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Addis Ababa University

Addis Ababa Institute of Technology (AAiT)

School of Civil and Environmental Engineering

Post Graduate studies in Geodesy and Geomatics Engineering

Web GIS-Based Decision Support System for Urban Storm Water Infrastructure

Management: A Case of Nifas Silk Lafto Sub-City, Addis Ababa

By

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Addis Ababa, Ethiopia

Declaration

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Addis Ababa Institute of Technology (AAiT)

School of Civil and Environmental Engineering

Post Graduate Studies in Geodesy and Geomatics Engineering

This is to certify that this research work entitled ‘Web GIS-Based Decision Support System for Urban Storm Water Infrastructure Management’ is my own work under the supervision of Dr. Worku Zewdie. This work has not been presented elsewhere for assessment. All relevant materials used in this research have been duly acknowledged.

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As Master research advisor, I hereby certify that I have read and evaluated this MSc. thesis prepared under my guidance.

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List of Abbreviations

AACRA.....	Addis Ababa City Road Authority
ACA.....	Advance Condition Assessment
AMP.....	Asset Management Plan
BCA.....	Basic Condition Assessment
CIP.....	Capital Investment Plan
DSS.....	Decision Support System
EPSC.....	European Petroleum Survey Group
GII.....	Geospatial information institute
GUI.....	Graphic user interface
JICA.....	Japan International Cooperation Agency
MCDA.....	Multi-Criteria Decision Aids/Analysis
PostgreSQL.....	Postgres Structured Query Language
RCM.....	Reliability-Centered Maintenance
SDSS.....	Spatial Decision Support System
SP	Structure Plan of Addis Ababa city
SRID.....	Spatial Reference Identifier number
SQL.....	Structured Query Language
URL.....	Uniform Resource Locator
WFS.....	Web Feature Service
WGBDSS.....	Web GIS-Based Decision Support System
WGUMS.....	Web-GIS based Utility Management System
WebGIS.....	World Wide Web Geographic Information System
WMS.....	Web Map Service
WWW.....	World Wide Web

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Abstract

Urban drainage infrastructures' life-cycle management and associated complex decision making processes require exploitations of the benefits of advanced digital-technologies and/or spatial decision support systems. But, actually how this hypothetical concept can be materialized in line with varying ground contexts and other related factors do require investigation and scientific reasoning. And thus, the purpose of this study is to model an urban storm water drainage infrastructure maintenance management scheme through a Web GIS-Based Decision Support System (WGBDSS) taking the case of Nifas Silk Lafto sub-city of Addis Ababa. In this theme, the study explores the synergy between WGBDSS and drainage infrastructure maintenance management core issues through integration of drainage infrastructures' physical condition assessment, current drainage management practice of study area, hydrologic analysis, web technology, Multi-Criteria Decision Aids (MCDA) and Analytic Hierarchy Process (AHP) method for analysing and organizing complex decisions based on objective standards of judgment. Web GIS-based decision support tools that exploit multi-criteria matrices for optimization algorithms of structured query language (SQL) were also utilized. In addition, starting from data collection to final output production of the overall study, freely available softwares and open source resources have been exploited. Besides, ArcGIS, PostgreSQL, PostGIS, Survey Master and Kobo toolbox mobile applications, Global mapper, and surveying equipment like Differential Global Positioning System (DGPS-RTK; for drainage routes' locational information collection) were utilized in data processing, analysing, and presentation. On top of this ApacheTomcat, Open layer, GeoServer, map store were also used to publish the geospatial database and related outputs on developed portal of the Web GIS platform. Moreover, slope analysis, the runoff flow direction, flow accumulation, watershed delineation and flood vulnerable area identification, and the like hydrologic analysis were thoroughly performed and respective maps were also produced using desktop ArcMap application. The findings of basic and advanced physical condition assessment of drainage networks of the study area revealed that 80% of urban drainage routes out of the total networks demand repair type of intervention, 8% of drainage structures call for upgrading type of intervention, another 8% require for replacement and the rest 4% demand for planned type of maintenance. Eventually, the final result of this study implies that decision making through ranking competing and complex problematic drainage networks for maintenance prioritization purpose need a paradigm shift from the conventional drainage infrastructure life-cycle management approach (i.e. more of "fix when failed") to WGBDSS.

Keywords: *Decision making, Decision Support Systems (DSS), Drainage Infrastructure, Maintenance Management*

CHAPTER ONE

1. Introduction

1.1. Background of the study

Roadside storm water drainage infrastructures' failures and improper functioning of the system often result in runoff problems. Flooding damages properties, negatively impacts well-being of society with regard to health, safety, economic activities, and also significantly affects environmental and social safety. On top of these consequences, the complexity and extent of urban flooding problems widens fast from year to year. Global climate change, population growth combined with a fast rate of urbanization, especially in developing countries, and malfunctioning and less resilient drainage system management practices igniting the problem (Zeng et al., 2021; Jamali et al., 2020; Huong and Pathirana, 2013). Road and drainage infrastructure administering bodies are under growing pressures that force them to adopt proactively improved infrastructure management strategies (Halfawy et al., 2008).

On the other hand cities' successfulness regarding sustainable storm water management scheme highly depend on the quality of urban drainage infrastructure development plan, determinations of concerning bodies towards plan implementation and overall comprehensive urban management practices. Appropriate physical infrastructure maintenance tasks reduce the risks, life-cycle costs, and resources needed to preserve tolerable performance and service levels of infrastructure assets (Zoeteman, 2001; Sinha et al., 2017; Grussing, 2014; Galar et al., 2017). Hence, structural solutions that include new construction and maintenance of the existing flood controlling structures (such as drainage channels, ditches, dikes, culverts, manholes, inlets and outlets, etc.) are often necessary and a part of inevitable jobs in sustainable urban storm water management schemes. All these components of drainage infrastructure need to be managed for their integral and optimal performance up until the end of design period. In this regard one of the important and utmost jobs that have to be done is maintenance decisions making at various administrative tiers with new ways of thinking for managing life-cycle of existing drainage infrastructures.

Exploiting technological advancement particularly Web GIS-Based Decision Support System (WGBDSS) for Urban Storm Water Infrastructure Management is an emerging and helpful concept. This system can be used for both new infrastructure development planning and life-cycle management of existing physical infrastructures such as; roads, flood control structures, urban

utilities (such as electrical power supply systems, telecommunications, urban water supply networks, etc.), and related networked social and physical infrastructures. Physical infrastructure development and maintenance management task is lasting being complex issue year over year for cities of developing countries like Ethiopia. Besides, decision makers are confronted with the problem of prioritization of defective drainage networks for maintenance purposes. The question of which drainage project should be maintained first? how and which problem should be tackled next?; and the why questions could not have easy going or straightforward answers. And in this regard, this research thoroughly investigated the ground realities of drainage issues of the study area, and utilized Analytic Hierarchy Process (AHP) and multi-criteria decision making approach for organizing, analysing and prioritizing complex urban drainage maintenance decisions.

In general, physical infrastructure development and management problem are the fundamental issues in developing countries (Gurara et al., 2018; Tafazzoli, 2017; Akintoye and Beck, 2009). In addition availability, coverage and level of quality service provision of all necessary infrastructures can be taken as prerequisite concerns for socio-economic advancement of a nation at large. As important as new infrastructure development efforts, realizing a sustainable operational scheme for existing urban infrastructure asset management (Mastroianni et al., 2021), is also much crucial assignment for managers and decision makers of cities in developing countries. Though asset management has broad scope meanings; for the sake of this study, we considered it as delivering an established level of service during managing each asset to reduce the life-cycle cost with a tolerable level of risk. Asset management is not just about maintenance (AMP, 2011); however, maintenance is part of the stewardship of assets. According to this operational plan, the design, procurement, installation, commissioning, and operation activities and the like undertakings are also considered as parts of the whole asset management system.

Waste and storm water infrastructure development practices in Addis Ababa city dated back to the early nineteenth century (Dagnachew Adugna; Brook Lema; Geremew Sahilu; Jensen, and M. B., 2019). At the time of Italian occupation, a shared system for both waste and storm water was built in some parts of 'Piassa' and 'Mercato' of Addis Ababa. It is believed that starting from that time the city of Addis Ababa adopted the construction of storm water drainage facilities. Moreover, in 1997 Addis Ababa road authority was established and mandated to protect roads from flooding, and with a partial obligation to storm water management too. Here, it is important to note that in 1998 a flood master plan for the city of Addis Ababa was prepared in collaboration with Japan International Cooperation Agency (JICA, 2019), and since then many flood controlling structures have been constructed in different parts of the city.

Ethiopian cities' Asset Management Plan (AMP) that was developed with the expectation of supporting cities to manage existing urban infrastructures by allocating an appropriate maintenance budget to each assets (AMP, 2011), were one of the significant efforts made by the then called Ministry of Urban Development and Construction of Ethiopia. However, cities in reality are not capable enough to fully utilize AMP models due to numerous limitations observed while operationalizing the theme of the plan. This plan has shortcomings in how cities objectively prioritize one infrastructure project over another through its conventional voting approach of representatives of residents. Moreover, it lacks clarity on how to prioritize some out of many networked infrastructures (e.g. roads, drainages, water supply etc.) that have the same or different types of problems. For instance, sorting out a single (or some) drainage route out of the whole drainage networks (or from the domain of competing defective drainage routes) for maintenance purpose is much challenging task.

Physical drainage structures' vulnerability to malfunctioning, an increasing number of underperforming routes, ever-growing complexity of drainage networks design and associated difficulties, predictable and unpredictable sudden flooding risks, and so forth issues calling for significant change from conventional drainage asset management approach towards a new way of thinking and exploiting outputs of digital technology for drainage infrastructure asset management. In this regard, Web-Based Spatial Decision Support System (WBSDSS) is an emerging concept that consists of a computerized system to provide decision support information or the tools to the users through the web browser (Wu and Abdul-Nour, 2020). Moreover, optimizing the productivity and helpfulness of infrastructure management scheme within disordered and complex contexts require enhancing computer assisted decision support systems (Sivo and Ladiana, 2011). Further development in spatial and related science firms brought additional advantages in conjunction with application of web-technologies for infrastructure management concerns like urban drainage infrastructure maintenance issues. And thus, web technologies can play a great role in creating ease of communication among stakeholders and unreserved data sharing theme in a far better way than conventional practices.

As a matter of fact, Web GIS Based Decision Support System for urban drainage infrastructure management beyond its capability to show the spatial relationships of geographic phenomenon, it also creates a digital platform that links spatial and non-spatial information allowing remote data sharing. This platform provides real-time information sharing and supports decision makers even to see the correlation effect of malfunction of drainage facility over road network and vice-versa. Current practices and gaps of stakeholders in identifying core issues of drainage infrastructure asset

management, objectivity of proposed spatial relational database model, priority concerns in route selection for maintenance purpose and the way how to combat related challenges in a systemic manner through WGBDSS for urban drainage infrastructure management were paramount concerns of this study.

Despite the fact that numerous studies and publications produced in the area of urban drainage network management so far, there remain several questions that have not yet been satisfactorily answered in essence of urban drainage infrastructure maintenance management. Ethiopian urban centres' drainage infrastructure maintenance management practices are not yet getting due attention as a separate scheme than actually being existed coupled with road issues. Another challenge of drainage related issues is a lack of having centralized data management system (Goulden et al., 2018), and limitation to information access by stakeholders to forward their sayings and participate in overall decision making processes. And therefore, this study attempted to fill the gap by creating an online web-based information collection, storage and dissemination system in user friendly manner. Moreover, non-technical users and other stakeholders will get a relative opportunity to access both spatial and non-spatial information through internet technology as per their needs. And therefore this study systematically addressed the existing gaps further and contributes to the existing knowledge in the field.

And therefore, the overall research work was done with the intent of contributing a credible way out of the current challenges of urban drainage infrastructure maintenance management in Nifasilk Lafto sub-city, Addis Ababa. The major focuses of this study can be viewed in two ways; in one way it underlines assessing existing ground challenges and limitations of the current urban drainage infrastructure maintenance management of the study area. And on another way; based on the facts of the ground challenges and numerous limiting conditions of urban drainage infrastructure management vis-à-vis lack to exploit today's technological advancement to ease the asset management tasks. And finally, the study implied the way towards harmonizing the WGBDSS in improving the limitations of conventional urban drainage infrastructure management.

1.2. Statement of the problem

Research findings from varying sources showed that Addis Ababa often encountered overwhelming seasonal rainfalls that caused flooding risks in different parts of the city. For instance, Desybel Minwuylet (2020) revealed the severity of flooding problem within Akaki Kality Sub-city, (Dagnachew Adugna, 2020; Wubshet Teklu, 2020; Genet, 2018), showed the vulnerability of Nifas Silk Lafto Sub-city, and Minwuyelet Melese, 2004; Getnet Feyissa; Gete Zeleke; Ephrem

Gebremariam & Woldeamlak Bewket, 2018, and Davies, 2021, reported high flooding problems encountering part of Kolfe Qeraniyo sub-city. In general, several research findings have shown that Addis Ababa is one of the cities in the country that is susceptible to flooding vulnerability due to its natural topographic features of having many bumps and lumps, absence of sustainable storm water drainage management system, poor existing drainage system and facilities, and related factors letting the city vulnerable to severe flooding risks during heavy rainy seasons.

Though Addis Ababa has frequently encountered of destructive floods that should have been recorded for further intensive planning and interventions, the city lacks proper data documentation in this regard and consequences of flooding risk incidences (Beshir and Song, 2021; Hailu Worku, 2017; Arsiso et al., 2017). In heavy rainstorm seasons that range from mid-June to early September, observing terrible runoff even on streets of the city of Addis Ababa in general and particularly in the study area is a very common phenomenon. The unmanaged storm water flow of Addis Ababa causes tremendous disasters on both roads and storm water drainage infrastructures' functionalities and service life (Dagnachew Adugna, 2011). Deforestation of 'Dertu' and surrounding mountains, insufficient integration between road and urban storm water drainage routes networks, haphazard dumping of solid and liquid wastes, dumping of waste into drains that in turn reduce the hydraulic capacity of the system, and the like issues were mentioned as major causes of flooding in Nifas Silk Lafto sub-city (Tadele Assefa and Bassazin Ayalew , 2021; Girma Kebede, 2017) . Addis Ababa's roadside drainage pipes and channels are not only stormwater conveyance systems rather they are garbage disposal points and sewerage outlets too. Moreover, lack of city-wide drainage master plan, absence of appropriate and up-to-date hydrologic data during designing drainage structures are the main factors contributing to flooding problems in Addis Ababa. Addis Ababa city administration is continuously attempting to construct additional new drainage routes and related structures at different corners of the city to control severe flooding risks and its consequences. Despite the positive efforts of the city administration to develop new drainage infrastructure; existing drainage structures are deteriorating due to lack of appropriate maintenance and calling for an urgent and comprehensive life cycle asset management scheme.

AACRA's report, (2021) states that total lengths of 102 kilometers of roads with a total cost of construction of 8.4 billion ETB were invested on 18 different road projects within that stated budget year. This infrastructure development investment cost suggests that such a huge amount of money is spent on both roads and roadside drainage development activities plainly in per year. Though the effort of developments is lasting yet the city's drainage network coverage remains much less than what is expected to be actually on the ground. In contradiction to this less spatial coverage, existing

drainage infrastructures have a poor maintenance management track record (Kiwanuka et al., 2021; Dagnachew Adugna; Brook Lema; Geremew Sahilu; Jensen, M. B., 2019; Wakjira Takala, 2018), which is one of the major causes of drainage system malfunctioning. On top of that structural deterioration of drainage, infrastructure reduces the lifespan and reliability of the drainage systems of the study area. The characteristic of drainage infrastructure maintenance problem in general is kind of vicious circle. Another challenge related to drainage maintenance management is haphazard spatial and non-spatial data management practices that demand for improvement in data collection, storing, manipulation and ease of sharing data to concerning stakeholders.

Investment in urban drainage infrastructure maintenance and decision making process in this regard lacks not only a clear prioritization scheme and plan but also objectivity of criteria that shows why, when, how, and which problematic drainage route among the whole networks should come first for maintenance purpose and which ones need to come next and the like reasonable questions were identified as limitations that need further assessment. Furthermore, the type of intervention required (how and why rehabilitation, upgrading or renewal decisions) to the specific drainage network is also ambiguous, and yet there is no clear and bias free functional system in this regard too.

To sum up, though there is a continuous attempt to construct new and additional drainage infrastructure by the city administration, in most cases maintenance of existing ones (upgrading, restoring or fixing existing but damaged drainage routes & related infrastructure), lacks due attention or it is safe to say that highly neglected issue. The ground reality of having less drainage coverage coupled with the problem of inappropriate maintenance management practices resulted in weak flood risk control, and which in turn affected the livelihoods of citizens in many more ways. Eventually, taking into account and/or focusing particularly on the maintenance problems, this study assessed and addressed possible way out of the problem. More specifically, drainage maintenance management issues in the context of how to prioritize and realize a functional physical drainage infrastructure life-cycle management system with the help of Web GIS-based Decision Support System (WGBDSS) for Nifasilk Lafto sub-city of Addis Ababa, Ethiopia were thoroughly investigated.

1.3. General objective

The general objective of this study is to model an Urban Storm Water Infrastructure maintenance management scheme through Web GIS-Based Decision Support System for Nifas Silk Lafto sub-city of Addis Ababa.

1.3.1. Specific objectives;

- (1) To assess the existing urban drainage infrastructure maintenance management system and physical condition of drainage infrastructures in the study area.
- (2) To prioritize stormwater drainage infrastructure for maintenance decisions using multi-criteria decision aids (MCDA) and Analytic Hierarchy Process (AHP)
- (3) To design prototype Web GIS-Based Decision Support System geo-database model for Urban Drainage Infrastructure maintenance management
- (4) To develop a Web-GIS platform that supports the designed geo-database

1.4. Research questions

- (1) What are the existing practices of drainage infrastructure maintenance management and the physical conditions of drainage assets in the study area look like?
- (2) How to prioritize urban storm water drainage infrastructures for maintenance purpose using MCDA and AHP?
- (3) Does the developed prototype geo-database model have the capability of functioning for Urban Drainage Infrastructure maintenance management?
- (4) Would it be possible to integrate the developed database model with Web GIS online for Urban Drainage Infrastructure maintenance Management?

1.5. Significance

Web-based spatial decision support system model for drainage infrastructure maintenance management concerns can provide objective measurement capability during identifying and prioritizing complex and competing problematic storm water drainage networks. Decision makers in their routine storm water drainage maintenance management and planning process can exploit the advantages of this model to minimize probable biases that commonly occur while conducting maintenance priority and budgeting. The common questions of stakeholders of drainage infrastructure maintenance and beneficiaries of the service or public at large can get a clear answer for the why, when, how, and which problematic drainage route should be maintained urgently (now) out of the whole domain of many more drainage networks and the remaining routes to be maintained respectively in a less urgent (later) time framework. Eventually, the findings of this

study can be exploited as a supplementary resource and utilized as a springboard to move forward with both professional critique and further study in the future.

1.6. Scope of the Study

The spatial scope of this study was limited to the city of Addis Ababa, Nifas Silk Lafto sub city. This area was preferred due to its diverse drainage network types that suit for evaluation of the model, the purpose and ground reality of severe drainage infrastructure management problems. Moreover, due to stormwater drainage mismanagement resulted in the loss of lives of the resident within this study area in the recent past. And thus, the cumulative effects of these realities draw the attention of the researcher to focus on the specified area.

Thematically this research work emphasizes on web-based spatial decision support system modelling for urban drainage infrastructure maintenance management system. To reach a final output of the research theme an intensive drainage infrastructure inventory and physical condition assessment of existing drainage networks were conducted during field works, field data and other related spatial information was stored, updated, queried, analysed, displayed and organized through PostgreSQL/PostGIS database management system in a way that it suits for the access by remotely found stakeholders too.

1.7. Limitation of the study

The major limitations encountered in this study include;

- ❖ Lack to have up-to-date drainage network master plan of the study area,
- ❖ Lack to have closed-circuit television (CCTV) systems/cameras that can assist field data collectors while conducting detailed physical condition inspections of closed or underground drainage routes and culverts. Though the challenges were there, however, we used alternative options to combat the problem and minimize the effects of this draw backs on the overall quality of output of the research. For instance, during field inventory and spatial data collection of drainage infrastructures by using differential GPS (RTK), mobile application technologies, orthophoto of 2019, and road network and land use maps of the structure plan of the city of Addis Ababa were referred, and data cross-checking and triangulation were done and utilised accordingly.

1.8. Organization of thesis work

The overall research work of this study is organized into six chapters. The first chapter constitutes and underlined background of the study, statements of the problem, objectives, research questions, scope, significance of the study, and limitations were presented. Following, literature review were conducted on second chapter just emphasising on theoretical framework; prior similar studies and global, continental and local experiences with regard to Web GIS-based decision support system and urban drainage infrastructures were briefly addressed. In chapter three methods and materials used by researcher to conduct this research was thoroughly explained and detail procedures followed from the data collection phase to final analysis where also elaborated. In chapter four and five the results and discussions on findings were presented respectively. Eventually, in chapter six overall research work were concluded and accompanying recommendations were also forwarded.

CHAPTER TWO

2. Literature Review

This chapter begins with a short review of the related literatures regarding drainage infrastructure maintenance management issues. A brief theoretical review was conducted on previous literatures, limitations of reviewed previous literatures, research questions, and areas where research to be explored are thoroughly underlined.

2.1. Overview of urban storm water and drainage infrastructures

Storm water runoff is the water that washes over a developed area (rooftops, roadways, parking lots, etc.) after a precipitation occurrence (Göbel et al., 2007). The source of this precipitation is usually rainfall, sleet, or melting snow. In urban areas due to the characteristics of impervious surfaces, natural hydrologic cycle will be altered, and there will be less infiltration, interception, and even limited evapotranspiration occur compared to predevelopment phases (Javaid, 2012 and Shuster et al., 2005). This specific behaviour of urban fabric can generate of a large amount of storm water runoff that significantly contributes to flooding, sediment deposition, erosion, nonpoint source pollution and stream channel instability. The urban landscape and its environment are full of man-made constructions (Ahern, 2013), that prohibit natural infiltration of precipitations. Flooding on the other hand has the power of damaging properties and loss of lives of human beings and other animals (Balica et al., 2013). To avoid or minimize the risk of urban flooding problem, a large number of existing studies in the broader literature have examined and looked for the necessity of context specific storm water management scheme (Dhakal and Chevalier, 2017; Bach et al., 2020; Meenar et al., 2020; Sørup et al., 2019).

Storm water drainage system management is one of the big challenges for cities in developing countries (Parkinson and Mark, 2005; Chocat et al., 2007). Flooding risk increases in cities like Addis Ababa that has naturally intense seasonal rainfall, and significantly varying topography and percentage change in elevation (or slope) over certain distances. And thus, there exists a considerable body of literatures on storm water management issues in the city of Addis Ababa (Jemberie and Melesse, 2021; Herslund et al., 2018; Mohamed and Worku, 2021; Dereje Birhanu, Kim, H., Jang, C., & Park, S., 2016) addressed severity of flooding problems due to varying reasons, which includes the nature of city's rugged surfaces (or topography features with full of ups and downs), less coverage of flood control structures, mismanagement of drainage system and

existing facilities accompanied with heavy seasonal rainfalls, absence of sustainable storm water drainage management scheme, and so forth.

Flooding causes numerous costs and imposes much more direct and indirect burdens upon the lives of citizens in general and urban poor in particular who usually live within flood prone areas. Flooding from storm water drainage not only causes damage to the property and lives of human beings rather it carries harmful substances that include pollutant oils, fertilizers, pesticides, sediment, trash, bacteria, domestic waste, and animal waste, with the increased risk of waterborne diseases (Owa, 2013). In poorly drained areas where usually urban poor live, urban runoff mixes with sewage from overflowing latrines and sewers that later on resulting in many health problems for inhabitants (Parkinson, 2002). Scholars suggest close follow up and cleansing of storm water through various techniques like establishing storm water ponds or developing appropriate rain water harvesting mechanisms.

It was believed that flow of water controlling began in association with agricultural irrigation (Cun et al., 2019) in Mesopotamia and Egypt during the Neolithic Age (ca. 5700–2800 BCE). And according to (Mays et al., 2007; Angelakis, 2017) development of urban hydraulic systems revert back to the Bronze age (ca. 2800–1100 BCE), and as cited in (Cun et al., 2019) the urban storm water management systems have existed since 3500–1100 BCE (Angelakis, 2017).

Rapid and random growth of urban areas, vegetation removals, drainage infrastructures malfunctioning, and climate change are some of the major factors, which cause storm water drainage system management challenges in urban areas (Barbosa et al., 2012; Leopold, L.B, 1968; Semadeni-Davies et al., 2008; Rentachintala et al., 2022). In addition, several authors have recognized the significance of sustainable storm water management notions (Goulden et al., 2018; Damodaram et al., 2010; Qiao et al., 2019), which includes both structural and non-structural measures, to minimize tremendous effects of flooding risks. Realizing storm water retention and purification infrastructures (such as pipes, ditches, swales, culverts, and retention ponds) is also part of this notion.

To sum up, storm water systems are among highly important urban physical infrastructures. As stated above, the main functions of drainage infrastructures are to collect and convey storm water to the outlets. Well managed drainage system minimizes flooding; contributes a lot to property destruction protection due to flooding and health risks minimizing, and has a great role in averting many urban environmental pollutions and related problems (Cembrano et al., 2004; Mugume et al., 2015; Garofalo et al., 2017). In view of climate change and rapid urbanisation that alters rainfall patterns, urban land uses; the ability of drainage systems to comply with performance requirements

may be severely affected. Furthermore, these damaged systems require excessive financial costs for reconstruction, maintenance, rehabilitation and repair works, generating additional challenges for system management.

2.1.1. Urban drainage infrastructure

Drainage infrastructure commonly means the physical property that is used to convey storm water, and planned, designed and implemented to manage and control storm water runoff within the drainage utility system (such as culverts, catch basins, channels, conduits, creeks, detention ponds, retention ponds, ditches, manholes). Drainage infrastructures types, size, design standards, purpose and other features may vary from country to country and from urban centre to another urban centre, the difference observable even within a country. For the sake of meeting this study's objectives, and to be more specific in scope only open and closed drainage networks, culverts, and manholes were emphasised and also condition assessments were made on aforementioned components of drainage infrastructures throughout this study.

As part of a sustainable storm water management strategy, construction and maintenance management of existing runoff conveyance systems (or facilities), which include, gutters, open channels, ditches, buried piped drainage facilities, manholes, culverts and the like infrastructure is an important job but challenging tasks as well for drainage infrastructure administering body and other concerning stakeholders. Scholars of the field commonly agree on the major theme and importance of life-cycle management of urban infrastructure, however the issue of how to deal with its puzzling and complex process yet demanding for context specific scenarios (Jajac et al., 2009). Indeed, not only management but also physical infrastructure planning is likewise a complex task (Daniela, 2011). According to Lyu et al., (2019) less managed urbanization process, which leads to much more haphazard changes in urban form and that in turn worsens the overall performance of existing drainage systems. Besides, the climate change and fast urbanization rates not only impose substantial difficulties on effective functionalities of existing urban drainage infrastructures but also much cost over infrastructure administering bodies. Particularly, unmanaged high volume of storm water drainage is one of the big threats to today's urban centres.

Heavy rainfalls, which are a long-lasting natural phenomenon require both developments of man-made urban drainage infrastructures and life-cycle management of existing facilities in urban centres. This has been discussed by a great number of authors in many literatures, for instance (Karaa, 1989; Roy et al., 2008), were stated as physical infrastructure maintenance can improve servicing and operational capabilities of existing infrastructures. On the other hand, according to Moubray, (2001), maintenance works were classified as corrective and preventive maintenances.

Though the concept and definition of maintenance may seem differing based on the type of equipment to be maintained, infrastructure to be intervened, the generation on which maintenance output expectations fall under and so forth, generally it has a meaning of restoring and/or keeping statuesque. The ultimate goal of maintenance is to keep either infrastructure or equipment providing optimal and quality services as per the design intents. But for the case of infrastructures like ditches; the term maintenance refers to repairing activities to maintain or restore the capacity of ditches to transport storm water (Kalantari and Folkeson, 2013; Swift and Burns, 1999)

However, some scholars again classify maintenance into three categories as; routine maintenance; planned maintenance and emergency maintenance based on suits for their specific operationalization. Routine maintenance as its name indicates refers to frequent inspections of infrastructures repairing. And this type of maintenance is usually done regularly; every day, every week, every month or in an annual interval and it keeps the drainage systems up-to-date and efficient.

A more comprehensive description was given by Moubray, (2001) about the significance of maintenance in general, and specifically the evolution process of maintenance further categorized into four generations as indicated in Fig 2. 1.

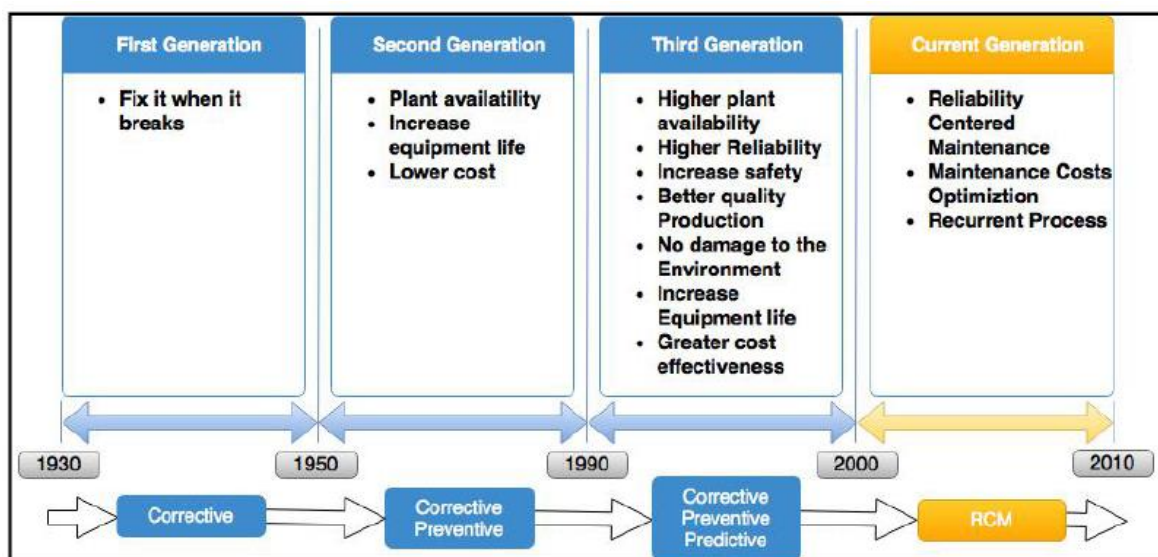


Fig 2. 1 Time line and four maintenance generations

Maintenance works were categorized in a broad term as corrective and preventive maintenance. With regard to Reliability-Centered Maintenance (RCM), Moubray, (2001) produced the popular literature that grouped how maintenance has evolved over sixty years into three generations up until the year 2000; as shown in Fig 2. 1.

According to Moubray, (2001) first generation views equipment failure as such not a priority issue. In the minds of most managers, nonetheless in second generation case due to the effect of World War II the demands for goods of all kinds increased since productive human power were fallen severely from industrial activities. At the then time the shortage of goods accompanied by human power deficiencies called for further increase in mechanization, and industries begin to highly depend on many more complex machines operation and the issue of down time of machineries become a big concern. The cumulative effect of all these things demands for the concept of equipment failure should be prevented. And since 1960's preventive maintenance notions, issue of managing of cost of maintenance, maintenance planning and control system become paramount questions. In third generation cases, more failures on equipment or infrastructure implies that less reliability and availability of services, environmental and safety risks, difficulties to sustain quality standards, and so on becoming a huge concern. And thus, new researches, new techniques, decision support tools, condition monitoring before conducting maintenance and the like issues begin to be addressed in the third generation.

As indicated in (Fig 2. 1) ever growing needs and complexities of infrastructure planning and management challenges are demanding shifting from a conventional approach to a systematic approach toward maintenance management of assets. In support of life-cycle management systems for infrastructure (Daniela, 2011) insists that existing asset management decisions are lacking to exploit appropriate information. Incorrect decisions on the other hand results in much of waste of time and efforts. A life-cycle management task of urban infrastructure projects is very complex process from both management and economic aspects (Jajac et al., 2009). According to (Chocat et al., 2007) advances in information technology, including the development of database management systems, Geographic Information System (GIS), graphical user interfaces (GUI), and the internet technologies are providing significant contributions to the improvement process of infrastructure management. Furthermore, frequent improvements in information technology enhance the quality and capability of big data gathering, processing, accessing and sharing (Kresse and Danko, 2012). Resource limitations, changing aspects of clients' compliance, the question of concerning parties' voice-hearing and need handling, ever varying magnitude of the problems, growing demands for quality service provision, and the like issues challenging infrastructure development and life-cycle management efforts.

2.2. Urban drainage infrastructure maintenance management

Infrastructures in general are being developed to provide optimal services for the public at large as per their needs. To ensure proper functioning and sustainable performance of physical facilities

during the entire design period these infrastructures must be managed professionally. Particularly, urban drainage systems that collect and transport domestic sewage, industrial wastewater, and rainwater (Wang et al., 2021), demand for continuous operation and maintenance management schemes to avoid or minimize the risk of flooding. The literature review shows that urban drainage infrastructures must be planned based on the prediction of future challenges such as upcoming climate change and urban growth dynamics (Ortiz et al., 2021; Zhou, 2014). The author also suggested that large urban centres require well-articulated master plan to correctly rank and schedule infrastructure development and maintenance of existing ones.

Maintenance refers to the work that is performed to maintain the situation of the transportation system or to respond to specific circumstances or events that restore the infrastructure to a functional state of operation (Waidelich, 2016). And the scope of infrastructure maintenance may differ from simple litter or debris removal to dredging or reconstruction of drainage infrastructure (Flynn et al., 2012). Scholars of the field stress the importance of drainage system maintenance, rehabilitation and replacement tasks of existing drainage infrastructure as a serious concern as new development and further expansion of facilities (Semadeni-Davies et al., 2008; Alegre and Almeida, 2009; Ana and Bauwens, 2010).

Maintenances can be either preventive (sometimes called routine) maintenance, which is a proactive and cost-effective type of maintenance for extending the life of infrastructure (Chen, 2016), and on the other hand routine maintenance that is performed in reaction to an event season, or overall deterioration of the asset (Adams and Dove, 1984). In this type of maintenance working on a regular base, and closely repeated attention, as well as action, is needed. Scholars again defined and redefined the concept of maintenance in many more ways, like stating as the combination of all technical and administrative actions, (Breesam and Jawad, 2021; Swanson, 2001), on which a set of organised activities are carried out. In this sense, fundamental maintenance activities are done to keep infrastructure (or an item) in its best operational condition with the least cost incurred. And maintenance activities include; repairing, replacing, overhauling, inspecting, servicing, adjusting, testing, measuring and detecting errors to avoid any probable failures, which in worst cases may lead to disruptions in service provision or production operations (Duffuaa et al., 2001; Tsang, 1995)

Though maintenance has tremendous advantages, usually in developing countries this task lacks appropriate attention and encounters bad practice of dominantly fixing only when failed approach (Butler et al., 2018). Drainage administering bodies shall understand that the reality of drainage systems corrode, erode, clog, collapse, and ultimately deteriorate to the point of failure and beyond (Butler et al., 2018; Kripka, 2012; Naseer and Tantray, 2021). Urban drainage infrastructure

maintenance is usually noticed only as a repair function, however, incorporates cumulative actions carried out to retain or restore to good status or an acceptable condition. According to Bhadbury and Shenoy (2014), maintenance concepts know and application to day to day life since world war II and attention to it increasing in an alarming rate since then.

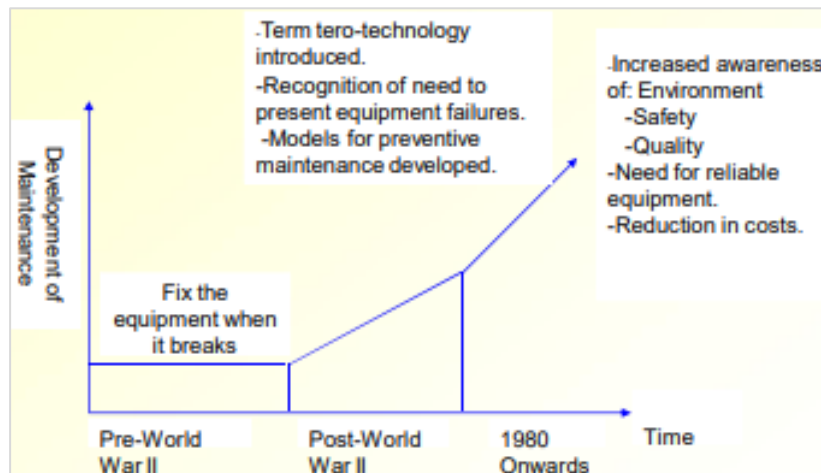


Fig 2. 2 Historic trajectory of maintenance development

(Source: Bhadbury and Shenoy, 2014)

In reality, maintenance keeps (or guarantees) that the entire drainage system to be kept reliable, productive and efficient in its service provision.

