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ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

PERFORMANCE ASSESSMENT OF SEWER NETWORK IN ADDIS ABABA: THE CASE OF KALITY CATCHMENT

A thesis submitted and presented to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the Master of Science in Civil Engineering (Water Supply and Environmental Engineering)

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DECLARATION

I, the undersigned, declare that this thesis entitled **Performance Assessment of Sewer Network in Addis Ababa: A Case of Kality Catchment** is my original work, and has not been presented for a degree in Addis Ababa University or in any other University and that all sources of materials used for the thesis have been fully acknowledged.

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APPROVAL

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As a member of the board of examiners of MSc, thesis open defense examination, we certify that we have read, evaluate the MSc, thesis prepared by Getye Fekadu Abraw and examined the candidate.

We recommend that the thesis be accepted as fulfill the MSc thesis requirement for the degree of Masters of Science in civil engineering (Water Supply and Environmental Engineering).

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ABSTRACT

Urban development usually exerts enormous pressure on the existing sewer network systems. The deficiency in the performance of the sewer network becomes one of the most critical issues in the sewer system sector that requires immediate action. Kality Catchment sewer system has problems related to sewer system coverage, manholes overflow, and capacity deficiency. The main objective of this study is to assess the performance of existing sewer network in Kality's Catchment with respect to pipe capacity (depth/rise), and surcharge using Bentley SewerGEMS CONNECT. Both primary and secondary data were collected and TOOLS such as Arc GIS, AutoCAD, Microsoft Office Excel, and Geographic positioning system (GPS) were used. Model analyses were conducted under three possible scenarios. The wastewater generations for the first and second scenarios were estimated based on water consumption bill data by considering active and potential sewer customers for both scenarios, respectively. Additionally, a projected wastewater generation was derived from land use data for the third scenario. The sewer system coverage in the Kality Catchment was estimated to be 17.63%, showing only the proportion of active sewer customers relative to water customers in the study area. The steady-state analysis of the sewer network, considering peak flow conditions, revealed that approximately 1.01%, 1.49%, and 4.16% of pipes exceeded their capacity (d/D) (>90%) values. This accounts for lengths of 5,415.10m, 7,956.20m, and 22,249.10m for the first, second, and third scenarios respectively. Additionally, approximately 2.88%, 3.74%, and 8.35% of pipes experienced surcharge, accounting for lengths of 15,372.40m, 20,019.10m, and 44,654.50m for the respective scenarios. The pipe capacity (d/D) exceeded when the d/D ratio reached 0.9(90%), and surcharge occurred when the water level rose above 15cm of the manhole rim elevation during peak flow conditions. These locations with deficiencies in both pipe capacity (d/D) and surcharge covered lengths of 1,691.90m, 5,334.80m, and 17,577.50m for the first, second, and third scenarios respectively. It is recommended that the utility upgrade the existing sewer network, as well as expand a new sewer system and connect to the system unserved areas and customers.

Key Words: Addis Ababa, Kality Catchment, Hydraulic Model, Sewer Network, and SewerGEMS

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ACRONYM

AAWSA	Addis Ababa Water and Sewerage Authority
MWIE	Ministry of Water Irrigation and Energy
MWE	Ministry of Water and Energy
ECDSWC	Ethiopian Construction Design and Supervision Works Corporation
AACSP	Addis Ababa Commission Structural Plan
GPS	Global Positioning System
GEM	Geospatial Engineering Model
ABR	Anaerobic Baffled Reactor
MBR	Membrane Bioreactor
MBBR	Membrane Biological Based Reactor
UASB	Up flow Anaerobic Sludge Blanket
OM	Operation and maintenance
WWTP	Wastewater Treatment Plant
CSO	Combined sewer overflows
GIS	Global Positioning System
SWMM	Storm water management model
BAR	Built up Area Ratio
NRW	Non Revenue Water

1. INTRODUCTION

1.1 Background

Wastewater or sewage is one of the two major urban water based flows that form the basis of concern for the drainage engineer. Wastewater is the main liquid waste of a community. Safe and efficient drainage of wastewater is important to maintain public health and protect the receiving water environment (David, 2004).

As population, urbanization and economic activities rapidly increase the pressure on freshwater resources increases. Steady increase in living standards, economic development and piped water supply means an increase in water consumptions. These lead to increasing volumes of wastewater and if untreated increasing volumes of pollution. Pollution load into the environment has caused and continue to cause gradual but steady deterioration of water resources and the ability to provide safe drinking water to the population decreases. As a result, the basis of economic activities becomes threatened. With strong sustained growth in population and economy, problems associated with poor wastewater management are expected to increase.

Sewer system manhole overflow in Addis Ababa poses significant challenges to the city's infrastructure and public health. The occurrence of manhole overflow is primarily caused by factors such as inadequate system capacity, blockages, aging infrastructure, and unauthorized connections. These factors lead to the backup and overflow of wastewater through manholes, resulting in detrimental effects on the city (AAWSA, 2014)

The effects of manhole overflow are far-reaching. Firstly, it poses a severe risk to public health as the overflowed wastewater can contain harmful pathogens and contaminants. This can lead to the spread of waterborne diseases and pose a threat to the well-being of residents. Secondly, the environmental impact is substantial, with the overflow contaminating water bodies, soil, and vegetation. Aquatic ecosystems suffer damage, and the overall ecological balance is disrupted. Additionally, manhole overflow causes property damage and disrupts daily life, as flooding occurs in streets, homes, and businesses (Patil & Kadam , 2019).

The collection and delivery of water-based wastewater to a suitable treatment facility is the responsibility of wastewater collecting systems. The collection system simulates a tree that branches out from the treatment plant to collect sewage from people, much like a distribution system for water delivery. The collection system receives wastewater from individual homes via a service line (Jumma & Lillian, 2014).

There are three possible layouts for sewerage systems: separate, storm, or combined. Only sanitary sewage, industrial wastes, or both may run through a separate system of sewers. Sanitary sewage is not allowed to pass through storm sewers. Combined sewer conveys both sanitary and storm sewage. Whether to use a combined or separate sewerage system depends on practicality. Separate, mixed, or storm sewers may make up different parts of an identical system (Harold, 1992).

According to the Addis Ababa Water and Sewerage Project-Component-2 of 2004 and the Addis Ababa Sewerage Improvement Master Plan study conducted by NEDCO in 2001, the city is divided into three sewer catchments: the Eastern catchment, which covers 15,700 ha, the Kality catchment, which covers about 21,600 ha, and the Akaki catchment, which covers 20,300 ha. The only catchment that is currently connected to sewer lines and served by the existing wastewater treatment plant is the Kality catchment. All other catchments use on-site sanitation systems, with the exception of condominium house, which are served by localized neighborhood sewerage system (AAWSA, 2016).

Sewer system modeling is acknowledged as a useful method for forecasting wastewater response to various wet weather events and assessing implications on water quality when comparing various management measures and alternatives.

In collection systems, steady-state and unsteady flow modeling are also used. For a model to represent the changing conditions of the system, steady state models take into account constant flow rates at all points in the system. Although a wastewater system's flow is not actually constant, determining whether or not there is enough capacity to handle peak flows is of utmost importance to the designer. The best models for forecasting these peak flows are steady-state models.

Steady-state models can also be used to figure out whether the velocities at lower flow rates are adequate for self-cleansing. This steady-state technique is suitable for the majority of design problems. Simulation of unsteady-flow conditions becomes crucial for larger systems or systems with highly variable flows, such that pump cycling or storage in the pipes is significant. This is done by either solving the more difficult hydrodynamic equations or by routing flows across the system using a hydrologic routing technique (Walski, et al., 2007).

1.2 Statement of Problem

Demand for water supply is rising due to the rapid rise of the population, urbanization, and economic activity. Due to this increase in water use, more wastewater is generated, which, if untreated, becomes a substantial cause of pollution. Pollutants released into the environment not only spread disease but also deteriorate the quality of the water, affecting both the availability of safe drinking water and the basis for economic activity. These problems are anticipated to get worse as the population and economy expand, especially in densely populated cities that are seeing expansion of the residential and commercial sectors. To maintain the availability of clean water and sustained economic development, these challenges must be addressed because they place a significant burden on water resources.

In the developing countries in particular, governments face problems of provision of social facilities, especially provision of adequate sewerage system for good sanitation services at a reasonable price to their citizens. The shortage of modern sewerage system management is one of the most pressing problems facing humanity especially urban cities.

In the existing sewerage system of the study area there are a number of observed problems. There are sewer overflows at several locations with their adverse effects on the public and environmental health and image of the city, in the rainy season it is not uncommon to see stormwater inflow and infiltration that causes sewer surcharges.

The sewer system in Kality Catchment faces significant performance challenges, impacting the city's infrastructure, public health, and environmental sustainability. The system experiences issues such as frequent, manhole overflow, blockages, sewer line surcharges, inadequate capacity, and inefficient wastewater treatment. These problems result in sewer contamination of water bodies, and the spread of waterborne diseases. Additionally, the aging infrastructure and lack of regular maintenance further exacerbate the performance shortcomings of the sewer system. Therefore, there is a pressing need to comprehensively assess and address the factors affecting the performance of the sewer system in Addis Ababa to ensure efficient wastewater management, protect public health, and enhance the overall livability and sustainability of the city.

Immediate and safe collection of wastewater from its source of generation, followed by proper treatment and disposal is important to ensure good public health and environmental quality. Liquid waste management problem in Addis Ababa is immense and has seriously affected the overall environment in general and the public health in particular. Illegal connection of the septic tanks to the roadside storm drainage system and poor wastewater disposal practices in the city create bad odor and become breading sites for flies, and other vermin at different corners of the city. Additionally, illegal connections of sanitary wastes to the storm drainage system, nearby rivers and indiscriminate disposal wastes are the major causes of environmental pollution and diseases. Illegal discharge of stormwater to the sewer pipes during the rainy season is creating great problems for operation and maintenance of the existing wastewater treatment plant, as the treatment units are designed only for sanitary waste.

1.3 Objectives of the Study

1.3.1 General Objectives

The overall aim of this study is to assess the performance of sewer network and suggest ways to overcome some of the challenges in Kality Catchment, Addis Ababa.

1.3.2 Specific Objectives

- To check capacity and performance of the existing sewer network.
- To identify deficient locations in the existing sewer network.
- To assess the sewer system coverage in the study area.
- To recommend feasible improvement measures.

1.4 Research Question

- Is the existing sewer system capacity technically feasible for the required service?
- What is the performance of the existing sewer system in the study area?
- How the numbers of customers affect sewer system's performance?
- Is there any critical or deficient location in the existing sewer network?
- How good is the existing sewerage service coverage in the study area?
- What can be done to improve or overcome the sewer system problems?

1.5 Significance of the Study

In this study it is expected to assess the coverage and performance the Kality Catchment sewer system by using hydraulic modeling software. This can be used as significant input to Addis Ababa city sewer work sector to check their system and to take necessary improvement measures with regards to service coverage and hydraulic performance of sewer system. The study findings is also intended to help implementers, as well as policy makers, planners and donors, in sewer sector as working document and benchmark data for any further investigation.

1.6 Scope and Limitations of the Study

The scope of the study is limited to only Kality Catchment and focus on assessing the performance of the existing sewer network in terms of key parameters pipe capacity (d/D) and surcharging comparing with and recommended system design criteria, sewer system coverage and identifying deficient locations. The study used hydraulic network analysis Bentley SewerGEMS Editing connection 10 software to evaluate the capacity and performance of sewer network.

There were some limitations during the study. Comprehensive effort has been made to compile the sewer network in to one GIS shape file to be used in existing system sewer line modeling. The pipe layout has been drawn with GIS shape files representing diameters of pipes and the pipe material has been annotated. The location of Manholes at pipe connections, pipe diameter and pipe direction change and in some intervals of straight segment collected from the layout drawings. The basic manhole information required for model building and analysis is the ground elevation extracted from TRex method in SewerGEMS and manhole depth (ground elevation-invert elevations) of manholes gathered and extracted from hard copy sand soft copy of as built drawings which were gathered from different branch offices and head office. As well-organized existing sewerage data was not available, a lot of data related to the sewerage system was collected from relevant hard copies and field surveys and that made the research work laborious.

