drainage status in the area?
9. Is there any ongoing project working on drainage facility and related things on the site?

Probe 1.: Prior to the implementation, was there any assessment done to understand the requirements?

Probe 1.1.: How do you ensure that the design is the appropriate solution?

10. What do you believe is the foremost accomplishment of the ongoing project till date?

11. Can you elaborate on specific situation/moment when drainage affected the transportation?
12. How do you think poor urban drainage affects road pavements and the road in general?