2.3. Decision support system

Decision Supports Systems (DSS) are computer-based information systems designed with the aim that supporting decision-making activities and/or helping managers to select one/some out of the many alternative solutions to a problem (Power, 2004, Al-Mamary et al., 2014). It is one of the application areas of information systems. Moreover, according to Heidarkhani et al., (2013), a decision support system (DSS) helps decision makers by providing information for their decisions that require modelling, formulation, calculating, comparing, selecting the best option, or predicting the scenarios. Today, many more context specific decision support systems are being designed and developed to assist decision makers to make relatively good decision with regard to a situation where there are uncertainties about the outcomes and/or complex and competing issues. Decision support systems (DSS) are decision aids or DSS supports but do not replaces judgments, and improve the effectiveness of decision makers rather than their efficiency (Timmermans, 2003).

2.3.1. Spatial decision support system

According to Sprague (1982), as cited in (Voudouris and Voutsas, 2012), a spatial decision support system (SDSS) is defined as an interactive, computer-based system intended to support a user or

group of users in realising higher effectiveness of decision making during resolving spatial problems. Spatial Decision Support Systems are designed to assist decision makers to solve complex spatial problems (Sugumaran, 2007), such as site selection, drainage route ranking for maintenance priority, and transport route selection for public bus, social amenity development location selection and so forth concerns may require SDSS. A literature review reveals that SDSS has three fundamental elements: a geographic database management system for handling geographic data, model which assists prediction of the possible outcomes of decisions, and a user interface interaction platform of the user to model scenarios. In consistency with, Armstrong and Densham, (1990), states five key modules are required in a spatial decision support system, such as; database management system (DBMS), analysis procedures in a model base management system (MBMS), display generator, a report generator, and a user interface.

As cited Keenan, (1997) in (Rinner, 2003) researchers could not agree on the meaning of spatial decision support systems (SDSS) and on how to demarcate SDSS from GIS. SDSS is commonly considered as application specific software solutions, and GIS is described as initiator for SDSS. The common geographic information systems (GIS) frequently focus on capturing, storing, manipulating, analysing and displaying of spatial data. Meaning, GIS indirectly developed to support spatial decision-making activities. However, GIS does not support rational decision-making for many spatial problems (Densham and Goodchild, 1989), it lacks analytic modelling capabilities and system designs are also not possible to be done in a flexible manner that accommodates the difference in the context or the process of spatial decision making. The fundamental purpose of SDSS is to assist users in solving complex, semi-structured decision problems (Armstrong et al., 1991). And as a response to GIS drawbacks spatial decision support systems were developed.

2.3.2. Multi-Criteria Decision Making (MCDM)

Multiple criteria decision making (MCDM) refers to making decisions just having multiple, generally conflicting, criteria (Hwang and Yoon,1981). Problems that demand multiple criteria decision making methods are very common. It is a scientific process that would help in framing Decision-Making Problems (DMPs) and developing comprehensive evaluations of options. For instance to mention here only a few; decision making on locating and selecting sustainable urban drainage systems (Jiménez Ariza et al., 2019; García et al., 2015), integrated rehabilitation prioritization (Tscheikner-Gratl et al., 2017), wind farm site selection (van Haaren and Fthenakis, 2011), multi-criteria decision-making methods for infrastructure management (Kabir et al., 2014), and so and so forth issues usually demands for multiple criteria to be considered while conducting decisions. Managing complex issues, which requires incorporation of diverse perspectives of

interest groups and reaching at efficient decisions is not an easy task. The literatures in this regard are enormous and continuously increasing from time to time. Besides, the development of a perfect decision making method for various actual real life decisions still remains an indescribable goal (Triantaphyllou, 2000). Decision makers to minimize ambiguities and levels of mistakes from their jobs, or to maximize the efficiency of their decisions usually set and use contexts specific criteria to reach conclusions. On the other hand the most important thing in decision making process is choosing appropriate factors that going to be used for the decision making.

In addition, parameters used for decision making need to be rated, weighted and other mathematical computation shall be conducted. To this end, the Analytic Hierarchy Process (AHP) proposed by Satty, is an approach for decision making that comprises structuring multiple choice criteria into an order (Sehra et al., 2012). The Analytic Hierarchy Process (AHP) is a multiple criterion evaluation methodology (Wind and Saaty, 1980) that is both descriptive and prescriptive. AHP is a method for organizing and analysing complex decisions, using math and psychology. It was developed by Thomas L. Saaty in the 1970s and has been refined since then, and is usually referred as the Saaty method (Yang and Kuo, 2003), which has been used in almost all the applications related to decision-making (Vaidya and Kumar, 2006). AHP allows the decision makers to decide how much inconsistency is reasonable if any, and whether not rank reversal (a reflection of relative rather absolute worth) should be permitted. In general, AHP offers a sensible framework for a required decision by quantifying its criteria and alternative options, and linking those components to the overall goal.

Application of multi-criteria decision-making (MCDM) for urban drainage network maintenance purposes can employ computational techniques. And thus, with the help of AHP that computes a list of criteria accordingly, and ranks the preferences by evaluating and selecting the best option out of many competitors for the sake of the desired outcome.

2.4. Database

Database in general refers to storage or a collection of logically related information (Kumar et al., 2013). Database management system (DBMS) is not an information system rather it is software (e.g. MySQL, Oracle, SQL, PLSQL etc) that is used to manage the database. Inside the database management system data will be stored in a way that easily accessible, managed and updated by users. Moreover DBMS refers to a collection of programs that enable users to access the data electronically from computer system with the help of DBMS software and another

additional interlinked application programs (like C++, C and JAVA) as portrayed in Fig 2. 3.

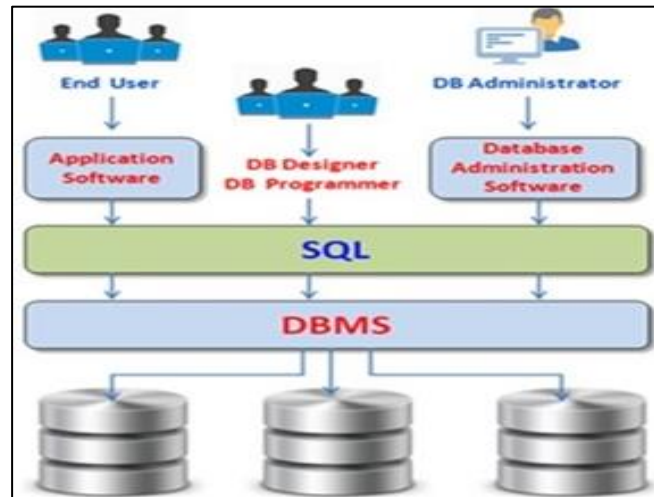


Fig 2. 3 Database management system

PostgreSQL/PostGIS database differs from GIS by the technique it organizes spatial datasets as a collection of tables (or as geom table); but GIS organizes spatial data as a set of layers and attributes stored as tables. Database users are persons (application programmers, database administrators, end users such as online users), who are operating on data to add information, delete, update, manipulate, query and so and so forth tasks assisted by application programs. And therefore, database users require both application programs and database administration software to communicate with data that found in database. Database security, access control, backup, and disaster recovery jobs are usually managed by database administrators (DBA). For efficient functionality of a database all its major components such as hardware, software, data, procedure, and database access language shall operate in an organized manner to provide the necessary services.

The term '*data*' entirely within this paper refers to piece of information or facts that related to the urban storm water drainage infrastructures. Data are values stored in a computer disk, and information is something understood by a person. And therefore the data which is stored in computer memory or on disk must be converted to useable information with the help of database management system (Coronel and Morris, 2016). For instance data related to drainage infrastructure includes drainage route's name, year of construction, type of drainage facility, its size, shape, location information, existing condition, proposed intervention required etc. And in context of this study all the above listed information and other related data were stored in geo-database.

Database technologies receipts data and store, organize, and process it in a manner that enables database users to simply find facts they are searching for. But data is not only limited to facts (e.g. measurements, statistical data, location information etc.) rather pictures and images can also be considered as data. Spatial facts about urban drainage infrastructure was collected in the form of points, maps, and pictures and presented in a well-articulated manner. Map readers, decision makers and other end users can understand spatial forms and structures in a clear and informative manner. They can distinguish important characteristics or issues of the storm water drainage infrastructure to fulfill needs of database users.

To understand the relationship between data and database, it will be wise firstly to know about the concepts of terms like field which contains the most detailed information about the object, records which is also a collection of related fields, and the table itself that is a collection of related records having a specific table name. In simple terms database is a collection of related tables.

2.4.1. Types of database management systems

There are four types of database management system (Roy-Hubara and Sturm, 2020), which includes;

- Relational database management system: RDBMS comprises many tables of data with rows and columns that communicate to each other through distinct key fields.
- Hierarchical database systems: which resembles a tree structure similar to a folder architecture
- Network database systems: has a hierarchical structure and the thing which makes it different from hierarchical model is that instead of using a single-parent tree hierarchy, this model supports many to many cardinality constraint approaches.
- Object-oriented database systems: the information is denoted as object, with various types of interactions possible between two or more objects.

2.4.2. Spatial Database

Database concepts are basically passing through various magnificent evolutionary developmental processes since many years back till today. According Vanathi and Uthariaraj, (2011) the first commercial database management system was developed using hierarchical and network data models in the late 1960s. However, these types of DBMS were not capable enough to support high-level query languages. And another problem of these types of DBMS was their limitations to retrieve data. The system designed to retrieve data through a graph or tree of data elements; which in turn demand for users to know details about technical aspects of the physical data arrangement.

As cited in Vanathi and Uthariaraj, (2011) in the early 1970s, the relational data model was introduced by Codd (1970). That works come up with a simplified process of accessing data and relational database management systems. In Relational data model data presented to the user in a two dimensional tables, and a different data types such as number, character and string are being to be stored in each cell of the table. This model is a bit complex in its internal storage structures just to facilitate efficient data manipulation. And high level SQL for efficient data base programming purpose is also supported.

On the other hand, cities' haphazard development and varying technical and organizational capacities demanding for systematized view and management skills for urban physical infrastructures. The need for data organization in a database, and even the perspectives towards data storing, accessing and easily sharing practices challenging overall infrastructure planning and management tasks today. And therefore, the dynamics of digital innovations and enhancing culture of exploiting its returns for handling such complex asset management related issues through exploitation of technology outputs is crucial thing for city of developing countries. Moreover, evolution of DBMS yet ongoing as in Fig 2. 4 shows.

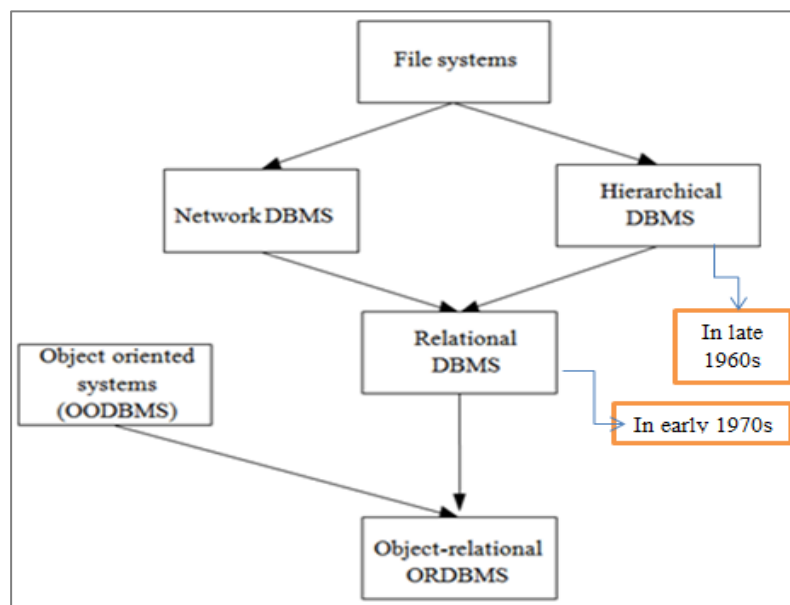


Fig 2. 4 Evolution of DBMS technology

(Source: Adopted from (Vanathi & Uthariaraj, 2011))

2.4.3. Web technologies

Web technologies refer to the way computers or other devices interconnect with each other using mark-up language. The World Wide Web is a system of interlinked hypertext documents and programs that can be accessed via the internet primarily by using HTTP. Besides, the internet is a

massive network of networks that connects millions of computers worldwide; and Fig 2. 5 shows a simple pictorial representation of client-server-side computing.



Fig 2. 5 Client-server-side computing

It includes communication across the web, and creates, deliver or manage web content using hypertext mark-up language (HTML). HTML is the standard that used to create hypertext documents for the WWW. Computers connected to the internet can communicate with one another with a number of protocols such as HTTP, SMTP (Simple Mail Transfer Protocol), FTP (File Transfer Protocol), IRC (Internet relay chat), IM (instant messaging), Telnet, and P2P (peer-to-peer) etc. The World Wide Web (abbreviated WWW or the Web) is an information space where documents and other web resources could be found out by Uniform Resource Locators (URLs), interlinked by hypertext links, and can also be accessed via the Internet (Berners-Lee, 1992; Aghaei et al., 2012; Berners-Lee et al., 1992).

World Wide Web (WWW) is shortly referred as the information universe. Currently, advancement in information technology field letting user to have spatial information from World Wide Web through internet technology. WebGIS is an advanced form of Geographic Information Systems (GIS) available on web platforms (Chilela, 2016). It creates an opportunity for GIS to run in web browsers, Web GIS serving desktop and mobile devices too. It uses Web technology to communicate a GIS server (identified by a URL) and a client (a web browser), a desktop, or a mobile application. According to Balcıoğlu, (2015) the communication is via Hypertext Transfer Protocol (HTTP/HTTPS) and the format of the response can be HTML, binary image, XML (Extensible Markup Language), GML (Geography Markup Language), or JSON (JavaScript Object Notation). Protocol is a set of rules that govern data communications, and defines what is communicated, how it is communicated, and when it is communicated.

World Wide Web (Berners-Lee et al., 1994) has advanced, developed, and stimulated use of decision aid technologies to support decision-making responsibilities. As a result of the rising interest in the Web, there are many continuing efforts to develop and implement WBDSS in numerous areas, such as infrastructure planning and management, environmental protection activities, land use planning, and so forth. The major advantage of this technology is to allow users unreservedly and remotely access, share, and manipulate geospatial data on the web platform.

2.4.4. Web GIS-Based Decision Support system

Spatial Decision Support Systems (SDSS), is a system which support spatial analysis and decision making (Sugumaran, 2007; Zhang et al., 2011) are getting much attention in various application extents. It was reported in literature that the web technology has added a new dimension to Spatial Decision Support System (Silva et al., 2014; Jain, 2010), and Web GIS-Based Decision Support System (WGBDSS) are under continuous development in many more ways. The global Internet and the World Wide Web are now the fundamental empowering technologies for carrying out a decisions just assisted by computerized decision support systems (Bhargava et al., 2007).

WebGIS application is widening its scope since recent past and playing a remarkable role in data sharing, visualization and interoperating diverse spatial data (Ajwaliya et al., 2017). In similar way (Levy et al. 2014) mentioned capabilities of spatial decision support system for big data handling, ease of updating, analysis at needed spatio-temporal scales, modelling and so forth.

According to Armstrong and Densham, (1990) spatial decision support system (SDSS) provides a framework for integrating: analytical and spatial modelling competencies; both spatial and non-spatial data management; domain knowledge; visualization capabilities; and reporting capabilities. In agreement with, (Swetnam et al., 1999; Power 2004; Carnegie and Napier, 1996) stated recording and documenting the history of any field of study will help upcoming researchers to develop further things in the field of interest, and the archive serve as a spring board to move forward. And thus, spatial decision support system application development trend shall also be investigated and documented. In this regard, this research as its starting point briefly oversees about spatial decision support system and application areas where it focused on. The history of DSS begins in 1960s (Belciug and Gorunescu, 2020; Power 2004) with the aim of providing integrated support for managers working alone, in teams and in organization hierarchies to manage organizations and make more rational decisions. The broad application areas and technological advancement with regard to decision support system are still evolving. For further insights, the decision support system classification scheme expressed by (Power, 2004) was adapted to

categorize a list of existing literatures in relation to WBSDSS. The stated sample list of literatures in Table 2. 1 could not incorporate numerous PC-based SDSS designed for various application area, and models that could not found on internet were also missed. Decision support systems are full of interaction between users and computers or computer-based systems and subsystems that planned to aid decision makers use communications technologies, data, documents, knowledge and/or models to complete decision process tasks. And therefore, literatures or WGBDSS classified in this respect as;

- **Data driven:** type of WBSDSS developed to query data warehouse to pursue particular returns for some specific purposes.
- **Model-driven:** are complex systems that support analyse decisions or select one or more from different options. These types of DSSs can be deployed via software/hardware in stand-alone PCs, client/server systems, or the web.
- **Knowledge-driven:** The usual deployment technology used to set up such systems could be client/server systems, the web, or software running on stand-alone PCs.
- **Communication-driven WBSDSS** and eventually type of respective application was determined based on its emphasis Table 2. 1 briefly summarized the author(s), application area, application type, and technology exploited and architecture;

Table 2. 1 Summary of the literature review on Web GIS-based DSS tools and applications

Author(s)	Application area	Categories of DSS	Web & GIS; Architecture
Tang et al., 2022	Wastewater Surveillance for COVID-19 Monitoring	Data driven	Client side
Zeng et al., 2021	Real-time urban storm water management	Model driven	Mixed client- and server-side WBSDSS
Pahmeyer et al., 2021	Agriculture-for crop rotation decision support	Data driven	Client side
See et al., 2020	Mapping urban drainage infrastructure	Data driven	Client side

Lan et al., 2020	monitoring the risk of water contamination	Model driven	Client- side
Jan, 2018	Heritage Resources Management	Model driven	Mixed client- and server-side WBSDSS
Allende-Prieto et al., 2018	Storm water management in urban areas	Data driven	Mixed client- and server-side WBSDSS
Mwaura & Kada, 2017	Geothermal exploration	Model driven	Mixed client- and server-side WBSDSS
Fiduccia et al., 2016	Monitor and manage costal environment	Data driven	Client- side
Saikrishna et al., 2015	Management and monitoring of water utility assets	Model driven	Mixed client- and server-side WBSDSS
Silva et al., 2014b	Environmental sustainability	Data driven	Client- side
Eissa, 2013	Infrastructure resource allocation	Data driven	Client- side
Park & Kim, 2013	Sewer infrastructure management	Model driven	Mixed client- and server-side WBSDSS
Verma et al., 2012	Water resource management	Model-driven	Mixed client- and server-side WBSDSS
Burdziej, 2012	Accessibility analysis	Data driven	Client-side WBSDSS
Ellis et al., 2011	Selection of Sustainable Urban Drainage Systems	Model driven	Mixed client- and server-side WBSDSS
Zhang et al.,	Watershed management	Model	Client- side

2011b		driven	WBSDSS
Santos et al., 2011	Vehicle routing	Data driven	Client-side WBSDSS
Mansourian et al., 2011	Urban planning	Model driven	Mixed client- and server-side WBSDSS
Mutua, 2010	Water development and management	Model driven	Mixed client- and server-side WBSDSS
Halfawy et al., 2008	Renewal planning of sewer networks	Model driven	Mixed client- and server-side WBSDSS
Wang & Cheng, 2007	Flood forecasting and flood risk mapping	Model-driven	Mixed client- and server-side WBSDSS
Choi et al., 2005	Watershed management	Model driven	Mixed client- and server-side WBSDSS
Dymond et al., 2004	Watershed management	Model driven	Mixed client- and server-side WBSDSS
Carver, 1999	Improving access to data science	Data driven	Client- side WBSDSS

According to Keenan and Jankowski, (2019), the field of SDSS developed incredibly without depending on the development pace of broad DSS. Ever-growing demand of big data space-time analytics along with spatial applications with the help of DSS and an overlapping interest in business analytics are the major driving forces for tremendous growth in the field of SDSS. Today, at all corner of the globe people are exploiting an advantages of WBSDSS in various application areas that includes, but not limited to; transport management, waster shade management, infrastructure management, enhancing public participation in urban planning processes, spatial planning and governance, sustainable development, emergency responses, and in all majors areas listed down on (Table 2. 1) summary of classification of the existing Web-Based Spatial Decision Support System (WBSDSS) applications.

However, literature review implies that WBSDSS for the sake of physical urban drainage infrastructure life-cycle management issue is rare or completely there are no such practices. These days' academic literatures on WBSDSS are largely focused on applications and implementations related issues of numerous fields of studies. However, the use of WBSDSS, is very rare for spatially explicit studies such as urban drainage infrastructures' life-cycle management. And therefore, in this study integration of various discipline-specific concerns were seriously investigated and a prototype SDSS were also developed. For instance physical urban drainage asset management issue, web issue, internet technology, and SDSS model all issues together interconnected for drainage infrastructure maintenance management scheme development; which is rarely addressed in this regard.

2.4.5. Empirical Review on Web GIS-Based Decision Support System (WGBDSS)

This section focused on the previous studies that have done on WGBDSS from a global perspective, continental perspective, and Ethiopian perspective. The empirical review includes the method of each research in this regard, the datasets used in conducting that specific research, and the findings of the research are briefly highlighted. And thus, in this section, prior studies related with WBSDSS were compiled and shortly discussed.

2.4.6. Previous studies around the world

Web-based spatial decision support system is under continuous development process in many parts of the world over the last decades, and significantly expanding its horizon of applications (Jelokhani-Niaraki and Malczewski, 2015; Bancheri et al., 2022; Balla et al., 2022; Di Gangi and Belcore, 2022; Tang et al, 2022). Urban drainage Infrastructure planning and management has numerous uncertainties and complexities while project planning, implementation and post project realization. And such challenge of infrastructure investment decisions require to have decision support system to help decision makers. According to (Rutledge et al., 2007) decisions up on physical infrastructures that involves many actors, have many possibilities to solve the problem, and issues having high uncertainty can better managed by exploiting an advantages of web and spatial decisions support systems (SDSS), which is basically developed to make simplify weakly-structured or unstructured problems.

In Spain, Allende-Prieto et al. (2018), explores the synergies between Geographic information system and urban storm water management with the approach of exploiting only freely available software and open platforms. The researchers used freely-available software from data collection to final result finding. The U.S. EPA Storm Water Management Model (SWMM), QGIS, PostgreSQL, PostGIS, SagaGIS, and GrassGIS linked with GISWATER on the process of the research work.

The findings of the research shown that the combination of many types of freely-available software linking with GISWATER, and integrating hydraulic analysis software package (such as SWMM) with either QGIS or SagaGIS and spatial databases of PostgreSQL or PostGIS can advance usability, making the outcomes more user-friendly and letting perfect multi-user connections. Moreover, the final outputs of the research amplified the importance of combining WebGIS and storm water management design tools to compare the effectiveness of different storm water management strategies for the case study city of Gijón (northern Spain). It also demonstrated the system can help engineers and planners during designing and assessing storm water management system in urban centers.

In Portugal, Coutinho-Rodrigues et al. (2011), assessed spatial decision support systems for the specific urban infrastructure planning applications, and capability of offering users with a flexible and user-friendly platform. Case study from the city of Coimbra, Portugal was assessed for the stated specific application of spatial decision support system. The capability of system to display available alternative maps that can provide an additional support for decision makers in their urban infrastructure planning were realized in a way that helps problem evaluation. Finally, the system was crosschecked for its ability to store, retrieve, and display of type of information the users/decision makers needed. Moreover, the research finding reveals that the major functions of developed system constituted; investment option evaluation; investment option comparison and selection; and communication/interaction with the system and sensitivity analysis were clearly presented. Eventually, the researchers developed a prototype WebGIS-based Multi-Criteria Planning of Urban Infrastructure Systems (MCPUIS) and concluded the result obtained was robust and also tested for its workability with regard to assistance for planners in infrastructure planning.

Furthermore, in Portugal spatial decision support system we utilized in wide areas like for wildfire risk management within an uncertain environment (Pacheco et al., 2015), municipality of Oeiras, in Portugal, was taken as case study and spatial decision support system were developed to assist spatial planning by integrating the risk management component at municipal level. The study results proved that decision-making on the conversion of land uses from one land use type to another land use type by considering risk analysis can be better assisted by information obtained from a spatial decision support system.

According to Halfawy et al. (2008), the application of GIS-based decision supports system for renewal planning of sewer networks were assessed in Regina, Canada. Three fundamental criteria; such as condition of existing sewer network, probable risks (if in case the failures encounter), and costs were utilized as a baseline parameters to asset prioritization, selection of best fit methods, and

so forth purposes. The research finding implies that renewal planning and management tasks of sewer networks can significantly be improved by integrating sewer renewal planning with spatial decision support system.

In the case study city of Innsbruck, Austria,(Mikovits et al., 2017), investigated impact of climate change and urban development on the drainage system performance. The integrated modelling approach that shows possible physical expansion of urban environment and climate projection were analysed as a major components. The combined alternative scenarios were simulated with the help of hydro-dynamic solver and Web-GIS platform were used both for analysing and visualization purposes. The final result shows that spatial decision support system can give an insight for long-term drainage infrastructure planning. And, this method can also help planners to find weak point before failures occurs, and concluded web-based spatial decision support platform can give an opportunity to show the outputs to stakeholders, politicians, or the public at large.

In china, according to (Yu et al., 2006) there is considerably growing attention towards application of web-based spatial decision support system for urban drainage network planning and management. A Framework of WEB-GIS for urban drainage network system (Yu et al., 2006) were developed after having thorough investigation of management system. General Packet Radio Service (GPRS) technology in combination with web advancements was utilized to develop an interactive user-friendly spatial decision support system for urban drainage network management. The system can provide functions, which includes dynamic format of hydraulic model, urban drainage network optimization for suit of design and planning, visual information management, dynamic state analysis and real time monitoring. The researchers concluded Web-Based Spatial Decision Support System as an effective means for the design, planning and management of urban storm water drainage infrastructures.

2.4.7. Previous studies in Africa

As far as urbanization remains continuous global phenomenon, planning and management various issues shall go hand in hand to guide the over urban development process. Particularly the rate and level of urbanization occurrences is dramatically changing over time within sub-Saharan countries (Dorosh and Thurlow, 2014). Rapid urbanization, which is an important characteristic of African development, is emitting a clear signal on importance of existing urban infrastructures management scheme improvement and the need for further development on traditional approach of asset management. Urbanization by its nature come up with numerous demands for new infrastructure development and provision, and on the other hand imposes huge burden on existing facilities (Mguni et al., 2016). Africa is relatively a continent with a bit behind in utilizing fundamental

advantages of technological advancement with regard to Web-GIS, SDSS, remote sensing data and other computer assisted IT solutions for its complex urban infrastructure planning and management tasks. Geographic information utilizing activities in Africa need to shift just from making maps or collecting observations than to further developing spatial decision support system as a supporting means while conducting decision making on various complex issues.

There were attempts and a few researches were conducted in Africa with regard to application of web-based spatial decision support system for various issues in different field of studies. For instance in Benin, west African country, assessment of agricultural land resources by employing spatial decision support system for national deciders were realized (Roehrig and Laudien, 2009); Spatial Decision Support System (SDSS) for radar-meteorology data in South Africa (Löwe, 2004), decision support for sustainable urban drainage system management; a case study of Jijel, Algeria (Benzerra et al., 2012), a research conducted in Egypt with the theme of large dam planning and operation in Africa and decision support systems were exploited (McCartney, 2007), application of a spatial decision support system (SDSS) to minimize soil erosion in northern Ethiopia (Dragan et al., 2003), Planning in East Africa using a participatory SDSS (William et al., 2007) and, so and so forth area of application of SDDSS were addressed. But yet, a lot has to be done to improve the existing practices and use interactive front-end of WBSDSS for informed decision-making on infrastructure life-cycle management.

2.4.8. Previous studies in Ethiopia

In Ethiopian cities are attempting to prepare Capital Investment Plan (CIP) and Asset Management Plan (AMP) for physical urban infrastructure development and life-cycle management respectively. Capital investment planning refers to systematic approach to enhance a city's capacity to deliver services to its citizens through expanded infrastructure development (CIP, 2011). And, Asset Management Plan (AMP) on the other hand describes the state of the art of managing assets across their entire life cycle in a way that it optimizes cost of the asset at the appropriate point in time (AMP, 2011). Though theoretically importance of these plans seems sound positive, however the actual practices on the ground implies big disparities exists with the theme of the aforementioned plans. Both plans' preparation and decision making process for investment on urban infrastructures lacks; transparency, reasonable participation process, objectivity of decisions and prioritization criteria, exploitation of spatial decision support system in data management practices (ground realities show more of analogue data management practice and so forth challenges exists.

In this regard, drainage infrastructure development plans and management efforts in Ethiopian urban centres facing many more long-lasting and outstanding challenges. The issue was not yet appropriately addressed and owned by stakeholders to combat it. Urban physical infrastructures and other utility administering authorities (such as road, water and sanitation, telecommunication, electric power supplying authorities etc) lacks effective institutional coordination among each other even for basic information sharing purpose. There is a limitation in exploiting real time spatial and non-spatial information for decision making. And also less consideration of preferences of community for whom the infrastructure being constructed is also remain as an issue.

On the other hand, one of the great challenges of Ethiopia urban centres with regard to urban storm water drainage planning and management is lack to have short time; medium and long time strategies for sustainable storm water management and above all implementation decision were solely done by elected and appointed city administration officials. And therefore, maintenance management ground practice of drainage infrastructures of Addis Ababa city show that concerning bodies usually give a low status and consideration towards maintenance issues; which is rather unfortunate.

There has been a few researches conducted in an area of urban storm water management issue in city of Addis Ababa, but mostly these researches looked at flooding problems from the perspective of challenges of urbanization, and climate change issues (Dereje Birhanu, Kim, H., Jang, C., and Park, S., 2016; Hailu Worku, 2017; Mengistu Jemberie and Assefa Melesse, 2021) and sometimes design and related engineering aspects (Dagnachew Adugna, 2011; Dagnachew Adugna, Brook Lema, Geremew Sahilu, Jensen, M. B., 2019), however rarely in existing drainage structures maintenance point of view. Furthermore, seeking or investigating operational ways to improve traditional drainage infrastructures maintenance management approach are evidently neglected. On this basis, this research emphasised on the gaps and puts forward suggestions of development of WBSDSS for complex infrastructure management concern. And detail potential opportunities of advanced spatial decision support system exploitation efforts, planning and proactive interventions, and flexible investment options were highlighted. Prioritization of drainage networks for maintenance, and repair, renewal or replacement decisions support interactive platform were also developed.

Furthermore, the review of related literatures in relation to drainage infrastructure maintenance management and Web-Based Spatial Decision Support System (WBSDSS) application statuesque implies that many jobs were not done to exploit technological advancement. And on the other hand, researches in this regard were focusing either only on a single storm water drainage matter or some specific aspects of problems that causing poor performance of the drainage system. This implies

that prior studies gave less emphasis towards exploiting of technological advancement and benefits of spatial decision support for drainage infrastructure maintenance management application. Moreover, integration of core aspects of web technology, internet, open source resource exploitation, using of real time spatial information, frequent field data updating and incorporation of these data while decision making, how to exploit decision support system for drainage asset management concerns were missed up in prior researches related to infrastructure life-cycle management. Objectivity matter in prioritization and MCDA with web-technology, spatial and non-spatial data integration, unreserved data access by key stakeholders; and bringing all these matters in a single platform is missed while reviewing of different related literatures.

Again it is worth mentioning here that urban drainage networks' maintenance management concern of city of Addis Ababa neither strictly following traditional maintenance approach nor employing technological advancement in its current status. The identified gaps emphasise the need for a new methodology and approach to improve the existing drainage maintenance management limitations of the city in general and particularly the study area. More over spatial and non-spatial information are loosely coupled that have a power of ultimately distracting quality of decision making processes. Above all, with regard to web-based spatial decision support system for urban drainage infrastructure maintenance management issue; no or insignificant number of researches were conducted typically in Ethiopian urban centres contexts. And therefore, conducting such specific research for city of Addis Ababa in this regard is demanding and vital concern.

CHAPTER THREE

3. Materials and Methods

3.1. Description of the study area

Addis Ababa, the capital city of Ethiopia, was established in 1886 (SP, 2017). Nifas Silk Lafto sub-city is one of the 11 sub-cities of Addis Ababa, which is the focus area of this research. And it is located between latitude $8^{\circ} 54' 45.59''$ N and $9^{\circ} 01' 29.89''$ N, and longitude $38^{\circ} 39' 25.05''$ N and $38^{\circ} 44' 48.80''$ E. Total area of the study is 87.71 square kilometers, and the location map is depicted for further reference in Fig 3. 1.

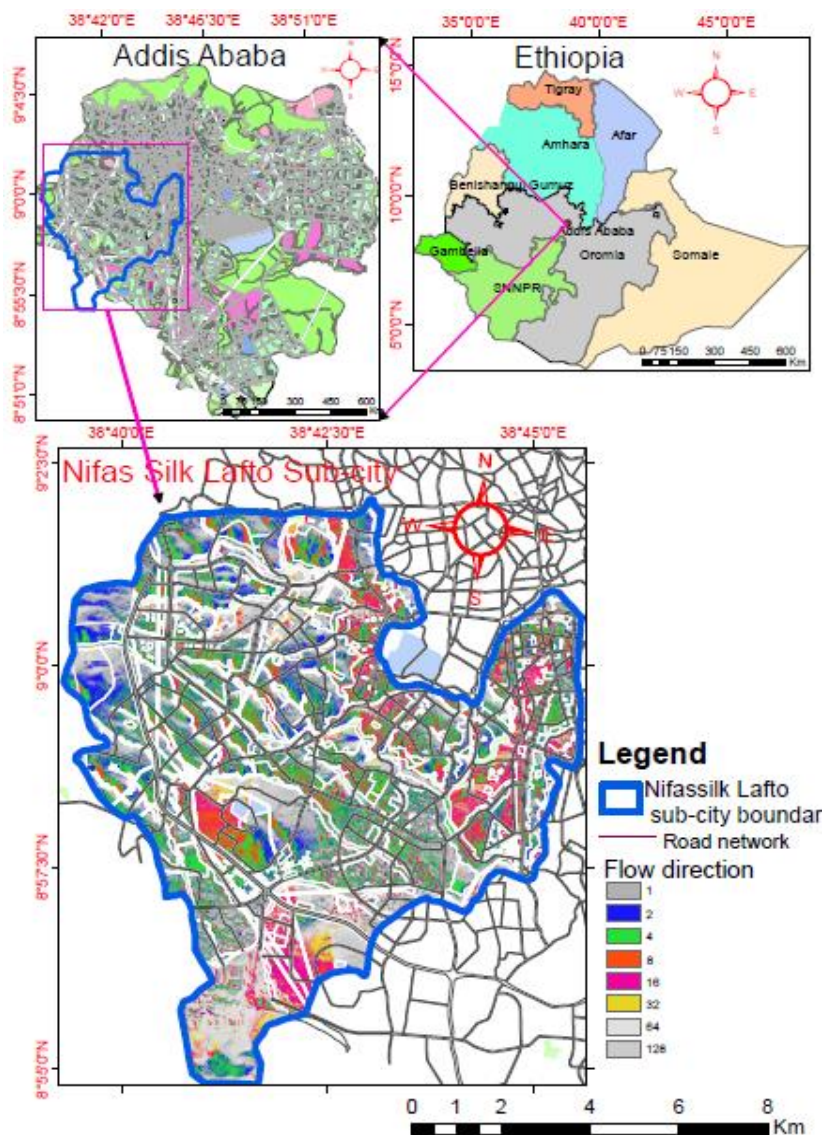


Fig 3. 1 Location map of the study area

The city remains a federally chartered city as indicated on Addis Ababa City Government Charter Proclamation No. 87/1997. According to the constitution of the Federal Democratic Republic of Ethiopia, Proclamation No. 1/1995, article forty-nine (49) and sub article two (2) the residents of Addis Ababa have a full measure of self-government. The city has a decentralized system of city administration that is structured into three levels; the central executive city level or Addis Ababa city administration, which is called the mayor and its cabinet; the second layer composed of the 11 sub-city administrations; and the third-level of the administrative division are the number of woredas under each sub-city, which are the smallest local units of the city administration.