2. LITRATURE REVIEW

2.1 Urban Sewerage System

Urban sewerage system, also referred to as the "urban conscience," an infrastructure designed to processed, collect and discharges both rainfall and municipal sewage. It is crucial component of public spaces in cities. In order to safe guard urban people and maintains normal life in urban areas. The entire urban drainage systems goal is to rapidly discharge rainwater, domestic sewage, industrial sewage and flood water from the city through the urban surface drainage system. Urban rainfall sewage, waste water and flood water treatment and reuse can also conserve water resources and safeguard the environment (Yun-Fang, 2017).

The urban sewerage system is a highly developed network of pipelines, pumps and treatment facilities for the removal of waste water from homes, business, and industrial buildings when waste water enters the treatment facility, impurities and contaminates are removed using physical, chemical and biological processes. The water is released back into the environment after treatment. For the protection of the environment and general wellbeing, the urban sewerage system is crucial infrastructure. It provides clean water for drinking, recreation and agricultural uses and has significantly decreased infections transmitted through water. However, due to aging and poor maintained, the system is susceptible to serious issues like leaks, backups, and overflows investment in the urban sewer system is there for essential for ensuring its efficiency and long term viability. It necessities adaptation to shifting climatic circumstances (Valley R. , 2006).

2.2 Source of Waste Water

Human excreta and worthless, fifty waste water are collectively referred to as liquid waste and they are typically collected from septic tanks and pit latrines. In the city of branch sub city, there are several sources of liquid waste as well. The main among them are the waste from latrines and septic tanks in residential, institutional, commercial and industrial institutions hotels restaurants, shops and organizations. The waste water produced by homes includes waste liquid that flash into sewers from toilets, baths, showers, kitchens and sinks .sewage in many places also contains liquid waste from business and industry. The Addis Ababa water supply and sewage authority is responsible for maintain the sewage system in Addis Ababa (MWIE, 2018).

Depending on the type of collecting system employed the components (sources) that makeup the waste water flow from a community may include the following (S.K Garg, 2008).

2.2.1 Domestic (Sanitary) Sewage

Residential, commercial, industrial and other comparable facilities wastewater discharges. The majority of municipal waste water treatment facilities release effluent in to rivers, lakes, or oceans. Increased nutrient levels encourage the growth of algae which use oxygen levels in rivers can affect aquatic life.

2.2.2 Industrial Sewage (Non-Domestic)

Industrial wastes are primary presents in the waste water. Prior to releasing their effluent either directly in to surface waterways or into municipal sewer systems for additional treatment, several industries offer pretreatment. The effects on people and the environment that follow when industries are allowed to release their effluent without sufficient pretreatment are often observable in many nations.

2.2.3 Storm Water

Runoff from precipitation and snowmelt. Runoff from open ground and impermeable areas such as paved streets, parking lots, and buildings, during rainfall and snow events produces storm water discharges. Although it is typical practice to release storm water runoff through a single put fall pipe, such discharges are actually better categorized as nonpoint pollution sources storm water runoff typically contains contaminates in high enough concentrations to have a negative impact on the water quality,. Best management practices are the main mean of regulating the quantity and quality of storm water discharges.

2.2.4 Infiltration/Inflow

Water that both directly and indirectly enters the sewer system. Extraneous water infiltrations occur when it seeps into the sewer system through leaky joints, breaks and cracks, or porous walls. Rainwater that enters the sewer system through manhole covers, roof leaders, foundation and basement drains, or storm drain connections (catch basins) is referred to as inflow

2.3 Waste Water Collection Systems

Storm water from residential, commercial, institutional and industrial sources are both collected by combined sewers. Many older areas of large cities have these sewers. Waste water is released into receiving waters by old combined sewers. A separate sewer system is required to lesson or eliminate the pollution issues caused by combined sewers. Rainwater is often less dirty than waste water, therefore treating mixed waste water and rain water during periods of heavy rain is challenging, leading to untreated overflows(usually referred to as combined sewer overflows, or CSOs).mixed sewage is more difficult and expensive to treat. A separate sewer system seems most appropriate in a place like beach place where there are significant amounts of storms water inflows. According to (Choi, 2003), the following four waste water collection system options are described.

2.3.1 Convectional Gravity Sewers System

Traditional gravity sewers use gravity flow to move wastewater from high to low areas. They are made to maintain flow toward the discharge point without surcharging manholes or pressurizing the pipe by having the right slope and size. To collect and carry domestic wastewater convectional gravity sewers continue to be the most often utilized method. In addition to handling the grit and sediment in sanitary sewage, well designed systems can also maintain a minimum velocity that lowers the formation of methane and hydrogen sulfide. Deep excavations, the addition of pumping or lift stations, or both may be necessary to accommodate the need for a self-cleansing slope

As alternatives to traditional sewers, a variety of wastewater collection methods have been created. An alternate collection systems piping network can be installed in much shallower and smaller excavations. Additionally, they don’t have to be laid out in straight line or with a constant gradient. They can therefore be arranged out in a way that makes it simple to avoid difficulties.

2.3.2 Vacuum Sewers System

Waste water is removed using vacuum sewer systems from a holding tank. Vacuum valve inside the holding tank opens when the waste water reaches a predetermined level, allow in the tanks contents to be sucked into the collection system of pipe work. A. vacuum station at a central location creates the vacuum inside the system. Small structures known as vacuum stations contain a sizable storage tank and a network of vacuum pumps.

2.3.3 Pressure Sewers System

Pressure sewers use the pressure force supplied by pumps to deliver waste water to a central location from each property. A pressure system is a small diameter pipeline (typically 100mm), shallowly buried, and following the contour of the land. The systems eliminate the need for lift stations of a convectional system and also infiltration is eliminated because manholes are not required, thus piping materials are not exposed to ground water fluctuations. There are two types of pressure systems distinguished by the type of pump used.

2.3.4 Small Diameter Gravity Sewers System

Small diameter gravity sewers merely transport the waste water and perform primary treatment at each connection. This system is comparable to STEP system in that residents would still be responsible for maintain their current septic tank. The flow is separated from grit, grease, and other bothersome solids that could choke collector mains, and these materials are retained in septic tanks. Each tanks effluent is gravity-fed into the collection sewer because solids are not moved through the system; the needed velocity is lower in sewers. As a result the pipes don’t need to be as big or as sloped.

2.4 Types of Sewerage System

The science and practice of collecting, processing and disposing of sewerage is known as sewerage. The complete system used for the collection, treatment and disposal of liquid waste is known as the sewerage system. This applies to all sewage disposal infrastructures such as pipes manholes and buildings (Steel & McGhee, 1979).

This modern water conveyance sewerage system helps in both the removal of storm water runoff as well as the removal of residential and industrial waste waters. Storm runoff is occasionally carried through the sewage system, or more commonly it is carried by a distinct system of drains (open or closed) that discharge their drainage into body of water like a lake or a river. no treatment is necessary for the drainage discharge because rain runoff is not as bad as sewage. Sewerage system’s typically come in three different flavors (S.K Garg, 2008).

2.4.1 Separate Sewerage System

In this system two different sets of sewers are used to transport sanitary sewage and storm water. Storm water is dumped into rivers untreated while the sewage is sent to waste water treatment plant.(WWTP).the separated system is appropriate when there is a specialized storm sewer outlet that is only used during the rainy season. In dry season, waste may clog it. The cost of upkeep is higher because there are two sets of sewers installed. Due to the difficulty of lying two sewers in tight roads traffic suffers greatly while repairs are being made (Rauch & Mikkelsen , 2006).

There are always a chance that storm water will get into sanitary sewer and overflow, putting a lot of strain on the treatment facility. Separate sewerage systems are the type of sewer systems used throughout Addis Ababa.

2.4.2 Combined Sewerage System

This system transports both sewage and storm water to the waste water treatment plant (WWTP) for treatment and eventual disposal in a single system of sewers. The topography allows storm water to be disposed of into natural drains and water is readily available. Simply put, it is not viable economically to build capacity for this flow along the entire length of the sewers. Additionally, the treatment operations at the treatment facility would not be able to accommodate this capacity. Therefore, the solution is to install sewer system structures that direct flows above a certain level away from the sewer system and into unnatural watercourse during medium or heavy rainfall. Combined sewer overflows, or CSOS are the name given to these constructions.

The primary purpose of a CSO is to take in storm water and wastewater during periods of rainfall. Portion of the flow is kept in the sewer system and goes on to the treatment facility. The CSOs setting, which refers to the quantity of this flow, is crucial feature. The remainder, often known as the “spill flow”, overflows into the river.

2.4.3 Partially Separate Sewerage System

This system is the compromise between separate and combine system taking the advantage both systems. A form of drainage system known as a partially separate sewerage system divides of waste water into two flows; surface water and wastewater. Urban regions have the system installed to handle the large amounts of water during heavy rains. This system, the wastewater is transported via pipes to treatment facility. Surface water, on the other hand, travels through a different pipeline and is released into a natural water sources including rivers, streams and lakes for managing both surface water and foul water in cities, accost effective option is offered by the partially separate sewerage system. It lessens the probability of sewage overflows, flooding and water source pollution.

2.5 The Patterns of Collection Systems

For the collections and disposal of sewage a network of sewers to be laid. The pattern of sewer layout system depends on the following factors. The sewerage system adopted whether combined, separate or partially separate system. The area to be drained location of disposal point and the topography and hydrological feature of the area. According to (Arshad, 2018). The following are most common among the various patterns of collection system.

2.5.1 Perpendicular Pattern

In this pattern number of sewers are laid in such a way that each reaches to the respective outfall point through the shortest route. The sewers are useful for carrying storm water in separate system; otherwise the river will get polluted in several points. Some of the characteristics of perpendicular pattern sewer layout are

- Suitable for separate systems and partially separate system
- Not suitable for combined system
- Treatment is difficult due to many outlets
- Pollutes the water of natural course

2.5.2 Interceptor Pattern

A number of main sewers are installed in this system, each one serving separate zone. Big size intercepting sewer connects the mains at their outfall ends once more, transporting the sewage to a pump house of treatment facility. At the intersections of main sewers, intercepting sewers maybe equipped with overflows that will transport more, less polluted storm water to rivers. Typically, a large sized sewer is created to intercept sewers and bring sewage to a common location where it can be disposed of with or without treatment.

2.5.3 Radial Pattern

This pattern is applied for sanitary sewage in areas where the areas center is elevated and slopes downward continuously toward the edges. Only in situations when there are numerous disposal locations accessible may this layout design be used. Sewers are laid radically outwards from the city center in this way, and there are several outlets available. It is cost effective to serve suburbs with relatively short and compact sewer lines. This patterns' drawback is that it necessities a lot of disposal effort.

2.5.4 Fan Pattern

With this layout, sewers can be constructed so that all sewage flows to a single treatment facility at a common location (the outfall sewer).when natural topography slopes down toward an outfall point and short valleys form along a more or less central line, this type of system is employed suitable for partially separate systems as well as mixed systems. It benefit is that it offers treatment in a single unit. The downside is that the main trunks are enormous and that suburban expansion is constrained by the rise in loads it might contaminate natural water sources.

2.5.5 Zone Pattern

Because the full amount of sewage is collected and transported using just one huge intercepting sewer in the interceptor pattern. It is overloaded. When there are various zones with various heights this pattern is used. Here, a number of intercepting sewers are placed accordance with the zones elevations. Storm overflows are immediately dumped into the river, but sewages is transported to a central location for treatment. In combined flow, this type of system is advantageous.

2.6 Components of Sewerage System

In order to transport sewage from individual residence to the sewage treatment plant, network of sewer pipes is installed. House sewers (or individual house connections), lateral sewer, branch sewers (or sub mains), main sewers (sometimes refers to as trunk sewers), and outfall are all possible components of this sewage network. Sewer(the sewer that carries sewage to the place where intervals to make cleaning and inspection easier. in order to prevent widespread water source pollution and to maintain clean water supplies, inlets known as catch basins are built in the sewers that convey drainage discharge either alone or in conjunction with sewage (S.K Garg, 2008).

2.7 Layout of Sewerage System

Setting out the overall system layout which includes a map of the area to be sewed roads streets, buildings, other utilities, topography, soil type, and the cellar or lowest floor elevations of all buildings to be drained, is the first step in panning a sewage system. Care must be made to install appropriate terminal manholes that can subsequently be connected to the system built serving the region when apportion of the drainage area to be served is undeveloped and proposed development plans are not yet available (AL Ashhab & AL Halawani, 2008).

2.8 Performance Assessment of Sewer System

Sewage is processed and used in a sewer system collectively with the sewage and human waste that are discharged, processed and used. As a result, sewer system reduces flooding, enhance the quality of life and regulate water quality. In order to transport sewage away from the living area, a sewer is buried underground. Depending on how the sewage is discharged, the sewer system is categorized as either separate sewer or a mixed sewer system (Mugambi, 2014).