The total urban space of the city is about 54,000 hectare of land (SP, 2017); out of this 5,199 hectare of land is covered by roads. The main roads radiate from the centre to 5 outlets (that include; outlet toward Jimma, Ambo, Gojam, Debrebrehan, and Adama city). Addis Ababa currently has a comprehensive and functioning structure plan with the power of legally binding role in both spatial and non-spatial affairs for the range of years 2017-2027. According to SP, (2017), the total length of roads (with 7m width and above) of the city was 3,731km, out of this 1,807km (48.4%) is asphalted, 1,777km (47.63%) was gravel and the rest 147km (4%) was cobblestone. At the time of this plan preparation there was 214 roads of arterial level (PAS and SAS) which structure the city. The road density of the city was 13%, which was almost half times less than acceptable urban planning standard (i.e.25%) of the city. Furthermore, as per SP report 53% of streets in the city core do not have appropriate pedestrian facilities. Even, existing pedestrian ways and street itself in some cases are congested due to on-street parking, passenger and goods loading/unloading activities, and informal trading activities which all have significant impact on non-functioning of drainage routes. Addis Ababa city road authority has mandated to construct and administer road side drainage networks found coupled with SAS and above street classifications.

3.1.1. Topography

Addis Ababa city is situated at a high elevation in general and has areas with the lowest height altitude of 2048m to a maximum altitude of 3041m above sea level. The topographic nature of the city can let Addis Ababa as one of the flood vulnerable cities of the country. Further details about topographic features are highlighted in the form of map in Fig 3. 2.

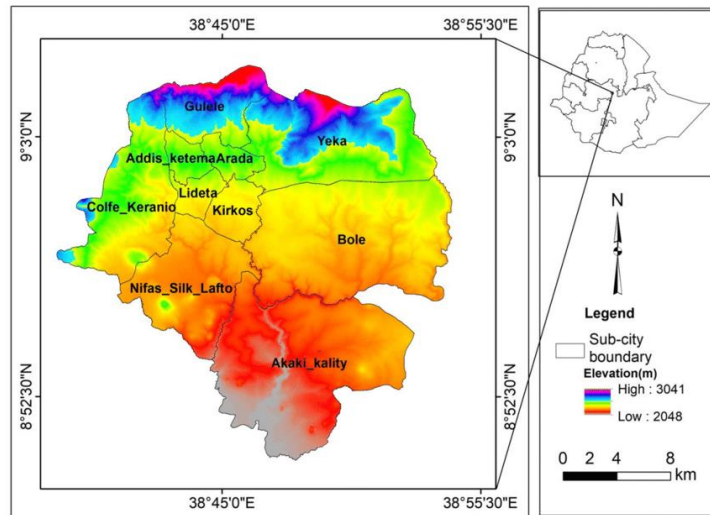


Fig 3. 2 Elevation map

3.1.2. Land-Use and Land-Cover

Water bodies, built-up, forests, urban agriculture and bareland are the major land uses that overviewed in the study area as portrayed in

Fig 3. 3. The south-western area has dominantly covered by agricultural and bare lands, and the river sides looks relatively have better green developments that need to be preserved and have great importance in sustaible flood risk management efforts. The rest portions of the study area are built-up and which in turn has a clear implication of dominance of impervious surfaces that prohibit infiltration of precipitation.

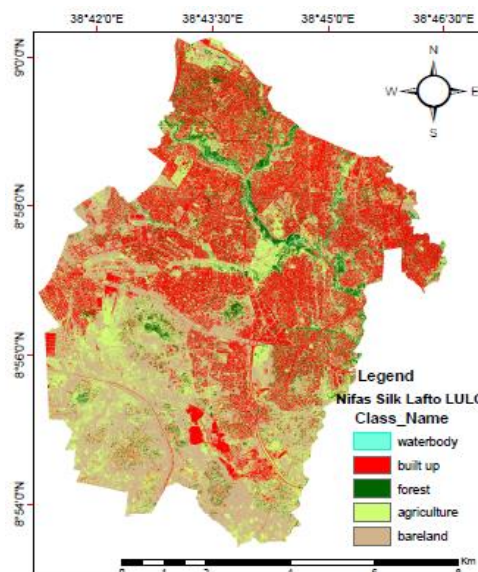


Fig 3. 3 Land-use and land-cover map

Land-use and land cover classification accuracy assessment

To cross check the classification accuracy level of land use and land cover classes, a total of twenty sample ground control points were taken from all land use categories. The sample size determination were based on ASPRS (American Society for Photogrammetry & Remote Sensing), which classified study areas coverages into 3 categories for positional accuracy assessment purpose as; areas less than or equal to 500, 501-to-750, and 751-to-1,000 square kilometers and recommended sample size (points) to be taken as 20, 25, and 30 checkpoints respectively. And thus, the study area of this research covers 87.71 square kilometer; according to ASPRS for areas less than 500 square kilometers taking 20 GCPs can be optimal and were generated as ground reference information from google earth pro since the land-use and land-cover classification were made based on aerial photograph produced in a year of 2017 (or recent spatial data/image classification). Eventually, classification error matrix (confusion matrix), which compares the association between known reference data (ground truth) and the corresponding results of the classification were observed. The overall accuracy is computed by sum up the number of pixels classified correctly (diagonal values in error matrix) and divided by the total number of pixels, and the result obtained was 87%. The accuracy is basically a measure of how many ground truth pixels were classified correctly, and in this regard usually kappa coefficient (the measure of agreement or accuracy) computing technique was utilized. It is the way to measure the actual agreement and a chance agreement between the reference data and classified data.

$$\check{K} = \frac{\text{Observed accuracy} - \text{chance agreement}}{1 - \text{chance agreement}} \quad (1)$$

Finally, the computed value of kappa coefficient for land-use and land-cover classification done in this research is 0.89; meaning a probable 89% better accuracy than if the classification resulted from a random, unsupervised, assignment instead of the employed maximum likelihood classification. This kappa coefficient value that is approaching to 1 implies a good classification or strong agreement.

3.1.3. Population

The urbanization process of Ethiopia is very rapid but from its low base. Ethiopia's urban population in 2015 was 19.4 percent of the total population of the then time 90.1 million people (CSA 2013). Addis Ababa, the capital city of Ethiopia is the largest and the most populous city in the country, with a population size of 2,739,551 (CSA, 2007). But this figure has old information,

though the country has not done a formal population census since 2007, there are several population projection tasks are undertaking by different stakeholders. For instance, according to World Bank Group report, (2021) Ethiopia’s current population is estimated to be 115 million, and it also expected to surpass 200 million by the end of 2049. The population is growing at a rate of 2.7% annually.

3.1.4. Climate

In Addis Ababa, the rain fall varies from the highest of 419mm in August to the lowest record of 7mm in the month of December. August is also the highest humid month with 87.04%, and February has the lowest humidity (44.35%). Most of the days of both July and August are full of frequent rainfall intensities that require proactive flooding risk managing interventions and pre-awareness creation for vulnerable communities too. The maximum temperature record can be obtained in April and March being the hottest months and the lowest average temperature can be found in or near to 14.4 °C in December.

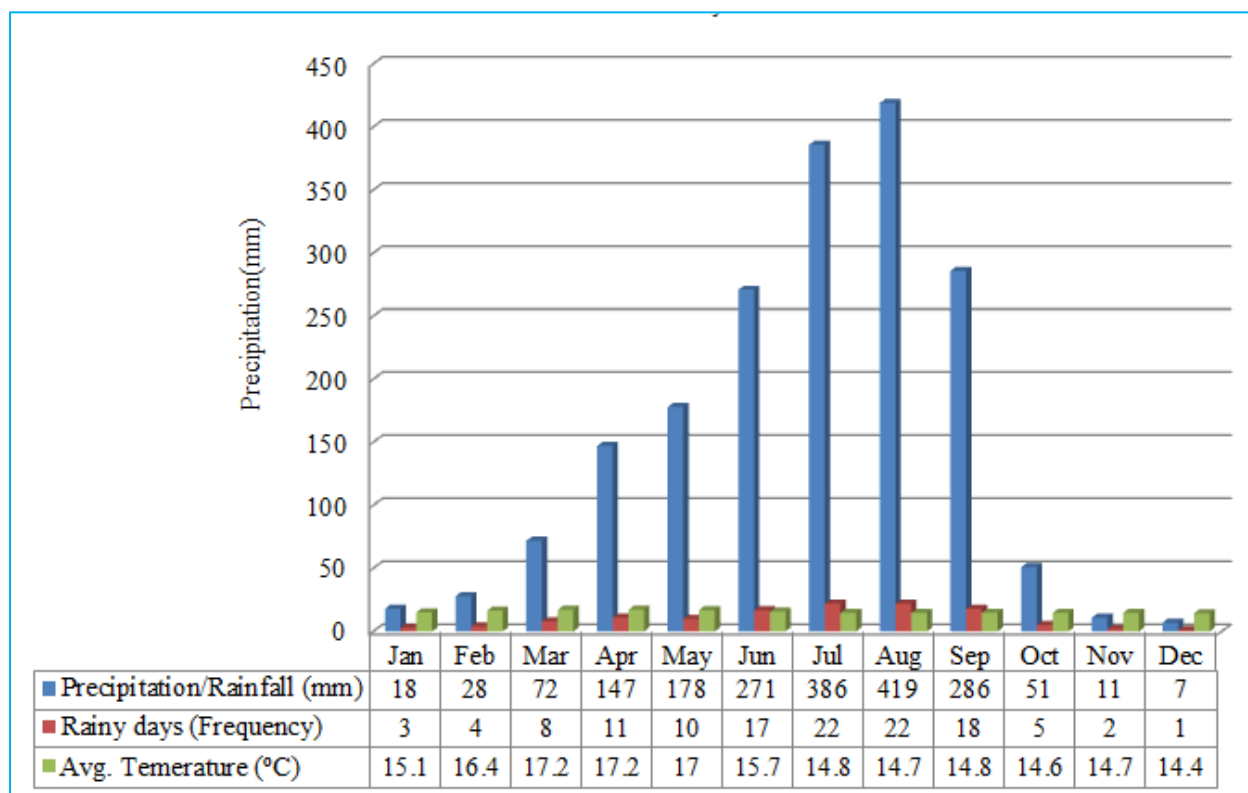


Fig 3. 4 Addis Ababa weather by months

(Source: <https://en.climate-data.org/africa/ethiopia/addis-ababa/addis-abeba-532/>)

3.2. Research Design and approach

The study used both descriptive and analytical type of research design. Descriptive research design was preferred because this design is convenient to classify, compare, measure data, and describe the existing nature of challenges that the study area is facing due to mismanagement of storm water drainage infrastructures. Meanwhile, analytical research design were preferred because it assists the overall process by evaluating the extent of the problem and the implications of poor urban drainage infrastructure maintenance management on the ground. And also it helps to see cause and effects, and current practices and understandings of maintenance management that calls for a paradigm shift from a conventional approach exploitation of recent advancement in digital technology for complex life-cycle drainage management. Futher more, mixed research approach was used in which both qualitative and quantitative data were collected and analysed.

Concerning study area selection, purposive sampling techniques were employed. In which some basic list of factors were taken into consideration during area selection process, which includes; existence of diverse types of drainages routes within the study area, severe vulnerability for flooding risks, varying hierarchies and physical condition of drainage networks, suitability to achieve this researches particular purpose. And having these issues in mind, a quick reconnaissance survey were conducted and eventually Nifas Silk Lafto sub city were preferred for this research work. Moreover, the following sections will highlight which tools were used and how they materialized while data collection and research analysis phase of this work.

3.3. Data and Data Source

In this section types of data and the sources from where those data were obtained were elaborated and presented. To this end, both primary and secondary data sources were exploited, and existing urban drainage infrastructure management gaps of Addis Ababa City Road Authority (AACRA) were thoroughly investigated in relation to planning and maintenance management practices of the organization. Importantly, interviewing key officials and experts, organizing focus group discussion sessions with selected engineers of the firm, and various levels' of city administrations and AACRA's reports, supporting official documents, and research conducted by different parties in Addis Ababa city drainage issues were also thoroughly reviewed.

3.2.1. Primary data collection

Primary data sources were used, and the data collected from these sources were utilized along with secondary source data while developing a prototype drainage infrastructure maintenance management model for the pilot study area. Primary source data were gathered through field inventory and assessment of major urban drainage infrastructures, and these data were exploited later on to evaluate each infrastructure's physical conditions and performance level. Furthermore, the collected data were utilized in developing spatial plans of drainage infrastructure for maintenance, repair, and replacement and generally for decision making purpose at different layers of decision making. Data collection techniques in this modality include; interviewing drainage firm engineers, and technicians with a long year of service record and conducting focus group discussion with six experts who are currently working for AACRA. An additional six experts from Nifas Silk Lafto sub-city (total of 12 experts) participated in discussions that were held to collect supplementary information and their perceptions about drainage networks.

Focus group discussion was organized in two different sessions. The first meeting was held with six AACRA's experts and at another time similar meetings were held separately with sub-city level engineers and related practitioners. The processes of discussion were intentionally focused on urban storm water and related infrastructure maintenance issues just by forwarding fact-finding enquires. These professionals are knowledgeable experts in the field and more important information was collected through this process. Essentially, the questionnaires were dispatched to each expert to make them aware of issues and to let them gather all basic information just before three days of the focus group discussion.

Moreover, checklists & templates were prepared ahead of condition inventory tasks. These checklists and templates were designed and turned into the form of a mobile application (i.e. Kobbo toolbox) template for field data recording using a mobile application. Kobbo toolbox mobile apps were exploited for non-spatial condition inventory data collection, and also SW Maps while spatial field data collection purposes were utilised. SW maps were utilized to identify data collected routes, to plan daily activities of field data collection, to identify where the data collector actually exists, to guide the overall surveying team and make compliance of collected drainage route data as ascending and descending routes based on the standards of AACRA.

Another more important primary data, which were collected for this study purpose include data collected by the conventional ground surveying techniques using DGPS-RTK and collecting coordinates (point data) of centrelines of drainage channels. In this process, Lyca DGPs (GNSS) receivers were utilized; and spatial data collection process was commenced just by using two

second order ground control points found within the study area as base points. These two base points were collected from Geospatial Information Institute and further densification was made along the centreline of drainage routes of the area of interest by RTK modality. And letting the base receiver at “Germen adebabay or base point one” and the reset two receivers were used to collect the centrelines of drainage channels, manholes, culvert locations, bridges, junction points of roads were collected. Data collection works were assisted by ‘SurveyMastor’ mobile application that was connected to GNSS receivers through Bluetooth functions of smart phone of the data collector. It serves the data collector by easing the process of data recording in a smart phone that was connected with a GNSS receiver, simultaneously when the receivers were positioned on the points of interest where data were intended to be collected.

3.2.2. Secondary Data Collection

Secondary source data were collected and compiled in a way that it suits, and assists the overall research work activities. The sources exploited during data collection include but are not limited to; gathering Addis Ababa city’s stormwater drainage related published and unpublished documents, exploring to findings of related studies, websites, books, journals articles, collecting and exploiting Orthophoto 2019 with positional accuracy of 25cm, DEM from Geospatial Information Institute (GII), ALOS 2009 (Alaska Satellite imageries) images, drainage & land use maps of the Addis Ababa city administration, as-built drawings (indicating year of construction), non-spatial data such as metrological data of study area and many more supportive documents were collected and referred in depth. Eventually, fundamental data sets that serve as base data for the study of stormwater drainage infrastructure maintenance management issues and their data sources were identified. The data collected from main sources were cleared, organized, stored in to database in a suitable manner to manage and process queries easily for various decision making purposes. Data and data sources are from where all important primary and secondary sources are presented in Table 3. 1.

Table 3. 1 Data and data Sources

Data	Source
Aerial photograph	Geospatial Information Institute (GII)
Study area's as-built drainages network	Addis Ababa Plan Commission and AACRA
Physical condition inventory and assessments	Field survey using Kobbo toolbox mobile app
Ground surveying data	Field survey using DGPS and survey master mobile application
Physical characteristics affecting runoff	DEM from GII
Temperature and rainfall data	World climate website

3.4. Software and instrument used

A list of software and instrument used both in data collection; processing, analyzing and displaying final outputs of the study are shown in Table 3. 2.

Table 3. 2 Software and instruments used

Software/Equipment	Purpose
ArcMap 10.4	Used for thematic map production, spatial analysis, chart and tables production
PostgreSQL x64 14/PostGIS	To create RDBMS , for spatial and non-spatial data storage and processing
VSC	Visual studio code (VSC) is used as a platform to write and edit scripts
Survey Master mobile app	To collect field data linking it with GNSS and mobile device through Bluetooth
Kobbo Tollbox	Used while drainage infrastructure field inventory and physical condition assessment
DGPS/RTK	Used to establish GCPs for the study area and each drainage route's centreline points (coordinates) were captured in association with locational information
GeoServer, Mapstore	For Publishing data on web-based platform
Apache Tomcat	To store geoserver, map store, bootstrap, jquery supporting, open layer software

3.5. Methodology

In this section, the entire strategy that was used to achieve the objective of the study or the way how this research was performed, and research problems addressed methodically were elaborated. Basically, urban storm water drainage infrastructure maintenance management modelling using web-based spatial decision support system consists of four major stages: Firstly, assessing the existing physical condition of drainage infrastructures of the study area, and evaluating overall practices of maintenance management of concerning bodies based on collected primary and secondary source data (spatial and non-spatial) analysis. Afterwards, important spatial and non-spatial data need to be stored in a data bank where data can be organized, manipulated, displayed, shared and easily accessed by decision makers and other stakeholders as per their simple or complex queries and so forth benefits shall be gained through well-developed geo-database model. Accordingly, objective criteria were made available for making quality decisions; and multi-criteria decision analysis was also conducted in a way that can assist decision making process. Eventually, enhancing unreserved access to basic public information through web-technology about drainage infrastructure maintenance management issues irrespective of location limits of an interest group (or individual) was also the main concern of this study. Finally, the methodology employed in this study is presented in a flow chart (Fig 3. 5).

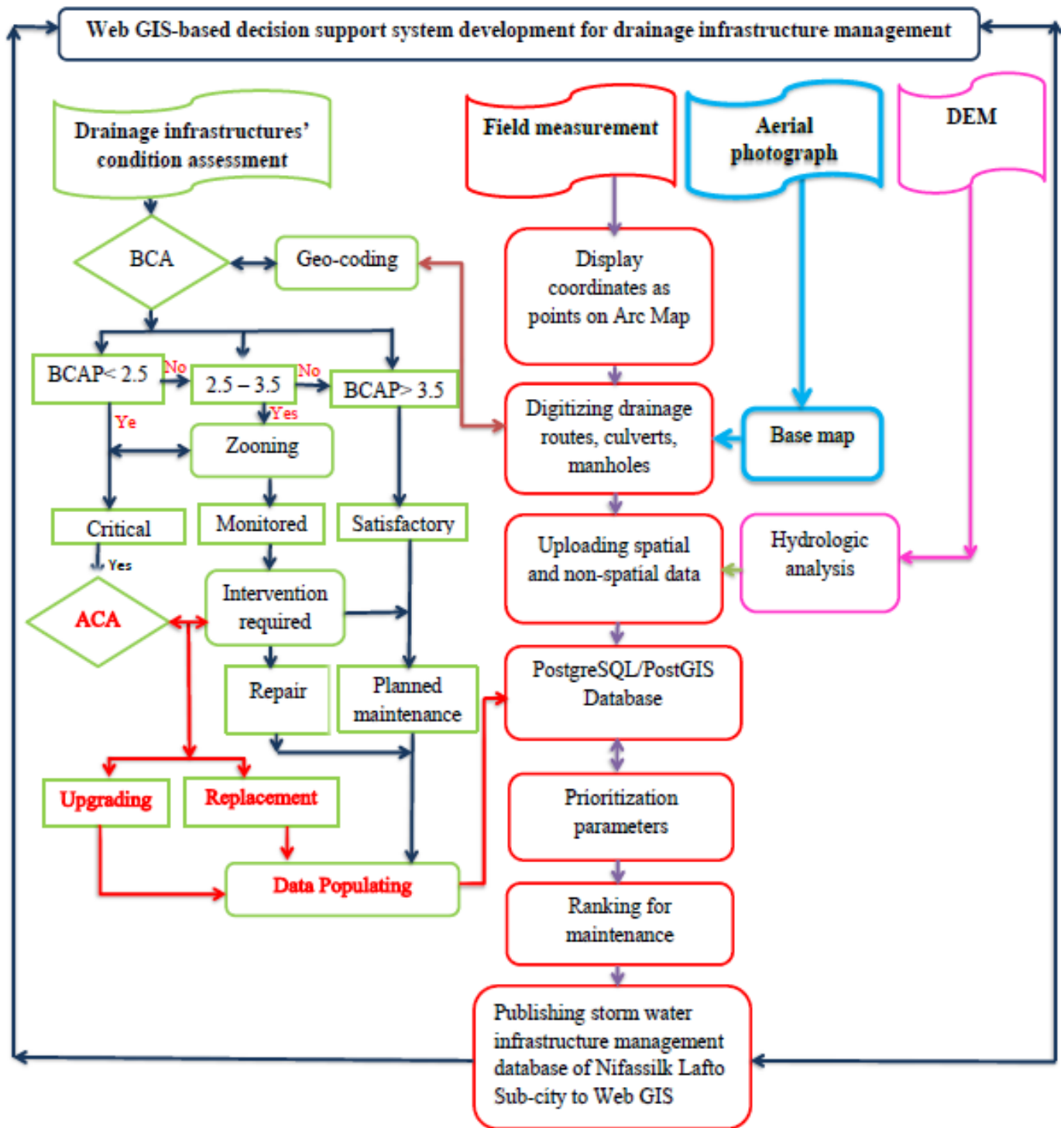


Fig 3. 5: Methodology flowchart

3.6. Conducting situation analysis

Drainage infrastructures' maintenance decisions demand for understanding and having appropriate information about existing conditions of targeted infrastructure from the field. Possible drainage infrastructures' interventions or types of treatment required, decision prioritization of numerous drainage infrastructures, identification of strategic drainage routes, level of damages and urgency for maintenance intervention, risk factor, and so forth issues can be better identified and visualized while conducting field inventory and assessment. And thus, in this study detailed field measurement and condition assessment were conducted and later on desk reviewed along with secondary source data.

Physical condition inventories and assessments were performed using pre-developed checklists, and uploading data recording template to Kobo toolbox mobile application. Level of damage in each segment, length of drainage section and routes, width, type of construction material/ or surface lining material, type of treatment needed (renewal, upgrading, rehabilitation) were identified and inspected. Field measured and observed facts were documented and stored in database for further analysis. Physical information of each drainage infrastructures such as; size/dimension, shape, age, distribution, location, the extent and spatial limits (i.e., distance, direction, volume) were collected thoroughly. Based on the condition assessment result of roadside drainages; each route was categorized as per its specific maintenance requirements. Routes that don't demand further maintenance, and those that require minor maintenance and major maintenance were jotted down separately in varying categories.

3.6.1. Drainage infrastructures' physical Condition assessment model

Asset management business in general is a continuous life cycle process that includes but is not limited to; construction, maintenance, operation management and replacement when in need to optimize service provision and to minimize cost during the entire design span. For the sake of uninterrupted functioning of the system, infrastructure owning bodies need to have information about existing assets, their up-to-date condition assessment and remaining service lifespan. Field information has a great role in further planning, designing, and implementing decisions on physical drainage structures.

Drainage routes, culverts, manholes, and the like infrastructures which are not checked, diagnosed and maintained regularly may deteriorate faster than designed lifetime due to hydraulic, various changing social and environmental conditions. Lack to have appropriate information like drainage infrastructure's physical condition, size, shape, geographic location, its current age, remaining

service year, and so and so forth issues have a cumulative negative effect on decision making. The type of specific intervention needed, the time on which action need to be made, the quality of service required vis-à-vis actual realities will be unclear and vague for decision makers unless and otherwise existing situations data were updated frequently and information collected and stored in a well-organized database.

And therefore, to minimize the magnitude of the problem related to information access towards stormwater drainage infrastructure maintenance decision making; in this study all physical inventory and inspection data were organized and stored in one stop PostgreSQL/PostGIS relational database management system. The condition assessment model basically constitutes a set of protocols that identifies the drainage infrastructure, performance level, the reasons for its inefficient services, forecasts when failure is likely to occur and also helps in developing preventive and reactive maintenance plans for drainage asset preservation. Maintenance works are part of life-cycle management activities of urban drainage infrastructures. In this study generally maintenance tasks were classified as routine maintenance and periodic/scheduled maintenance. In some literatures it is also mentioned as preventive (proactive) and reactive maintenance based on the type of intervention proposed to be done.

Drainage asset inventory, physical condition assessment, and prioritization practices for infrastructure maintenance decisions vary from country to country, region to region, depending on ground contexts and country specific protocols. In this study, a detailed guideline for condition inventory and inspection protocols/manuals/ were reviewed from Transportation Asset Management for Local Government Agencies,(2006), and adopted in a way that suits with the context and issues of Ethiopian urban centres drainage problems. In addition, the study entitled '*asset management approach for drainage infrastructure and culverts*' that were conducted by a consortium of four universities (Najafi, 2008) in the USA (which constitutes Midwest Regional University Transportation Center (MRUTC) at the University of Wisconsin, Michigan State University, Center for Underground Infrastructure Research and Education (CUIRE) at the University of Texas at Arlington (UTA), and the University of Cincinnati, Ohio (UC)) were also referred thoroughly and adopted.

Moreover, additional standardized templates, a list of drainage infrastructure condition inventory manuals, procedures, list of components and practices of Australia and the United States (Roy et al., 2008, and Haris et al., 2016), were also referred. And capital investment plan and asset management plans of Ethiopia, (CIP and AMP, 2011) and its guidelines were also referred and adopted accordingly in condition inventory checklist and template preparation process. Eventually, a major

list of items to be included (of data requirements were listed down), the necessary information to be recorded, the required steps to be followed during inventory and assessment, asset condition rating and, so and so forth matters were reviewed and compiled to contextualize with the study area's ground reality accordingly. Generally, the condition assessment model is divided into two categories; Basic Condition Assessment (BCA) and Advanced Condition Assessment (ACA).

3.6.2. Basic Condition Assessment (BCA)

Basic condition assessment is as its name indicates a general inspection type of the drainage infrastructures. This type of physical condition assessment was conducted to see the overall condition of major constitutes of drainage infrastructure and its adjacent area that may have direct or indirect impact on the performance of drainage system. While conducting basic condition assessment within the study area general location identification information about project site and the drainage structures' were recorded in mobile apps that were designed for this specific task.

For further empirical analysis of existing roadside urban drainage infrastructure's physical condition data were collected and each routes assessed separately. Route's status was rated as excellent, good, fair, poor and as failure or critical condition. And the minimum condition and factors were listed down in such ways that help to define the status of infrastructure as excellent, good or other. In this regard, numerical points (or values) were given for each factors as per the condition of drainage routes based on the list of items included in the checklist while conducting condition assessment works. Eventually results of this processes utilised as one parameter in ranking competing routes for the sake of maintenance planning and management. Different types of intervention such as repair, renewal and upgrading were also endorsed accordingly to each route to improve the service delivery capacity of the system.

Condition rating

Mathematical computations were done based on the results of existing condition rating for each drainage routes. Storm water drainage elements and related structures were given a condition rating values, and the numerical value indicates statuesque of each storm water drainage route. We put scale value from 1- to- 5 and the lowest reclassified value infers critical physical condition of the drainage route, and greater values infer relatively better condition till the maximum value reach 5 which means new physical drainage condition. And, scale values (or scores) will be given for a certatin physical condtion (or type of defects) of drainage infrastructure based on list of stated conditions. For instance, a drainage route component's (e.g. manholes, inlet and outlet etc) physical condition can be rated (or called) as 'poor condition' if and only if it fulfills the condntions (or

criteria) listed under that rating scale (i.e. poor condition or score 2); and further details in this regards are portrayed in tables attached as (Appendix 5: Presents the condition rating system for storm water drainage’s embankment and curbs Appendix 10. Several authors have recognized MRUTC models and it was practically tested as an operational technique in USA for urban drainage physical conditions rating. And therefore, the physical condition of each drainage route and other drainage associated infrastructures were rated with condition rating values that have five (1-5) rating scales. Drainage route with a condition rating score of 5 means a new or excellent physical condition, and on the contrary condition rating score of 1 means a drainage route that exists within a critical physical condition. For all the the rest of drainage performace impacting factors/parmeters and rating techniques and criteria are presented from Appendix 6: Presents condition rating system for condition of manholes to Appendix 10.

Table 3. 3 Basic condition assessment rating scales and scores

Rating scale	Score
New or excellent condition	5
Good condition	4
Fair condition	3
Poor condition	2
Critical condition	1

Source: Adopted from (Najafi, 2008)

AHP bases on mathematical analysis and human psychology while conducting numerous computations. While conducting basic condition assessment in the field both general and structural information was recorded. In general information; owner code, place code, drainage id, year built, date of inspection were recorded, and, in structural information cases shape, material, type of treatment, geometric dimensions etc, were documented using mobile application and geo-location of each specific drainage route was done.

3.6.3. Components of storm water drainage for condtion rating

Having a review of related literatures, conducting reconnaissance survey over study area, and thorough discussions with experienced experts of the firm, five components of a typical drainage system were identified, adopted and utilized for basic condition assessment purpose. Major

elements of storm water drainage infrastructures' that were utilised in this study for the sake of basic condition assessment of drainage routes constitute;

- (1) embankment and curbs,
- (2) manholes
- (3) storm water drainage's inlet & outlet,
- (4) storm water drainage walls,
- (5) storm water drainage floor
- (6) drainage infrastructures overall condition

To construct a matrix expressing the relative values of a set of attributes or components of drainage routes and surrounding; a popular and widely used Analytic Hierarchical Process (AHP) model or decision support system was utilized. AHP decision support system bases on mathematical analysis and human psychology while organizing and analysing complex decisions (Saaty, 1988). AHP as its name indicates is a hierarchical process in which relative weights for each component is assigned in comparison to other competing attribute importance, and finally drainage route performance score can be calculated. AHP consists of three basic stages: the creation of hierarchical structure, pair-wise comparisons, and synthesis of the relative priorities.

According to Saaty, (1988), individuals to groups or organizations are continuously engaged in decision making or having a choice of something in day-to-day lives. Employing Saaty's AHP idea to drainage infrastructure maintenance management; decision makers constantly make choices concerning what drainage tasks to do or not to do, when to do them, and whether to do them at all or partially (prioritizing issue), but by whatsoever means our choices must depend on some concrete evidence or criteria.

And therefore, Analytic Hierarchical Process (APH) support decision making procedures by computing numerical performance score of every single storm water drainage routes. Drainage route under consideration was categorized in one of the three performance condition zone based on the computed performance scores range. Each drainage route components were endorsed to pass through pair wise comparisons process in relation to counterpart's importance for the overall performance of the route. Pair-wise comparison matrix can be computed with the help of scale of relative importance of one factor over another factor with importance level and description presented in (Table 3. 4).

Table 3. 4 Scale for relative importance in pair wise comparison

Importance Level	Description
1	Equal Importance
2	Moderate Importance
3	Intermediate Importance
4	Strong Importance
5	Extreme Importance

Techniques and procedures followed to compute final BCA performance scores for each drainage routes pass through the following matrix computations;

Step-1: Conducting condition rating

Table 3. 5 BCA condition rating for drainage route with ‘xx’ unique code

Rating components	Condition rating
Condition of embankment and curbs	X
Condition of manholes	X
Condition of inlets & outlets	X
Condition of storm water drainage walls	X
Condition of storm water drainage floor	X
Overall condition of storm water drainage route	X

of these listed elements/or components of each specific storm water drainage routes were assessed and condition rating/scores (‘X’ values) were given (with rating scale of 1-5) taking into account the hydraulic, structural, environmental and social factors and soforth as details are listed in (Appendix 6 to Appendix 10. And eventually, the overall performance levels of drainage infrastructure were figured out by computing performance score. Condition assessment can vary from one asset to another according to assigned performance evaluation criteria. The data to be used for such purposes either be qualitative and/or generic (e.g. excellent, good, bad etc) or detailed and quantitative in accordance to established practices and standards (e.g. condition or performance index).

Step-2: Judgement of relative importance of each component in pair wise comparison

Table 3. 6 Matrix of pairwise comparison for drainage route

Factors	Embankment and Curb	Manholes	Inlet & Outlet	Wall	Floor	Overall route
Embankment & Curb	1	Q	w	x	y	z
Manholes	1/Q	1	y	z	x	w
Inlet & Outlet	1/w	1/y	1	x	x	x
Wall	1/x	1/z	1/x	1	y	z
Floor	1/y	1/x	1/x	1/y	1	w
Overall route	1/z	1/w	1/x	1/z	1/w	1
Column sum	A	B	C	D	E	F

A, B, C, D, E, and F are the column sum of values of components in pair wise comparison, and 1, Q, w, x, y, z are the relative importance values or scores (within 1-5 scale) for each components. The principal diagonal has scores of ‘1’, since each factor is as important as itself (or the same factor). Besides, list of values below diagonal (identity matrix) matrix of (Table 3. 6) are the reciprocals of the corresponding elements above the identity value.

Step-3: Normalize matrix values indicated in table 3.6 above.

Table 3. 7 Normalized matrix

Factors	Embankment and Curb	Manholes	Inlet & Outlet	Wall	Floor	Overall route
Embankment & Curb	$1 \div A$	$Q \div B$	$W \div C$	$X \div D$	$Y \div E$	$Z \div F$
Manholes	$1/Q \div A$	$1 \div B$	$Y \div C$	$Z \div D$	$X \div E$	$w \div F$
Inlet & Outlet	$1/w \div A$	$1/y \div B$	$1 \div C$	$X \div D$	$X \div E$	$x \div F$
Wall	$1/x \div A$	$1/z \div B$	$1/x \div C$	$1 \div D$	$Y \div E$	$z \div F$
Floor	$1/y \div A$	$1/x \div B$	$1/x \div C$	$1/y \div D$	$1 \div E$	$w \div F$
Overall route	$1/z \div A$	$1/w \div B$	$1/x \div C$	$1/z \div D$	$1/w \div E$	$1 \div F$

As indicated in (Table 3. 7) are normalized under each column by sum up of all the elements (entries) of a specific column and then dividing each values/ entries to the computed sum values(such as A, B, C, D, E and F accordingly).

Step-4: Relative weight computation

Following normalizing the matrix, relative weights (sometimes it’s called importance or value) of each factors (such as; condition of embankment and curbs, condition of inlet & outlet, condition of storm water drainage walls, condition of storm water drainage floor, overall condition of storm water drainages) were computed.

And thus, the relative weights of each determinant factor of drainage performance can be computed by adding up the entries/values of each rows of normalized matrix and then that sum value were divided by the number of components (or entries), which was six for this study case and details are presented in Table 3. 8.

Table 3. 8 Sum of normalized matrix records

Factors	Embankment and Curb	Manholes	Inlet & Outlet	Wall	Floor	Overall route	Relative weight
Embankment & Curb	$1 \div A$	$Q \div B$	$W \div C$	$X \div D$	$Y \div E$	$Z \div F$	$R1/6$
Manholes	$1/Q \div A$	$1 \div B$	$Y \div C$	$Z \div D$	$X \div E$	$w \div F$	$R2/6$
Inlet & Outlet	$1/w \div A$	$1/y \div B$	$1 \div C$	$X \div D$	$X \div E$	$x \div F$	$R3/6$
Wall	$1/x \div A$	$1/z \div B$	$1/x \div C$	$1 \div D$	$Y \div E$	$z \div F$	$R4/6$
Floor	$1/y \div A$	$1/x \div B$	$1/x \div C$	$1/y \div D$	$1 \div E$	$w \div F$	$R5/6$
Overall route	$1/z \div A$	$1/w \div B$	$1/x \div C$	$1/z \div D$	$1/w \div E$	$1 \div F$	$R6/6$

For a matrix having 6X6 the denominator will be take six (6). In addition to the reviewed literatures (or operational manuals) listed in Drainage infrastructures’ physical Condition assessment model asset inventory and physical condition assessment, maintenance standards derived from the Washington state department of ecology’s concerning storm water management of eastern Washington (Ecology, 2014) were also reviewed and contextualized.

Basic Condition Assessment (BCA) Performance score computation

Eventually, to compute BCA performance score; first we need to compute relative weights (sometimes it’s called importance or value that is calculated in (Table 3. 8) of each factors such as condition of embankment and curbs, condition of manholes, condition of inlet & outlet, condition of storm water drainage walls, condition of storm water drainage floor, and overall condition of storm water drainages) were computed. Each factor has its own roles on overall performance of the drainage. If the condition of the storm water drainage’s walls was much more important than condition of floors; overall performances of drainage route was much more affected due to failed

walls condition than damaged drainage floor. The BCA performance score of the drainage route can be computed using (Najafi, 2008), formula;

$$\text{Performance score of the drainage route} = \{\sum \text{Condition Rating X Relative Weight}\} \quad (2)$$

The performance score of a drainage route is a factor used as a benchmark to develop short and long term plan of maintenance. Based on the performance score, the drainage routes were grouped into three zones i.e.; Critical zone (Red), Monitored zone (Yellow), and Satisfactory zone (Green). In this computation the maximum score drainage routes can have is five (5) and minimum is zero (0). The practices of computing performance scores for each drainage route assist decision makers to reach a meaningful and objective judgement, and that in turn implies which route to be intervened, when, and with what type of intervention modalities. And moreover performance score was used as one of the major criteria to prioritize routes for maintenance purposes. Ultimately based on the computed performance score, each drainage routes were categorized into one of the three zones as details are presented in Table 3. 9;

- **Critical Zone (Red zone):** Urban roadside drainages those falls under critical zone were considered as they exist on the verge of failure and need immediate attention. These routes require major activities to be done to restore; upgrade crushed and/or collapsed parts or demanding for total replacement of the existing drainage structure.
- **Monitored Zone (Yellow zone):** storm water drainage routes categorized in this zone were those found in an intermediate phase. They require routine/minor maintenance (e.g. removing accumulated sediment and debris, or cutting overgrown vegetation etc.)
- **Satisfactory zone: (Green zone):** drainage routes within this zone were safe and free from significant deterioration, or require no significant maintenance works.

Table 3. 9 BCA performance scores, and respective zones

Performance Score	Zone	Zone Meaning
Above 3.5	Satisfactory (Green)	Safe
3.5 - 2.5	Monitored (Yellow)	Intermediate
Below 2.5	Critical (Red)	Danger

Source: Adopted from (Najafi, 2008)

Furthermore, the drainage routes, those falls under the risk zone were directed for further investigation by Advanced Condition Assessment (ACA) model. After having categorized each routes to its respective performance zone, short and finally long range planning for maintenance purpose were suggested

The drainage routes in critical zone were inspected in-depth for particular problems and given a condition rating between 0-5. Rating or giving a score is a measurement of how good the drainage infrastructure is in its current status. Where zero (0) is a complete collapse of the route and 5 implies an excellent or new condition. The ACA performance score computation matrix follows the same procedure as BCA performance computation as details described in Components of storm water drainage for condition rating except the parameters variations.

Advanced Condition Assessment (ACA)

Advanced condition assessment is an exhaustive inspection of storm water drainage route's structures. ACA is an extension of BCA of drainage routes' performance computation for those drainage routes which fall under critical zone. Drainage routes categorized under the critical zone based on BCA performance scores were jotted down and let to pass through detail and specific problems which caused inappropriate performance of the drainage route. ACA determines the problem causing specific deterioration to the routes and compute relative weights or magnitude of contribution of each factor for bad performance of the drainage route.

In ACA activities detailed inspection is done on storm water drainage's inlets, outlets, and inside the drain channel, and through this intensive field observations and measurements condition rating factors such as; Inlet-outlet blockage, breaking, joint opening, scouring, deposits of debris and silts, cracking were examined. This type of condition assessment differs from basic condition assessment since it performs in depth inspection of the drainage infrastructures' real problems. The condition rating points/values were given to each factor and relative weights were computed similarly using AHP as stated in prior sections of basic condition assessment. The ACA performance score was calculated in the same fashion as BCA performance score computation through matrix except the factors of both cases differ from one another.

In this study the Midwest Regional University Transportation Centre (MRUTC) inspection techniques and protocols were reviewed, adopted, and accordingly contextualized for drainage route inspection of the study area (Najafi, 2008). The numerical condition rating system approach with the range fall between 5-0 was used as a benchmark in identifying the problems of drainage infrastructures. Performance score for each drainage route were also computed using (Najafi, 2008) formula:

$$\text{ACA Performance Score} = [\sum \text{Condition Rating} \times \text{Relative Weight}] \quad (3)$$

Eventually, the inspector endorses repair (restore to previous status through minor intervention), renewal/upgrading (improving by size, quality, or by any other means that improves the bad performing statuesque of routes), replacement (completely elimination the existing ones) and/or combination of two or more intervention types for each routes of drainage just assisted by the ACA performance score and condition rating to fix the specified problem that causing deterioration. Advanced condition rating factors (or major componens) for drainage routes constructed with concrete & masonry were identified as;

- (1) Cracking
- (2) Breaking
- (3) Joint opening
- (4) Scouring
- (5) Deposits or debris
- (6) Inlet and outlet blockages, and further rating scales for each component and stated criteria are portrayed in Appendix 5 -to-Appendix 10

3.7. Hydrological analysis

Situation analysis of the study area with regard to drainage infrastructure maintenance issues demand for looking hydrologic matters such as stream network and patterns, watershed, basin, slope analysis and so forth. Forinstance, from bunch of drainage networks due to hydrological facts and figures the specific routes may be sorted out (or prioritized) from the whole networks for maintenance purpose or any related kind of interventions.

Assessing natural and man-made drainage network pattern helps to predict risk factors, proactively to plan for flood disaster risk management strategy development and understand the possible consequences and spatial extent of flooding problems too. And therefore hydrological characteristics of the study area were analysed and mapped in different modalities in a way that they support overall decision making process. Digital Elevation Model (DEM) that was obtained from Geospatial Information Institute (GII) of Ethiopia was used as a base data to analyse study area's slope, watershed, hillshade, and flooding plain. Study area's topographic maps, slope analysis, flooding risk area identification (flooding damage threat or vulnerable areas), and emergency response map (for rescue from unforeseen flooding damages), were also proposed and produced as an output too. Topographic map was developed to see the pattern of the distribution of natural drainage lines vis-à-vis existing man-made physical facilities and other artefacts (e.g. buildings, roads, open spaces etc). Terrain of the study area was also investigated in drainage

infrastructure management context and used to visualize big image of the geographic reality of the study area for further routine decisions.

3.8. Urban drainage network naming and coding

Physical condition inventory and assessment data of drainage routes need to be documented in an appropriate way and easily identifiable manner. Providing a unique name and code to the asset about which condition data collected is an inevitable tasks during infrastructure management tasks especially for complex networked urban utilities such as urban drainages, urban road networks, water supply lines, telecom and power supply lines, etc. To conduct geocoding some sort of ground rules and parameters need to be in place. A network referencing scheme shall be organised in a way that it can be identified easily and suit for smooth data collection and further asset management activities including decision making.

The asset management division of Addis Ababa City Transport Program Management Office (TPMO) developed an asset identification and label installation guide for permanent asset coding of transport infrastructure assets. According to the guideline; each physical transport asset is proposed to be coded and named considering street classification of the Addis Ababa City Road Authority (AACRA). AACRA's road classification system (such as; PAS, SAS, CS, LS, and RR) is used as a basic starting point criteria for coding and naming of transport infrastructure assets. The study held by JICA (2019) project for the development of road maintenance capacity of Addis Ababa City Administration was also referred to and considered while coding drainage infrastructures for this study purposes.

According to the manual roads' routes were sub-divided into sections, and again sections into numerous segments for asset inventory and condition assessment. Routes, sections and segments are given a unique identification or reference number. Since roadside ditches are integral parts of streets and coexist with the specific wayside. In this study street coding theme was preferred to be adopted in drainage infrastructure naming and coding too. A drainage route is best identified for the sake of numerous operations if its naming and coding were associated with street coding. In addition, drainage infrastructure asset inventory and condition assessment were conducted just subdividing the route into sections, and sections into segments in the range of 100 meter as per the city's asset identification label installation guideline.

Rule for Geocoding Drainage Asset: Drainage infrastructure assets, which exist along roadsides, were made to have the same coding technique as road asset except it adds a prefix of the first two

letters of the word ‘DRAINAGE’ on respective street code. For example ‘DR-P001- 01-01’ means drainage route on PAS roadside that was assigned with the code of ‘P001-01-01’.

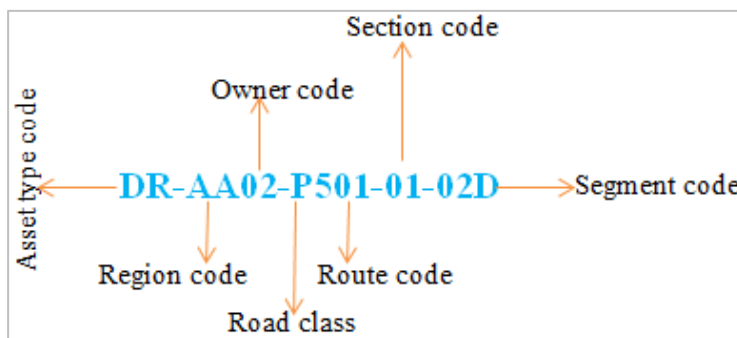


Fig 3. 6 Sample coding of drainage network

Techniques of classifying routes

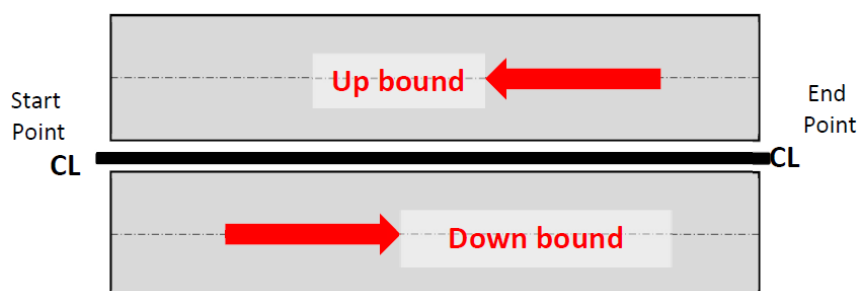
The start point of the route lay on the near-side to “Meskel square” or “Axis road” of the road under subject, and the end point of the route considered the far-side to “Meskel square” or “Axis road”. The route number shall fall within the range of 1-500 inside the Ring Road, and 501- 999 outside the Ring Road. The nearer to city center (Meskel square,) took the lower number. The routes originating from Meskel square will be considered as start point. For other routes, the start point will be a higher order category of the road.

Axis is route in North-South (from Dilber to Akaki) and East-West (from Ayat Makedonia to Ambo road direction.) as per TPMO manual.

Section Code rule

Section code assigned with two digit numbers (i.e. 01, 02, 03 ...99), and it begins starting from initial point of the route under subject. Coding for section on the next new route starts with ‘01’ again.

The PAS route shall be sectioned when it intersect or touch with PAS and SAS, and the SAS route sectioned when it intersects or touches with PAS and SAS. Collector route were sectioned when it intersects with PAS, SAS and CS. The LS route shall be sectioned when it intersect or touch with PAS, SAS and CS. In case of two ways roads, the road is divided into UP bound and down bound.



Routes from start point to end point or down bound direction is considered as ascending, whereas up bound taken as descending for drainage routes in two ways roads.

Techniques of classifying sections

The start point of a sectioning is the side of the start point of its route, and the end point of the sectioning is the side of the end point of its route.

Segment code rule

Again the segment code has two digit numbers (01, 02, 03 ...99) that were assigned starting from the initial point of the SECTION. If someone intended to go to the next section, he/or she starts with segment "01" again.

A segment has 100 meter length, and if in case the last segment is less than 50 meter long, it shall be added on the preceding segment else shall be counted as new segment.

3.9. Field Measurements

In general, at the very beginning of field works of this study; necessary checklists, templates, equipment and other guiding questionnaires were prepared and used as data collection tools while collecting spatial and non-spatial data. Mobile application prepared for data collection were tested on field for its functionality for the intended purpose by collecting sample data from 3(three) block of settlement as a mini pilot work. And then reconnaissance survey were also conducted a bit ahead of intensive ground surveying works (using DGPS both static & RTK techniques, and survey master mobile application) done.

3.9.1. Ground survey works

Devices and measuring instruments used during condition inventory and assessment includes; DGPS, Smart phone camera, and measuring tape and measuring coil, Vernier calipers were also used to measure size of wear of surface lining material during field works. Using measuring tape width, depth, breadth of drainage infrastructures was measured. Measuring coil was used to measure distances between two consecutive segment points and it also help to proceed from one point to next point. Along centreline of each drainage route within 100 meter interval of length coordinate points at inlets of drainage section, at mid points, and at the outlets of each drainage routes of the study area observations were taken using differential GPS- RTK (real time kinematics mode). To map existing drainage network facilities with better positional accuracy point data collection at junctions, inlets and outlets of each route was also taken.

One base DGPS receiver at base station (“German Square”) and the rest two rovers were used to collect data (or coordinates) of drainage routes. The two rovers were connected through bluetooth with smart phones of the data collectors that has survey master mobile application, which later on eases data collection process. Three reference ground control points (GCPs) were obtained from Gespatial information institute of Ethiopia. And DGPS RTK (real time kinematics) or using dynamic mode of receivers each drainage channels’ centrelines was collected. Another reason that require doing of ground surveying were incapability of Orthophoto to show drainage routes clearly and also existence of underground or closed drainage facilities demand intensive ground surveying works.

The data collected by this technique was used for geo-locating each drainage sections, validation and geo-referencing purpose. We used Global mapper to conduct datum transformation of point coordinates that were collected using DGPS with WGS-84 datum were transformed to Adindan UTM Zone 37 datum. This was done because most local spatial data like road networks, drainage maps, and land use maps of structure plan of city of Addis Ababa exists with Adnidan UTM Zone 37 datum, which needs compliance with field measurements of DGPS data that uses WGS-84 datum.

Existing drainage infrastructure planning and management system of city administration (at city level, at sub city and woreda level urban infrastructures etc) in the process of life-cycle management practice of spatial data exploitation, routine maintenance which includes silts and other obstructions removing practice were also thoroughly investigated.

Storm water drainage routes, manholes, culvert structures and other related geographic entities within the study area were identified and geo-located with the help of information collected through ground surveying works along with orthophoto of the study area. Geocoding each drainage line having coordinates of start and ending points, existing drainage infrastructure network facility and pattern identification through field inventory, urban land use classes, existing and proposed road maps were also overviewed for assessment of geometric relationships with drainage infrastructures maintenance management under the study.

According to See et al., (2020) the extent or size of point data to be collected vary depending on defined assessment boundary, purpose of the study, survey method and equipment used. In this regard these authors suggested collecting of coordinate points at all road intersections coupled with drainage facilities of the study area as one alternative. Taking an additional coordinate measurement along centrelines of drainage routes, measuring invert elevations at bridge crossings, recording of

coordinate values on field papers contribute much in developing positional accurate spatial data outputs. Furthermore measuring and recording the cross-section dimension at the ends of each street block (where drains channels intersect each other), recording an average condition of drainage infrastructure with in each segments of the route (specifying as, Excellent, Very good, Good, Fair or Poor), and also taking appropriate additional notes is also important.

3.10. Prioritization

Problems related to urban drainage infrastructure management system of the study area in a broad view can be categorized as man-made and natural problems. Storm water drainage routes within the study area have varying levels of physical condition, age, size, shape, type of construction material and relative impact on neighbouring residents if in case it fails. Probable consequences and magnitude of resulting problem of defective drainage structure vary from one neighbourhood to another due to topographic nature of areas, and possible volume of rain water flowing vary from place to place. On the other hand, type of interventions required, cost to be incurred, and approaching techniques to combat observable facts of the problem differ from one route to another. On top of that again level of urgency for intervention against existing problems of each route significantly varies. Topographic realities vis-à-vis vulnerability level of settlements for flooding risks also differs from a neighbourhood (or from an area) to another quarter. Above all, current road authority's and its stakeholder's capacities (both financial and human resource) to manage all existing urban drainage infrastructure assets at a time is also much limited and problematic too. And thus, both theoretically and practically attempting to avoid all kinds of urban storm water drainage problems at a time is totally impossible task. Beside that neither the owner nor the stakeholders of urban drainage infrastructure management offices have clear, comprehensive and well organized information about their resources at the ground.

Addis Ababa road authority, for instance don't have its urban drainage infrastructures' updated information (about size, shape, worth, existing status etc), where each infrastructure exists, in what physical condition it exists, when it was constructed and even maintained, what kind of intervention each drainage infrastructure demanding for, and the like questions are not yet getting sound answers.

And thus, this study firstly developed organized database that grasp all basic and inevitable types of information about urban storm water drainage infrastructures' that will help in life-cycle management. After having all necessary existing physical condition information about drainage infrastructures (e.g. which drainage infrastructure, where, in what condition, with what quantity and

quality etc.), issue of planning to invest on drainage assets maintenance with limited budget also need to be addressed. Besides, the drainage system is expected to function well and each drainage infrastructure needs to deliver a quality service up until the end of their design period. As mentioned earlier, however resources in general and infrastructure maintenance management budget is much limited.

Most importantly, what is needed to be done and focused on in such circumstances is just prioritizing issues. Storm water drainage route prioritizing (or choosing specific route out of other competing and candidate routes) for decision making purpose with regard to maintenance issues need to base on more than one criterion. In general decision making techniques that involves numerical analysis in selection process among alternatives and commonly pass through three steps; which includes; first identifying and agreed up on the criteria and alternatives, second linking numerical measures to the relative importance of each criteria, third ranking the alternatives just by processing (through matrices) the numerical values. On top of that Multi-Criterion Decision Aid (MCDA) method being utilized.

MCDA is a method that support decision makers in selection and/or prioritization of possible alternatives based on multiple factors (Greene et al., 2011). It follows a wide range of quite varying approaches. Due to the complexity of problems as well as the existence of a big data increases the interests toward utilisation of formalized decision-analytical tools (Tscheikner-Gratl et al., 2017) are growing from time to time.

And thus, in this study five fundamental parameter (or criteria) were used as major issues to prioritize competing drainage routes. These factors are;

- (1) Drainages routes' existing physical condition,
- (2) Risk factor,
- (3) Road classification,
- (4) Level of urgency,
- (5) miscellaneous factors.

These factors were developed after having thorough literature review and contextualizing practices of different countries, and having in-depth discussions with concerning experienced engineers of the firm of the study area, findings from field observations and results of gap analysis implied importance of using the aforementioned parameters. Details are highlighted as follow;

3.10.1. Overall physical condition as one parameter for maintenance decision prioritization

Physical condition assessment result of urban drainage infrastructure have capability to show and convey information about type of intervention needed, extent of investment required, and depth of the probable and real difficulties residents facing due to bad drainage structures' condition and its malfunctioning status. In previous sections of this paper physical condition inspection issues of urban drainage infrastructures were discussed in detail and each component's contribution for overall under performance of a route were also weighted and described. Here only existing physical conditions' statuses of a route vis-à-vis its impact in prioritizations theme for maintenance purpose was underlined. Although conventionally decision making for maintenance purpose mainly influenced by physical condition factor, in this study drainage route prioritizations for the sake of maintenance purpose takes into account other important factors. And therefore, final decision making and ranking of competing routes for maintenance purpose take into account overall physical condition rating scores that computed in prior sections as one of the major element but not as the only factor.

3.10.2. Risk factor for maintenance decision prioritization

Risk factor is one of the major elements that need to be focused while managing drainage assets and it was also used as one of the basic prioritization parameter. In principle municipal service delivering infrastructures need to have utmost less risk, and/or may have minimal allowable social, economic, environmental and the like risks during failures due to some known and unforeseen reasons. This is one of the principal reasons for the importance of life-cycle management of physical infrastructures. A safety standard issue for residents is as equal concern as quality service delivery, or in other words it shall be considered as different faces of the same coin. And therefore, measuring the level of risk of different areas that have varying level of exposure to flooding would help decision makers while prioritizing drainage routes of the overall networks for maintenance purpose.

There are two components of risks i.e.; Probability of Failure (PoF) and Consequence of Failure (CoF). The two main components of risk are Probability of Failure (PoF) and Consequence of Failure (CoF). In this study theme PoF predicts probable time of a drainage route to fail; CoF provides a signal of the impact of a failure. The following formula is used to calculate risk:

$$\text{Risk} = [\text{Probability of failure} * \text{Consequence of failure}] \quad (4)$$

Probability of Failure (PoF)

The PoF score indicates the projected time until the asset fails to function at the established levels of service. For instance level of quality of service for drainage assets depends on channel stability that impacted by erosion and accumulation of sedimentation which eventually prohibit storm water flow conveyance. Channel stability can be inspected while conducting condition inspections. In addition to that the PoF score for each drainage asset routes was based on the age of the asset, and it can be classified and rated. The PoF was classified into three rating scales (i.e., Low, Medium, and High probability of failure). This study adopted the PoF rating five scale rating scale just to have the same alignment of analysis with other parameters of prioritization. Each drainage route is further categorized based on their level of criticality, and rated with 1 to 5 rating scales; where 1 being in a most critical situation.

Consequence of Failure (CoF)

CoF refers to the criticality of a drainage asset, which is, how huge an impact the defective drainage route will have if in case or unfortunately it fails. The impact of a drainage route failure was assessed in terms of economic, social, and environmental views. For instance a bigger diameter drainage pipe obviously will have a higher CoF value compared to lesser diameter drainage pipe. In another words larger size closed drainage pipes will have higher cost of failure (or negative consequences) and also flooding due to obstruction of that type of pipe will have much more social and environmental impacts. Besides, the geospatial factors such as road classification, urban land use type, basic facilities that exists at proximity to drainage route, drainage asset class/size and other related miscellaneous factors were taken in to account while assessing the CoF for the drainage assets.

3.10.3. Road classification as factor for drainage maintenance prioritization

Street classification is also used as one of the major factors for route prioritization for the purpose of maintenance. Drainage routes found on large roadsides (e.g. PAS, SAS) got a greater preference than drainage routes found on smaller roadsides (like LS). And therefore, weighing roadside drainage routes for maintenance purpose were done by taking a street class as one prioritization factor, and considering how huge the probable impact of a specific defective drainage route. The size of the road vis-à-vis its left and/or right side defective drainage route usually has a direct correlation with respect to how large the possible impact they can cause on one another and urban residents of the area. Further details are annexed in the form of table in (Appendix 13).

3.10.4. Level of urgency of routes for maintenance work

Level of urgency in the context of prioritization implies that how far a specific drainage route's maintenance concern calls for urgent intervention. It was one of the important factors that were considered while conducting route prioritization for possible interventions required for changing the status quo; and more details for this parameter is also portrayed in table form in Appendix 14.

3.10.5. Miscellaneous Rating Factors

In the context of life-cycle management of drainage infrastructures; directly and indirectly influencing issues shall be considered and information needs to be comprehended and brought to table of decision makers. For instance miscellaneous factors such as; flooding victims' compliant and relative ground condition, asset class, emergency encounters, and land use type, facility type, proximity to other important social services, cost estimation for maintenance, matching fund contribution, and the like factors were taken under consideration just before final maintenance decisions making for defective routes restoration or replacement. Further rating scale and situations of miscellaneous rating factors are described in a table format in (Appendix 15).

The above mentioned miscellaneous factors and othe realted issues have a relative degree of impact on social, environmental, and economic viability of residents in realtion to mulfunction of flood control strucures or lack of maintenance. And based on the above listed prioritizing factors drainage routes' of the study area were ranked, mapped, and the results are stored in database in a suitable way for decision makers and remote access of the information by concerning stakeholders were maintatined.

3.11. Database development

Having all necessary data at hand, data clearing, organizing, populating and/or storing, manipulating, querying, displaying and, so and so forth demands can be fulfilled in due courses if and only if an appropriate database were in place. To this end, the way of data processing, analysing and transforming into a usable form (or information) can be easily realized if there is a way to manage data by some sort of database management system. And therefore, for the purpose of this study geo-database was developed following three basic phases of database design, which includes; conceptual, logical and physical design phases. To cross-check whether the developed geo-database is actually instrumental or not; a mini pilot storm water drainage network data were collected, populated, manipulated, queried and displayed.

Developing (or designing) the Relational Database Management System (RDBMS) for drainage infrastructure planning and maintenance management in general require having a separate attribute table/or template for data recording purpose. To this end, the researcher developed RDBMS using PostgreSQL (that bases its data storage role in the form of tables) an extension were made up on it in a way that this PostgreSQL database could also able to support spatial data by linking it with PostGIS, supports spatial data. PostGIS stores spatial data in the form of geom-table. And therefore, as details are presented in this regard in chapter four section 2.4, the developed relational database of this study includes tables that containing rows and columns, which stores valuable data to extract decision making information any time when needed. The database is designed in a way that suits coupling with web technology or different types of related data compliance. The procedure followed while database designing is dipcted in Fig 3. 7.

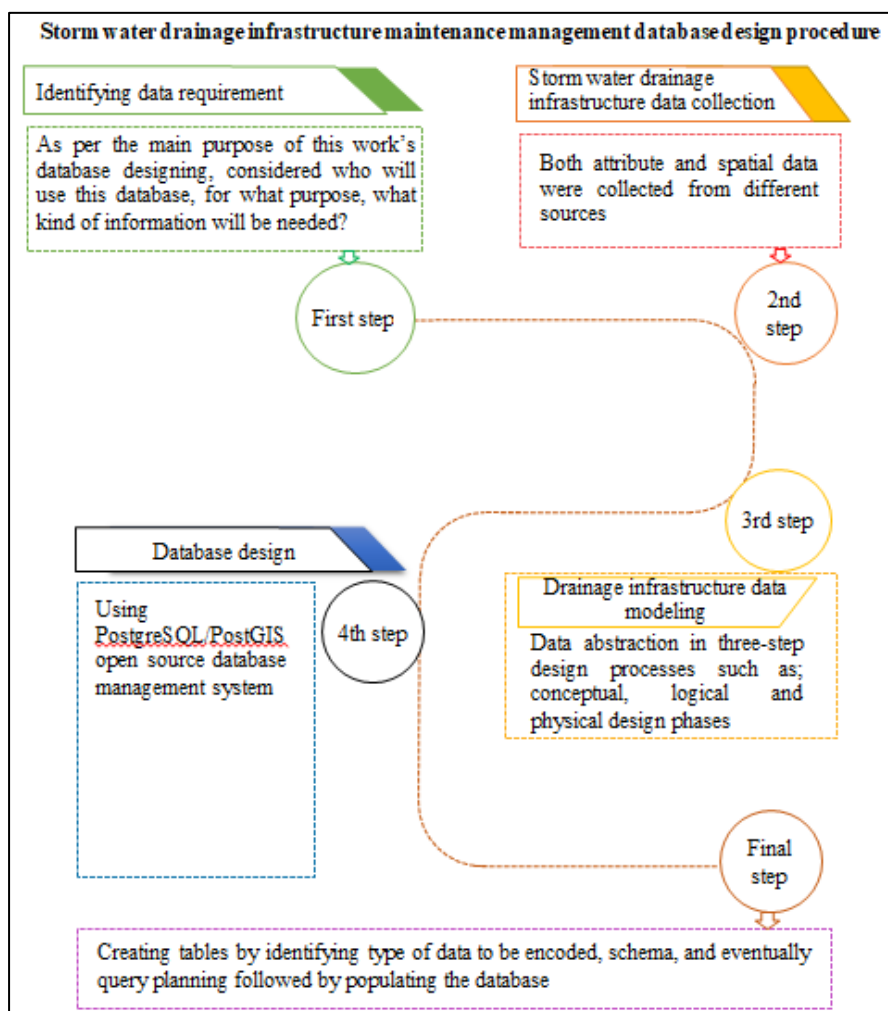


Fig 3. 7 Procedure of storm water drainage infrastructure database design

3.11.1. Publishing database to web platform

One of the specific purpose of this study was to develop a workable web-based prototype spatial decision support system for urban drainage infrastructure planning and asset management processes and publishing the outputs. The system was developed and realized in a way that it can perform both on off-line and online platforms (with internet connection). After populating the designed geo-database with spatial and non-spatial data uploading it to open source web platforms followed. Open source Web-based platforms have advantages of easy, unreserved and remotely accessing drainage infrastructure planning and asset maintenance management information about the study area on a real time bases. This system not only helps decision makers to easily define and analyse the investment priorities but also creates a web-based platform for frequent updating and meaningful participation of key stakeholders too. During publishing the database to open source web platforms freely available applications such as; Geoserver, Mapstore, Apache Tomcat, openlayers and so forth open source applicatins were exploited.

3.12. Data analysis and interpretation

The outputs of this analysis were presented by graphs, charts, tables, and map forms. Generalizing and processing of diverse data and symbolically displaying them as a meaningful and functional portrayal were also done. The findings were cross-checked, compared and contrasted with related studies' findings, context specific issues were also addressed, and the scope and framework of this study were also taken into consideration while interpreting the results.

Drainage infrastructure planning and maintenance decision making require exploitation and setting out of investment priorities to fix or replace the problematic drainage infrastructure networks. Competing demands of equally important drainage infrastructure routes for maintenance were evaluated, prioritized and eventually decisions were made based on objective multi-criteria decision aids. And therefore, demands of many routes for maintenance vis-à-vis the capacity of the municipality to perform rehabilitation, renewal or upgrade require further analysis and ranking of alternatives just considering several factors that were discussed in prioritization section.

CHAPTER FOUR

4. Result

In this chapter the study results are presented with brief explanatory and supporting analysis outputs in the form of illustrations, figures, maps and tables.

4.1. Existing situation of drainage network

Field observations were done at segments (or at an interval of 100m), sections and drainages' route level within the study area. While doing so drainage routes were given specific geo-located codes that later on would help route identification and integration of spatial data with their respective attributes. And eventually ease of communication among stakeholders on the matter can be improved, and simplicity of decision making process will also be enriched since the existing situation analysis reveals quite good ground facts that may convince stakeholders on maintenance decisions.

4.1.1. Drainage infrastructures' inventory and physical condition assessment

Field survey results showed that the majority of drainage which is about 60.77% of routes within the study area were constructed with masonry, and 35% by concrete and 4.23% are earthen as indicated in Fig 4. 1. And which implies that cracking of concrete surfaces, breaking and joint opening on walls of masonry drainage channel and the like defects on drainage infrastructure with such construction materials is common phenomenon that were observed on the field and demand for maintenance interventions.

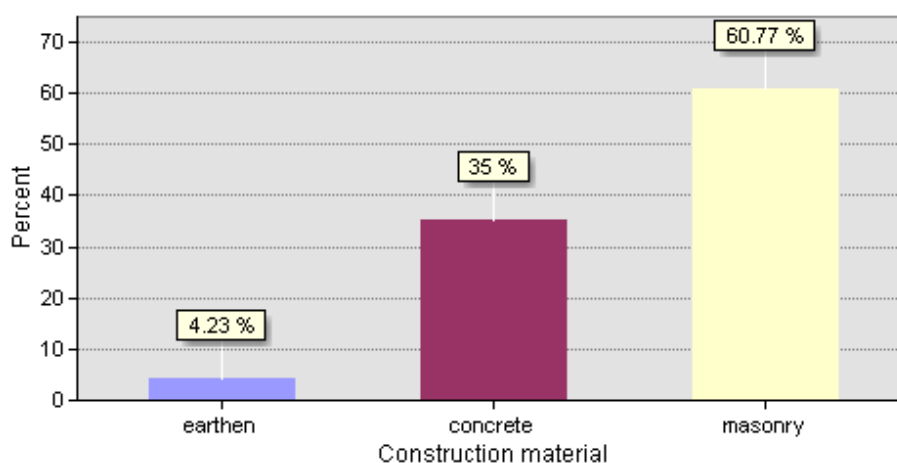


Fig 4. 1 Proportion of drainage segments by construction materials

Consequently, if we see the field survey result from the point of view of geometric shapes of drainage segments; 65.77% of drainage segments have a rectangular geometric shape, 25% circular, and the rest 9.23% are truncated circular shapes as illustrated in Fig 4. 2.

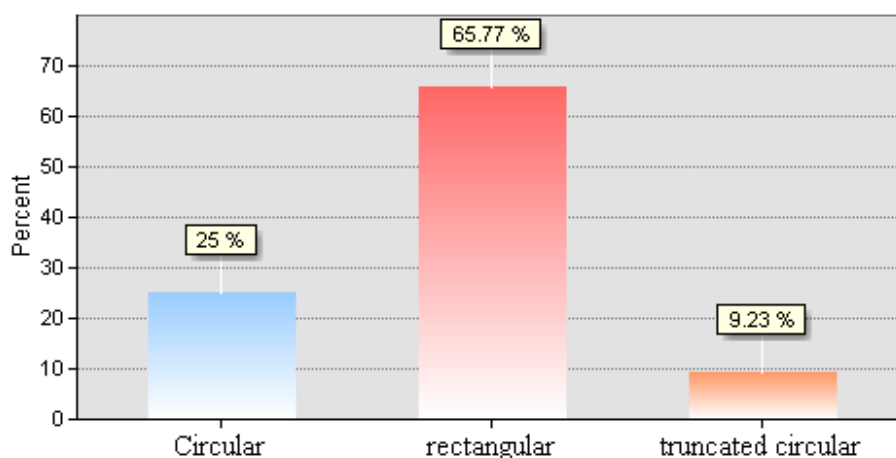


Fig 4. 2 Drainage segments by their geometric shapes

This statistical figure of geometric shapes can provide information about probable cost required, manpower, depth of the works required and other related knowledge about defective drainage routes will be drawn out by decision makers during maintenance planning. In addition, the field survey result reveals that 31% of drainage routes found within the study area are buried pipe type drainage facilities, and the rest 69% are open type. Having much proportion of open drainage channels implies that the study area’s drainage channels are much susceptible to being domestic and other types of waste dumping within it (unless and otherwise appropriate drainage management scheme be in place), and significantly contributing to environmental pollution within the study area.

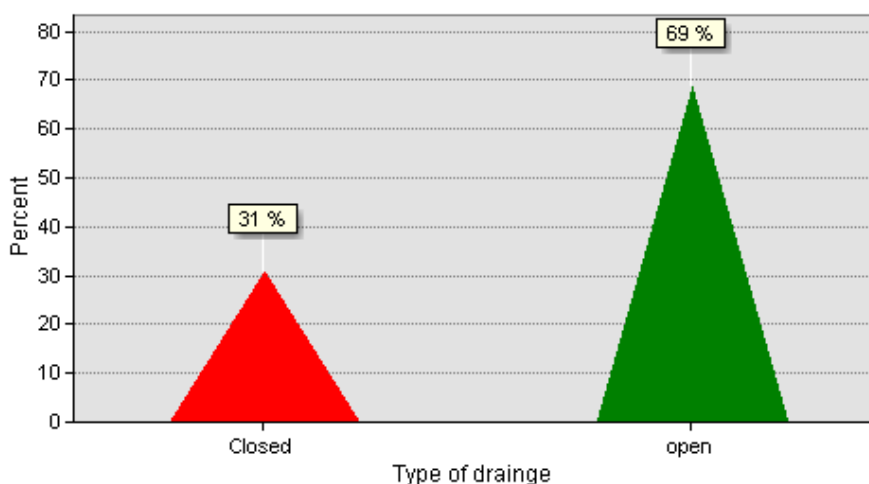


Fig 4. 3 Proportion of open and closed types of drainage routes

4.1.2. Basic condition assessment and performance scores of drainage routes

Based on field survey and situation analysis’s findings, a detail computation matrix was done and BCA performance scores were computed for each drainage route as presented in Fig 4. 4.

```

Stormwater_Drainage_Infra=# SELECT final_route, road_class, bca_perfor, zoning, interventi FROM swd_route_dataa;
  final_route | road_class | bca_perfor | zoning | interventi
-----
DR-AA02-L626 | LS | 2.7000000000 | Monitored | Repair
DR-AA02-L619D | LS | 2.1500000000 | Critical | Upgrading
DR-AA02-L631 | LS | 2.5700000000 | Monitored | Repair
DR-AA02-L606D | LS | 2.8400000000 | Monitored | Repair
DR-AA02-L601 | LS | 2.8400000000 | Monitored | Repair
DR-AA02-L602D | LS | 2.7000000000 | Monitored | Repair
DR-AA02-L603D | LS | 2.3200000000 | Critical | Replacement
DR-AA02-L627 | LS | 2.6900000000 | Monitored | Repair
DR-AA02-L634 | LS | 3.5600000000 | Satisfactory | Planned maintenance
DR-AA02-L630 | LS | 2.8500000000 | Monitored | Planned maintenance
DR-AA02-L623D | LS | 2.6900000000 | Monitored | Repair
DR-AA02-L604D | LS | 2.3200000000 | Critical | Upgrading
DR-AA02-L635 | LS | 3.2700000000 | Monitored | Repair
DR-AA02-L628 | LS | 2.5600000000 | Monitored | Repair
DR-AA02-L629 | LS | 3.0000000000 | Monitored | Planned maintenance
DR-AA02-L625 | LS | 3.1200000000 | Monitored | Repair
DR-AA02-L622D | LS | 2.8400000000 | Monitored | Repair
DR-AA02-L622 | LS | 2.8400000000 | Monitored | Repair
DR-AA02-L620 | LS | 3.5400000000 | Satisfactory | Repair
DR-AA02-L616 | LS | 2.6900000000 | Monitored | Repair
DR-AA02-L607 | LS | 2.6900000000 | Monitored | Repair
DR-AA02-L615 | LS | 3.1200000000 | Monitored | Repair
DR-AA02-L613D | LS | 2.6000000000 | Monitored | Repair
DR-AA02-L644D | LS | 2.5200000000 | Monitored | Repair
DR-AA02-L644 | LS | 2.2800000000 | Critical | Replacement
DR-AA02-L614 | LS | 2.8400000000 | Monitored | Repair
    
```

Fig 4. 4 Drainage routes with BCA performance scores, zoning, and intervention required

The results of BCA performance score (which is portrayed in Fig 4. 4) of each drainage route implies; decision makers to identify zone where each drainage route could fall in, and it also helps to propose type of intervention required, and to develop short and long term plans of maintenance.