In separate sewer system, sewer pipe is divided from a storm water pipe so that only sewage can be treatment facilities. Since sewage is not released into rivers during rainfall, this increases the operation efficiency of treatment plants and aids in controlling the water quality. The disadvantages of this method, however, include the fact that the heavily contaminated initial storm water is immediately released in to rivers, the sewage pipes is buried underground, and the complexity is increased by building two different types of pipelines. On the other hand in a combined sewer system sewage and storm water are both delivered in the same pipe. By using this separation technique it is possible to collect some initial storm water let storm water clean the pipelines and lessen the complexity of a pipe network. The usage of combined and separate sewer systems depends on the circumstances because combined sewer systems result in a combined sewer overflows (CSO) which pollute rivers and because the gather a lot of storm water which reduces processing efficiency at treatment facilities (Rauch & Mikkelsen , 2006).

2.9 Performance Indicators of Sewer System

Development of a centralized water conveyance sewer system, its influence over elected officials could. These sewer system performance indicators are crucial for ensuring the system runs effectively. For the sewer system to function properly, the flow rate, level, and velocity of sewage must be monitored. To prevent clogs and overflows, it's crucial to consider the amount of sewage processed and the concentration of solids in the sewage. To make sure that the water is safe to release into the environment, the effectiveness of the sewage treatment process should be evaluated. To guarantee that the sewage is delivered to the treatment plants without delay, regular inspections of the pipe's condition and integrity are necessary to prevent leaks and breaks (Viklander & Hedstrom, 2020).

Sewer system performance indicators are crucial for guaranteeing efficient wastewater management and environmental protection. The performance of sewage systems can be monitored using the key indicators listed below:

2.9.1 Flow Rate of Sewer System as Performance Indicator

The flow rate is a critical performance indicator for any sewer system. It helps in identifying potential issues and optimizing the system design for optimal efficiency and it's also efficiently the sewage is being transported through the pipes. It represents the volume of wastewater that is flowing through the system per unit time. A high flow rate indicates an efficient system, whereas a low flow rate suggests a clogged or malfunctioning system. In essence, the flow rate determines the capacity of the sewer system. Engineers use the flow rate data to design and optimize the system to ensure that it can handle the maximum amount of wastewater that it is expected to receive (Mattsson, 2015).

2.9.2 Pipe Capacity (d/D Ratio) as Performance Indicator

A sewer system's capacity is calculated by its d/D ratio, where D is the pipe's diameter and d is the effective depth of flow. The system has more ability to handle wastewater when the d/D ratio is higher. A high d/D ratio also indicates that there is less chance of debris clogging the sewer system. Calculating the pipe size and D/d ratio accurately is crucial to ensuring a sewage system's maximum capacity. Based on elements such soil type, slope, and the location of laterals, this computation can be made. Blockages and overflow incidents are less likely in an effective sewer system with the right D/d ratio. A sewage system's capacity or D/d ratio is essential for minimizing blocks and maintaining efficient wastewater management. Homeowners and governments can take proactive measures to maintain the performance of their sewer system by being aware of the significance of this ratio (Valley R. , 2006).

2.9.3 Infiltration and Inflow of Sewer System as Performance Indicator

Important performance indicators for a sewer system include infiltration and inflow. Water that enters the sewer system through manholes, leaking service connections, or other sources is referred to as inflow, whereas infiltration happens when groundwater seeps through fractures or breaches in the sewer pipes. Both infiltration and inflow have the potential to overburden the sewer system, resulting in backups, overflows, and other functional problems. Sewer administrators can increase the effectiveness and dependability of their systems by monitoring and lowering infiltration and inflow. To recognize and resolve infiltration and inflow problems, a variety of techniques can be utilized, including smoke testing, flow monitoring, and sewer rehabilitation. Infiltration and inflow control are high priorities for many cities and towns due to the potential for large economic savings and environmental advantages that can be achieved through successful management of these elements (Saletti, 2021).

2.9.4 Blockages of Sewer System as Performance Indicator

Especially if they are not discovered and resolved promptly, sewer a blockage can be a major issue. In addition to flooding and property damage, they can also produce unpleasant odors. Grease buildup, tree roots, and foreign objects are just a few of the items that might clog the sewer system. A good performance indicator for sewer systems is to keep track of how frequently and severely blockages occur. Municipalities can actively prevent blocks from occurring in the future by detecting trends and patterns in them (Alshami , Elsayed , & Kineber).

2.10 Performance of Sewer Network Modeling

Networks of sewer pipes should function with little or no disruptions. The expense of operation and maintenance is significantly increased by the complicated nature of breakdowns in sewer networks that happen at random and are caused by blockages. Blockages are important because they occur as a result of sewage backup or basement flooding. Sewer pipe networks must therefore continually be evaluated for performance in order to maintain the appropriate service levels at a reasonable cost (Alshami , Elsayed , & Kineber).

The relative relevance weights of pipes and manholes are taken into account when calculating the total sewer network performance, as previously demonstrated. A criticality analysis for manholes and pipelines in the sewer network is used to achieve this. The full evaluation of a sewer network as a whole hasn't gotten much attention in the literature. The procedure for determining the grade is still unclear, despite the fact that various report cards are released to inform the community on the general grade and state of infrastructure components. Several municipalities and agencies also use the mean value of all conditions to represent the performance of the sewer network as a whole (Alshami , Elsayed , & Kineber).

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2.10.1 Dry Weather Flow

The basis of hydraulic sewer models is accurate estimation of wastewater collection system flow rates. Sometimes these flow rates are referred to as loads or demands. In a model, flows are assigned to nodes (sometimes referred to as loading points) that reflect sites where flow enters the system or are divided along the length of the pipe. The sewer system's flow is unaffected by precipitation. It equates to the wastewater generated by homes in the area covered by a virtual tank in an urban sewer system. It typically makes up very little of the overall flow during any rain storm. However, it is crucial to consider it because it is the source of polluting agents that could spill in the event of an overflow (Ane Høyer & Miguel, 2023).

2.10.2 Over Flow of Sewer

Untreated sewage from sanitary sewer collection systems overflows into streets, homes, basements, and receiving waters. This is known as a sanitary sewer overflow (SSO). SSOs are likely to happen when sewer carrying capacities are lowered due to obstructions or when flows are substantially higher than a sewer's design capacity.

When flows are strong because of inflow and infiltration (I/I), SSOs are often most common during and immediately after wet weather. Along with I/I, other variables that contribute to SSOs include non-wet weather-related debris, grease buildup, sedimentation, and sewage obstructions caused by root intrusion. SSOs typically have high concentrations of harmful contaminants, pathogenic bacteria, suspended particles, floatables, nutrients, oxygen-demanding organic materials, oil, and grease (Salinas, 2021).

Among the many effects of SSOs are the following: (1) closure of beaches and recreational areas; (2) prohibition of fishing and shellfish harvesting; (3) risks to public health from raw sewage in basements, drainage ditches, and surface waters; (4) inhibition of potential development from sewer connection moratoriums; and (5) financial liability of a community from PR issues. Sanitary sewer overflows (SSOs), which occur when a pipe is blocked and raw sewage wastewater leaks out of a manhole or other facilities are the main cause of worry for collecting systems. Grease buildup and root infiltration are the two main causes of SSOs. Sanitary sewage overflows can also be caused by numerous other factors, including vandalism, lift station failures, pipe failures, and debris (Salinas, 2021).

2.10.3 Inflow and Infiltration (I/I)

Surface water known as inflow generally enters the sewer system through perforated or open manhole covers during heavy downpours. Water entering the collection system from the ground through damaged pipes, pipe joint connections, or manhole walls is known as infiltration. These extraneous flow components, which ineluctably become a part of the total flow, must be allowed for in the sewer system design capacity.

The availability, sufficiency, and location of storm water drainage facilities, the age and condition of buildings, the materials and methods of construction, the location of the groundwater table, and the characteristics of the soil all play a role in determining how much inflow and infiltration (I/I) enters the system. Many regulatory agencies use generally known techniques for estimating I/I in the absence of flow monitoring data. For the purposes of this study, the peak wet weather flow formula mentioned above includes extraneous flow resulting from inflow and infiltration. The study will be revised in consideration of newer data if it becomes available later for particular places (Valley R. , 2006).

2.10.4 Surcharging

Sewer surcharging normally happens when the hydraulic grade line (flow line) rises over the top of the pipe during high-flow or flooding situations. Different sewer systems have different surcharge designs. Surcharging can also happen if a sewage pipe is partially obstructed by an obstruction or has collapsed. Surcharging typically happens at low spots in the system under heavy wet-weather loads with extra inflow and infiltration upstream. The hydraulic grade line and the pipe crown are compared in the model to estimate the magnitude of the surcharge. Wastewater flows in a surcharged state if the hydraulic grade line (indicated in manhole A) is between the top of the pipe and the elevation of the ground. An overflow happens if the hydraulic grade line is higher than the manhole's (manhole C) rim height. The overflow volume will be calculated by some models (Walski, et al., 2007).

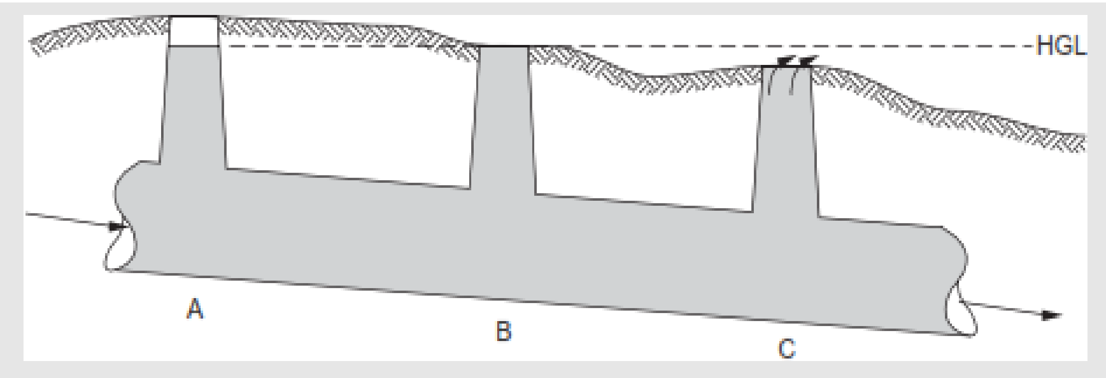

Figure 2: 1 Surcharge of manhole (Walski, Thomas E., Eric, LaVere B., Noah, & Brian E., 2007)

2.11 Problems of Urban Sewer System

An integral component of any urban infrastructure that is frequently disregarded and neglected is the sewer system. In order to ensure that wastewater is gathered and sent to authorize disposal places, the sewer system is crucial. However, issues with the sewer system provide a difficult task for many city planners and may have an impact on the populace's health and safety. Aging infrastructure, obstructions, and overflows are just a few of the causes of sewer system issues. Blockages in the sewer system brought on by trash, pipe damage, or incorrect materials flushed down the toilet are among the most frequent issues. Blockages result in sewage and water backing up into buildings, which damages them and poses a major health danger (Patil & Kadam , 2019).

Infiltration and inflow are two more typical sewer system issues. This happens when rainfall or groundwater leaks into the system through pipe breaks or perforations. System overflows and backups may result from this overloading. Additionally, it can lead to the discharge of raw sewage into neighboring rivers. Sewer system issues can be expensive to repair and seriously interrupt daily living. Numerous issues can be avoided with routine upkeep and rapid repairs. If you think there might be an issue with your sewer system, it's crucial to call a qualified plumber or sewer system specialist (Saletti, 2021).

2.11.1 Overload on Sewer System Problem

In many urban locations, sewer system overload is becoming a serious issue. The problem occurs when a sewer system's capacity is exceeded, causing sewage to overflow and to pollute nearby rivers. As cities become more populated and weather patterns change, this issue has become more prevalent.

The rise in urban population density is one of the main reasons of sewer system overflow. There is an increase in the production of waste and sewage as cities get denser. To meet the strain, larger and more comprehensive sewer systems are required. However, many older communities have outdated sewer systems that are overloaded because they were not built to manage the current population density (Patil & Kadam , 2019)

2.11.2 Dynamics of City and Sewer System

Maintaining a city's sewer system is crucial to keeping its residents healthy and clean. The sewer system is crucial for trash removal and disease prevention. Effective management is required to prevent obstacles and backlog that could need costly and dangerous cleanups. City planners must consider the type of sewage treatment facilities required the collection and transportation system, as well as the equipment and personnel needed to maintain the infrastructure. For the system to stay in good shape, regular monitoring, upkeep, and upgrades are required (Patil & Kadam , 2019).