Based on the physical condition and values of BCA performance scores, the drainage routes of the study area were grouped into three zones i.e.; as critical zone (Red zone), Monitored zone (Yellow), and Satisfactory zone (Green) as details are portrayed in Fig 4. 4. In light of this, field inventory and physical condition assessment results reveal that only 14.67% out of the total drainage coverage of the study area wa found in satisfactory physical condition. And 70.67% out of the total coverage falls under monitored zone, and the rest 14.67% are in critical physical condition as depicted in Fig 4. 5. In general, the physical conditions of drainage infrastructure of the study area are in high demand of maintenance interventions as samples are portrayed in

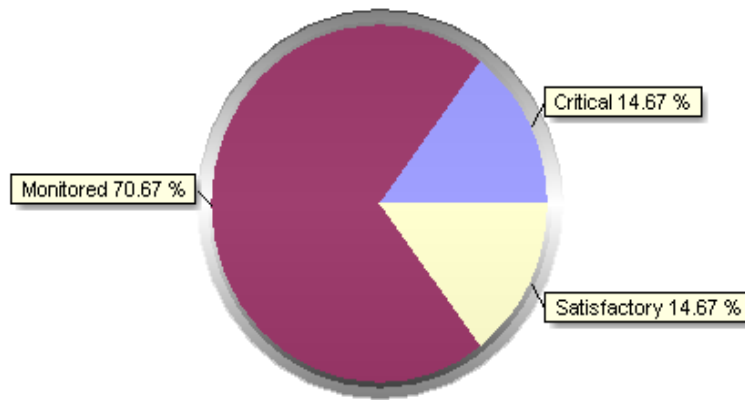


Fig 4. 5 Zoning of drainage routes

From the perspective of types of intervention require this study result shows that 80% of the drainage routes require repair type of intervention, 8% upgrading, 8% replacement and the rest 4% demand for planned type of maintenance actions (Fig 4. 6). Again here the statistics of condition implies that due consideration of existing drainage infrastructure maintenance management is a crucial concern, and concerning administering body needs to value the importance of restoring, fixing defects and maintaining existing drainage assets.

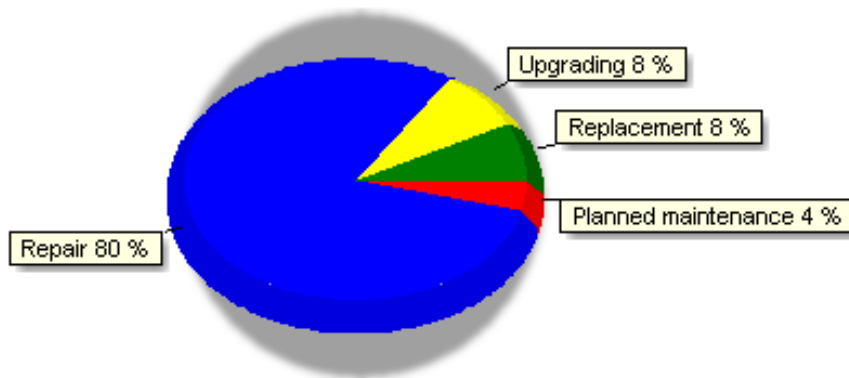


Fig 4. 6 Type of intervention required

The summary result of computation of matrix of ACA performance scores of each drainage route, and effected SQL command is;

```
SELECT final_rout, road_class, bca_perfor, zooning, aca_perfor, interventi FROM swd_route_dataa ORDER BY aca_perfor>1 desc
```

and eventually returns from PostgreSQL database is presented below in Fig 4. 7.

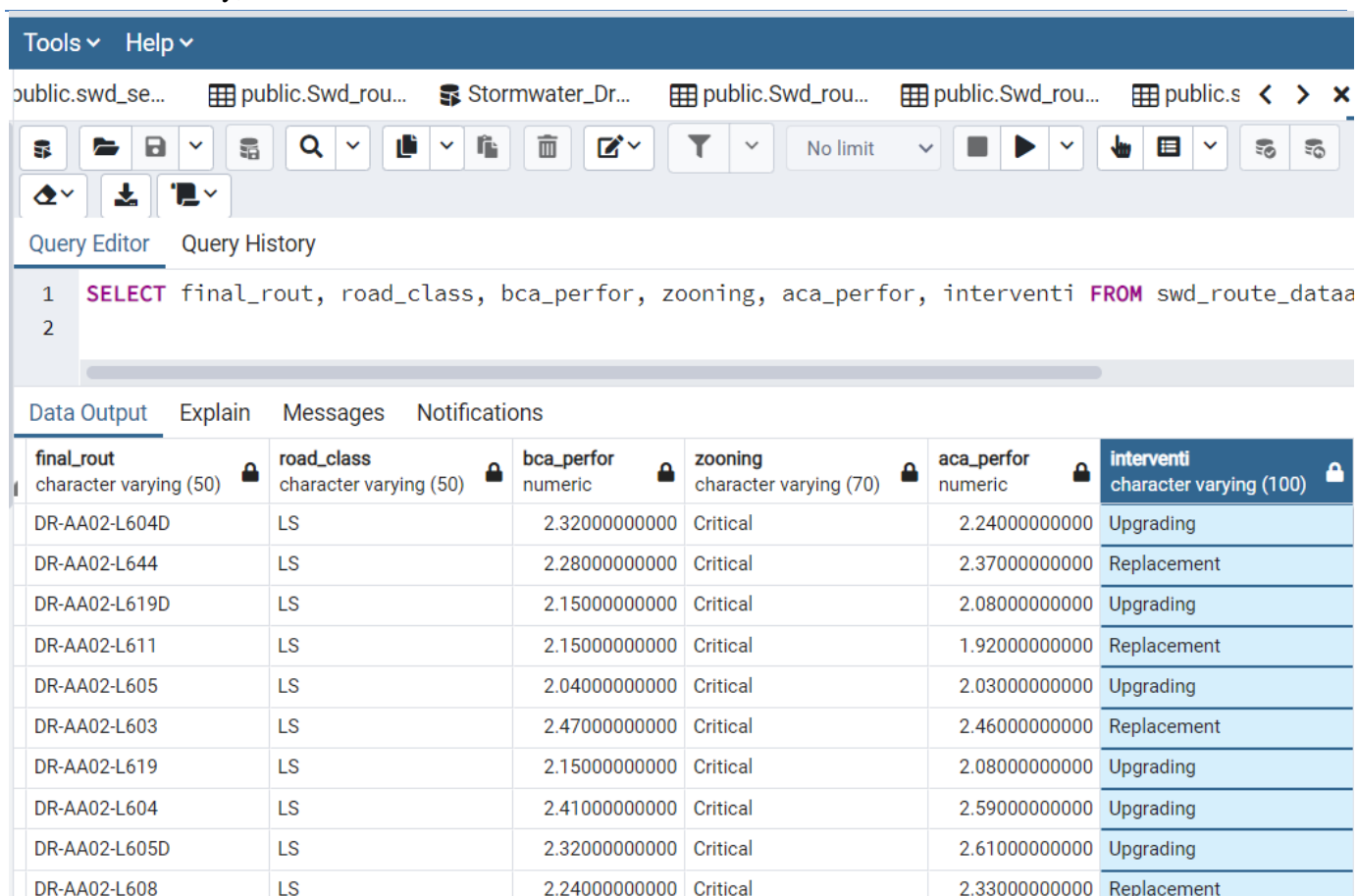


Fig 4. 7 Drainages peformance scores with list of geo-coded drainage routes

The drainage routes rating procedures was presented in detail in chapte three section 3.6.2 to 3.6.3, and the way how drainage system were named and coded were also elaborated in chapter three section 3.8. The ACA performance computation result of Fig 4. 7 reveals that cluster of networks of drainage channels fall under critical physical condition, the type of intervention required, the road class with which that specific drainage route coupled with, ACA performance scores and the like informations are displayed in tabular form and portrayed as a map too. Coordinate data collected using GNSS-RTK technique were used to map and geo-locate each drainage routes of the study area as depicted in Fig 4. 8.

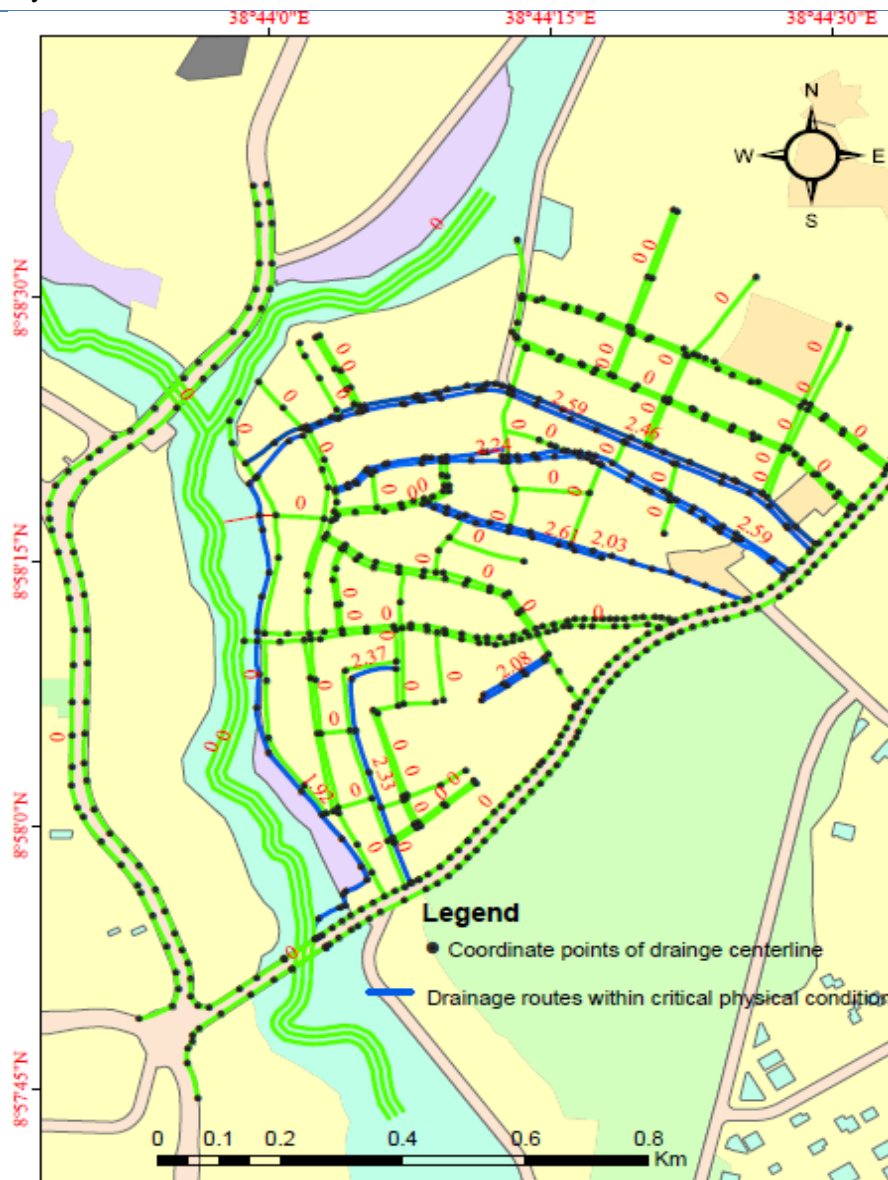


Fig 4. 8 Results of drainage routes with critical physical condition

- Green colour = drainage BCA performance score greater than 2.5
- Non zero numerical scores implies ACA performance scores

4.1.3. Results of general hydrology

Understanding the broad topographic characteristics of the study area can help decision makers of drainage infrastructures in many more ways, like in identifying severe flood prone areas, finding drainage routes with high probability failure due natural terrain and responsible to convey great volume of storm water, in prioritizing drainage routes for maintenance purposes, in existing settlement relocation and in so forth concerns.

The study area general hydrology characteristics indicate that areas subjected to flooding and water stagnation (<1%) identified, and areas with an excessive slope for urban development activities (>

20%) were also drawn out. The details of drainage routes overlay slope computed result, hydrologic characteristics of the study area, and the slope-wise area computation are presented in Fig 4. 9 and table Tabel 4. 1

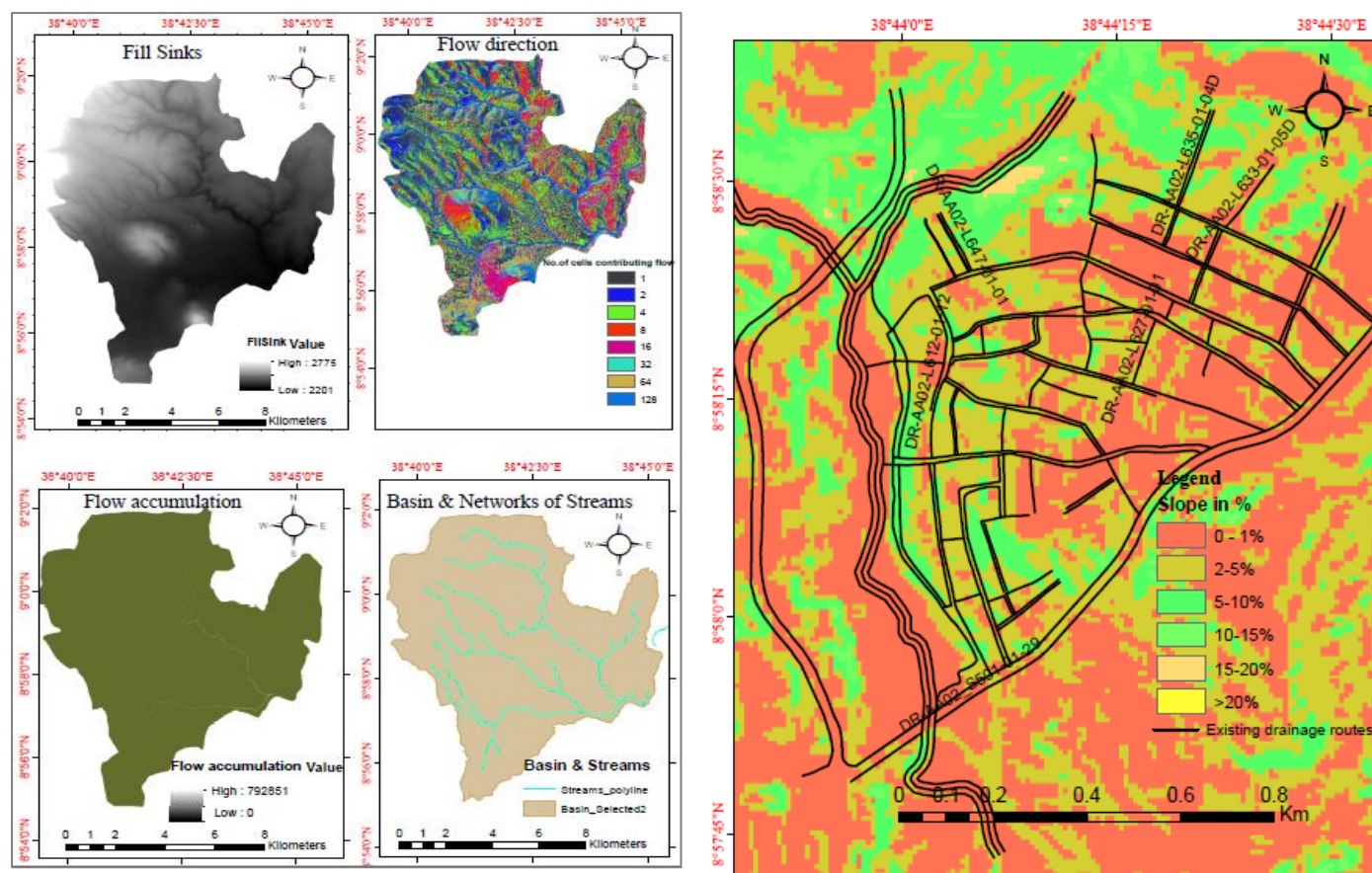


Fig 4. 9 Hydrologic characteristics and drainage routes overlay on slope analysis

Tabel 4. 1 Slope-wise area calculation

Classes(%)	Slope-wise surface area (m ²)	Area of each class in percent
0 – 1	7,187,100	8.73
2 – 5	4,312,100	5.24
5 – 10	59,064,400	71.72
10 – 15	7,511,800	9.12
15 – 20	841,500	1.02
20 – 25	3,435,500	4.17

The summarized area calculation implies that the largest portion of the study area (i.e. 71.72%) has fallen within the slope class of 5-10% and 1.02% or the smallest part of the study area falls within 15-20% slope class of the total study area. The area calculation result again indicates that 8.73% of the total basin falls within the slope class of 0 – 1% which is highly susceptible to the accumulation

of stagnant storm water that in turn may be a cause for many more water born problems on residents' life.

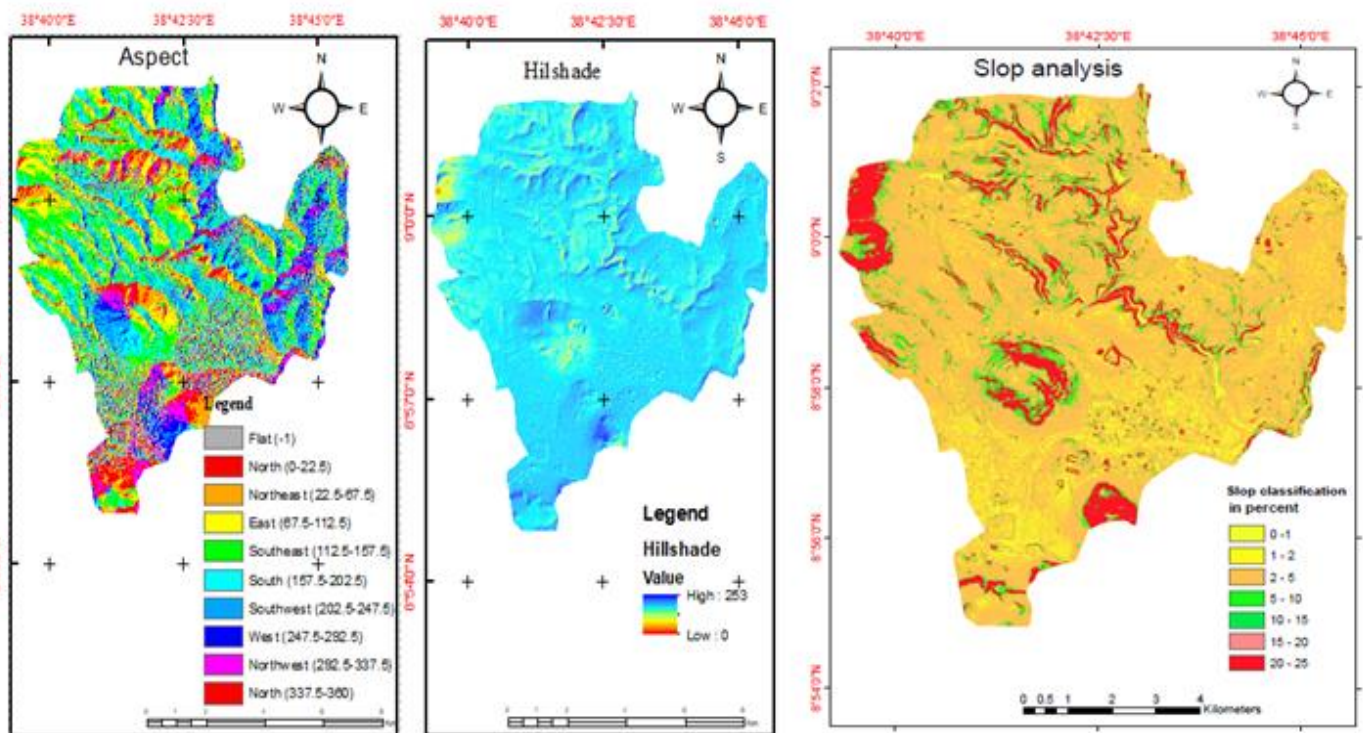


Fig 4. 10 The aspect, hillshade, and slope analysis of the study area

The slope classification map infers that majority of south-east and south west of the study area fall under the range of 0-1% and 1-2% slope classes; and that implying these areas are relatively low land areas, which is convenient for significantly stormwater layover it.

4.2. Database development

For this specific study, database was created by using PostgreSQL GUI, and named as '*Stormwater_Drainage_Infra*'. The database can be accessed by running the PostgreSQL interactive terminal program called SQL shell (psql), which allows the user interactively to encode, edit, and execute SQL commands or by using an existing graphical frontend (i.e. pgAdmin) tool. Afterwards desired number of tables can be created within the database either using GUI of PostgreSQL data management tool; PgAdmin, or using SQL shell (psql) command line.

The screenshot shows a web-based GIS interface. At the top, there are menu items 'Tools' and 'Help'. Below that, a toolbar contains various icons for navigation and editing. The 'Query Editor' is active, showing the following SQL query:

```
1 SELECT * FROM public.swd_segments_data
2 ORDER BY gid ASC
```

Below the query editor, there are tabs for 'Data Output', 'Explain', 'Messages', and 'Notifications'. The 'Data Output' tab is selected, displaying a table with 11 rows of data. The columns are: woreda, date_data, road_class, unique_rou, section_id, segment_id, fina_drai, shape_of_d, avg_depth, and avg_width.

woreda	date_data	road_class	unique_rou	section_id	segment_id	fina_drai	shape_of_d	avg_depth	avg_width
woreda - 05	2022-01-24	LS	L610	01	06	DR-AA02-L610-01-06	truncated circular	30	40
woreda - 05	2022-01-24	LS	L626	01	01	DR-AA02-L626-01-01	open surface dr...	30	30
Woreda-05	2022-01-24	LS	L619D	01	02	DR-AA02-L619-01-02D	rectangular	35	40
Woreda-05	2022-01-24	LS	L607D	01	09	DR-AA02-L607-01-09D	truncated circular	30	25
woreda - 05	2022-01-22	LS	L631	01	01	DR-AA02-L631-01-01	rectangular	70	75
woreda - 05	2022-01-24	LS	L600	01	01	DR-AA02-L600-01-01	rectangular	40	50
Woreda-05	2022-01-24	LS	L606D	01	08	DR-AA02-L606-01-08D	rectangular	80	80
woreda - 05	2022-01-22	LS	L604	01	06	DR-AA02-L604-01-06	rectangular	40	50
Woreda-05	2022-01-24	LS	L606D	01	14	DR-AA02-L606-01-14D	rectangular	60	65

Fig 4. 11 Data from developed data base on physical condition inventory and assessment

Information that is required to be printed out from the developed database depends on the specific information requirement of the PostgreSQL/PostGIS database user; can be displayed within a fraction of seconds. The findings of geocoded drainage route identification number (or code), road class, basic condition assessment (BCA) performance score, physical condition zoning, proposed intervention required and other information about some routes or all routes are drawn out by executing SQL statement as portrayed in Fig 4. 12.

```

Stormwater_Drainage_Infra=#
Stormwater_Drainage_Infra=# SELECT final_rout, road_class, bca_perfor, zooning, interventi FROM swd_route_data;
  final_rout | road_class | bca_perfor | zooning | interventi
-----|-----|-----|-----|-----
DR-AA02-L631 | LS | 2.5700000000 | Monitored | Repair
DR-AA02-S501 | SAS | 2.6800000000 | Monitored | Repair
DR-AA02-L601 | LS | 2.8400000000 | Monitored | Repair
DR-AA02-L603D | LS | 2.3200000000 | Critical | Replacement
DR-AA02-L627 | LS | 2.6900000000 | Monitored | Repair
DR-AA02-L634 | LS | 3.5600000000 | Satisfactory | Planned maintenance
DR-AA02-L634D | LS | 3.8400000000 | Satisfactory | Repair
DR-AA02-L602D | LS | 2.7000000000 | Monitored | Repair
DR-AA02-L626 | LS | 2.7000000000 | Monitored | Repair
DR-AA02-L630 | LS | 2.8500000000 | Monitored | Planned maintenance
DR-AA02-L635 | LS | 3.2700000000 | Monitored | Repair
DR-AA02-L635D | LS | 2.9900000000 | Monitored | Repair
DR-AA02-L628 | LS | 2.5600000000 | Monitored | Repair
DR-AA02-L625 | LS | 3.1200000000 | Monitored | Repair
DR-AA02-L632 | LS | 4.1600000000 | Satisfactory | Repair
DR-AA02-L622D | LS | 2.8400000000 | Monitored | Repair
DR-AA02-L620 | LS | 3.5400000000 | Satisfactory | Repair
DR-AA02-L616 | LS | 2.6900000000 | Monitored | Repair
DR-AA02-L607 | LS | 2.6900000000 | Monitored | Repair
DR-AA02-L615 | LS | 3.1200000000 | Monitored | Repair
DR-AA02-L613D | LS | 2.6000000000 | Monitored | Repair
DR-AA02-L644D | LS | 2.5200000000 | Monitored | Repair
DR-AA02-L629 | LS | 3.0000000000 | Monitored | Planned maintenance
DR-AA02-L622 | LS | 2.8400000000 | Monitored | Repair
DR-AA02-L618D | LS | 3.1600000000 | Monitored | Repair
DR-AA02-L617 | LS | 2.8400000000 | Monitored | Repair
    
```

Fig 4. 12 Print out of decision support information

In summary to develop the database in PostgreSQL/PostGIS database management system the researcher undertaken steps of sorting out some specific information from a bunch of data found in a table of PostgreSQL/PostGIS database induced by using keywords like ‘ORDER BY’, ‘ASC’, and ‘DESC’; (i.e. ASC refers to ascending order or from small to large numeric values, strings alphabetically from “A” to “Z”, or “date”, and DESC (descending) which is the reverse of ASC.

Furthermore, the researcher have tested the functionality of the developed database management system. The process undergone to manage such step were sorted out based on data types such as; date of field inventory/or year of contraction, strings (e.g. condition zoning), or numeric values of a field in an ascending or descending order as per the wish list of the database user. Thus, Fig 4. 13 displays a sample of decision aid information from the database.

Query Editor Query History

```
1 SELECT * FROM swd_route_data ORDER BY bca_perfor DESC;
```

Data Output Explain Messages Notifications

bca_perfor numeric	zooning character varying (70)	aca_perfor numeric	rate_of_ov numeric	interventi character varying (100)	rate_road_ numeric	rate_risk_ numeric
4.160000000000	Satisfactory	0.000000000000	3.000000000000	Repair	5.000000000000	2.000000000000
3.840000000000	Satisfactory	0.000000000000	4.000000000000	Repair	5.000000000000	3.000000000000
3.840000000000	Satisfactory	0.000000000000	4.000000000000	Replacement	5.000000000000	4.000000000000
3.560000000000	Satisfactory	0.000000000000	4.000000000000	Planned maintenance	5.000000000000	4.000000000000
3.540000000000	Satisfactory	0.000000000000	3.000000000000	Repair	5.000000000000	3.000000000000
3.270000000000	Monitored	0.000000000000	3.000000000000	Repair	5.000000000000	4.000000000000
3.160000000000	Monitored	0.000000000000	3.000000000000	Repair	5.000000000000	2.000000000000
3.160000000000	Monitored	0.000000000000	3.000000000000	Repair	5.000000000000	3.000000000000
3.160000000000	Monitored	0.000000000000	3.000000000000	Repair	5.000000000000	4.000000000000
3.120000000000	Monitored	0.000000000000	3.000000000000	Repair	5.000000000000	3.000000000000
3.120000000000	Monitored	0.000000000000	3.000000000000	Repair	5.000000000000	5.000000000000
3.000000000000	Monitored	0.000000000000	4.000000000000	Planned maintenance	5.000000000000	4.000000000000
2.990000000000	Monitored	0.000000000000	3.000000000000	Repair	5.000000000000	4.000000000000
2.990000000000	Monitored	0.000000000000	3.000000000000	Repair	5.000000000000	3.000000000000
2.850000000000	Monitored	0.000000000000	4.000000000000	Planned maintenance	5.000000000000	4.000000000000
2.840000000000	Monitored	0.000000000000	3.000000000000	Repair	5.000000000000	4.000000000000

Fig 4. 13 Sorting out information based on BCA performance score in descending order

In this study to induce relevant datas the following conditions **DISTINCT**, **WHERE CLAUSE**, **AND**, **OR**, **GROUP BY**, **ORDER BY**, **ASCENDING**, **DESCENDING**, **RANK**, **MAXIMUM**, **MINIMUM**, **SUM** computations techniques were utilized.

The result show that in ‘Woreda-05’, basic condition assessment (BCA) result of drainage route with less than **2.5 BCA** performance score, condition status zooning fall under ‘**Critical**’ zone, and these drainage routes indicates for specific maintenance intervention ‘**replacement**’. The following Fig 4. 14 (screenshot); shows processed result for the specific stated condiction.

```
SELECT * FROM swd_route_data WHERE woreda = 'Woreda-05' AND zooning = 'Critical' AND interventi = 'Replacement'
```

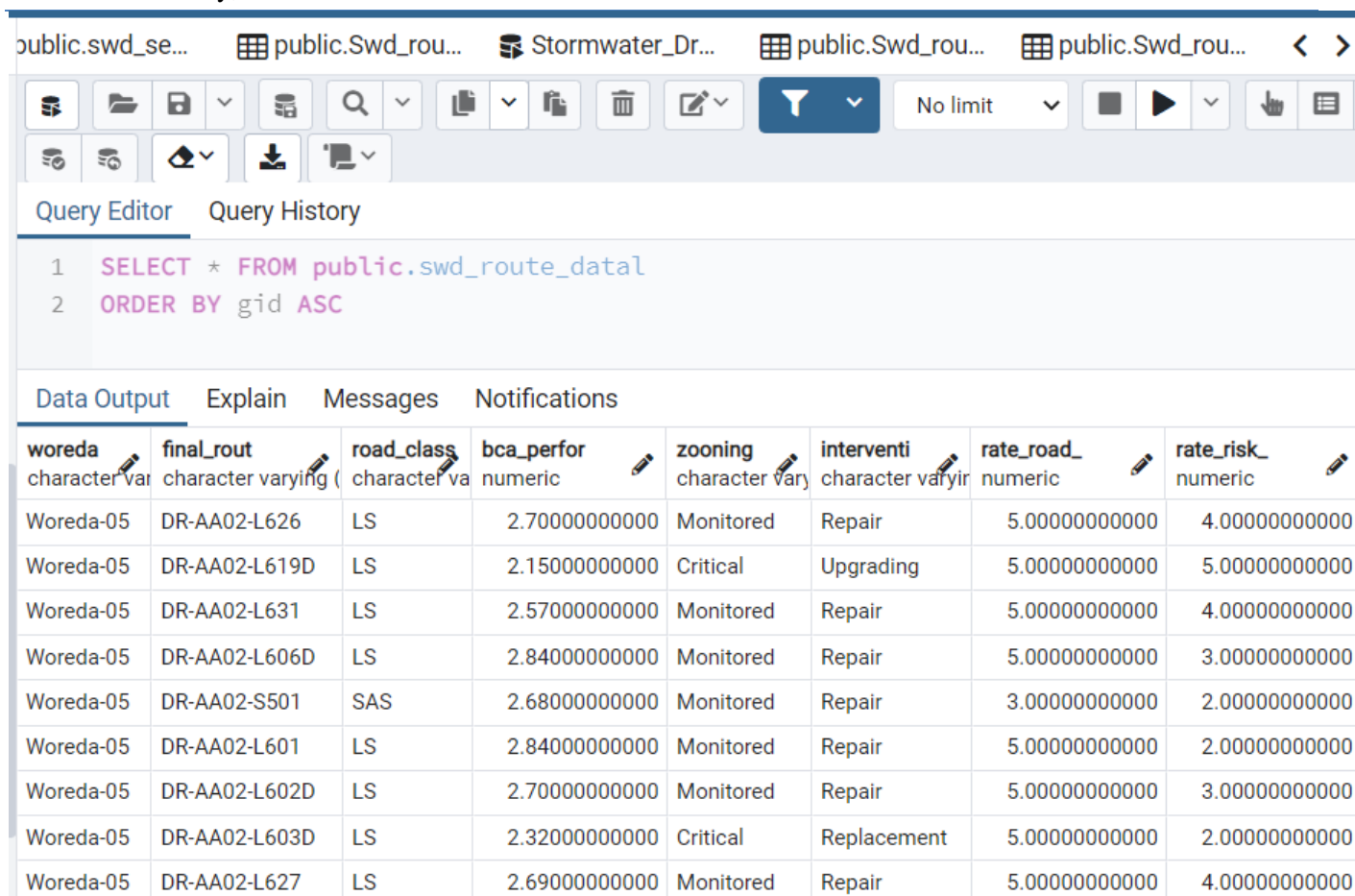


Fig 4. 14 Sorted out DS information from big dataset

4.3. Prioritization of drainage networks for maintenance work

As details were elaborated in chapter three section 0 about prioritization of drainage routes for maintenance purpose, in this sub-section weighted sum result of rate of factors for each drainage route were computed. And records or rate of parameters of different fields (but of the same row) were added up together and routes were identified by unique id as indicated in screenshot of SQL statement. The rating scale for each parameter was out of five (5) and five parameters were also utilized to rank drainage networks for maintenance prioritization purpose. And weighted sum value were first computed from individuals values given to each parameter with specified rating scale (i.e. 1-to-5) and eventually sum up of of these values were done. The highest rating value or value od five was given for a route with excellent condition, and on contrary rate value 1 was given to worst/or poor condition while ‘overall physical condtion’ assessment parameter rating/weighing, and details is annexed as Appendix 1. List of factors utilized for urban drainage maintenance prioritization includes; overall physical condition, road classification, risk factor, level of urgency for maintenance, and miscellaneous factors (such as, end users complaint, affordability, etc). And the detailed returns are shown in Fig 4. 15.

for	rate_of_ov	interventi	rate_road_	rate_risk_	rate_level	rate_misce	weighted_s	rank_for_m	unique_rou
numeric	character varying (100)	numeric	numeric	numeric	numeric	numeric	numeric	numeric	character va
00000000	3.000000000000	Repair	5.000000000000	4.000000000000	4.000000000000	4.000000000000	20	0.000000000000	L626
00000000	2.000000000000	Upgrading	5.000000000000	5.000000000000	4.000000000000	4.000000000000	20	0.000000000000	L619D
00000000	3.000000000000	Repair	5.000000000000	4.000000000000	4.000000000000	4.000000000000	20	0.000000000000	L631
00000000	3.000000000000	Repair	5.000000000000	3.000000000000	3.000000000000	3.000000000000	17	0.000000000000	L606D
00000000	3.000000000000	Repair	3.000000000000	2.000000000000	2.000000000000	2.000000000000	12	0.000000000000	S501
00000000	3.000000000000	Repair	5.000000000000	2.000000000000	2.000000000000	2.000000000000	14	0.000000000000	L601
00000000	3.000000000000	Repair	5.000000000000	3.000000000000	3.000000000000	3.000000000000	17	0.000000000000	L602D
00000000	2.000000000000	Replacement	5.000000000000	2.000000000000	2.000000000000	2.000000000000	13	0.000000000000	L603D
00000000	3.000000000000	Repair	5.000000000000	4.000000000000	4.000000000000	4.000000000000	20	0.000000000000	L627
00000000	4.000000000000	Planned maintenance	5.000000000000	4.000000000000	3.000000000000	4.000000000000	20	0.000000000000	L634
00000000	4.000000000000	Repair	5.000000000000	3.000000000000	3.000000000000	3.000000000000	18	0.000000000000	L634D
00000000	4.000000000000	planned maintenance	5.000000000000	4.000000000000	4.000000000000	4.000000000000	21	0.000000000000	L630
00000000	3.000000000000	Repair	5.000000000000	4.000000000000	4.000000000000	4.000000000000	20	0.000000000000	L624
00000000	3.000000000000	Repair	5.000000000000	3.000000000000	2.000000000000	3.000000000000	16	0.000000000000	L623D
00000000	2.000000000000	Upgrading	5.000000000000	3.000000000000	2.000000000000	3.000000000000	15	0.000000000000	L604D
00000000	3.000000000000	Repair	5.000000000000	4.000000000000	4.000000000000	4.000000000000	20	0.000000000000	L625

Fig 4. 15 Weighted sum values of five prioritization factors for each drainage routes

The rate of each parameter per drainage routes were added up along rows for each geo-located drainage routes, and the final result of computed weighted sum values were eventually utilized to rank each storm water drainage routes for maintenance purpose accordingly.

4.3.1. Ranking

In this study prototype ranking algorithms were utilized, and the SQL statement that is shown as a screenshot, and final returns were also presented in Fig 4. 16.

```
SELECT * , rank_for_m FROM swd_route_dataa ORDER BY rank_for_m ASC;
```

The ranks of each drainage route for further intervention are shown in Fig 4. 16.

aca_perfor	rate_of_ov	interventi	rate_road_	rate_risk_	rate_level	rate_misce	weighted_s	rank_for_m	unique_rc
0.0000000000	3.0000000000	Repair	3.0000000000	2.0000000000	2.0000000000	2.0000000000	12.0000000000	1.0000000000	P501
0.0000000000	3.0000000000	Repair	3.0000000000	2.0000000000	2.0000000000	2.0000000000	12.0000000000	1.0000000000	S501D
0.0000000000	3.0000000000	Repair	3.0000000000	2.0000000000	2.0000000000	2.0000000000	12.0000000000	1.0000000000	P502
0.0000000000	3.0000000000	Repair	3.0000000000	2.0000000000	2.0000000000	2.0000000000	12.0000000000	1.0000000000	S501
2.4600000000	2.0000000000	Replacement	5.0000000000	2.0000000000	2.0000000000	2.0000000000	13.0000000000	2.0000000000	L603
2.5900000000	2.0000000000	Replacement	5.0000000000	2.0000000000	2.0000000000	2.0000000000	13.0000000000	2.0000000000	L603D
0.0000000000	3.0000000000	Repair	5.0000000000	2.0000000000	2.0000000000	2.0000000000	14.0000000000	3.0000000000	L601D
0.0000000000	3.0000000000	Repair	5.0000000000	2.0000000000	2.0000000000	2.0000000000	14.0000000000	3.0000000000	L601
2.5900000000	2.0000000000	Upgrading	5.0000000000	3.0000000000	2.0000000000	2.0000000000	14.0000000000	3.0000000000	L604
0.0000000000	3.0000000000	Repair	5.0000000000	2.0000000000	3.0000000000	2.0000000000	15.0000000000	4.0000000000	L641
2.2400000000	2.0000000000	Upgrading	5.0000000000	3.0000000000	2.0000000000	3.0000000000	15.0000000000	4.0000000000	L604D
0.0000000000	3.0000000000	Repair	5.0000000000	2.0000000000	3.0000000000	2.0000000000	15.0000000000	4.0000000000	L641D
0.0000000000	3.0000000000	Repair	5.0000000000	2.0000000000	3.0000000000	2.0000000000	15.0000000000	4.0000000000	L632
0.0000000000	3.0000000000	Repair	5.0000000000	2.0000000000	3.0000000000	2.0000000000	15.0000000000	4.0000000000	L637
0.0000000000	3.0000000000	Repair	5.0000000000	3.0000000000	2.0000000000	3.0000000000	16.0000000000	5.0000000000	L609

Fig 4. 16 Prioritization of drainage routes for maintenance purpose and respective ranks

As the figure shows maintenance planning, and operation works can easily be identified based on the ranks since each drainage routes were associated with geo-located or respective coded drainage routes’ spatial information. Here the choice of a specific and appropriate type of maintenance decisions depends on existing condition and level of service of drainage infrastructure under consideration.

4.3.2. Drainage routes rank for maintenance and mapping

In this study drainage networks were ranked into 10 levels based on the weighted sum of rates of all five prioritization parameters. The results implied that drainage networks coupled with primary arterial streets (PAS) and secondary arterial streets (SAS) prioritized for maintenance at first level, and all the rest local roads were ranked according to their respective weighted sum values as details shown in Fig 4. 17.

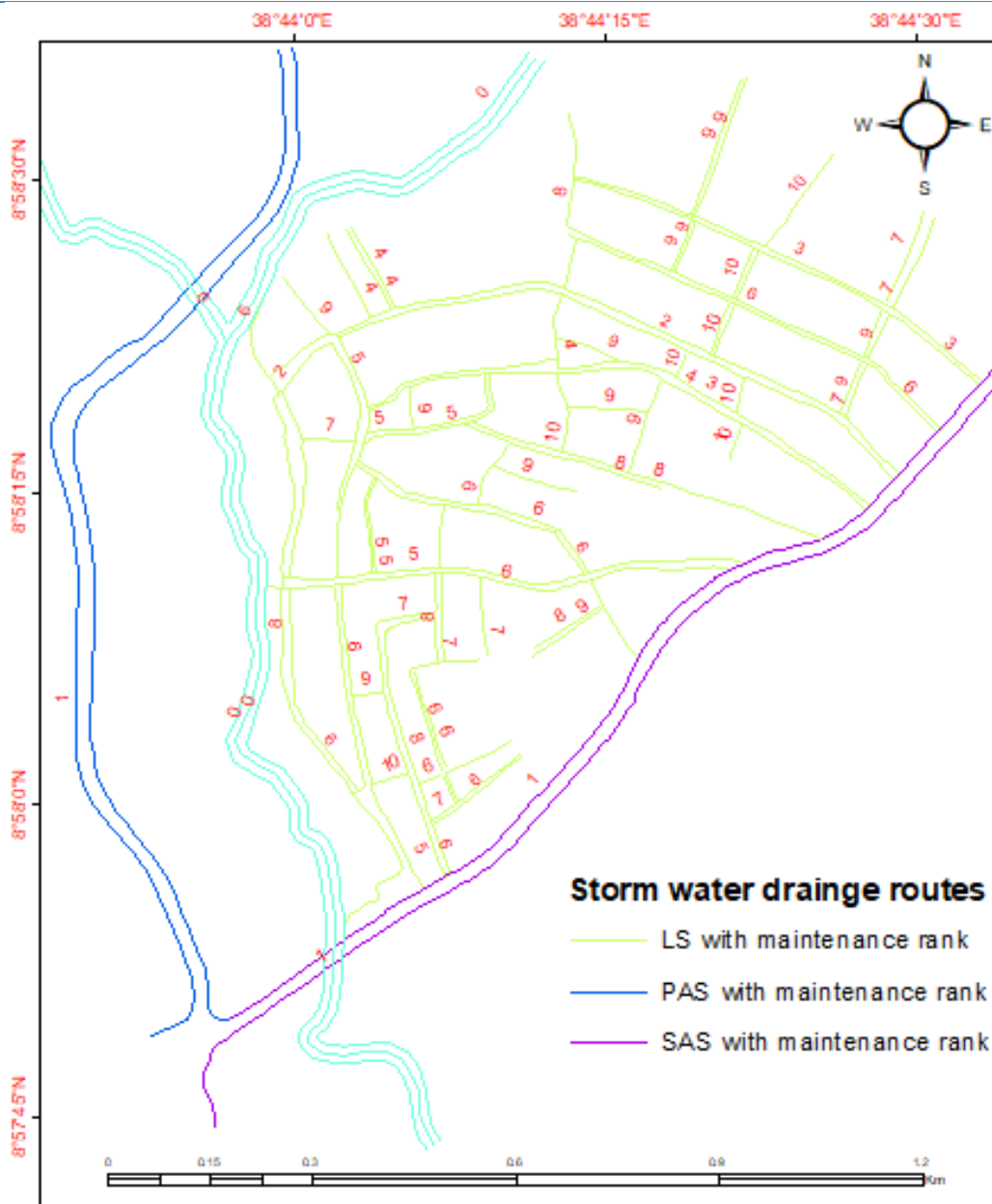


Fig 4. 17 Map of drainage networks priority for maintenance

The system developed in this study, allows sorting out of information based on the rank of drainage maintenance attribute data. In this regard, each drainage route's locational information with corresponding figures of rank for maintenance purposes are portrayed in map form for easy visualization, and understanding.

4.4. Web-publishing of database of drainage networks

In this study, WebGIS applications were developed from the very scratch using an open source applications such as; Geoserver, Openlayers 6, Apache Tomcat, mapstore and PostGIS for storm water drainage maintenance management concern. And an additional typical tools and supporting softwares or application programming intervaces (**API**) such as; layer-switcher for open layers, bootstrap, JQuery-UI libraries (these are used for query panel realization of graphic user face interaction like drop down boxes and arrows, zoom, select functions etc), PostgreSQL/PostGIS were also exploited. APIs are software intermediary, which allows two applications to communicate one to the other. All needed softwares were downloaded, installed and configured in a way that meet the objective of this study. For instance apache tomcat was used for storage (or as a webserver) for the rest of the softwares to be deployed in and spatial database were created and ultimately shape files uploaded through Postgis database.

The geoserver that was deployed to apache tomcat can be accessed by multi users anytime, and anywhere by the particular URL <http://localhost:8082/geoserver/web/>, and the default user name and password given were; **admin**, and **geoserver** respectively. URL (Uniform Resource Locator) is the means used by browsers to retrieve every published resource from the web. After downloading, installing, configuring, and deploying GeoServer in apache tomcat, project specific work spaces were created, data layers from different sources like vector data sources (e.g. shape files, goopackages, PostGIS database etc) and raster data sources (e.g. GeoTIFF, image mosaic, ArcGrid etc.) were added as shown in Fig 4. 18.

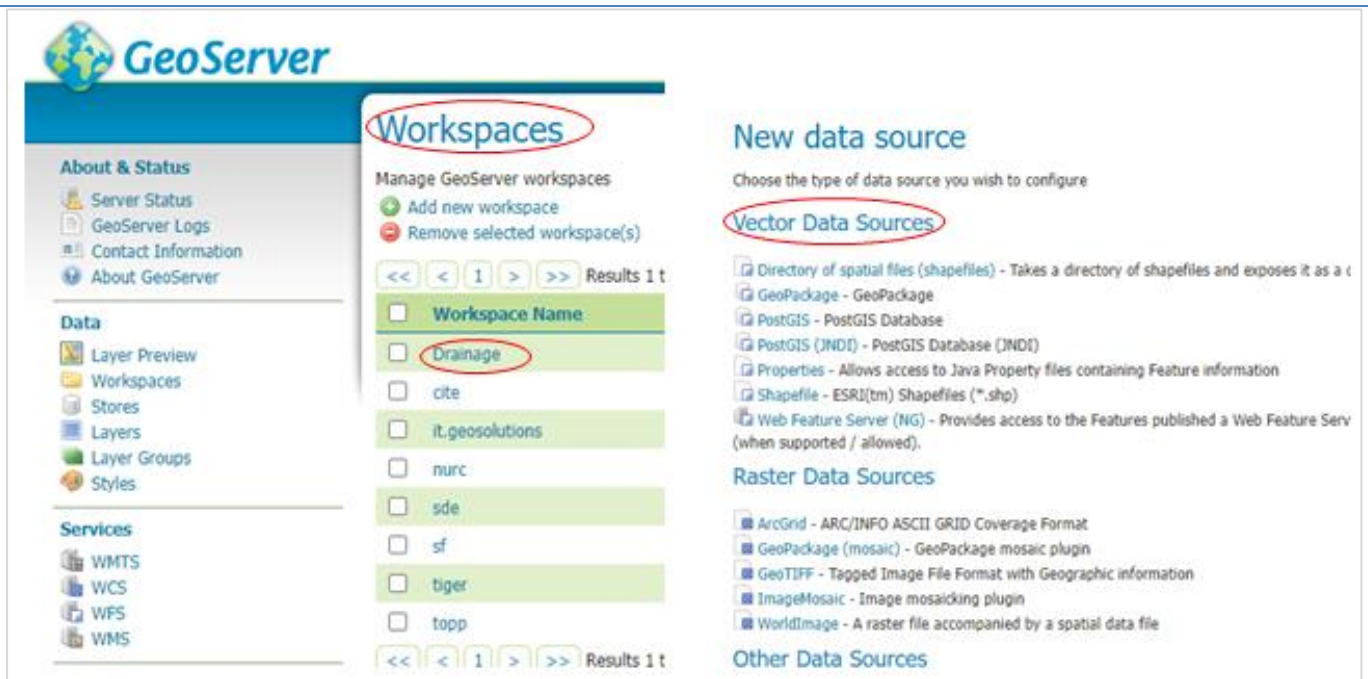


Fig 4. 18 Workspace created in geoserver and data sources

Data layer's screenshot portrayed in Fig 4. 19 shows segments of data of drainage networks that were published on GeoServer along with all attributes that can be exploited from web platform by decision makers for further actions.

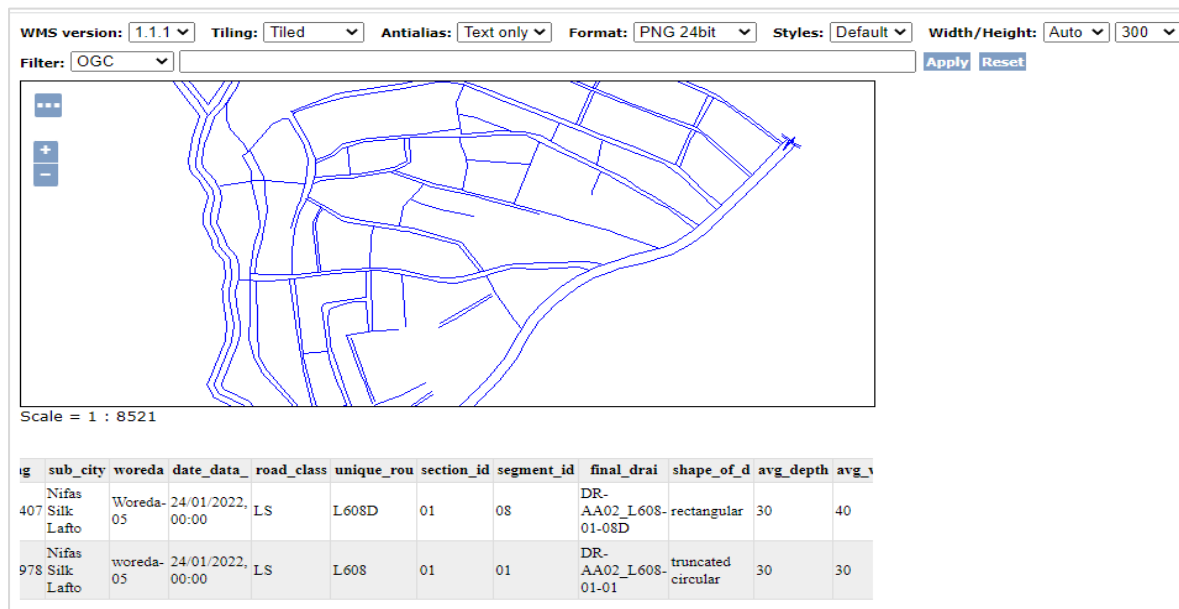


Fig 4. 19 Preview of part of drainage networks that published on geoserver

The preview of drainage segments that highlighted in Fig 4. 20 constitutes a bunch of physical condition assessment data of drainage networks of the study area. And eventually the WebGIS application [html](#) pages were developed using java script. The developed web page has several

spatial and non-spatial information query executing and returning capabilities. Any web user who has an interest in accessing drainage data or related resources of Nifas Silk Lafto sub-cty of Addis Ababa's storm water drainage existing infrastructure can follow the URL <http://localhost:8082/mapstore/#/viewer/openlayers/39> and the user name: **admin**; password: **drainage** and access available resources easily through internet and web technology as shown in Fig 4. 20.

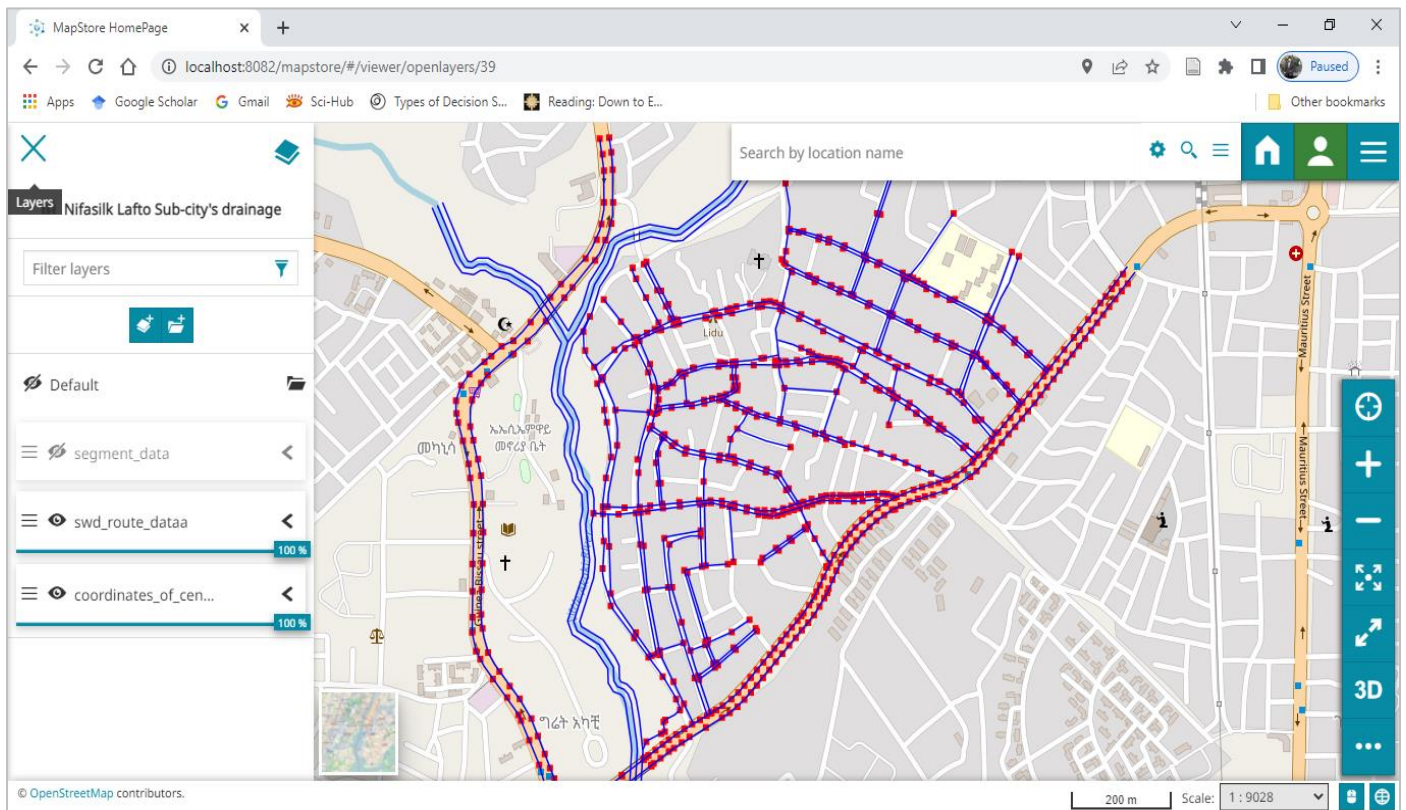


Fig 4. 20 Prototype WebGIS application for Nifas Silk Lafto sub-city of Addis Ababa

The data that was needed for the purpose of maintenance decisions were organized in the form of PostgreSQL/PostGIS database and published on webGIS platform that was prepared to be visualized and transparently accessed by concerning stakeholders through privileges that database administrator can provide to all whom it may concern. After login, users can click on layers button that found at upper left corner of the web page and access list of layers, select layers, add additional layers, open attribute table, create a widget for the selected layer, export/import layers, compare data of different layers, create graphs, charts and, so and so forth as per the limit of privilege given to the user. The screenshot of overall style of the web page and demonstration of GUI of WebGIS application for drainage maintenance management was presented. Moreover, multiple users can access the page at a time and see, comment, manipulate the drainage network maps, layers and

related attributes as per the individual or group purpose on the home page of map store by following the URL as portrayed in Fig 4. 21.

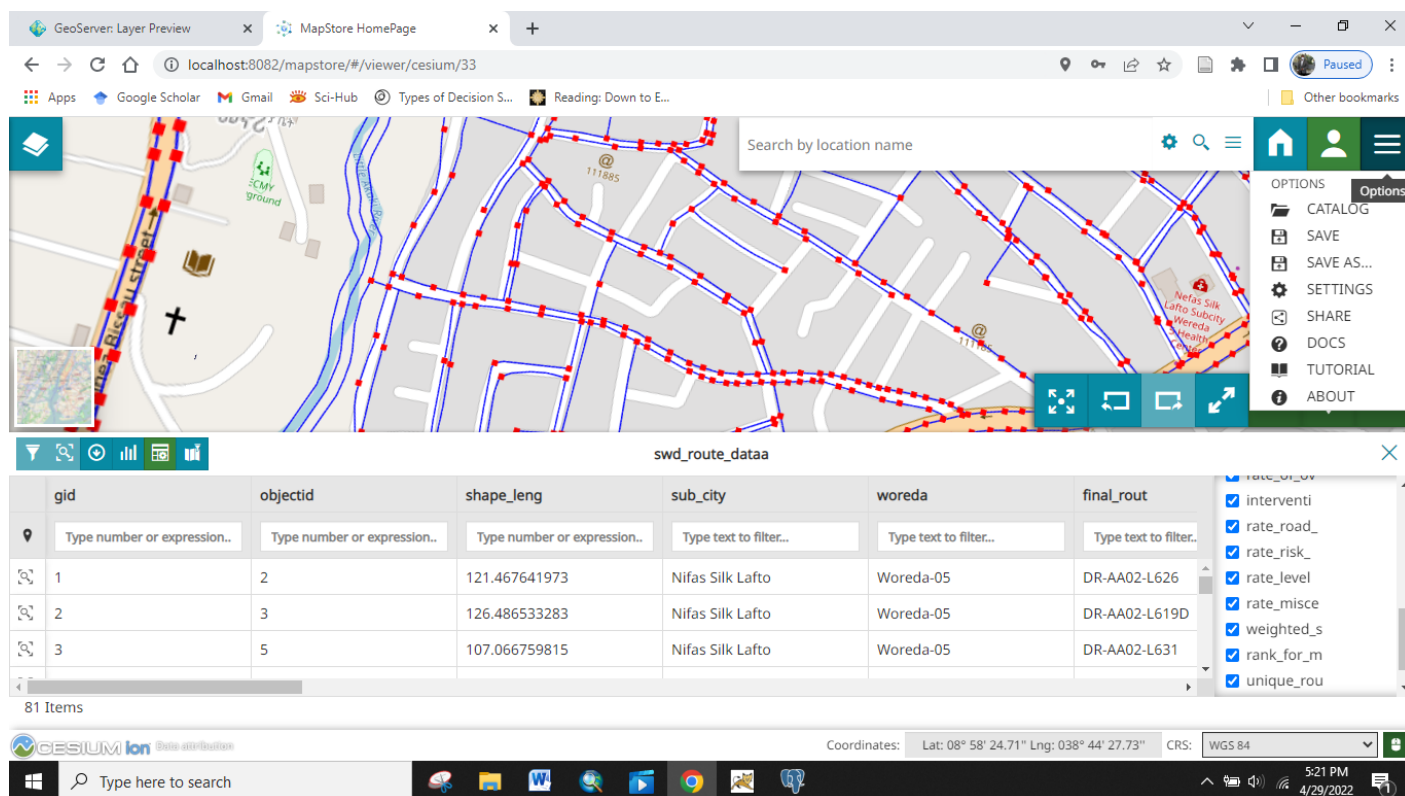


Fig 4. 21 Nifasilk Lafto sub-city’s drainage infrastructures data presentation on web apps

A typical website/webpage and its content can be framed or limited by the publisher, and sometimes content is further developed and determined in cooperation with users in an interactive way. The websites development varies based on the purpose; for instance, it might be for the sake of providing information, for decision support concern, for entertainment, commercial, governmental, or non-governmental organizational purposes or many more. In this study map store combined with other supporting open source applications were exploited while developing this specific web page. Map Store is an open source highly modular webgis framework initially developed to create, manage and securely share maps and mashups. Contents from Google maps, OpenStreetMap, and related servers can be used as base map in MapStore platform in compliance with the Open Geospatial Consortium (OGC) standards such as Web Feature Service (WFS), Web Map Service (WMS), and Catalog Service for the Web (CSW), and the Tile Map Service (TMS). Web based spatial decision support system can provide tremendous information and support for multi-users anytime and anywhere, ease of information exchanges, cut costs of data mining, client positive inputs towards drainage infrastructure maintenance planning and operation, perceptions and complaints can easily be gathered, and has so forth benefits.

In summary, basic information that web based spatial decision support system provide to decision makers or other related stakeholders concerning urban storm water drainage maintenance management issues include; drainage inventory and physical condition assessment outputs in the form of relational database managements system, hydrologic analysis of the study area, proposed and existing drainage networks, existing drainage networks' BCA and ACA performance scores, type of intervention proposed to assist decision making process, drainage network maintenance prioritization parameters, other supporting geo-located spatial data, and so forth information compiled in a fashion of one-stop databank service. This developed WebGIS platform intended to provide a list of information for decision makers and other multi users irrespective of geographic locations.

CHAPTER FIVE

5. Discussion

In principle, urban drainage infrastructure life-cycle management tasks are one of the crucial responsibilities of city managers, urban social service providers and infrastructure administering bodies. Drainage infrastructure management jobs are not a single time job, rather concerning authorities and other stakeholders shall be engaged in frequent and continuous decision making processes and actions too. The city administration of Addis Ababa in general needs to have a short, medium and long term storm water drainage network management scheme. Besides, drainage networks new development and maintenance investment decision making basically requires having reliable information about the subject under consideration, understanding of real pictures of complex and multifaceted issues. And also having objective criteria for ranking and selection of a single route or some routes out of many thousands of defective city-wide networks for maintenance decisions and prioritizing of competing drainages are very important.

On the other hand storm water drainage infrastructure maintenance prioritization, exploiting advantages of decision support systems (DSS) for drainage infrastructure life-cycle management, and integration of decision support system with advanced information technology aids and web applications to combat current managements problems in this regard are timely issues and were the major focuses of this study too. Existing physical conditions of drainage infrastructures within the study area were thoroughly assessed through field measurements and maintenance management practices of AACRA (Addis Ababa city road authority) were also investigated. Furthermore, experiences of different countries in this regard were reviewed, gaps were identified and eventually context specific prototype web based spatial decision support system for drainage infrastructure life-cycle management were developed.

Addis Ababa, the capital city of Ethiopia has tremendous drainage infrastructure management related problems, which result in improper functioning of the existing drainage systems (Jemberie and Melesse, 2021, Mulatu Wubneh, 2013, Dagnachew Adugna, 2011). Nifas Silk Laft sub-city in this regard particularly can be the best showcase for flooding problems and mismanagement of existing drainage infrastructures. In reaction to flooding, it is very common to see villages, organizations and households inhabiting within the study area (areas like Mekanissa, Gofa camp, German square areas etc) attempting to make their own defences against flooding that include

structural adaptations by raising plinth levels, constructing permanent and removable flood barriers, digging depressions, natural waterways conversion and flow obstructions and many more small scale landscape based temporary mitigation techniques were being employed at community level. And on top of all these efforts and severe flooding implications; again observed facts reveal that significant number of households particularly urban poor yet living within the area of high risk of flooding (for instance the case of small Akaki riverbank settlements and other flash floods prone areas can be mentioned).

According to (Dereje Birhanua, Kim.H., Jang.C, Parka.S, 2016), quantified peak flow of storm water in Addis Ababa, and their study's result indicated that a 10% of increase in peak flow due to climate change, and 25% increase because of urbanization effect (like the creation of impervious surface). Although the rapid urbanization and climate change impact flooding trends; flood disasters are not only happening just due to heavy rainfall events but also poor management practice of existing flood control structures are also contributing significantly to flooding risks. Moreover, improper management of existing flood protection structures lowering quality of services provision. Field observed facts reveals that structural failures, debris depositions in drainage channels, blockages, and lack of maintaining drainage networks and the like problems are evidently reducing capacity of drainage facilities to convey storm water. It is also worth mentioning that a large number of buildings and households in Addis Ababa illegally connect their sanitation facilities and indoor waste water to storm water drains. And thus, dirty stagnant water in open drain systems of the study area has bad odours with numerous consequences of health problems.

Field inventory and physical drainage infrastructure condition assessment output reveal that only 15% out of the total drainage coverage of the study areas exists in satisfactory physical condition and the rest 85% of drainage networks demanding for varying level of maintenance interventions. The problem of undersized side drains particularly local roadside drainages that demand for redesign and/or replacement in combination with the existence of non-functioning structures are worsening the extent of flooding problems of the study area. In consistence to findings of this study,(Kiwanuka et al., 2021) assessed that the existing side drain of city of Addis Ababa and their study results implies that 900 mm diameter sized circular pipes could not convey the maximum storm water flow. In addition research conducted by (Dagnachew Adugna, Brook Lemma, Jensen. M.,Geremew Sahilu, 2019), on hydraulic capacity of existing drain systems of city of Addis Ababa shows 28% of drainages found within old city areas were also stated as inefficient for conveyance of storm water to their respective outlets.

Moreover, the current existing situation assessment of drainage networks of the study area revealed that 69% of existing structures are open type drainage facilities and 31% out of the total drainage networks were buried pipe types. This implies that open drainage channels of the study area are being exposed for solid waste dumping, and which in turn causes a severe blockage for storm water flow and lowers hydraulic competencies in rainy seasons. Again the field inventory and physical condition assessment of drainage segments of the study area reveal that 80% of the drainage routes require for repair type of intervention (intervention type that do not require as such sophisticated engineering solutions), 8% drainage structures demand for upgrading type of intervention, another 8% replacement and the rest 4% demand for planned type of maintenance (that do not demand urgent interventions rather scheduled interventions are needed). Once more the statistics of status of physical condition of drainage networks implies that routine maintenance task of drainage networks are overlooked job and this study strongly suggest a due consideration of this matter.

Drainage administering bodies need to value importance of repairing, restoring, and fixing defects as equal as new infrastructure development efforts. In this regard (Ali Mohammed and Eyasu Elias, 2017) also emphasised the issue of poor domestic solid waste management practice of the city of Addis Ababa as resulting in another consequential challenges of environmental impacts and malfunctioning of storm water drainage channels. In addition, a recent study made by (Eshetu Gelan, 2021) on municipal solid waste management practices of city of Addis Ababa showed that out of the total solid waste generated (including waste produced by household units, commercial centres, road sweeping, industries/factories, hotels, and health institutions); 80.28% of solid wastes were collected, while 19.72% of the squander were not collected within the year between 2016 to 2020. Noticeably 19.72% wastes were dumped in anywhere and later on storm water might carry it to open and closed drainage systems.

Enhancing and advancing of operational status of the existing chain of solid waste collection, storage, and transportation and disposal system has direct implications for storm water drainage system management. Within the study area villages have no more than three (3) solid waste communal collection containers, and residents are either forced to travel a long distances to use containers or dispose wastes somewhere else. Another observation was temporary waste collection container sites were not demarcated and protected from rain or sun that making rubbish to cause bad odour, ugly urban scene and worsening the overall wellbeing of the neighbourhoods. The container sites are also exposed to interferences of animals like dogs, cats, and other scavenging that disseminates the waste in the surrounding area including drainage ways. Properly uncontrolled

and uncollected solid wastes usually end up at drain systems and eventually that cause blockage of storm water conveyance systems.

The finding of this study is consistent with previous studies of (rauch et al., 2005), in which importance of local capacity building and empowerment, and promoting public participation in routine drainage infrastructure maintenance duties were amplified. Moreover, continuous awareness creation, capacitating local communities in proper waste collection and disposal means can provoke public to shoulder and share social burdens from government side. In the long run, sustainable storm water management system establishment can help drainage channels in many more ways and improve efficient functionality of storm water drainage conveyance system. And therefore, a routine type of maintenance of drainage channels shall be done in a regular base scheme through public participation.

Interview and focus group discussions held with AACA engineers and lower level infrastructure administrators show that drainage infrastructure information were not well organized, there is no central database management system, real time spatial and non-spatial collection and updating system does not exist. Moreover, drainage networks prioritization lacks objectivity and clear criteria of maintenance project selection. Planning process, participatory budgeting notion and operation management lacks to encourage participation of key stakeholders. Although legally binding Capital Investment Plan (CIP) and Asset Management Plans (AMP) exists, however many cities yet handling project screening, selection, and appraisal and implementation process partially or totally disregarding the objectives of those obligatory plans. Sometimes they pay no (or less) attention to public says during project prioritization, project implementation, and related process of project realizations. On contrary, consents of experts and authorities of different levels prevail much more on final decision of project prioritization. The final goals of CIP and AMP preparations utmost were to ensure investment decisions (both new development and existing once maintenance) on infrastructures matter to be made based on the wish lists and needs of direct beneficiaries or public at large.

However, CIP and AMP process guiding documents sometimes lacks further details for decision making process. For instance both plans focus mostly on broad sense of ranking of different projects (i.e. comparisons of one social or physical infrastructure with another infrastructure like road versus drainages, bus station versus hospital construction or maintenance preferences etc.), but do not compare identical type of infrastructures. And thus, they lack prioritizing a single type of infrastructure development or maintenance demand within the same type of infrastructure (e.g. especially for networked infrastructures like drainage and road networks).

Identifying all those limitations of drainage infrastructure maintenance management of the study area; this study were conducted to find out practical, workable and context specific drainage planning and maintenance management scheme. The overall study result suggests that high importance of improving public participation at local level in solid waste management and routine maintenance (e.g. removal of accumulated silts and debris, clean drainage channels, and other minor repairs) tasks are what really most likely needed besides of structural or engineering solutions. In similar way, (Dagnachew Adugna, Brook Lemma, Jensen. M., Geremew Sahilu, 2019) recommended that educating the local community and stakeholders regarding waste management and developing culture of not dumping wastes illegally into drainage system is fundamental job need to be done. Polluters or waste disposing residents shall be made accountable through strong enforcement measures. In addition, drainage infrastructure maintenance management practices of Nifas Silk Lafto sub-city require information technology (IT) supported, functional and operational system establishments. Short term, medium and long term comprehensive and sustainable storm water management scheme shall also be developed.

To meet increasing demands of present day urban storm water drainage network management task, this study thoroughly assessed geographic factors that have spatial implications with regard to storm water drainage networks functionalities like slope analysis, flow accumulation, flood plains and streams networks and related hydrologic analysis were conducted as details were presented and described in chapter four section 4.1.3. Consequently, the hydrologic analysis result reveals that taking into account and exploitation related spatial and non-spatial information eases maintenance decision making particularly while drainage network prioritization cases. Spatial data were collected from diverse primary and secondary sources and comparative analysis were done just by overlying one map on another map (e.g. a layer of slope analysis map with the dataset of existing drainage map, basic condition assessment result map versus flood plain map to the effect of one on another). After having appropriate information and clear understanding about the overall study area of NifaSilk Lafto sub-city, evaluation and getting weighted sum values of rates of parameters were computed and that later on helps decision makers to rank bunch of drainage networks for maintenance purpose. This conclusion is consistent with the prior findings of (Ebrahimian et al., 2015), using multi-criteria decision analysis technique to select the urban drainage networks with higher priority or influence help decision makers and improve efficiency of the final decisions too. Drainage network maintenance demand and the number of problematic routes are also may be much more than handling capacity of administering body. And therefore, issue prioritizing is vital. This conclusion has consistency with Ebrahimian et al. (2015) in which prioritization process of projects need to consider various key drivers. For instance, several valuation criteria, issue

interdependencies, and doubts about project performance as well as financial and other related limitations (Mild et al., 2015) need to be considered in annual maintenance plan of dozens of competing projects screening and selection.

Finally, based on arithmetic findings and detailed spatial and non-spatial analytics clusters of drainage routes were ranked accordingly for the sake of maintenance prioritization. In the process competing and conflicting interests, drainage system complexity ranging from the initial planning phase to overall implementation tiers, resource availability, and other miscellaneous multi-directional perspectives were overviewed. And as for ease of complication while decision making in this study web based spatial decision support system was developed and the prototype model was tested for its functionality, and supposed significantly can improve the statuesque of city of Addis Ababa with regard to drainage infrastructure maintenance management practice. This conclusion is in line with the findings of Power (2004), who stated the web and internet technology inventions move faster the development of decision support systems and introduced a new dimension of spatial and non-spatial data storing, sharing and exploiting input incorporation in various proposals. Moreover, the availability of open source spatial and non-spatial data from different sources with varying spatial resolutions, significantly contributes to the improvement of conventional analytical techniques that in turn helps decision support system. The findings of this research is again consistent with (Choi et al., 2005), that backed up combination of geographic information system with internet has created an opportunity to get the better of limitations of other computer assisted decision support systems with regard to preparing, storing and visualizing of geo-spatial information. According to (Choi et al., 2005) conculusion, exploitation of web technologies for networked infrastructure management particularly for urban drainage infrastructure life-cycle management were mentioned as very important. Moreover, the research finding complies with (Mansourian et al., 2011) web-based SDSS has the power of advocating participatory planning to ease public participation; that has many advantages in drainage maintenance investment decisions.