2.11.3 Deficiency Location of Sewer System

It is necessary to identify the sewer system's flaws. This is an essential situation that needs to be handled right away. It is essential to locate the trouble spots and fix them because of the rising population and strain on the sewer system. Accurately pinpointing the faults is crucial to ensuring the sewer system runs without a hitch. This activity can be completed using a variety of techniques, including inspection, smoke testing, and dye testing. A camera is inserted into the sewer line as part of the non-destructive inspection process to record images of the interior of the pipe. Another method is smoke testing, which includes injecting smoke into the sewer system to find any pipe leaks (Valley, 2013).

2.12 Causes for Overflow of a Manhole in the Existing Sewer Network

There can be several causes for the overflow of a manhole in an existing sewer network. Some possible causes include:

Blockages: One common cause of manhole overflow is blockages within the sewer pipes. Blockages can occur due to the accumulation of solid debris, grease, tree roots, or other foreign objects. When the flow of wastewater is obstructed, it can lead to a backup and subsequent overflow at the nearest manhole.

Infiltration and Inflow (I&I): Excessive infiltration of groundwater or inflow of stormwater into the sewer system can overwhelm the capacity of the pipes and cause overflow. Cracks, leaks, or deteriorated joints in the sewer pipes can allow groundwater or stormwater to enter the system, contributing to the overflow of manholes.

Insufficient Capacity: If the sewer network is undersized or unable to handle the volume of wastewater generated by the community, it can lead to overflow at manholes. This can occur in areas experiencing rapid population growth or urban development, where the existing sewer infrastructure may not be adequately designed to accommodate the increased flow.

System Damage or Deterioration: Over time, sewer pipes can deteriorate due to age, corrosion, or other factors. This can lead to structural damage or collapses, causing blockages and subsequent overflow at manholes.

Design or Construction Deficiencies: Poorly designed or constructed sewer systems can contribute to manhole overflow. Inadequate slope, insufficient pipe diameter, or improper installation can impede the flow of wastewater and lead to backups and overflows. It's important to note that the causes of manhole overflow can often be interconnected. Addressing these issues requires a comprehensive approach that includes regular maintenance, capacity assessments, infrastructure upgrades, and stormwater management strategies to ensure the reliable and efficient operation of the sewer network.

2.13 Improvement of the Sewer System

Sewer system improvement is essential for a community's health and wellbeing. We prevent the spread of dangerous diseases and safeguard our environment by making sure wastewater is moved away from residences and businesses effectively and efficiently. We must evaluate the current infrastructure and pinpoint areas for improvement before we can upgrade sewer systems. In order to do this, it may be necessary to upgrade old pipelines, expand available space to accommodate expanding populations, and put new technologies in place to decrease leaks and enhance water quality. Public education programs can also assist decrease the amount of dangerous substances in our sewage and increase awareness of the significance of proper waste disposal. We can enhance public health and build a safer, more sustainable future for all by making improvements to our sewer systems (Salinas, 2011).

2.14 Feasible Improvement Measures of Sewer System

There are several feasible improvement measures that can be taken to improve the sewer system. The first is capacity improvement, o ensure adequate wastewater disposal and avoid overflowing, and sewer system capacity improvement entails increasing the capacity of current sewer systems or constructing new ones. The main goals are to increase the sewer system's overall performance and raise sanitation and public health standards. Improvements in sewer system capacity can be made through a variety of techniques, such as utilizing smart technology, expanding the capacity of sewer lift stations, planning and constructing additional sewer pipelines, and implementing cutting-edge wastewater treatment techniques. In general, increasing sewage system capacity is an important part of developing urban infrastructure since it ensures that untreated wastewater doesn't contaminate our water sources, protecting the environment and the general public's health (Valley R. , 2006).

The second measure is to clean and inspect the sewer lines regularly. This will help to identify any blockages or leaks before they become major problems. The third measure is to infrastructure upgrades by conducting a comprehensive assessment of the existing sewer infrastructure is crucial. This includes identifying areas with deteriorating pipes, undersized pipes, or outdated components. Upgrading these components with modern materials and technologies can improve the structural integrity and overall performance of the network. The fourth measure is to reduce the amount of infiltration and inflow into the system. This can be done by repairing cracks in pipes and manholes, installing backflow prevention devices, and reducing the amount of stormwater runoff entering the system. The fifth measure is to increase public awareness about how to properly dispose of household items such as wipes and cooking fats. These items can cause blockages in the sewer system and lead to major problems (Valley, 2013).

The final measure is to implement a sewer asset management program. This will help to improve the overall operation and maintenance of the sewer system. It will also help to prioritize improvements and ensure that limited resources are being used effectively. By implementing these measures, the sewer system can be improved to better serve the community and minimize environmental impacts. The final measure to improve the sewer system is to put in place a sewer asset management program. This program will enable the maintenance and operation of the system to be done more efficiently and effectively. It will also allow for an improvement in the prioritization of necessary improvements, ensuring that resources are used in the most effective way possible. These measures will have a positive impact on the community, as the system will be able to operate to its full potential, while reducing any negative environmental impact (Valley, 2013).

2.15 Sewer Network Capacity Evaluation

The hydraulic model of the sewer system is used to evaluate the effectiveness of the current system. The model may assess how well the system functions under various future expected flow scenarios in addition to assessing how well it functions in dry weather conditions now. A collection system's capacity and overall operational difficulties must be evaluated when it is dry outside. To help with the identification of potential issue regions caused by these causes, the model provides some generic information. The sewer system's potential trouble spots can be found using the hydraulic model. To determine the significance of the overflow, surcharged and overcapacity locations are examined (Salinas, 2011).

2.16 Wastewater and Sewer System- Addis Ababa

2.16.1 Waste Water Service in Addis Ababa

The Addis Ababa wastewater service was initially established centrally in 1928ECby trucking septic tank wastewater out of the city and dumping, it near repi on the banks of rivers. Sewage treatment facilities were built by the Addis Ababa water and sewerage authority to handle influent from sewage lines and vacuum trucks. Sewage treatment facilities are divided into two categories, centralized treatment facilities and dispersed treatment facilities. Bole lemi (Bole kotebe) waste water treatment plant and Kality waste water treatment are both part of the centralized treatment facility. The locations where Mike Leyland, Gelan, Gerjj, Hayatchefe, and bole houses are located are where the decentralized waste water treatment facilities were built (AAWSA, 2016).

2.16.2 Development of Sewer System Addis Ababa

The Kality waste water treatment plants construction was finished in 1981GC.the plants design capacity was around 7500m3/day with a 3500kg/day biochemical oxygen requirement load. The Kality waste water collection system was created to service an equivalent population of 200,000 based on a 150L/capita average water use.

Initially, only small portion of the Kality sewer catchment was covered by the sewer network. These areas included bole, Lideta, the old airport, the central part of the city, the Mekanissa and Kera area and more recently, Megenagna and the condominium buildings throughout the city, which were either connected to the city's existing central sewerage treatment or to their Respective localized treatment sites. However there are not many condo buildings in the eastern catchment served by the Kotebe waste water plants Hayat and summit area. The sewer network is situated in the Kality catchment and it consists of 450 km of laterals and secondary sewers in addition to approximately 75km of trunk sewers. About 13000 people were now using the system and another 27000 people or the equivalent of 27000 persons, were connected, as Gotera (12,500), Gofa (27000), and others (AAWSA, 2016).

2.16.3 Sewer Network Coverage and Service Area of Kality Catchment

The central Kality area was the focus of the sewerage network building in previous years. Kirkos, Lideta, Arada, and portions of bole and Yeka are among the sub cities that are already part of a core network that is served by the Kality WWTP. The Nifas silk network is still being built. With the WWTP serving as a base, the network is extended to the north and North West. The design of the network for Addis Ketema and apportion of the Kolfekeraniyo sub cities was just finished and the network is currently being built in Nifas silk lafto (ECDSWC, 2021).

2.17 Urban Land Use Change Conceptual Framework –Addis Ababa

Urban land use is one of the elements of an urban design, along with infrastructure, housing, open space, and road and transportation. The main causes of land use changes in urban areas are urbanization, population expansion and economic growth. Because anthropogenic influences cause land use to be dynamic and alter across time and space. The maps of Addis Ababa classified land use and land cover from 1986, 2000and 2010 are shown here. Built up areas are indicated by the darker tint. On the city's land use and land cover map from 1986, the northern and north western portions were dominated by forests, while the Southern, southeastern, and northeastern portions were dominated by crop and grasslands the middle portion was the only place that was heavily populated. The increase of populated regions and the reduction of forested lands are clearly depicted on the land use and land cover maps from 2000 &2010 (Kasa, 2011).

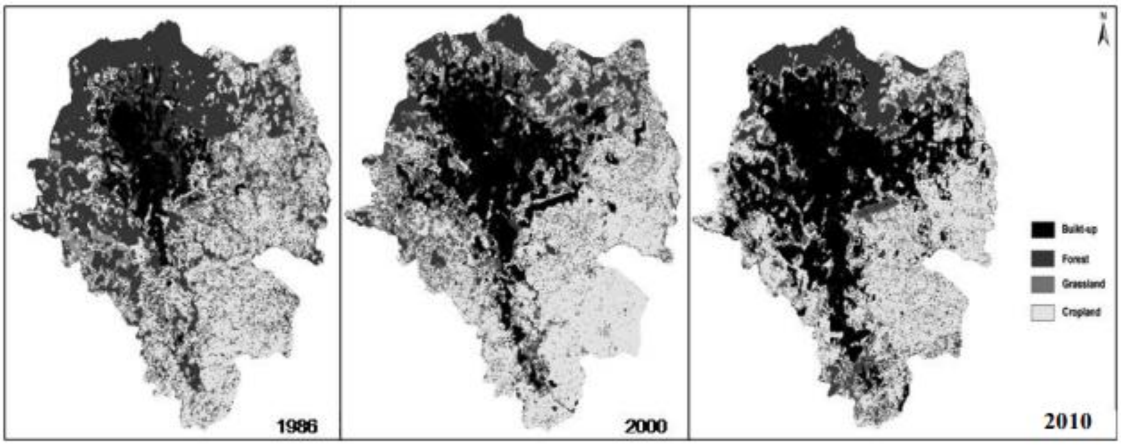

Figure 2: 2 Land use/land cover of Addis Ababa city in 1986, 2000 and 2010

Land uses in Addis Ababa range from agriculture to densely populated business centers. Planning for future natural resource management strategies requires important information about changes in land use and cover. World Bank Group 2021 claims that Addis Ababa is expanding and that built-up areas are expanding more quickly than both the population and the patterns of land usage. The Addis Ababa LULC trends from 1990 to 2003 revealed that while bare land and built-up area rose, grassland, agriculture, and vegetation land cover class decreased by 8.7%, 0.6%, and 0.4%, respectively. The dynamics of change between 2003 and 2020 applied to various LULC classes and the land use and land cove look like give below (Moisa & Gemeda, 2021).

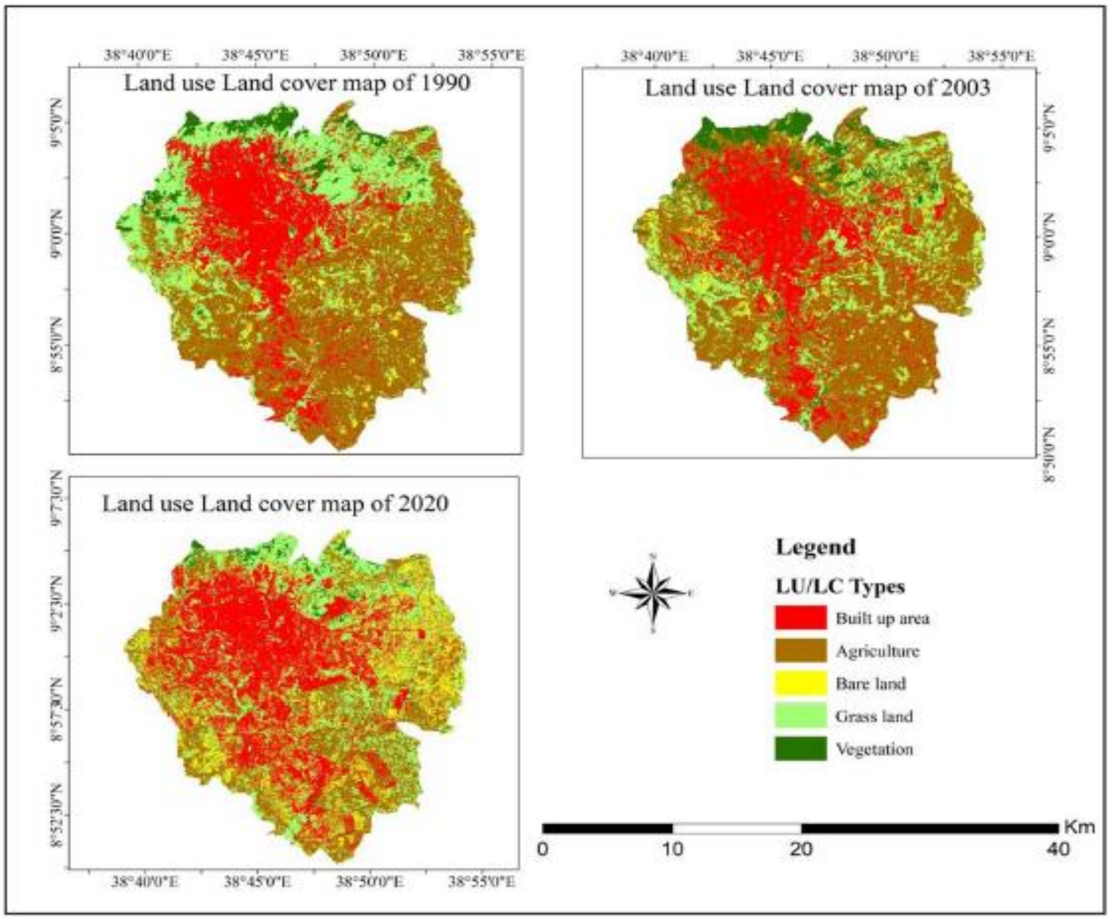

Figure 2: 3 Land Use Land Cover of Addis Ababa

2.17.1 Land Use City Planning and Infrastructure– Addis Ababa

The Addis Ababa Wastewater Master plan was prepared in 2002, which is an update of the 1993 Master plan, provided a sanitation plan for the city to the year 2020. This plan is now outdated. The New **Addis Ababa City Structure Plan (2017–2027)** is a legally binding technical, institutional, and administrative framework for directing the long-term social, economic, environmental, and geographical development of the city and its environs. Land use planning, sub-center development, transportation and roads, social and municipal services, housing, social and local economic development, industry, environment, agriculture, and tourism are all taken into account in this framework (AACSP, 2019).

The Structure Plan intends to enhance sanitary sewer system coverage, increase the amount of residential wastewater that is treated, and decrease water pollution from point and non-point sources in order to prevent continued pollution of surface and groundwater resources. By 2027 and 2040, respectively, the plan is for installing sewerage systems that can serve 70% and 100% of the population, respectively. A daily wastewater treatment capacity of 400,000 m3 for Addis Ababa. It is suggested to reach 500,000m3/day by 2027 and 1,000,000m3/day by 2040. To decrease the number of industrial discharge points and prevent the connection of industrial effluent to the municipal wastewater system, separate centralized WWTPs for industrial parks are advocated (AACSP, 2019).

The city is running out of undeveloped land, according to the Structure Plan, and there is not much room for horizontal development. It is encouraged to use land intensively. **Low and medium density** residential areas will have **a minimum gross density of 50 and 100** dwelling units per hectare, respectively, while **high density** mixed residential areas will have **a minimum gross density of 150 hu/ha**. In order to relieve pressure in the crowded city core, the Structure Plan encourages polycentric development and suggests major sub- and secondary centers inside the city (AACSP, 2019).

2.17.2 The Change of Land Use and Land Cover in the City - Addis Ababa

During the study period, the built-up area rose by 5.04 km2 year whereas the area covered by forests decreased by 5.20 km2. However, between 2000 and 2010, the rate of the forest cover's downward trend dramatically decreased. This might be explained by the enhanced tree-planting operations carried out in the city. Grass and farmland both had a diminishing trend. Croplands in particular displayed a large negative growth. The findings revealed that built-up areas are expanding at the expense of crop and forest lands (Kasa, 2011).

2.17.3 Impact of Land Use Change on Sewer System

The separate gravity sewer system is significantly impacted by changes in land use in developing countries like Ethiopia. The sewer system has been under pressure due to the growth of urban areas and population, which has negatively impacted public health and the sustainability of the environment. Sewers get overwhelmed as land is transformed from agricultural to residential or commercial usage, resulting in obstructions or overflows that can contaminate water supplies and spread illness (Rauch & Mikkelsen , 2006).

Additionally, a change in land use may change the location's topography, which may have an impact on the drainage pattern and wastewater flow. As the sewer system was created to operate under specific topographic and hydrological conditions, this could result in it malfunctioning. Land use planning and the construction of sanitation facilities must be combined in developing nations in order to address these problems. Communities can lessen the effect of land use change on the sewer system by supporting sustainable land use practices. In regions where the sewer system is inaccessible or would be too expensive to build, decentralized wastewater treatment systems, (Mattsson, 2015).

2.18 Fundamental Principles of Network Hydraulics

2.18.1 Conservation of Mass

According to the conservation of mass principle matter cannot be generated or destroyed. The amount of mass entering and leaving a system is equal, plus or minus the mass that has accumulated (or been destroyed) there. The storage S $(t+\Delta t)$ of fluid in the fixed location at the end of the time interval (that is, at time $t+\Delta t$) is equal to the original contents plus the additional fluid that entered during that time, less the quantity of fluid that departed during that time, according to the principle of conservation of mass (Walski, et al., 2007).

This is expressed mathematically as

$S(t+\Delta t)=S(t)+I(t)\Delta t-Q(t)\Delta t$………….(2.2)

Where t=time(s)

S $(t+\Delta t)$ =storage at the end of the time interval (ft., m3)

S (t) =storage at the beginning of the time interval

I (t) =volumetric inflow rate at time t (ft., m3)

Q (t) =volumetric outflow rate at time t (ft. m3)

A volumetric flow rate typically denoted by Q is referred to as a discharge in hydrologic and hydraulic engineering

2.18.2 Conservation of Energy

According to this law the rate at which heat energy is added to a system is equal to the rate at which the system performs work on its surroundings minus the rate at which heat energy is contributed to the system. In atypical sewage flow the stored energy is made up of internal energy, potential energy resulting from the fluids position in relation to an arbitrary datum plane and kinetic energy from the fluids motion. Since the expression that is used most frequently describes energy as energy per unit weight of a fluid (i.e per kilogram of fluid), the difference in energy between two points 1&2 is given by (Walski T. M., 2007) as written given below

$$\frac{p_1}{r} + Z_1 + \frac{\alpha_1 {V_1}^2}{2g} = \frac{p_2}{r} + Z_2 + \frac{\alpha_2 {V_2}^2}{2g} + h_{L-} h_{P+} h_T$$

Where P=fluid pressure (Ib/In, kpa)

ɣ=specific weight of the fluid (Ib/ft3, N/m3)

Z=elevation above an arbitrary datum plane (Ft, m)

A=velocity distribution coefficient

V=fluid velocity averaged over across section (ft. /s, m/s)

G=gravitational acceleration constant (ft. /s)

Hl=energy loss between cross sections 1 and2 (ft., m)

Hp=fluid energy supplied by a pump between cross sections1 &2(ft., m)

Ht=energy lost to a turbine between cross sections 1&2(ft., m)

The internal energy caused by a fluid pressure ,the potential energy caused by the fluid elevation the kinetic energy are each represented by the first three terms on each side of the equation is an average cross sectional velocity is employed the velocity is employed head terms on each side of the equation if an average cross sectional velocity is employed the velocity head terms in the above are corrected with the velocity distribution coefficient (a) because the velocities along different streamlines typically differ due to the impacts of pipe walls or channel sides.

2.19 Hydraulic Design Parameters

2.19.1 Design Capacity of Sewer

The quantity of waste water that needs to be transported is the primary design factor needed for sizing the sewer collection system. Local information is needed such as population data water consumption data, nondomestic water user's data and future growth plants in order to estimate the maximum amount of wastewater that may be collected from each service area (Mattsson, 2015).

Sewer design capacity when designing sewers hydraulically the depth of flow(d)must not be greater than 0.8 times the pipe diameter (D) or d/D=0.7at the maximum peak flow. This will guarantee appropriate airflow and stop simplicity, sewage is moving at a substantially higher velocity at this depth than when the sewers are fully loaded (Salinas, 2011).

2.19.2 Maximum and Minimum Velocities in Sewers

The hydraulics of flow in the sewers shifts from subcritical to supercritical or from supercritical to subcritical flow conditions depending on the slope of the sewers and the total inflows and outflows at the various sections of the sewers network. Whether the sewers experience subcritical or supercritical flows, the velocities of flows should be controlled between 0.6m/s and 3.0m/s in order to limit the adverse effects of organic and silt deposition, and scouring of the inner surfaces of the sewers that is in contact with the partial flow cross-sections. Excess velocity of flows exceeding 3.0 m/s also causes displacement of the pipe materials and slippage. At steep gradients, the maximum velocity of flow shall be limited to 4.6m/s for full flow condition (ECDSWC, 2021).

2.19.3 Roughness Coefficient

The range of acceptable n values for this formula is 0.013to 0.015.the pipe in portions longer than 1.5m with smooth inner surfaces, smooth bores, even joints, excellent to good condition, and well-constructed is considered to have the lowest n values

Older pipe having rough surfaces, open or protruding joints in fair to bad condition and poorly constructed is required to have higher n values. Values up to 0.017 are frequently acceptable for really deteriorated very ancient pipe(such brick or block sewers),or very badly constructed pipe with sags ,bellies, cracked or offset joints shattered wall portions, or interior corrosion. Some producers of asbestos and plastic cement pipes report n values ranging from 0.009to0.011.however n values less than 0.013 will typically not be allowed due to design and construction uncertainties, as well as a desire to provide a margin of safety experimental evidence on the variation of n with flow depth may be taken into account when building partially full sewers (Paul Guyer, 2010).

2.19.4 Sewer Slope

The slope for a circular sewer pipe must fall between the lowest and maximum slope which are defined by the minimum and maximum velocity. The technological and economical solution which is typically the exploitation of the natural ground slope is advised (AL Ashhab & AL Halawani, 2008).

2.19.5 Design Period

Any planning process needs to take the horizon year into consideration, and a well throughout and promptly built waste water collection and disposal system is no exception. the “design period “or the amount of time during which the proposed sewers will be able to adequately serve the anticipated population, is one of the first factors taken into account when predicting the sewage flow. The type of planning endower will determine the horizon, which is the end of a period and specified by a year. Long term (master plans), medium term (directory plans), and short term (crash programs) planning attempts are all used. However, the Kality Catchment sewage network design horizon gives particular attention to the current sewage line and it anticipated growth. For the analysis of existing Kality Catchment waste water collection system the current year data could be adopted (S.K Garg, 2008).

2.20 Urban Sanitary Sewer Models

2.20.1 Sewer CAD

SewerCAD is an easy-to-use sanitary sewer modeling and design software that thousands of municipalities and engineering firms around the world trust to design, analyze, and plan wastewater collection systems. The stand-alone interface offers unparalleled versatility with easy-to-use model layout tools, background support, conversion utilities from CAD, GIS, and databases, and unlimited undo and redo layout. The steady-state simulation analyzes the system under extreme flow conditions. Automated design features are available with a steady-state analysis type to find cost-effective sewer designs. The Extended Period Simulations allow modelers to visualize how the system behaves over time. Results can be animated through time to locate hydraulic jumps and surcharging sections. The design is flexible enough to allow users to specify the elements to be designed, from a single pipe size to the entire system, or anything in between, by simply entering their design restrictions: minimum and maximum velocities, covers and slopes; pipe and manhole matching offsets; allow (or not) drop structures. SewerCAD will automatically determine cost-effective pipe sizes and invert elevations avoiding unnecessary pipe trench excavation (Ravikiran K, 2016).