CHAPTER SIX

6. Conclusion and recommendation

6.1. Conclusion

Web GIS-Based Decision Support System (WGBDSS) for Urban Storm Water Infrastructure Management is the most recent innovation which is suitable means for administration of physical infrastructures like urban drainage resources relatively in a transparent manner. The study attempted to conduct a gap analysis on the current practice of drainage infrastructure maintenance management and physical conditions were also thoroughly assessed. Having done that a user friendly web based spatial decision support system for drainage network maintenance management purpose was developed with the help of open source tools. Lately, Web technology has added a supplementary aspect to Spatial Decision Support System (SDSS) and Web GIS-Based Decision Support System (WGBDSS) are being applied in many application domains. The system developed in this study can provide a platform that suits for data sharing (even using remote servers), storage, visualization through web map services (WMS) and editing of spatial data related to drainage infrastructure of the study area. The drainage network related data such as in depth field inventory and physical condition assessment, field measurements, hydrologic analysis, existing drainage networks' spatial and non-spatial data, and other base layers were organized and stored in one stop PostgreSQL/PostGIS database management system in a way that suit for decision making purpose. Field observations were conducted with the help of DGPs-RTK, Survey Master mobile application, and kobo toolbox, and all source data including open source data integrated with GIS application, and their applicability to urban drainage infrastructure maintenance management were also tested.

Decision making on the issue of infrastructure maintenance investments requires having appropriate information about the issue on which the intended decisions going to be realized. Cost in the process of decision making in terms of resources, time, and efforts shall be minimized and efficiency of the decision itself increases significantly by accessing and exploiting right information at the right time. Nowadays in this respect, internet and the application of World Wide Web (WWW) technology, has significantly transformed information collection, storing, sharing, analysing and the likewise processes. On top of that problems which has spatial connotation require having spatial information; geographic information system in general and WGBDSS in particular playing a great role in this regard. DSS is presented that includes a GIS, a database, a storm water system design template, and an optimization capability for screening alternatives.

In this crux, WORLD WIDE WEB (WWW) and internet technology invention improved communication network between computers in world-wide scope in much more ways and contributing a remarkable role in data management and decision support roles too. Decision support system (DSS) which generally refers to computer assisted decision making techniques, methods, and processes to arrive at worth final decision outputs were being under improvement from time to time. And therefore, in this regard this study emphasized on integration of web technology, decision support system, geo-database and synergy of drainage maintenance management issues for better decision making were thoroughly addressed.

PostgreSQL database that bases its operation on tables was developed and further extended to enable it for spatial data storage and other related spatial operations. Its extensibility refers to an extension of a database schema. And thus, spatial layers of stormwater drainage networks were imported to PostgreSQL/PostGIS database and then published as WMS and Web feature service (WFS) in Geoserver. Eventually, prototype web based spatial decision support system portals were developed and provided for use to decision makers and other key stakeholders for spatial data visualization and editing. A privileged web database administrator can provide separate authentication or limited access license (e.g. data visualization privilege) to the citizens and other government departments accordingly. And using this system stakeholder can provide inputs or decision makers; planners and drainage engineers can collect community perceptions towards drainage maintenance plans. In this research further multi-criteria spatial decision analysis techniques and objective criteria or parameters were also developed and employed to equip decision makers with the state of the art information and technologies regarding maintenance investment decisions and to support further management activities.

Findings of this research reveal the study area has much limited coverage of standardized drainage systems, and maintenance tasks of defective existing drainage infrastructures are overlooked jobs. Mismanagement of existing drainage infrastructures is contributing and worsening flooding risks in the aforementioned area. Though the existence of flood control civil structures is basically important, but it solely could not eliminate flooding risks in a sustainable manner. Besides, flooding problems of the city of Addis Ababa cannot be managed only by intensifying construction of new drainage infrastructure and/or only by repairing the existing structures rather the depth of the problem is calling for comprehensive storm water management scheme to be in place.

Urban storm water drainage life-cycle management issues are so vast and require multi-directional view, and this study intentionally narrowed the major focus point only to the way how to maintain existing drainage structures to let them deliver services at an optimal performance level. Life-cycle

management of drainage infrastructures basically demands efficient maintenance decision making at various levels. On top of that, generally decision making is at the heart of drainage infrastructure maintenance management task. In light of this study, attempts were made to bring a paradigm shift from conventional drainage maintenance practice of city of Addis Ababa (i.e. fix when failed approach) to proactive WGBDSS. To do so Analytic Hierarch Process (AHP) and Multi-Criteria Decision Aid (MCDA) approaches were exploited to rank defective drainage infrastructures for the sake of maintenance priorities based on objective parameters. Moreover, five potential factors such as; drainages routes' existing physical condition, risk factors, criticality rating based on street classification, level of urgency for intervention, miscellaneous factors were utilized as measurement parameters for prioritizing. Eventually, a correspondingly weighted sum model was utilized to rank routes for maintenance priority.

The research finding shows that 80% of urban drainage infrastructures in the study area even don't demand much sophisticated engineering solutions or exaggerated costs but rather require only routine maintenance interventions which have often been overlooked. The developed prototype WBSDSS's functionality test implied the possibility of minimizing the type of complex problems encountered the study area by supporting an efficient decision making process on drainage network maintenance.

Moreover, maintenance investment projects screening, selection, prioritization, and implementation process are better facilitated through the application of spatial decision support system themes and web technology on a small scale. Nifas Silk Lafto sub-city of Addis Abeba may take into a due consideration the findings of this research, particularly chapter four's section 4.3 prioritization results of the research findings portrayed well in Fig 4. 16 and and also mapped in Fig 4. 17 for ease of decision makers and/or for other concerning stakeholders to exploit it.

6.2. Recommendations

This study suggested the following recommendations based on the findings and discussions held in prior sections as follow;

Existing situation analysis job that includes field measurements, drainage asset inventory, and physical condition assessment of urban drainage infrastructures shall be assisted by innovations of technological advancement and real time data collection techniques and ease of information dissemination need to be realized in cities like Addis Ababa. Moreover for closed culverts, buried type drainage pipes and related invisible (by necked eye) parts of drainage infrastructures; to improve the quality of inspection works that has direct implication to maintenance management concerns; further studies in the future shall exploit technological advancement; which includes but not limited to using sonar, camera inspection, lamping, CCTV, smart phone, drones and the like technologies while conducting data collection tasks. In this research, we could not use benefits of these equipment due to the lack of such tools and limitations of resources too.

Route(s) prioritization using developed prototype WGBDSS model made possible, and developed database prioritization techniques may also be utilized by local drainage administering bodies and other related utility managing offices in limited scope. Moreover, the five key prioritization parameters proposed further need to be enriched by participating all concerning key stakeholders administration. Though the research findings implied that shift from “fix when failed” (or from reactive approach to proactive approach) to proactive and planned drainage infrastructure maintenance management approach as a fundamental concept it might be difficult to transform the existing drainage infrastructure management problem solely by improving drainage structures handling ways.

Realizing a sustainable storm water management schemes shall consider both structural and non-structural solutions, intercepting the run-off to minimize burdens from existing drainage facilities, regulating and storing storm water, frequently inspecting and controlling the system and so forth measures need once again a due consideration besides continuous maintenance jobs. WGBDSS and its database is usually designed with less consideration of non-technical users in mind and on the other hand these actors usually have a significant role in decision making processes especially in implementation phases. And therefore these entire dilemmas reveal that there is room for further

research and investigation of WGBDSS in the context of urban drainage infrastructure planning and maintenance management.

References

- Adams, L. W., & Dove, L. E. (1984). *Urban Wetlands for Stormwater Control and Wildlife Enhancement*. National Inst. for Urban Wildlife, Columbia, MD, 19 pp.
- Addis Ababa City Government Charter Proclamation No. 87/1997, 3rd Year No. 52 (July 7, 1997)
- Aghaei, S., Nematbakhsh, M. A., & Farsani, H. K. (2012). Evolution of the world wide web: From WEB 1.0 TO WEB 4.0. *International Journal of Web & Semantic Technology*, 3(1), 1–10.
- Ahern, J. (2013). Urban landscape sustainability and resilience: The promise and challenges of integrating ecology with urban planning and design. *Landscape Ecology*, 28(6), 1203–1212. <https://doi.org/10.1007/s10980-012-9799-z>
- Ajwaliya, R., Patel, S., & Sharma, S. (2017). Web-GIS based application for Utility Management System. *Journal of Geomatics*, 11, 86–97.
- Akintoye, A., & Beck, M. (2009). *Policy, Management and Finance of Public-Private Partnerships*. John Wiley & Sons.
- Alegre, H., & Almeida, M. do C. (2009). *Strategic Asset Management of Water Supply and Wastewater Infrastructures*. IWA Publishing.
- Ali Mohammed and Eyasu Elias, 2017 (2017). Domestic solid waste management and its environmental impacts in Addis Ababa city. *Journal of Environment and Waste Management*, 4(1), 194–203.
- Allende-Prieto, C., Méndez-Fernández, B. I., Sañudo-Fontaneda, L. A., & Charlesworth, S. M. (2018). Development of a geospatial data-based methodology for stormwater management in urban areas using freely-available software. *International Journal of Environmental Research and Public Health*, 15(8), 1703.
- Al-Mamary, Y. H., Shamsuddin, A., & Aziati, N. (2014). The role of different types of information systems in business organizations: A review. *International Journal of Research*, 1(7), 333–339.
- AMP (Asset Management Plan) (2011). *Urban Infrastructure Asset Management Plan Operational Manual*. Unpublished Report, Addis Ababa, Ethiopia.
- Ana, E. V., & Bauwens, W. (2010). Modeling the structural deterioration of urban drainage pipes: The state-of-the-art in statistical methods. *Urban Water Journal*, 7(1), 47–59. <https://doi.org/10.1080/15730620903447597>
- Angelakis, A. N. (2017). Urban waste-and stormwater management in Greece: Past, present and future. *Water Science and Technology: Water Supply*, 17(5), 1386–1399.
- Armstrong, M. P., & Densham, P. J. (1990). Database organization strategies for spatial decision support systems. *International Journal of Geographical Information Systems*, 4(1), 3–20. <https://doi.org/10.1080/02693799008941525>
- Armstrong, M. P., Rushton, G., Honey, R., Dalziel, B. T., Lolonis, P., De, S., & Densham, P. J. (1991). Decision support for regionalization: A spatial decision support system for regionalizing service delivery systems. *Computers, Environment and Urban Systems*, 15(1–2), 37–53.
- Arsiso, B. K., Tsidu, G. M., Stoffberg, G. H., & Tadesse, T. (2017). Climate change and population growth impacts on surface water supply and demand of Addis Ababa, Ethiopia. *Climate Risk Management*, 18, 21–33.

- Bach, P. M., Kuller, M., McCarthy, D. T., & Deletic, A. (2020). A spatial planning-support system for generating decentralised urban stormwater management schemes. *Science of The Total Environment*, 726, 138282. <https://doi.org/10.1016/j.scitotenv.2020.138282>
- Balcioğlu, B. (2015). An Improved spatio-relational database design for urban conservation and its performance analysis [Master's Thesis]. Middle East Technical University.
- Balica, S. F., Popescu, I., Beevers, L., & Wright, N. G. (2013). Parametric and physically based modelling techniques for flood risk and vulnerability assessment: A comparison. *Environmental Modelling & Software*, 41, 84–92. <https://doi.org/10.1016/j.envsoft.2012.11.002>
- Balla, D., Zichar, M., Kiss, E., Szabó, G., & Mester, T. (2022). Possibilities for Assessment and Geovisualization of Spatial and Temporal Water Quality Data Using a WebGIS Application. *ISPRS International Journal of Geo-Information*, 11(2), 108.
- Bancheri, M., Fusco, F., Dalla Torre, D., Terribile, F., Manna, P., Langella, G., De Vita, P., Allocca, V., Loishandl-Weisz, H., & Hermann, T. (2022). The pesticide fate tool for groundwater vulnerability assessment within the geospatial decision support system LandSupport. *Science of the Total Environment*, 807, 150793.
- Barbosa, A. E., Fernandes, J. N., & David, L. M. (2012). Key issues for sustainable urban stormwater management. *Water Research*, 46(20), 6787–6798. <https://doi.org/10.1016/j.watres.2012.05.029>
- Belciug, S., & Gorunescu, F. (2020). A Brief History of Intelligent Decision Support Systems. In S. Belciug & F. Gorunescu (Eds.), *Intelligent Decision Support Systems—A Journey to Smarter Healthcare* (pp. 57–70). Springer International Publishing. https://doi.org/10.1007/978-3-030-14354-1_2
- Benzerra, A., Cherrared, M., Chocat, B., Cherqui, F., & Zekiouk, T. (2012). Decision support for sustainable urban drainage system management: A case study of Jijel, Algeria. *Journal of Environmental Management*, 101, 46–53. <https://doi.org/10.1016/j.jenvman.2012.01.027>
- Berners-Lee, T., Cailliau, R., Groff, J.-F., & Pollermann, B. (1992). World-Wide Web: The information universe. *Internet Research*.
- Berners-Lee, T., Cailliau, R., Luotonen, A., Nielsen, H. F., & Secret, A. (1994). The world-wide web. *Communications of the ACM*, 37(8), 76–82.
- Berners-Lee, T. J. (1992). The world-wide web. *Computer Networks and ISDN Systems*, 25(4–5), 454–459.
- Beshir, A. A., & Song, J. (2021). Urbanization and its impact on flood hazard: The case of Addis Ababa, Ethiopia. *Natural Hazards*, 109(1), 1167–1190.
- Bhadbury, B., & Shenoy, D. (Eds.). (2014). *Maintenance Resource Management: Adapting Materials Requirements Planning MRP*. CRC Press. <https://doi.org/10.1201/9781482295351>
- Bhargava, H. K., Power, D. J., & Sun, D. (2007). Progress in Web-based decision support technologies. *Decision Support Systems*, 43(4), 1083–1095. <https://doi.org/10.1016/j.dss.2005.07.002>
- Breesam, H. K., & Jawad, Z. A. (2021). Factors affecting maintenance procedures for public buildings. *IOP Conference Series: Materials Science and Engineering*, 1090(1), 012120. <https://doi.org/10.1088/1757-899X/1090/1/012120>
- Burdziej, J. (2012). A Web-based spatial decision support system for accessibility analysis—Concepts and methods. *Applied Geomatics*, 4(2), 75–84.

- Butler, D., Digman, C., Makropoulos, C., & Davies, J. W. (2018). *Urban Drainage* (4th ed.). CRC Press. <https://doi.org/10.1201/9781351174305>
- Carnegie, G. D., & Napier, C. J. (1996). Critical and interpretive histories: Insights into accounting's present and future through its past. *Accounting, Auditing & Accountability Journal*.
- Carver, S. (1999). Developing Web-based GIS/MCE: Improving Access to Data and Spatial Decision Support Tools. In *Spatial Multicriteria Decision Making and Analysis*. Routledge.
- Cembrano, G., Quevedo, J., Salamero, M., Puig, V., Figueras, J., & Marti, J. (2004). Optimal control of urban drainage systems. A case study. *Control Engineering Practice*, 12(1), 1–9.
- Chilela, J. G. (2016). *Web Geographic Information Systems (WebGIS) for smart campus and facility management [PhD Thesis]*.
- Chocat, B., Ashley, R., Marsalek, J., Matos, M. R., Rauch, W., Schilling, W., & Urbonas, B. (2007). Toward the Sustainable Management of Urban Storm-Water. *Indoor and Built Environment*, 16(3), 273–285. <https://doi.org/10.1177/1420326X07078854>
- Choi, J.-Y., Engel, B. A., & Farnsworth, R. L. (2005). Web-based GIS and spatial decision support system for watershed management. *Journal of Hydroinformatics*, 7(3), 165–174.
- CIP (Capital Investment Plan) (2011). *Capital Investment Planning Guide for Ethiopian Cities ; Making cities efficient in service delivery*. Unpublished Report, Addis Ababa, Ethiopia.
- Coronel, C., & Morris, S. (2016). *Database systems: Design, implementation, & management*. Cengage Learning.
- Coutinho-Rodrigues, J., Simão, A., & Antunes, C. H. (2011). A GIS-based multicriteria spatial decision support system for planning urban infrastructures. *Decision Support Systems*, 51(3), 720–726.
- Cun, C., Zhang, W., Che, W., & Sun, H. (2019). Review of urban drainage and stormwater management in ancient China. *Landscape and Urban Planning*, 190, 103600.
- Dagnachew Adugna; Brook Lema; Geremew Sahilu; Jensen, M. B.(2019). Evaluating the hydraulic capacity of existing drain systems and the management challenges of stormwater in Addis Ababa, Ethiopia. *Journal of Hydrology: Regional Studies*, 25, 100626.
- Dagnachew Belete. (2011). Road and urban storm water drainage network integration in Addis Ababa: Addis Ketema Sub-city. *Journal of Engineering and Technology Research*, 3(7), 217–225.
- Damodaram, C., Giacomoni, M. H., Prakash Khedun, C., Holmes, H., Ryan, A., Saour, W., & Zechman, E. M. (2010). Simulation of Combined Best Management Practices and Low Impact Development for Sustainable Stormwater Management I. *JAWRA Journal of the American Water Resources Association*, 46(5), 907–918. <https://doi.org/10.1111/j.1752-1688.2010.00462.x>
- Daniela, L. (2011). Decision-support tools for municipal infrastructure maintenance management. *Procedia Computer Science*, 3, 36–41.
- Davies, R. (2021). Ethiopia-Deadly Flash Floods in Addis Ababa. *Fortune Magazine report on August 22*. PP.1A.
- Densham, P., & Goodchild, M. (1989). *Spatial decision support systems: A research agenda*. Undefined. <https://www.semanticscholar.org/paper/Spatial-decision-support-systems%3A-a-research-agenda-Densham-Goodchild/9560a307760485b04e13ff83289d69b573a6fc6f>
- Dereje Birhanu, Kim, H., Jang, C., & Park, S. (2016). Flood Risk and Vulnerability of Addis Ababa City Due to Climate Change and Urbanization. *Procedia Engineering*, 154, 696–702. <https://doi.org/10.1016/j.proeng.2016.07.571>

- Desybel Minwuyet (2020). A Geospatial Technology Based Study on Flood Risk Assessment: A case of Akaki Kality Sub City. Unpublished MSc Thesis, Adama Science and Technology University, Addis Ababa, Ethiopia, 102 pp.
- Dhakal, K. P., & Chevalier, L. R. (2017). Managing urban stormwater for urban sustainability: Barriers and policy solutions for green infrastructure application. *Journal of Environmental Management*, 203, 171–181. <https://doi.org/10.1016/j.jenvman.2017.07.065>
- Di Gangi, M., & Belcore, O. M. (2022). Risk reduction in transport system in emergency conditions: A framework for decision support systems. *Safety and Security Engineering IX*, 206, 299.
- Dorosh, P., & Thurlow, J. (2014). Can Cities or Towns Drive African Development? Economywide Analysis for Ethiopia and Uganda. *World Development*, 63, 113–123. <https://doi.org/10.1016/j.worlddev.2013.10.014>
- Dragan, M., Feoli, E., Ferneti, M., & Zerihun, W. (2003). Application of a spatial decision support system (SDSS) to reduce soil erosion in northern Ethiopia. *Environmental Modelling & Software*, 18(10), 861–868.
- Duffuaa, S. O., Ben-Daya, M., Al-Sultan, K. S., & Andijani, A. A. (2001). A generic conceptual simulation model for maintenance systems. *Journal of Quality in Maintenance Engineering*.
- Dymond, R. L., Regmi, B., Lohani, V. K., & Dietz, R. (2004). Interdisciplinary Web-Enabled Spatial Decision Support System for Watershed Management. *Journal of Water Resources Planning and Management*, 130(4), 290–300. [https://doi.org/10.1061/\(ASCE\)0733-9496\(2004\)130:4\(290\)](https://doi.org/10.1061/(ASCE)0733-9496(2004)130:4(290))
- Ebrahimian, A., Ardeshir, A., Rad, I. Z., & Ghodsypour, S. H. (2015a). Urban stormwater construction method selection using a hybrid multi-criteria approach. *Automation in Construction*, 58, 118–128.
- Ecology, W. A. (2014). *Stormwater Management Manual for Western Washington*. Washington State Department of Ecology.
- Eissa, A. (2013). *Spatial decision support system for infrastructure resource allocation* [Master's Thesis]. University of Twente.
- Ellis, J. B., Lundy, L., & Revitt, M. (2011). An integrated decision support approach to the selection of Sustainable Urban Drainage Systems (SUDS). SWITCH Conference: The Future of Urban Water.
- Eshetu Gelan (2021). *Municipal Solid Waste Management Practices for Achieving Green Architecture Concepts in Addis Ababa, Ethiopia*. *Technologies*, 9(3), 48.
- Fiduccia, A., Gugliermetti, F., Pagliaro, F., Mattoni, B., Nardecchia, F., & Canu, C. (2016). Web-Based Spatial Decision Support Systems to Monitor and Manage Coastal Environments. 18th Italian National Conference on Photonic Technologies (Fotonica 2016), 60 (4 .)-60 (4 .). <https://doi.org/10.1049/cp.2016.0920>
- Flynn, K. M., Linkous, B. W., & Buechter, M. T. (2012). Operation and maintenance assessment for structural stormwater BMPs. *World Environmental and Water Resources Congress 2012: Crossing Boundaries*, 3662–3673.
- Galar, D., Sandborn, P., & Kumar, U. (2017). *Maintenance costs and life cycle cost analysis*. CRC Press.
- García, L., Barreiro-Gomez, J., Escobar, E., Téllez, D., Quijano, N., & Ocampo-Martinez, C. (2015). Modeling and real-time control of urban drainage systems: A review. *Advances in Water Resources*, 85, 120–132. <https://doi.org/10.1016/j.advwatres.2015.08.007>

- Garofalo, G., Giordano, A., Piro, P., Spezzano, G., & Vinci, A. (2017). A distributed real-time approach for mitigating CSO and flooding in urban drainage systems. *Journal of Network and Computer Applications*, 78, 30–42.
- Getenet Adugna. (2020). flood modeling of jemo river catchement in addis ababa city. Unpublished MSc Thesis, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia, 100 pp
- Genet Alemu. (2018). Assessment of Content Validity of Grade Eight English Language in Two Government Schools in Addis Ababa Nifas Silk Lafto Sub-city in focus
- Getnet Feyissa; Gete Zeleke; Ephrem Gebremariam & Woldeamlak Bewket . (2018). GIS based quantification and mapping of climate change vulnerability hotspots in Addis Ababa. *Geoenvironmental Disasters*, 5(1), 1–17.
- Girma Kebede. (2017). *Living with urban environmental health risks: The case of Ethiopia*. Routledge.
- Göbel, P., Dierkes, C., & Coldewey, W. G. (2007). Storm water runoff concentration matrix for urban areas. *Journal of Contaminant Hydrology*, 91(1–2), 26–42.
- Goulden, S., Portman, M. E., Carmon, N., & Alon-Mozes, T. (2018). From conventional drainage to sustainable stormwater management: Beyond the technical challenges. *Journal of Environmental Management*, 219, 37–45. <https://doi.org/10.1016/j.jenvman.2018.04.066>
- Grussing, M. N. (2014). Life cycle asset management methodologies for buildings. *Journal of Infrastructure Systems*, 20(1), 04013007.
- Gurara, D., Klyuev, V., Mwase, N., & Presbitero, A. F. (2018). Trends and challenges in infrastructure investment in developing countries. *International Development Policy| Revue Internationale de Politique de Développement*, 10.1.
- Hailu Worku. (2017). Rethinking urban water management in Addis Ababa in the face of climate change: An urgent need to transform from traditional to sustainable system. *Environmental Quality Management*, 27(1), 103–119.
- Halfawy, M. R., Dridi, L., & Baker, S. (2008). Integrated decision support system for optimal renewal planning of sewer networks. *Journal of Computing in Civil Engineering*, 22(6), 360–372.
- Haris, H., Chow, M. F., Usman, F., Sidek, L. M., Roseli, Z. A., & Norlida, M. D. (2016). Urban stormwater management model and tools for designing stormwater management of green infrastructure practices. *IOP Conference Series: Earth and Environmental Science*, 32(1), 012022.
- Heidarkhani, A., Khomami, A. A., Jahanbazi, Q., & Alipoor, H. (2013). The role of Management Information Systems (MIS) in decision-making and problems of its implementation. *Universal Journal of Management and Social Sciences*, 3(3), 78–89.
- Herslund, L., Backhaus, A., Fryd, O., Jørgensen, G., Jensen, M. B., Limbumba, T. M., Liu, L., Mguni, P., Mkupasi, M., Workalemahu, L., & Yeshitela, K. (2018). Conditions and opportunities for green infrastructure – Aiming for green, water-resilient cities in Addis Ababa and Dar es Salaam. *Landscape and Urban Planning*, 180, 319–327. <https://doi.org/10.1016/j.landurbplan.2016.10.008>
- Huong, H. T. L., & Pathirana, A. (2013). Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. *Hydrology and Earth System Sciences*, 17(1), 379–394.
- Hwang, C.-L., & Yoon, K. (1981). Introduction. In C.-L. Hwang & K. Yoon (Eds.), *Multiple Attribute Decision Making: Methods and Applications A State-of-the-Art Survey* (pp. 1–15). Springer. https://doi.org/10.1007/978-3-642-48318-9_1
- Jain, S. K. (2010). *15-Spatial Decision Support Systems (SDSS)*. National Institute of Hydrology.

- Jajac, N., Knezic, S., & Marovic, I. (2009). Decision support system to urban infrastructure maintenance management. *Organization, Technology & Management in Construction: An International Journal*, 1(2), 72–79.
- Jamali, B., Bach, P. M., & Deletic, A. (2020). Rainwater harvesting for urban flood management—An integrated modelling framework. *Water Research*, 171, 115372.
- Jan, J.-F. (2018). Application of open-source software in community heritage resources management. *ISPRS International Journal of Geo-Information*, 7(11), 426.
- Javaid, M. S. (2012). *Drainage Systems*. BoD – Books on Demand.
- Jelokhani-Niaraki, M., & Malczewski, J. (2015). A group multicriteria spatial decision support system for parking site selection problem: A case study. *Land Use Policy*, 42, 492–508.
- JICA (Japan International Cooperation Agency) (2019). Project Completion Report for Development of Road Maintenance Capacity of Addis Ababa City. Unpublished Report, Addis Ababa, Ethiopia.
- Jiménez Ariza, S. L., Martínez, J. A., Muñoz, A. F., Quijano, J. P., Rodríguez, J. P., Camacho, L. A., & Díaz-Granados, M. (2019). A Multicriteria Planning Framework to Locate and Select Sustainable Urban Drainage Systems (SUDS) in Consolidated Urban Areas. *Sustainability*, 11(8), 2312. <https://doi.org/10.3390/su11082312>
- Kabir, G., Sadiq, R., & Tesfamariam, S. (2014). A review of multi-criteria decision-making methods for infrastructure management. *Structure and Infrastructure Engineering*, 10(9), 1176–1210. <https://doi.org/10.1080/15732479.2013.795978>
- Kalantari, Z., & Folkesson, L. (2013). Road drainage in Sweden: Current practice and suggestions for adaptation to climate change. *Journal of Infrastructure Systems*, 19(2), 147–156.
- Karaa, F. A. (1989). Infrastructure Maintenance Management System Development. *Journal of Professional Issues in Engineering*, 115(4), 422–432. [https://doi.org/10.1061/\(ASCE\)1052-3928\(1989\)115:4\(422\)](https://doi.org/10.1061/(ASCE)1052-3928(1989)115:4(422))
- KaurSehra, S., Singh Brar, Y., & Kaur, N. (2012). Multi Criteria Decision Making Approach for Selecting Effort Estimation Model. *International Journal of Computer Applications*, 39(1), 10–17. <https://doi.org/10.5120/4783-6989>
- Kiwanuka, M., Yilma, S., Mbujje, J. W., & Niyomukiza, J. B. (2021). FLOOD ANALYSIS AND HYDRAULIC COMPETENCE OF DRAINAGE STRUCTURES ALONG ADDIS ABABA LIGHT RAIL TRANSIT. *Journal of Environmental Science and Sustainable Development*, 4(2), 5.
- Kresse, W., & Danko, D. M. (2012). *Springer Handbook of Geographic Information*. Springer Science & Business Media.
- Kripka, M. (2012). Diagnosis of pathologies in bridges of the road system in Brazil. *CONSTRUCTII Journal*, 13, 26–34.
- Kumar, V., Raheja, G., & Singh, S. (2013). Review of database and prominent programmes. *International Journal of Computers & Technology*, 4(1a), 48–53.
- Lan, Y., Tang, W., Dye, S., & Delmelle, E. (2020). A web-based spatial decision support system for monitoring the risk of water contamination in private wells. *Annals of GIS*, 26(3), 293–309. <https://doi.org/10.1080/19475683.2020.1798508>
- Löwe, P. (2004). A Spatial Decision Support System for Radar-meteorology Data in South Africa. *Transactions in GIS*, 8(2), 235–244.

- Lyu, R., Clarke, K. C., Zhang, J., Jia, X., Feng, J., & Li, J. (2019). The impact of urbanization and climate change on ecosystem services: A case study of the city belt along the Yellow River in Ningxia, China. *Computers, Environment and Urban Systems*, 77, 101351.
- Mansourian, A., Taleai, M., & Fasihi, A. (2011). A web-based spatial decision support system to enhance public participation in urban planning processes. *Journal of Spatial Science*, 56(2), 269–282. <https://doi.org/10.1080/14498596.2011.623347>
- Mastroianni, E., Lancaster, J., Korkmann, B., Opdyke, A., & Beitelmal, W. (2021). Mitigating infrastructure disaster losses through asset management practices in the Middle East and North Africa region. *International Journal of Disaster Risk Reduction*, 53, 102011. <https://doi.org/10.1016/j.ijdr.2020.102011>
- Mays, L. W., Koutsoyiannis, D., & Angelakis, A. N. (2007). A brief history of urban water supply in antiquity. *Water Science and Technology: Water Supply*, 7(1), 1–12.
- McCartney, M. P. (2007). Decision support systems for large dam planning and operation in Africa (Vol. 119). IWMI.
- Meenar, M., Howell, J. P., Moulton, D., & Walsh, S. (2020). Green Stormwater Infrastructure Planning in Urban Landscapes: Understanding Context, Appearance, Meaning, and Perception. *Land*, 9(12), 534. <https://doi.org/10.3390/land9120534>
- Mengistu Jemberie & Assefa Melesse. (2021). Urban Flood Management through Urban Land Use Optimization Using LID Techniques, City of Addis Ababa, Ethiopia. *Water*, 13(13), 1721.
- Mguni, P., Herslund, L. & Jensen, M.B. (2016). Sustainable urban drainage systems: examining the potential for green infrastructure-based stormwater management for Sub-Saharan cities. *Nat Hazards* 82, 241–257. <https://doi.org/10.1007/s11069-016-2309-x>
- Mikovits, C., Tscheikner-Gratl, F., Jasper-Tönnies, A., Einfalt, T., Huttenlau, M., Schöpf, M., Kinzel, H., Rauch, W., & Kleidorfer, M. (2017). Decision Support for Adaptation Planning of Urban Drainage Systems. *Journal of Water Resources Planning and Management*, 143(12), 04017069. [https://doi.org/10.1061/\(ASCE\)WR.1943-5452.0000840](https://doi.org/10.1061/(ASCE)WR.1943-5452.0000840)
- Mild, P., Liesjö, J., & Salo, A. (2015). Selecting infrastructure maintenance projects with Robust Portfolio Modeling. *Decision Support Systems*, 77, 21–30.
- Minwuyelet Melese. (2004). City expansion, squatter settlements and policy implications in Addis Ababa: The case of Kolfe Keranio sub-city. *Ethiopian Journal of the Social Sciences and Humanities*, 2(2), 50–79.
- Mohamed, A., & Worku, H. (2021). Urban land cover and morphometric analysis for flash flood vulnerability mapping and riparian landscape conservation in Kebena River watershed, Addis Ababa. *Applied Geomatics*, 13(1), 15–28. <https://doi.org/10.1007/s12518-020-00318-3>
- Moubray, J. (2001). *Reliability-centered Maintenance*. Industrial Press Inc.
- Mugume, S. N., Gomez, D. E., Fu, G., Farmani, R., & Butler, D. (2015). A global analysis approach for investigating structural resilience in urban drainage systems. *Water Research*, 81, 15–26.
- Mulatu Wubneh. (2013). Addis Ababa, Ethiopia–Africa’s diplomatic capital. *Cities*, 35, 255–269.
- Mutua, J. (2010). Development of a web-based spatial decision support system for water development and management (a case study of Samburu district Water MIS, Kenya) [PhD Thesis]. University of Nairobi, Kenya.

- Mwaura, D., & Kada, M. (2017). Developing a web-based spatial decision support system for geothermal exploration at the Olkaria geothermal field. *International Journal of Digital Earth*, 10(11), 1118–1145. <https://doi.org/10.1080/17538947.2017.1284909>
- Najafi, M. (2008). An asset management approach for drainage infrastructure and culverts. Midwest Regional University Transportation Center, University of Wisconsin
- Naseer, A., & Tantray, M. A. (2021). Deterioration of concrete sewers. *IOP Conference Series: Materials Science and Engineering*, 1197(1), 012023. <https://doi.org/10.1088/1757-899X/1197/1/012023>
- Ortiz, A., Velasco, M. J., Esbri, O., Medina, V., & Russo, B. (2021). The Economic Impact of Climate Change on Urban Drainage Master Planning in Barcelona. *Sustainability*, 13(1), 71. <https://doi.org/10.3390/su13010071>
- Owa, F. (2013). Water Pollution: Sources, Effects, Control and Management. *Mediterranean Journal of Social Sciences*, 4(8), 65. Retrieved from <https://www.richtmann.org/journal/index.php/mjss/article/view/1760>
- Pacheco, A. P., Claro, J., Fernandes, P. M., de Neufville, R., Oliveira, T. M., Borges, J. G., & Rodrigues, J. C. (2015). Cohesive fire management within an uncertain environment: A review of risk handling and decision support systems. *Forest Ecology and Management*, 347, 1–17. <https://doi.org/10.1016/j.foreco.2015.02.033>
- Pahmeyer, C., Kuhn, T., & Britz, W. (2021). ‘Fruchtfolge’: A crop rotation decision support system for optimizing cropping choices with big data and spatially explicit modeling. *Computers and Electronics in Agriculture*, 181, 105948. <https://doi.org/10.1016/j.compag.2020.105948>
- Park, T., & Kim, H. (2013). A data warehouse-based decision support system for sewer infrastructure management. *Automation in Construction*, 30, 37–49.
- Parkinson, J. (2002). Urban drainage in developing countries-challenges and opportunities. *WATERLINES-LONDON-*, 20(4), 2–5.
- Parkinson, J., & Mark, O. (2005). *Urban Stormwater Management in Developing Countries*. IWA Publishing.
- Power, D. (2004). *Decision Support Systems: From the Past to the Future*. New York, 8.
- Qiao, X.-J., Liu, L., Kristoffersson, A., & Randrup, T. B. (2019). Governance factors of sustainable stormwater management: A study of case cities in China and Sweden. *Journal of Environmental Management*, 248, 109249. <https://doi.org/10.1016/j.jenvman.2019.07.020>
- rauch, W., Seggelke, K., Brown, R., & Krebs, P. (2005). Integrated Approaches in Urban Storm Drainage: Where Do We Stand? *Environmental Management*, 35(4), 396–409. <https://doi.org/10.1007/s00267-003-0114-2>
- Rentachintala, L. R. N. P., Mutukuru Gangireddy, M. R., & Mohapatra, P. K. (2022). Trends of surface water quality of the Krishna River, India during the urbanization process. *Environmental Quality Management*.
- Rinner, C. (2003). Web-based spatial decision support: Status and research directions. *Journal of Geographic Information and Decision Analysis*, 7(1), 14–31.
- Roehrig, J., & Laudien, R. (2009). Evaluation of agricultural land resources by implementing a computer-based spatial decision support system for national deciders in Benin, West Africa. *Journal of Applied Remote Sensing*, 3(1), 033502.