2.20.2 SWMM

It is a dynamic model for simulating rainfall and runoff that may be used for short-term or long-term simulations of runoff quantity and quality in mostly urbanized regions. The model keeps track of each sub's flow rate, water depth, and runoff amount and quality. It views a drainage system as a network of material and water movements between several significant environmental compartments. In general, the Saint-Venant equations control the flow routings through pipes and channels (Hlustik, 2017).

Each channel's and pipeline's simulation period is divided into many time steps. Maps of river basins, time series charts and tables, as well as statistical frequency studies, can all be used to present the results. The process of surface runoff and pollution is dependent on sub catchments that receive rainfall. Additionally, a system of conduits, manholes, storm water tanks, pumping stations, and treatment controls can be used to transport the runoff. The SWMM keeps track of each area's runoff's volume and quality. During the simulation, which consists of numerous time steps, it also keeps track of the flow rate, depth, and water quality in the different pipe and channel sections (Hlustik, 2017).

2.20.3 Sewer GEMS Editing Connection 10

The most sophisticated and effective program for analyzing and designing every component of a combined and sanitary sewer system in one package, after Sewer Cad stand alone and Sewer Cad V8i, is Sewer GEMs software. The Hasted and Bentley firms created a modified version of the Sewer Cad software. It has a wide range of functions, from simulating fire station discharge and water quality to computing energy costs and more complicated problems (Rai, 2020).

The first and only fully-dynamic system is SewerGEMS. It is a sanitary and combined sewer modeling tool that is built on many platforms (GIS, CAD, and Standalone). The SWMM technique or our own implicit solution of the entire Saint Venant equations are both options for doing the studies with SewerGEMS, which allows us to study all sanitary and combined sewer system components in one package. Improved Compatibility is provided by SewerGEMS. Additionally, it functions well across four distinct, well-known platforms, enabling evaluation of a single, shared project data source across all of them. These are the platforms: Windows stand alone for ease of use, accessibility, and performance (Sopariya & Patel, 2018).

Modelers can distribute sewer loads based on various GIS-based sources, such as customer water consumption billing data, flow measurement data for a specific area, and polygons with known populations or land uses, with the use of the Load Builder module. Users of SewerGEMS can also enter and save an infinite number of flow patterns, allowing them to precisely mimic flow fluctuations throughout the course of a day (Sopariya & Patel, 2018).

2.21 Sewer Model Simulation

Simulating is imitating the actions of one system using the operations of another. In this context, the use of a model, which is a mathematical representation of a real system, is referred to as simulation. Without interrupting the actual system, simulation can be used to forecast system responses to a variety of scenarios. This allows for the evaluation of potential solutions before time, money, and resources are committed to a real-world project. Depending on what the modeler is seeking to observe or predict, a model may execute one of two fundamental types of simulations. These are extended period simulation analysis and steady state simulation (Valley, 2013).

2.21.1 Steady State Analysis

At any location in the system, flows and boundary conditions in a steady-state model are constant in time. Although in reality flows change throughout the day, many analysis and design situations only call for a single, specific flow rate, such as the peak or minimum. It is then examined to estimate the required pipe capacity using this snapshot of the flow at the desired time (i.e., the time matching to design maximum flow rates). Different loading options may be used to model existing systems, depending on the model's intended use. The loading in a steady-state simulation is frequently determined by the highest or minimum flows. Estimates of the service area's maximum population and/or unit density are used to determine design maximum flow rates (Walski, et al., 2007).

2.21.2 Extended-Period Simulation (EPS)

Extended-period simulation (EPS) models show how a sewer network will behave over time. Wet wells, pumps, and the changes in pressures, hydraulic grades, and flow rates as a result of varied loading circumstances and automatic control techniques can all be studied using this type of study. For evaluating the hydraulic efficiency of various pump and wet well sizes, EPS is a helpful tool. Wet weather conditions frequently lead to unstable flow in wastewater collection systems. Modern sewer systems are supposed to exclude stormwater, and flow routing may not be necessary for modern sewer design (Walski, et al., 2007).

2.22 Model Calibration and Validation

Calibration is the process of using a set of input data to run a model, comparing the output to actual measurements, and then making the required corrections to ensure that the output of the model and the measurements themselves coincide. Calibration of hydraulic sewer models typically concentrates on reducing variations in projected and measured flows. The capacity of the model to forecast hydraulic grade elevation may also be assessed at key nodes in a network, such as diversion structures and overflow areas. In the end, the calibration criteria chosen are determined by the model's intended use. The vast majority of the time, hydraulic sewer models is calibrated to match known flows at various points along the system, including overflows. The model may also be calibrated to match the system's measured water surface elevations or velocities, depending on its intended use (Walski, et al., 2007).

In the calibration process is based on the premise that much of the data collection follows the initial development of the model. That is, only the data required to represent the physical system were initially available. Loads were estimated from demographic data. Later, flows were measured at a few selected points in the system to begin the calibration process (Walski, et al., 2007).

Model validation is the process of demonstrating that a given site-specific model is capable of making accurate predictions for periods outside the calibration period

3. MATERIAL AND METHOD

3.1 Description of the Study Area

Late in the 19thcentury,emperior Menelik II and his wife empress Taitu founded Addis Ababa in English, Addis Ababa means “New Flower” Ethiopia’s capital Addis Ababa is where urban planning efforts started when the Italians returned following 40 year absence following their defeat in 1896 by emperor Menelik le Corbusier and Guidi and valley, two architects, attempted to create a master plan for the city of Addis Ababa in 1936 and 1938 respectively, according to mahiteme, the second attempt to create a master plan took place in 2007 and was motivated by Lecorbusiers earlier work. It included a projected housing development with native and European residents living separately, waste management, road building, and a public transit system. The Addis Ababa waste water service was initially established centrally in 1928ec by trucking septic tank waste water out of the city and dumping it near Repi on the banks of rivers. Sewage treatment facilities were built by the Addis Ababa water and sewerage authority to handle influent from sewage lines and vacuum trucks. Sewage treatment facilities are divided into two categories centralized treatment facilities and dispersed treatment facilities. Bolelemi (bole kotebe) waste water treatment plant and kality wastewater treatment are both part of the centralized treatment facility. The locations where Mikeleyland, Gelan, Gerji, Hayat chefe, and bole houses are located are where the decentralized wastewater treatment facilities were built (AAWSA, 2006).

AAWSA originally created as a public utility business by proclamation no68/1971EC and then again by proclamation no 10/1995 EC as an independent public authority in charge of managing waste water and providing city water supplies. Since the 1970s, AAWSA has offered wastewater collection, transportation and treatment services to the metro area. The city’s sewerage system began operating in 1973EC with the building and commissioning of the first central treatment plant at Kality and all of its ancillaries had the ability and potential to serve around 200000 people by treating 7500m3/day (AAWSA, 2016).

The Kality catchment is covering a large part of the city and it is the only one where the existing sewerage facility is laid as a central wastewater treatment system, Introduced before 35 years back. Kality catchment covers, the North West part of the city with an area of 210km2 including the center of Addis Ababa. Kality wastewater treatment plant expanded to the design capacity of 100000m3/day, however the required quality of waste water is not yet collected and conveyed to the treatment plant to utilize the plant at its full capacity (ECDSWC, 2021).

3.1.1 Location

Addis Ababa lies at an altitude of 2300m above sea level, located at91’ 48’’N38 44’24’’ E. The city lies at the foot of mount Entoto. Its lowest point is around Akaki and its highest point is at Entoto. Addis Ababa city divided into two main administrative category .i.e. AAWSA division (ten branches) and municipality division (eleven sub cities). In Addis Ababa generally there are three main wastewater catchment namely Kality catchment, eastern catchment and Akaki catchment.

Kality Catchment sewer line area is located in the Kality wastewater catchment, located in the central and northwest side of Addis Ababa, the area of the catchment is subdivided into eight sub cities of Addis Ababa, i.e. Kirkos, Lideta, Arada, Addis ketema, Gullele, Nifasilklafto, Kolfekeraneio and some parts of Yeka, Akakikality and Bole and also divided AAWSA division branches i.e. Gulele, Arada, Addis ketema. Nifasilk, Mekanisa and some parts of Megenagna and Kality branches. In general kality catchment covers an area of about 21000 hectare. The catchment is shown below in figure 3:1.

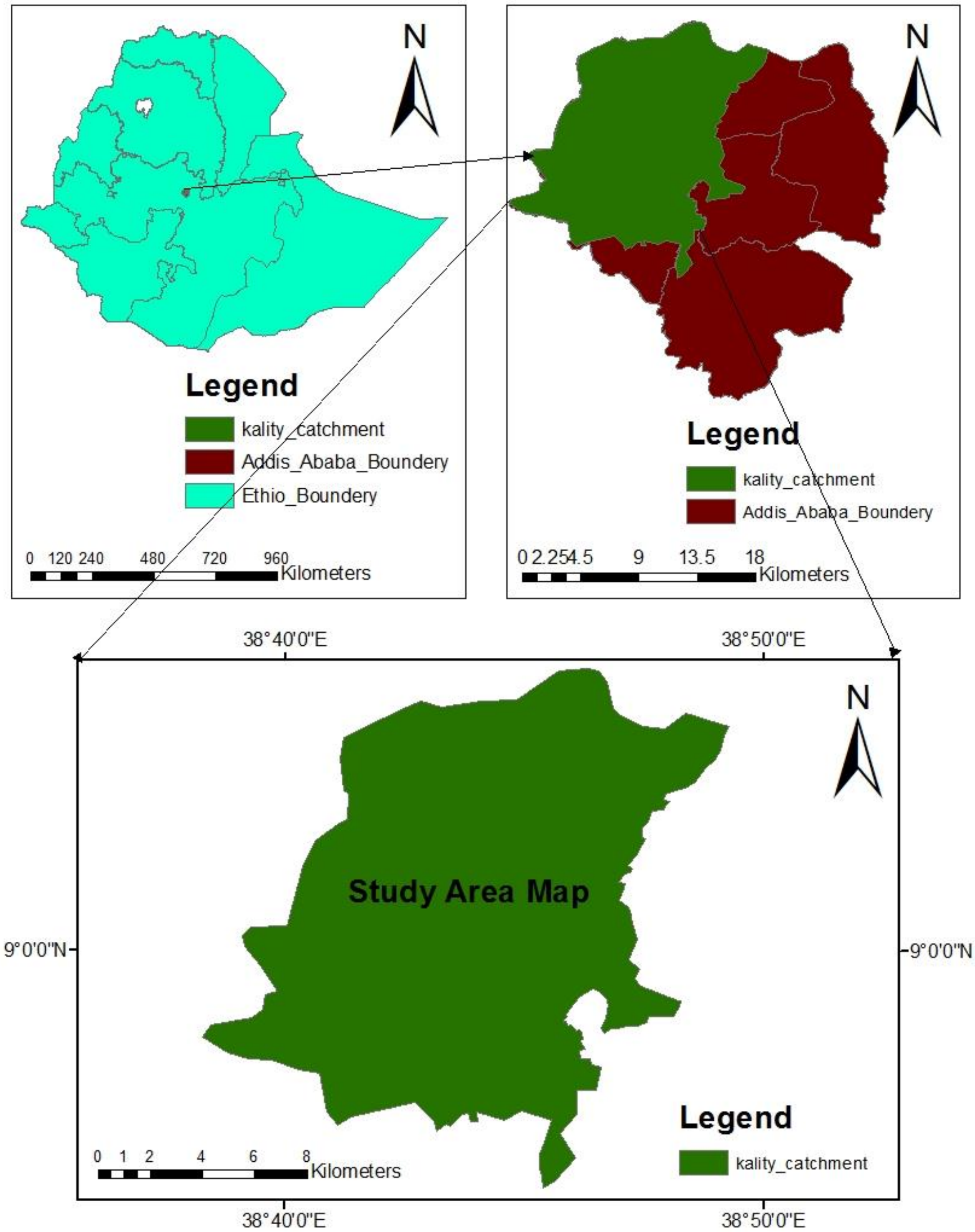

Figure 3: 1 Map of the study area adopted from ArcGIS

Addis Ababa is a capital city of Ethiopia and one of the prominent city of African continent. As per the 2002 the Master Plan study by Addis Ababa Water and Sewerage ProjectComponent-2 of 2004, Addis Ababa City is divided into 3 Sewerage Catchments, namely Kality Catchment which forms the core of the city and lies on the North-West, Eastern Catchment which is mainly a Condominium dominated area lies on the North-East of the City and Akaki Catchment which is mainly industrial and has Condominium sites, it lies towards South of the City. The Figure Show the location Plan of the previously planned Sewerage Catchments of the City (ECDSWC, 2021).

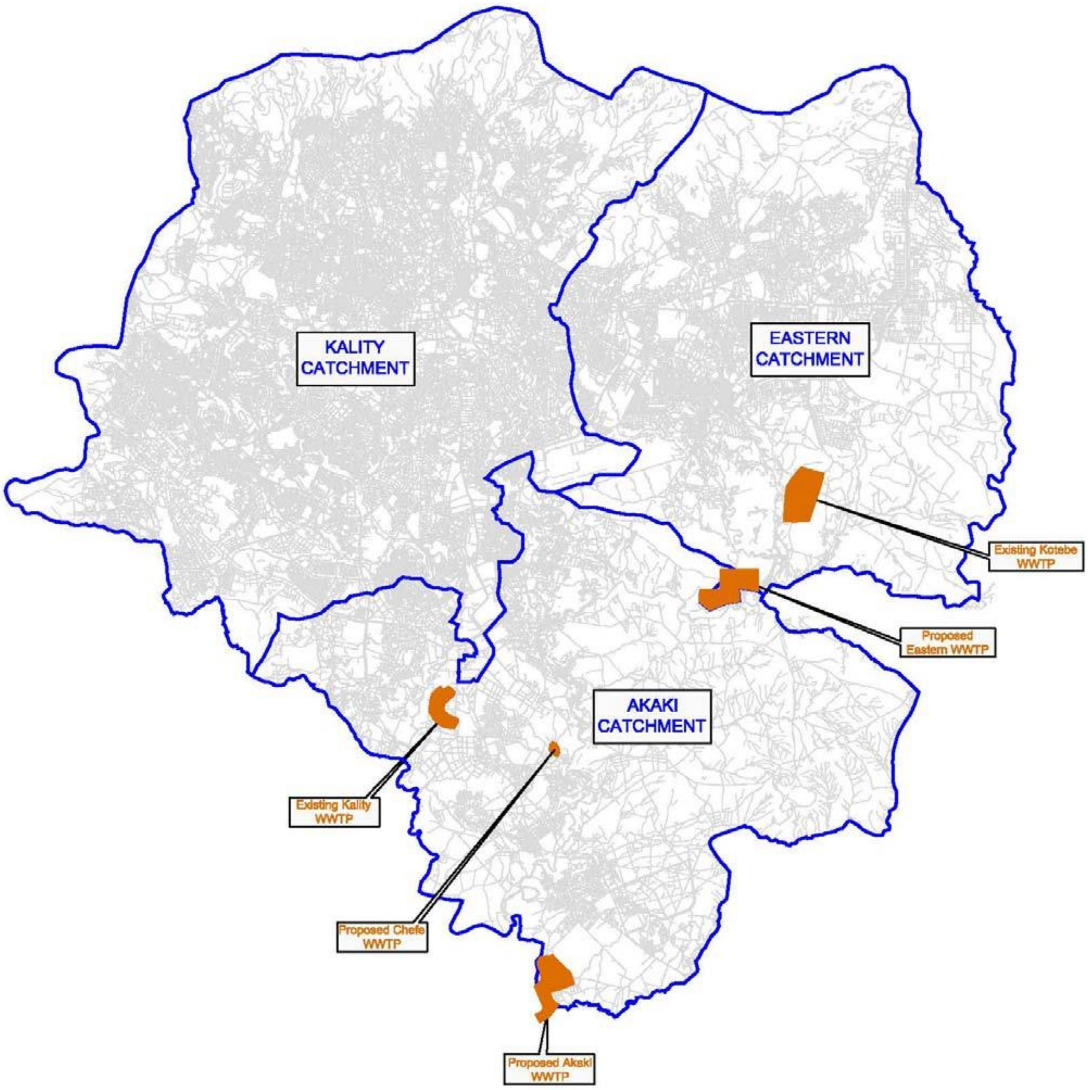

Figure 3: 2 The 3 main sewerage catchments of the city of Addis Ababa (AAWSA, 2016)

The Kality catchment sewerage collection system can be sub divided into four major sub catchments based on the topography of the area that allows gravity drainage system;

1. **Eastern Kality sub-catchment**; this catchment serves part of Yeka and bole sub cities that drain to Kebena River

2. **Central-eastern kality sub-catchment**; this includes majority of Addis ketema, Arada, and eastern Kirkos sub-cities;

3. **Central–western kality sub-catchment**; includes central part of the city including western Gulele, Addis ketema, Lideta, western Kirkos and northern Nifas silk lafto sub cities.

4. **Western Kality sub –catchment**; includes Kolfe-keranyo sub-city and part of Nifas silk lafto sub sub-city all area located south of little Akaki river.

Fig the four sewerage sub catchments of the Kality catchment (AAWSA, 2016).

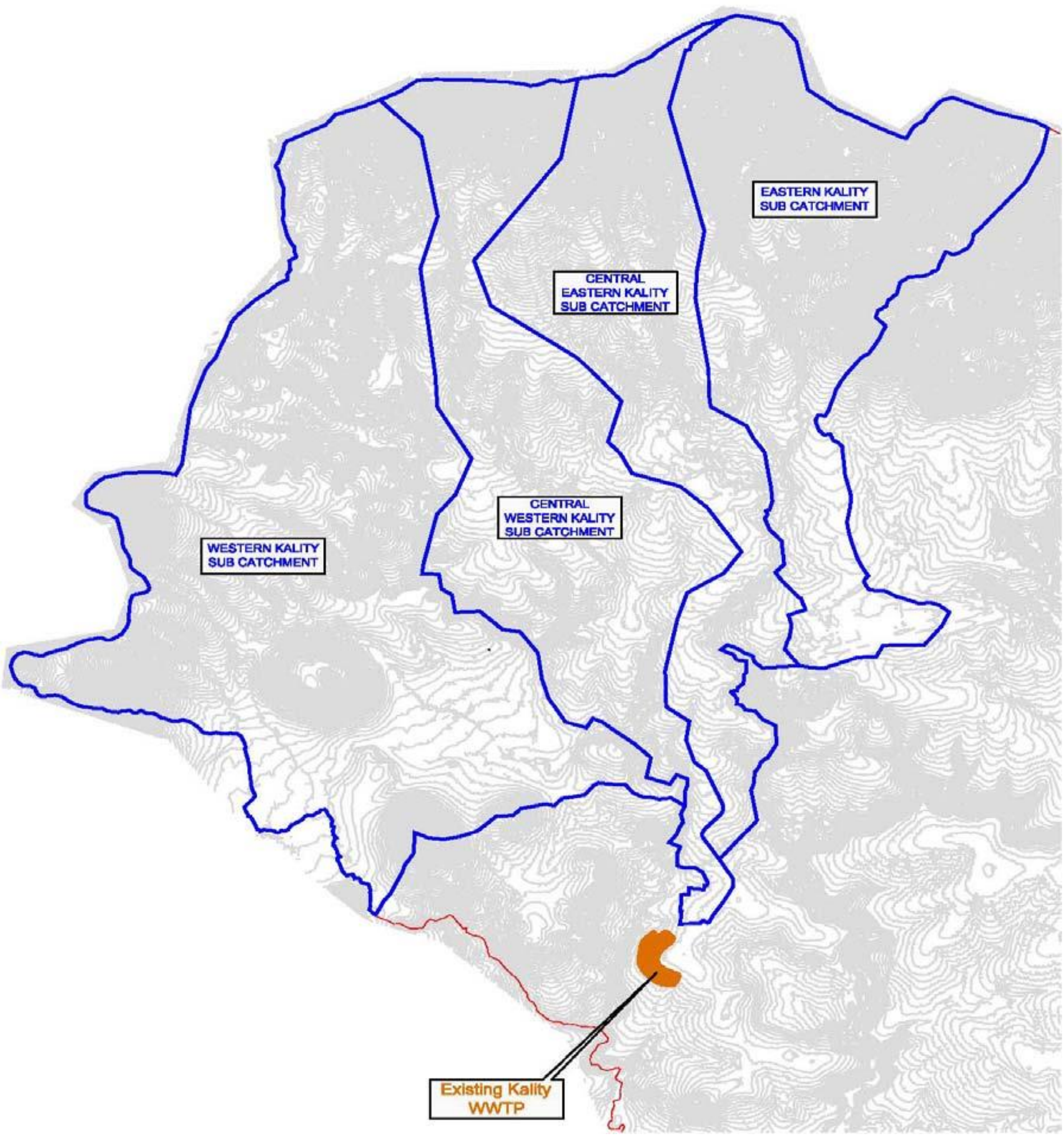

Figure 3: 3 The four major sub catchments of Kality sewerage system (AAWSA, 2016)

3.1.2 Topography

The elevation in Addis Ababa varies, ranging from 2700 meters in the north to 2200meters in the south. City development is constrained in the north by the Entoto range's steep slopes, which reach heights of more than 3000meters.the region around Addis Ababa has a complicated morphology. The topography of Entoto ridge is rough, featuring rapids, waterfalls, and steep slopes. Although there are some hilly features, the morphology changes to quite gentle slopes as you move south. The Kality Catchment is characterized by hilly areas with valleys, rivers, and streams and the altitude is ranging from 2170-3000m.a.s.l

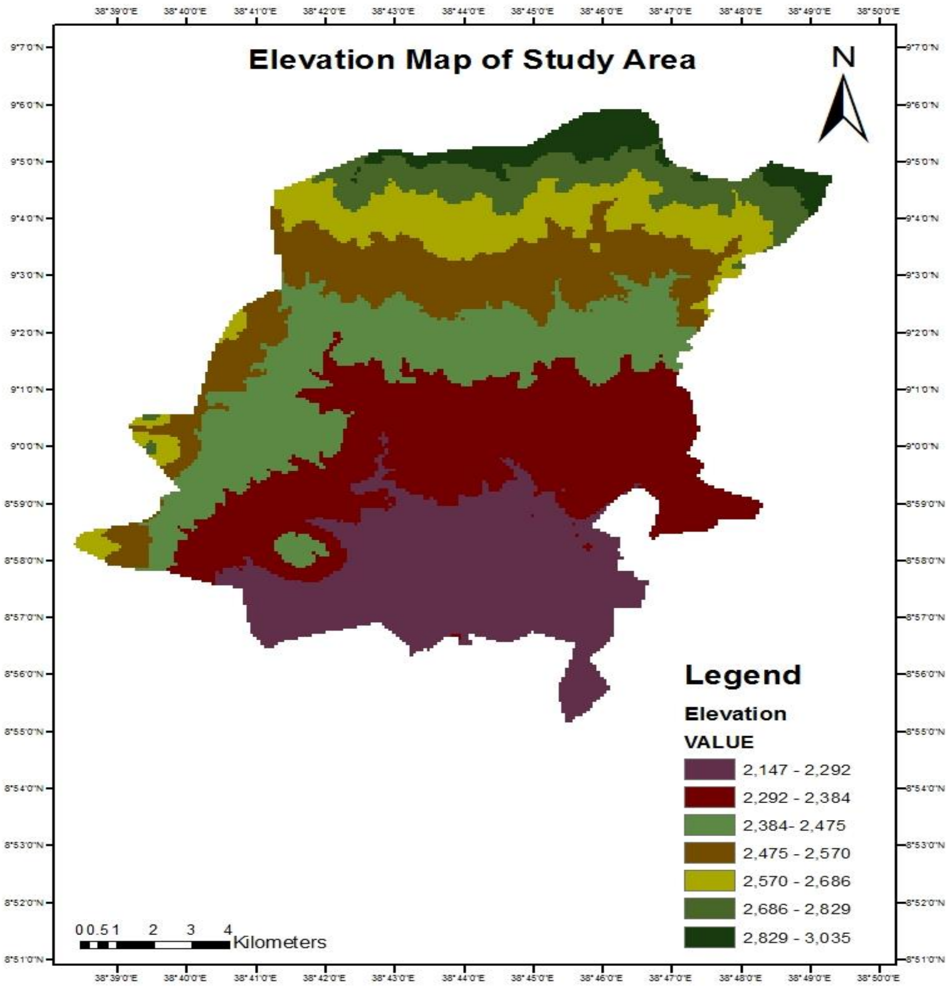

Figure 3: 4 Topographic map of Kality Catchment

3.1.3 Climate Condition

The majority of Ethiopia has a tropical climate that is mitigated by altitude and has a distinct wet season. With a hot, semi-arid to desert environment, the eastern lowlands (elevation less than 900 a.m.s.l) are substantially drier. In contrast the south western region of Ethiopia has a humid tropical climate with more than 1000mm of annual rainfall. Warm to cool semi-arid zone is where the study region is situated. The watershed’s highest point, where Entoto Mountain is located experiences colder temperatures. Inter annual movement and the location of inter tropical convergent zone

(ITCZ) greatly influence the spatial and temporary variation of rainfall in Ethiopia. Similar to how it is the rest of the country, the geographical and temporal change of ITCZ conditions has an impact on how rain falling the study region. As a result, there is a significant summer rainy season in the study area that occurs when the ITCZ condition exists in Ethiopia's northern region. Depending on height and dominant wind pattern, the city has a complex mix of highland and temperate zones, with temperature changes of up to 10^{o} C (Desalegn, 2011).