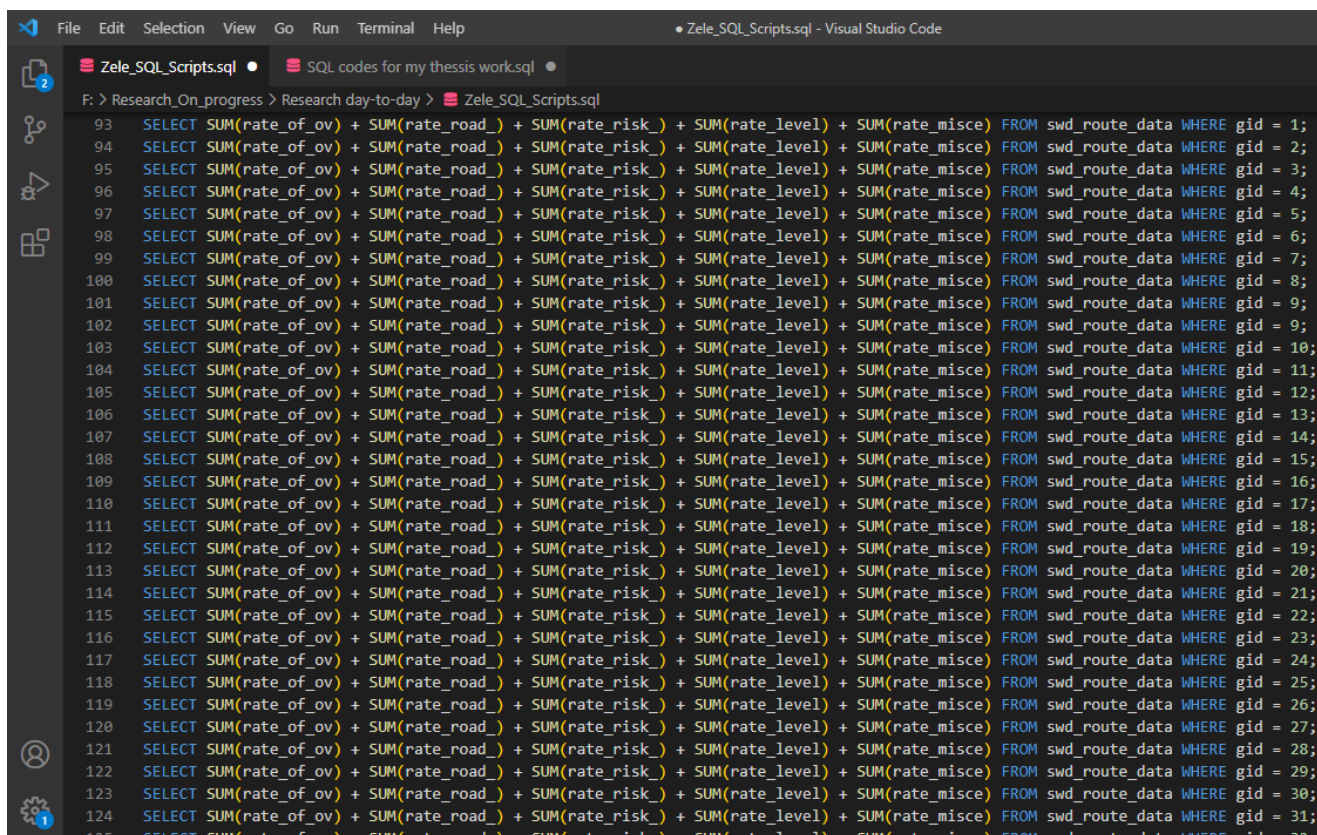
- Roy, A. H., Wenger, S. J., Fletcher, T. D., Walsh, C. J., Ladson, A. R., Shuster, W. D., Thurston, H. W., & Brown, R. R. (2008). Impediments and Solutions to Sustainable, Watershed-Scale Urban Stormwater Management: Lessons from Australia and the United States. *Environmental Management*, 42(2), 344–359. <https://doi.org/10.1007/s00267-008-9119-1>
- Roy-Hubara, N., & Sturm, A. (2020). Design methods for the new database era: A systematic literature review. *Software and Systems Modeling*, 19(2), 297–312.
- Rutledge, D., McDonald, G., Cameron, M., McBride, G., Poot, J., Scrimgeour, F., Price, R., Phyn, D., Van Delden, H., & Huser, B. (2007). Development of spatial decision support systems to support long-term, integrated planning. MODSIM 2007 International Congress on Modelling and Simulation, 308–314.
- Saaty, T. L. (1988). What is the Analytic Hierarchy Process? In G. Mitra, H. J. Greenberg, F. A. Lootsma, M. J. Rijkaert, & H. J. Zimmermann (Eds.), *Mathematical Models for Decision Support* (pp. 109–121). Springer. https://doi.org/10.1007/978-3-642-83555-1_5
- Saikrishna, V., Pandey, K., Bharath, B. D., & Karnatak, H. (2015). Urban water information system (uwis): A web based spatial decision support system for management and monitoring of water utility assets. OSGEO-India: FOSS4G.
- Santos, L., Coutinho-Rodrigues, J., & Antunes, C. H. (2011). A web spatial decision support system for vehicle routing using Google Maps. *Decision Support Systems*, 51(1), 1–9. <https://doi.org/10.1016/j.dss.2010.11.008>
- See, L. S., Calo, L., Bannon, B., & Opdyke, A. (2020). An open data approach to mapping urban drainage infrastructure in developing communities. *Water*, 12(7), 1880.
- Semadeni-Davies, A., Hernebring, C., Svensson, G., & Gustafsson, L.-G. (2008). The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Combined sewer system. *Journal of Hydrology*, 350(1), 100–113. <https://doi.org/10.1016/j.jhydrol.2007.05.028>
- Shuster, W. D., Bonta, J., Thurston, H., Warnemuende, E., & Smith, D. R. (2005). Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal*, 2(4), 263–275. <https://doi.org/10.1080/15730620500386529>
- Silva, S., Alçada-Almeida, L., & Dias, L. C. (2014). Development of a web-based multi-criteria spatial decision support system for the assessment of environmental sustainability of dairy farms. *Computers and Electronics in Agriculture*, 108, 46–57.
- Sinha, K. C., Labi, S., & Agbelie, B. R. (2017). Transportation infrastructure asset management in the new millennium: Continuing issues, and emerging challenges and opportunities. *Transportmetrica A: Transport Science*, 13(7), 591–606.
- Sivo, M., & Ladiana, D. (2011). Decision-support tools for municipal infrastructure maintenance management. *Procedia CS*, 3, 36–41. <https://doi.org/10.1016/j.procs.2010.12.007>
- SP (Structure Plan). (2017). Addis Ababa City Structure Plan Summary Report. Unpublished, Addis Ababa, Ethiopia
- Sørup, H. J. D., Fryd, O., Liu, L., Arnbjerg-Nielsen, K., & Jensen, M. B. (2019). An SDG-based framework for assessing urban stormwater management systems. *Blue-Green Systems*, 1(1), 102–118. <https://doi.org/10.2166/bgs.2019.922>
- Sugumaran, V., & Sugumaran, R. (2007). Web-based Spatial Decision Support Systems (WebSDSS): Evolution, Architecture, Examples and Challenges. *Communications of the Association for Information Systems*, 19. <https://doi.org/10.17705/1CAIS.01940>

- Swanson, L. (2001). Linking maintenance strategies to performance. *International Journal of Production Economics*, 70(3), 237–244.
- Swetnam, T. W., Allen, C. D., & Betancourt, J. L. (1999). Applied historical ecology: Using the past to manage for the future. *Ecological Applications*, 9(4), 1189–1206.
- Swift, L. W., & Burns, R. G. (1999). The three Rs of roads: Redesign, reconstruction, and restoration. *Journal of Forestry*, 97(8), 40–44.
- Tadele Assefa and Bassazin Ayalew . (2021). Current plastics pollution threats due to COVID-19 and its possible mitigation techniques: A waste-to-energy conversion via Pyrolysis. *Environmental Systems Research*, 10(1), 1–11.
- Tafazzoli, M. (2017). Strategizing sustainable infrastructure asset management in developing countries. *International Conference on Sustainable Infrastructure*, 375–387.
- Tang, W., Chen, T., Slocum, Z., Lan, Y., Delmelle, E., Chen, D., Mittal, N., Rice-Boayue, J., Shukla, T., & Lin, S. (2022). A Web-based Spatial Decision Support System of Wastewater Surveillance for COVID-19 Monitoring: A Case Study of a University Campus. *MedRxiv*, 2021–12.
- Timmermans, H. (2003). *Decision Support Systems in Urban Planning*. Routledge.
- Transportation Asset Management for Local Government Agencies: Threshold Levels and Best Practice Guide. (2006). Midwest Regional University Transportation Center, College of Engineering, Department of Civil and Environmental Engineering, University of Wisconsin, Madison.
- Triantaphyllou, E. (2000). Introduction to Multi-Criteria Decision Making. In E. Triantaphyllou (Ed.), *Multi-criteria Decision Making Methods: A Comparative Study* (pp. 1–4). Springer US. https://doi.org/10.1007/978-1-4757-3157-6_1
- Tsang, A. H. C. (1995). Condition-based maintenance: Tools and decision making. *Journal of Quality in Maintenance Engineering*, 1(3), 3–17. <https://doi.org/10.1108/13552519510096350>
- Tscheikner-Gratl, F., Egger, P., Rauch, W., & Kleidorfer, M. (2017). Comparison of Multi-Criteria Decision Support Methods for Integrated Rehabilitation Prioritization. *Water*, 9(2), 68. <https://doi.org/10.3390/w9020068>
- Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process: An overview of applications. *European Journal of Operational Research*, 169(1), 1–29. <https://doi.org/10.1016/j.ejor.2004.04.028>
- van Haaren, R., & Fthenakis, V. (2011). GIS-based wind farm site selection using spatial multi-criteria analysis (SMCA): Evaluating the case for New York State. *Renewable and Sustainable Energy Reviews*, 15(7), 3332–3340. <https://doi.org/10.1016/j.rser.2011.04.010>
- Vanathi, B., & Uthariaraj, V. R. (2011). Collaborative Context Management and Selection in Context Aware Computing. *International Conference on Computer Science and Information Technology*, 348–357.
- Verma, S., Verma, R. K., Singh, A., & Naik, N. S. (2012). Web-based GIS and desktop open source GIS software: An emerging innovative approach for water resources management. In *Advances in computer science, engineering & applications* (pp. 1061–1074). Springer.
- Voudouris, & Voutsas, D. (2012). *Water Quality: Monitoring and Assessment*. BoD – Books on Demand.
- Waidelich, W. (2016). *Guidance on Highway Preservation and Maintenance*. Memorandum. FHWA Office of Infrastructure, US Department of Transportation, Federal Highway Administration, Washington, DC.

- Wakjira Takala. (2018). A review of sustainability of urban drainage system: Traits and consequences. *Journal of Sedimentary Environments*, 3(3), 131–137.
- Wang, J., Liu, G., Wang, J., Xu, X., Shao, Y., Zhang, Q., Liu, Y., Qi, L., & Wang, H. (2021). Current status, existent problems, and coping strategy of urban drainage pipeline network in China. *Environmental Science and Pollution Research*, 28(32), 43035–43049. <https://doi.org/10.1007/s11356-021-14802-9>
- Wang, L., & Cheng, Q. (2007). Design and implementation of a web-based spatial decision support system for flood forecasting and flood risk mapping. 2007 IEEE International Geoscience and Remote Sensing Symposium, 4588–4591.
- William, A. S., Kenya Francis, L., & Kenya Marion, W. J. (2007). Rural Planning in East Africa Using a Participatory Spatial Decision Support System. *Population*, 13, 14.
- Wind, Y., & Saaty, T. L. (1980). Marketing applications of the analytic hierarchy process. *Management Science*, 26(7), 641–658.
- Wu, Z., & Abdul-Nour, G. (2020). Comparison of Multi-Criteria Group Decision-Making Methods for Urban Sewer Network Plan Selection. *CivilEng*, 1(1), 26–48. <https://doi.org/10.3390/civileng1010003>
- Wubshet Teklu. (2020). Hydraulic Performance of Storm Water Drainage Network in Nifas Silk Lafto Sub-city. Unpublished MSc Thesis, Adama Science and Technology University, Addis Ababa, Ethiopia, pp 102.
- Yang, T., & Kuo, C. (2003). A hierarchical AHP/DEA methodology for the facilities layout design problem. *European Journal of Operational Research*, 147(1), 128–136. [https://doi.org/10.1016/S0377-2217\(02\)00251-5](https://doi.org/10.1016/S0377-2217(02)00251-5)
- Yu, J., Ye, L., & Yang, C. (2006). A Framework of Web-GIS for Urban Drainage Network System. 94–102.
- Zeng, Z., Yuan, X., Liang, J., & Li, Y. (2021). Designing and implementing an SWMM-based web service framework to provide decision support for real-time urban stormwater management. *Environmental Modelling & Software*, 135, 104887.
- Zhang, Y., McBroom, M. W., Degroote, J., Kauten, R. L., & Barten, P. K. (2011). Web-based spatial decision support system and watershed management with a case study.
- Zhou, Q. (2014). A Review of Sustainable Urban Drainage Systems Considering the Climate Change and Urbanization Impacts. *Water*, 6(4), 976–992. <https://doi.org/10.3390/w6040976>
- Zoeteman, A. (2001). Life cycle cost analysis for managing rail infrastructure: Concept of a decision support system for railway design and maintenance. *European Journal of Transport and Infrastructure Research*, 1(4).

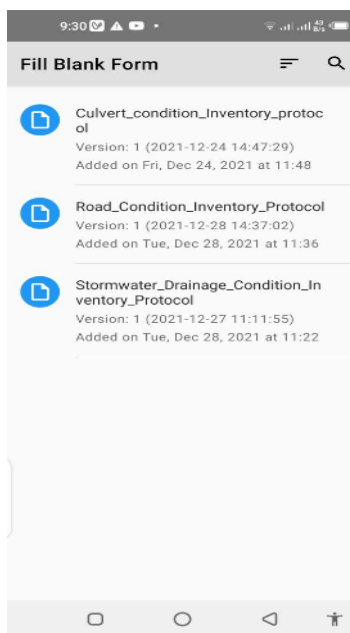
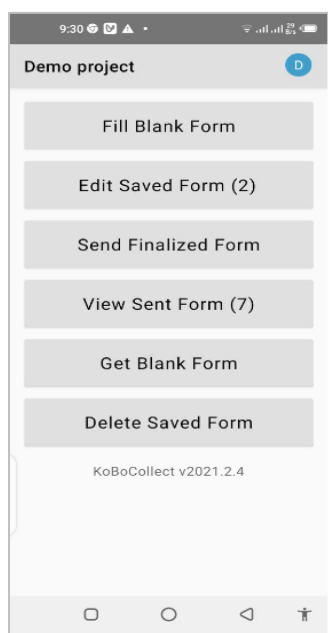
Appendixes

Appendix 1: Script to compute weighted sum from the rate of factors of prioritization



```
93 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 1;
94 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 2;
95 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 3;
96 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 4;
97 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 5;
98 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 6;
99 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 7;
100 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 8;
101 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 9;
102 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 9;
103 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 10;
104 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 11;
105 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 12;
106 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 13;
107 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 14;
108 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 15;
109 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 16;
110 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 17;
111 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 18;
112 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 19;
113 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 20;
114 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 21;
115 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 22;
116 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 23;
117 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 24;
118 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 25;
119 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 26;
120 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 27;
121 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 28;
122 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 29;
123 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 30;
124 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 31;
125 SELECT SUM(rate_of_ov) + SUM(rate_road_) + SUM(rate_risk_) + SUM(rate_level) + SUM(rate_misce) FROM swd_route_data WHERE gid = 32;
```

Appendix 2: Mobile apps (kobo toolbox)



Appendix 3: Focus group discussion’s guiding questions

GUIDING QUESTIONS FOR FOCUS GROUP DISCUSSION SESSIONS (FGD)

My name is Zeleke Lerango. I am Msc student at Addis Ababa University AAiT, and conducting research entitled as Urban Storm Water Drainage Infrastructure Maintenance Management Modelling Using Web-Based Spatial Decision Support System: A Case of Nifas Silk Lafto Sub-City, Addis Ababa. The primary objective of this study is to assess the contribution of a Web-Based Spatial Decision Support System for Urban Drainage Infrastructure Management. Therefore, I need to understand what the situation on urban drainage infrastructure life-cycle management looks like within the study area . And thus, I would like to discuss with you on this subject. The responses collected will be kept confidential by the researcher to the maximum extent allowable by law.

1. Would you please describe the existing functional storm water management practices of city of Addis Ababa, Ethiopia?

How often do you inspect and conduct condition inventory of drainage infrastructures?

- ✓ Do you investigate the performance of urban drainage infrastructures? If yes, how often? In schedule base or in haphazard way?
 - ✓ Do you have scheduled condition inventory and inspections?
 - ✓ Do you have clear drainage route prioritization parameters, and procedures for routes with competing maintenance demands?
 - ✓ Do you have a functional system in place which may ensure citizens’ participations in life-cycle management processes (involvement in routine maintenance tasks) of drainage infrastructures? Or other stakeholders involvement?
 - ✓ Does your organization use various options of storm water management techniques/options rather than sticking only on conventional flooding control drainage channels/ditch constructions?
2. Do you think current urban drainage infrastructure management practices have visible problems? If yes, what are the main challenges and difficulties in life-cycle management of urban drainage infrastructures?
- ✓ In relation to various drainage issues being communicated among stakeholders? How, when, where concerns?
 - ✓ receiving residents’ complaints, and giving feedback to residents’ queries related to flooding problems (lack to have clear communication protocol)
 - ✓ Data collection, storing, manipulating, analysing, disseminating and displaying of spatial and non-spatial data to be utilized by concerning stakeholders
 - ✓ Decision making transparency and decision’s qualities, etc
3. Do you think current urban drainage infrastructure management practices of Nifas-Silk Lafto sub-city have some good practices that need to be enhanced? If any exemplary practices please list down them
4. In what aspects would you think the existing drainage infrastructure management practices shall be changed or what shall be done to improve the situation in the future?
5. Do you think computerized decision support system linked along with web-based data base management system may help in alleviating the drainage asset management problems?

Appendix 4: Interview questions (only some part)

1. Which of the following factors are considered in the inspection guideline of culverts? Please rank the factors in order of their importance.

Hydraulic capacity:	<input type="checkbox"/> Yes	<input type="checkbox"/> No	<input type="checkbox"/> Yes	<input checked="" type="checkbox"/> No	Rank:	<input type="checkbox"/>
Soil Conditions:	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	<input type="checkbox"/> Yes	<input checked="" type="checkbox"/> No	Rank:	<input type="checkbox"/>
Joint Failures:	<input type="checkbox"/> Yes	<input type="checkbox"/> No	<input type="checkbox"/> Yes	<input type="checkbox"/> No	Rank:	<input type="checkbox"/>
Corrosion:	<input type="checkbox"/> Yes	<input type="checkbox"/> No	<input type="checkbox"/> Yes	<input type="checkbox"/> No	Rank:	<input type="checkbox"/>

Wall Thickness: Yes No Yes No Rank:

Deflection: Yes No Yes No Rank:

Cracking: Yes No Yes No Rank:

Others: (please explain)

Hydraulic Capacity includes:

Amount of sediments in the culverts

Surface condition of pipe material

Inlet and outlet conditions

Change in flow condition due to land development in upstream

Original hydraulic design of majority of drainage infrastructures like culverts in your sub-city is based on :

- 10 year flood
- 20 year flood
- 50 year flood
- 100 year flood

Others: (please explain)

2. How often do you inspect drainages located within sub city's highways and in local roads?

- Less than 1 Year
- Every 1-2 years
- Every 2-5 years
- More than 5 years
- No specific frequency

3. What factors are considered when replacing or renewing drainage routes and other drainage infrastructures?

- Hydraulic problems
- Structural problems
- Deflection
- Material degradation
- Roadway Surface
- Inspection results
- Age of the culvert
- Other, (please explain)

4. Do you have any culvert failure cases reported? (Failure is collapse of culvert due to deterioration)

- Yes
- No

Don't Know

5. Which division or who makes decisions regarding drainage infrastructure repair, renewal or replacement projects or programs in your organization?
6. Is there a model or formula that your sub-city uses in order to predict the life expectancy of culverts and other drainage infrastructures?

- Yes
- No
- Don't Know

If “Yes” to above, please provide a link to access the associated files via Web or attach a copy of it with this questionnaire.

7. Explain briefly how you overcome confined space problems while inspecting culverts.
 CCTV inspection (Closed Circuit Television Video)
 Don't inspect inside, just inlet and outlet
 Others (please explain):

8. What are the major structural or hydraulic drainage infrastructure problems that you encounter in your sub-city wide?

9. What are the major **repair methods** do you use for aforementioned problems?

10. What are the major **renewal methods** you use for problems listed in question 12?

11. Does your organization have a computer database inventory for Drainage infrastructure?
 Yes
 No
 Don't Know

12. If “Yes” to the above question, what software is used for drainage infrastructure?

Appendix 5: Presents the condition rating system for storm water drainage’s embankment and curbs

Rating	Condition
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5	Well compacted soil or other selected materials appropriately retained near to drainage channel, no erosion in and around drainage structure
4	Minor erosion away from the drainage structures, no significant problem to the structure of the drainage,
3	Moderate erosion near the structure, no significant cracks on the upper surface of drainage structure
2	Slop stability problem near the drainage structure, parts of pavements damaged, parts of curbs damaged, significant amount of erosion, pavement clogging due to organic matter and sediment, planted vegetation becomes excessively tall, nuisance weeds and other vegetation start to take over, damaged road shoulders, water infiltrated into the pavement
1	Embankment has totally collapsed or failure is imminent, soil from adjacent areas washed into drainage routes

Appendix 6: Presents condition rating system for condition of manholes

Rating	Condition
5	Looks new and in excellent condition
4	Minor cracks on manholes cover, no sediment lay on the cover and within manholes, no significant problem in overall structure of the manhole, walls are not collapsed
3	Moderate erosion near the structure, no cracks on the upper surface of manhole structure
2	Joint failures/separation and any openings or voids allowing material to be transported into drainage facility, deteriorations of concrete slabs, breaking or deformation, misalignment, over displaced from its base joint,
1	Manhole covers collapsed or failure is imminent, covers missing or only partially in place, manhole's wall collapsed, excessively accumulated sediment, trash or debris exceeding 30cm or impeding flow from inlet or outlet pipes, could not locate

Appendix 7: Presents the condition rating system for storm water drainage's inlet & outlet

Rating	Condition
5	Looks new and exist in excellent condition
4	Minor inlet and outlet facility damage, no vegetation cover, trash, debris around inlet and outlet facilities, soil and other external materials are not entering the catch basin through inlet

3	Moderate vegetation grown across and blocking less than 10% of the inlet, harmful matter entrance prevention facilities are (like grids are) in place
2	Wall structure is unsound, flaking and deposits on walls, lateral drains & flooding outside the channel, sever cracks,
1	Sever damage on walls of drainage facility, wall collapse,

Appendix 8: Presents the condition rating system for storm water drainage’s walls

Rating	Condition
5	Looks new and in excellent condition
4	Minor cracks on walls of drainage, no significant joint opening between blocks
3	Moderate cracks and breaking loose from the walls
2	Joint failures/separation, deteriorations of upper concrete slabs (if any), top slab with holes larger than 0.31 square cm or cracks wider than 0.635cm, cracking, fracturing, Surface mortar stripping from joint or top walls, masonry block breaking and loose from the walls, not glued/sealed wall materials
1	Serious damage to joint from the walls of the channel, complete collapse

Appendix 9: Inlet & outlet Presents the condition rating system for storm water drainage’s floor

Rating	Condition
5	Looks new or in excellent condition
4	Age deterioration is minor, no or less settlement of the debris, drainage floor is not eroded
3	Age deterioration is moderate, some distortions of the lower ground floor , moderate cracks and settlement of debris, moderate floor erosion
2	Age deterioration is significant or failure of the floor is coming up, floors are heavily eroded, large settlement of sediments and debris, major cracks, under drains clogged/blockage, seepage
1	Floors are totally /partially broken in a way that significantly affect overall drainage operation

Appendix 10: Condition rating system for overall condition of the storm water drainage

Rating	Condition
5	Newly installed drainage pipe or lined drainage channel
4	Looks new with possible discoloration of the surface, partially worn hairline cracking, no debris inside the structure, light erosion inside and outside of the drainage system
3	Medium erosion, pinholes throughout the drainage facility, minor cracking, minor settlement of debris inside the culvert
2	Heavy erosion, major cracks with spalling, exposed surface of the reinforcing steel, heavy settlement of the debris inside the conveyance structure, visible settlements of materials from erosion of the adjacent roads, wearing pavements courses, outlet clogged, overflow symptoms.
1	Storm water drainage facility structurally or hydraulically incapable to function, exceeded its design life, culvert partially collapse or collapse is imminent

Appendix 11: Rating for ACA and parameters of drainage routes constructed with concrete & masonry

Rating	Cracking	Breaking	Joint opening	Scouring	Deposits or debris	Inlet-outlet-blockage
5	No cracking or hair cracks at the surface less than 1/2ft, no sign of distress, minor spalling of stone surface	No evidence of breaking of drainage route wall, floor, partially or fully	Tight Joint, No opening at joints	No evidence of scour at either inlet or outlet of culvert or minor scour holes developing at inlet or outlet.	No Debris – The flow is not obstructed	Inlet-outlet is open as per its design
4	Minor transverse or longitudinal cracks less than 1/16 of inch in width & less than 2 ft in length, minor spalling of stone surface scaling of stone surface less than 1/2inch	Minor breaking of stone wall, concrete surface, and pit holes at some locations.	Minor openings at the joints less than 1/2 inch, minor infiltration, loss of mortar at joints	Minor scour holes developing at inlet or outlet less than 1 ft in depth in scour hole.	Minor waterway blockages are Caused between 0 to 10% of the totals cross sectional area of drainage routes. Sediment built up in channel, trees or bushes growing in the channel. Moderate	Minor blockage, at inlet and outlet which obstruct inflow and outflow

3	<p>Moderate transverse and longitudinal cracks having width less than 1/16 of inch and length less than 4ft causing little infiltration. Diagonal or vertical shear crack through several courses of stone with displacement. Displacement may be bulge or leaning stones. Total displacement is less than ¼ of stone depth</p>	<p>Moderate breaking of stone wall, concrete surface, and pit holes at some locations.</p>	<p>Moderate - Joints opening (less than 1 inch) due to differential movements of sections causing backfill infiltration , offset due to opening less than 4 inches , Severe loss of mortar.</p>	<p>Minor scour holes developing at inlet or outlet less than 3 ft in depth, Footings along the side are exposed. Damage to scour counter measures. Bottom of footing is exposed. Major stream erosion behind headwall that threatens to undermine culvert</p>	<p>obstruction are caused due to debris between 10 to 45% of the total cross sectional area of specific route, rock settlement causing rock dams, trees or bushes growing into the channel, at peak flows overtopping of roadway occurs.</p>	<p>Inlet and outlet moderately obstructed</p>
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2	<p>Heavy cracking throughout the walls, floors cracks more than 1/8inch in width and more than 4ft in length diagonally, back fill infiltration, displacement of section at the cracks; Large unsound areas several stones are displaced or missing. Misalignment of mortar joints, large fractures or erosion of stone surfaces greater than 5 inches. Spalls on beam seats causing reduced bearing area</p>	<p>Sever breaking of stone wall, concrete surface, and pit holes at some locations, loss of block walls</p>	<p>Opening at the joints. between 1 to 3 inches causing significant infiltration and loss of backfill material at the opening, offsets greater than 4 inch, minor misalignment, severe loss of mortar</p>	<p>Major scour holes at inlet or outlet more than 3 ft in depth. Undermining cut-off walls or headwalls. Streambed. Degradation causing severe settlement.</p>	<p>Heavy obstructions are caused due to settlement of debris 45%-80% of the total cross-sectional area of drainage route is lost, overtopping of roadway is frequent, sediment accumulation and other messes are huge</p>	<p>Sever obstructions at inlet and outlet, structures around inlet and outlet broken, sediments severely accumulated</p>
1	<p>Structure partially or totally collapsed heavy displacement of sections at cracks, heavy backfill infiltration. Numerous missing or displaced stones. Displacement greater than 1/3 of stone depth. Partially collapsed wing wall</p>	<p>Partially or fully collapse of drainage channel due to breaking of stone structure</p>	<p>No connection at all, loss of alignment in series of section.</p>	<p>Total failure of culvert because of channel failure.</p>	<p>Channel completely blocks, total loss of hydraulic capacity, road closure due to overtopping</p>	<p>Totally the inlets and outlets blocked</p>

Source: Adopted from (Najafi, 2008)

Appendix 12: Drainage routes' rating for criticality level

Rating	Condition	Description
5	Excellent	No probability of failure (PoF), newly constructed drainage route, structural and hydrological viability is great
4	Good	Slight risk of failure, assets with low probability of failure were assets that had used up 50% or less of their useful lives. Drainage routes with minor cracks, few sediments etc
3	Fair	Moderate risk of failure, assets with medium probability of failure were assets that had used up more than 50% and less than 85% of their useful lives.
2	Poor	Significant risk of failure, assets that had consumed 85% or more of their useful life. And consequence of failure is also much significant
1	Critical	Sever risk of failure, critical

Appendix 13: Level of Criticality Rating Based on Street Classification

Rating	Road classification	Descriptions
5	LS	Defective drainage routes that found at local street roadside
4	CS	Defective drainage routes that found at collector street roadside
3	SAS	Defective drainage routes that found at road class of sub-arterial street roadside
2	PAS	Defective drainage routes that found a road class of major-arterial street roadside
1	Express way	Defective drainage routes that found a road class of express way roadside

Source: road classification were taken from urban planning manual of Ethiopia (2018)

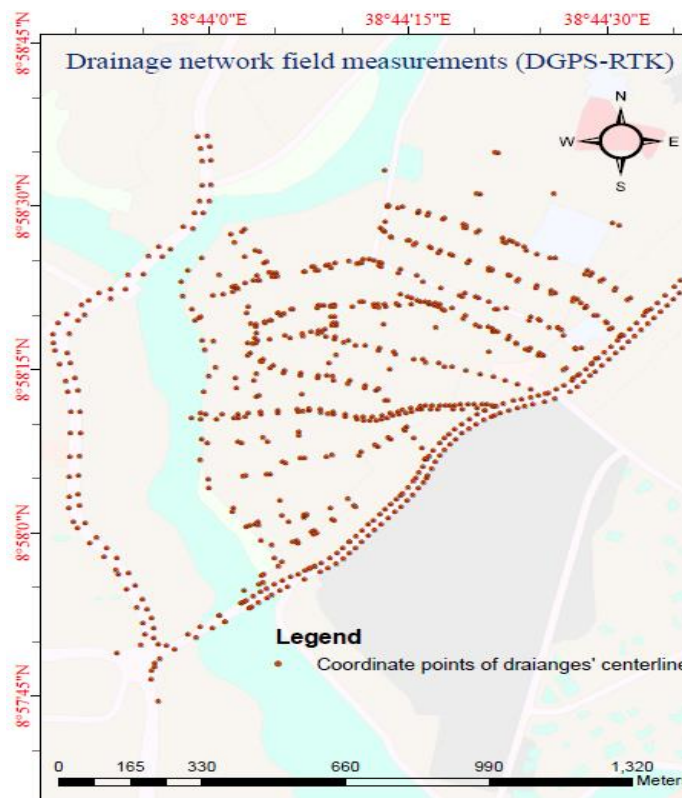
Appendix 14: Rating for level of urgency for maintenance

Rating	Intervention urgency	Descriptions
5	No interventions required	A drainage route with its new physical condition, no structural damages and other construction related failures, or the status is in its excellent condition
4	Intervention required, but neither urgent nor important	A drainage routes having some defects but the existing size, the geographical location where that route found, even less earlier investment costs, predictable less level of negative impact (if in case the route collapsed totally), relatively the route's importance is very less and not demand for urgent intervention than other routes too.
3	Urgent, but not important	Level of deterioration calls for maintenance of the route under subject need an urgent intervention but that route is not as such important than others
2	Important, but not urgent	Maintenance of the route under subject is necessary but in sense of urgency the route does not require as such a quick intervention exactly by now, tolerable level of damage; for instance a route with some tolerable level of sediments at dry season.
1	Urgent and important	Such drainage routes at the top list of decision makers and other stakeholders, high cost initial investment up on it, much significant importance in terms of storm water drainage collection and conveyance, with greater size of drainage pipe or channel and serving as main route of flow, high discharge volumes carrying structure, drainage route with high consequence of failure due to flooding risk,

Appendix 15: Miscellaneous rating factors

Rating	Situation	Description
5	Excellent	No compliant, no track record of sudden failures of the drainage routes under subject, good soil type, excellent topographic characteristic, relatively low cost for restoration etc
4	Very good	Relatively less probable damage due to failure of the route, land use of not residential, commercial, less cost investment etc
3	Good	Moderate complaint exists about maintenance by residents, no matching fund compared to other routes with the same status and society
2	Bad	Complaint exists, sometimes unforeseen failures of the route happen
1	worst	Frequent compliant of clients, sudden failure happen often, etc.

Appendix 16: Drainage networks' centreline coordinate points of storm water



Appendix 17: Naming and detail drainage route codes of the study area

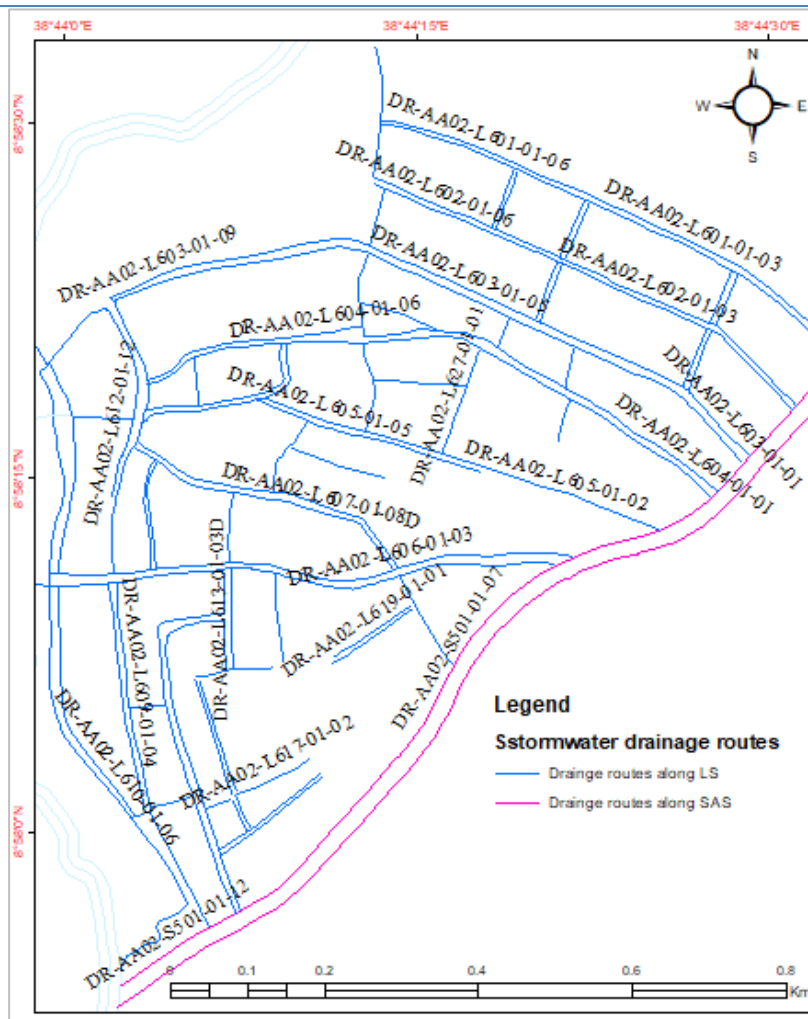


Fig 4. 22 Drainage routes and respective codes of each route

Appendix 18: Field survey (GNSS-RTK) coordinate data of drainage routes' centerline

Z						
2246.199	175	DICHC	471432	991870.83	2249.8	200
2247.649	176	DICHC	471424	991876.96	2249.2	201
2229.963	177	DICHC	471403	991876.66	2248.7	202
2253.71	178	DICHC	471395	991881.27	2248.4	203
2262.222	179	DICHO	471370	991907.08	2246.9	204
2260.316	180	DICHO	471365	991898.53	2246.7	205
2240.19	181	DICHC	471340	991927.96	2245.5	206
2256.638	182	DICHC	471318	991925.47	2244.8	207
2254.657	183	DICHC	471322	991922.51	2244.7	208
2254.207	184	DICHO	471308	991931	2243.9	209
2255.385	185	DICHO	471311	991940.3	2244	210
2255.117	186	DICHO	471301	991943.37	2243.7	211
2240.83	187	DICHO	471299	991936.5	2243.5	212
2240.197	188	DICHO	471287	991938.07	2242.9	213
2253.48	189	DICHO	471286	991944.97	2243.1	215
2253.607	190	DICHC	471278	991945.49	2242.4	216

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2253.689	191	DICHC	471267	991947.5	2241.5	217
2252.855	192	DICHC	471260	991949.55	2241.1	218
2252.979	193	DICHC	471247	991955.58	2240	219
2252.324	194	DICHC	471238	991959.36	2239.3	220
2252.178	195	DICHC	471220	991967.29	2238.4	221
2249.912	196	DICHO	471246	991938.12	2240.1	222
2246.702	197	DICHO	471218	991935.22	2238.6	223
	198	DICHO	471211	991941.27	2238.4	224
	199	DICHO				
			471187	991931.77	2237.1	

Appendix 19: Sample photographs taken during field survey