3.1.4 Soil Cover

The dominant geological formation found in the city area is volcanic rocks (ignimbrites, hyalites, basalts, scoria, etc.) the soil type of the study area is extracted from 1; 1000000 soil map of Ethiopia. Categorization of the soil type was made based on their permeability, which is expressed by hydrological soil group. The dominant soil type (54%) are sand, silt loam, or loam soils (calcic xerosols, eutric vertisols, orthic solochanks and vertic cambisols), while clay loam, silty clay loam and silty clay soils (humic nitisos, chromic luvisols, chromic vertisols, pellic vertisols and Leptosols) covers about 46%of the pipe crossing drainages.

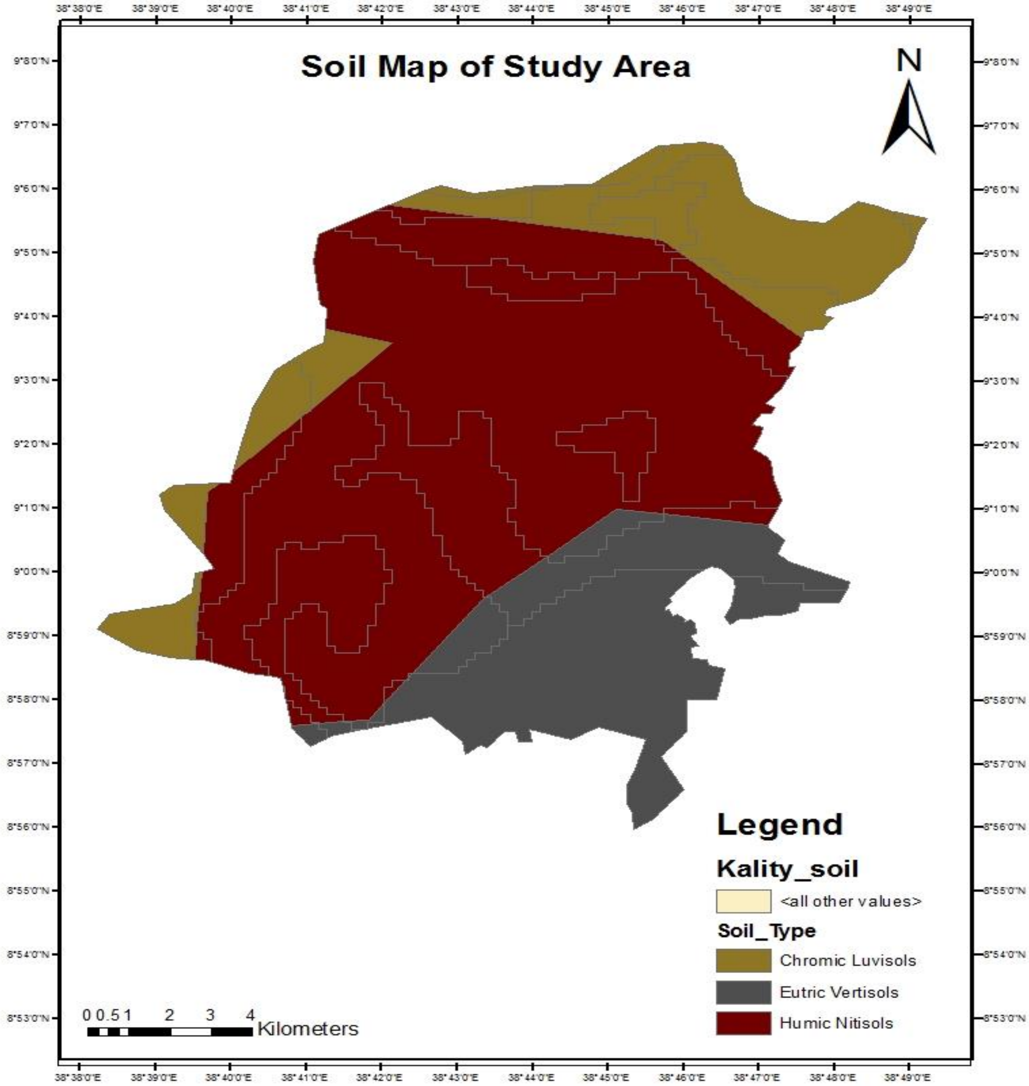

Figure 3: 5 Topographic map of Kality Catchment

3.1.5 Land Use/Land Cover

In line with population expansion, Addis Ababa administrative border grew from an estimated 32km2 in 1912 to 218km2 in 1984 and 527km in 1994 (CSA, 2020). The city's built-up regions as well as the greater metropolitan area both grew. Built up land area in the metropolitan region increased from 80.6km2 in 1984 to 198.7km2 in 2005 and then 364.5km2 in 2015 see figure 3:6 below.

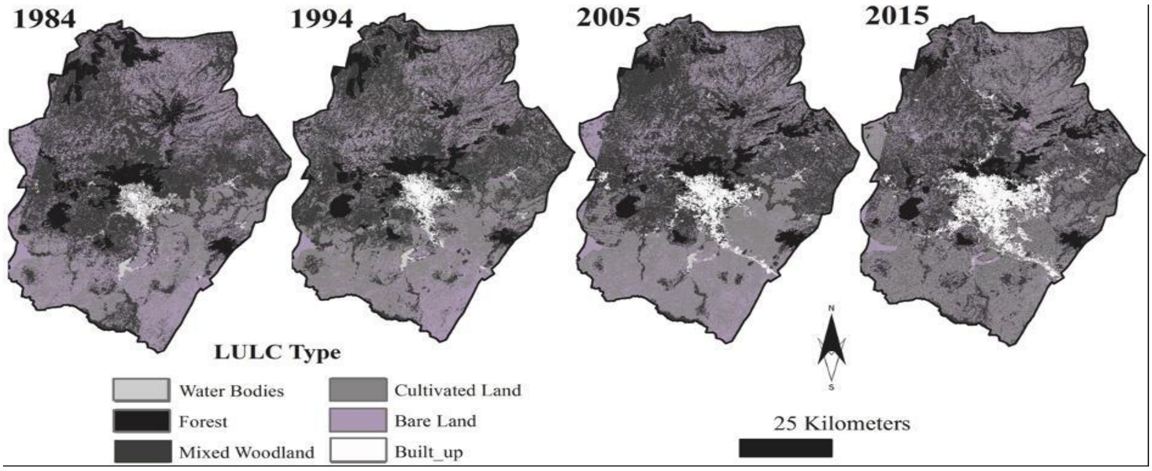

Figure 3: 6 Expansion of urbanization in Addis Ababa region (1984-2015)

A structure plan is defined as a legitimately authoritative arrange along with its explanatory content defined and drawn at the level of a complete urban boundary that sets out the basic minimum prerequisite with respect to physical advancement the satisfaction of which may deliver a coherent urban advancement in socio-financial and spatial sphere. (MUDC, 2012).The current Addis Ababa structure arrange is built on the principles of this widely accepted description. Additionally, its level of detail is tailored to the city's current circumstances and what the city hopes to accomplish by 2040.

The finical, social, and natural aims of the structure arrange are reflected in its spatial components in coordinate manner. In a city like Addis Ababa, where spatial change and physical improvement are happening more quickly, spatial ideas inside the structure arrange (the spatial system) focus on larger-scale critical issues that should be taken into account or that cannot be misused in any manner during use.

The arrival is primarily used for mixed development, which combines a variety of private, commercial, social, organizational, or mechanical jobs where such capacities are physically coordinated and which calls for standard sewerage service.

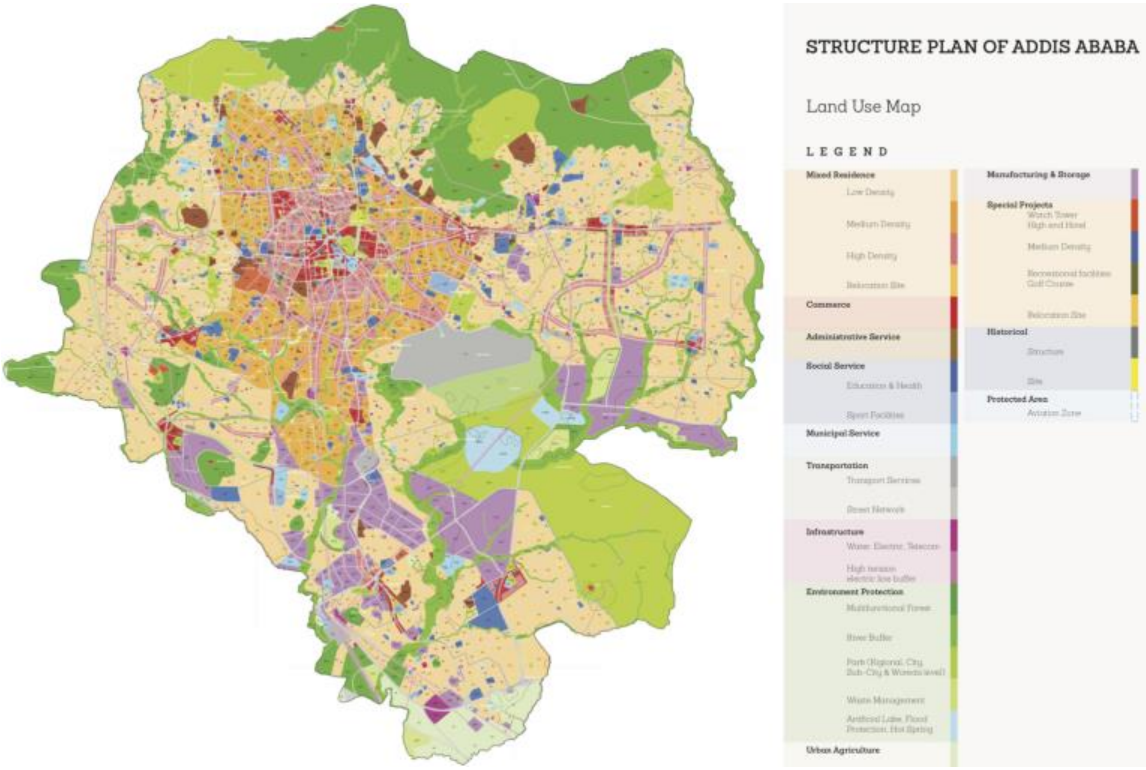

Figure 3: 7 Land use map of Addis Ababa by (AACSP, 2019)

The wastewater management issue in the Kality watershed is still getting worse as a result of recent construction activities, making it more difficult to comply with the standards. The catchment is distinguished by mountainous terrain with valleys, rivers, and streams and its elevation ranges from 2170 to 3000 meters above sea level. The area mainly includes the following

- Mixed residential
- Commercial areas
- Administrative, social and municipality services areas like KG ,health centers,schools,firestations,sportfields,cemeterychurches,mosquesetc
- Environmental protection multifunctional, forest, river buffer, park, waste management, artificial lake, flood protection and hot spring
- Urban agriculture
- Manufacturing and storage
- Mixed Residence

Mixed Residence

The concept of mixed-use neighborhoods places an emphasis on the blending of various yet complementary activities inside private areas. By moving closer to places of employment, dwelling, and use of services, this reduces travel. The fundamental idea of mixed use, or "mixity," is the cornerstone of a dynamic ecosystem. To do this, it is essential to combine private housing with local business and a showcase, which should include lower-level services, access to boulevards, community open spaces and play areas, and a neighborhood stop. The lodging thickness, which refers to the total number of private lodging units in a given arrival location, is a benchmark. The Structure Arrange specifies three degrees of gross thickness for combined private arrival use. High-density, medium-density, and low-density are the three different types of mixed-use housing (AACSP, 2019).

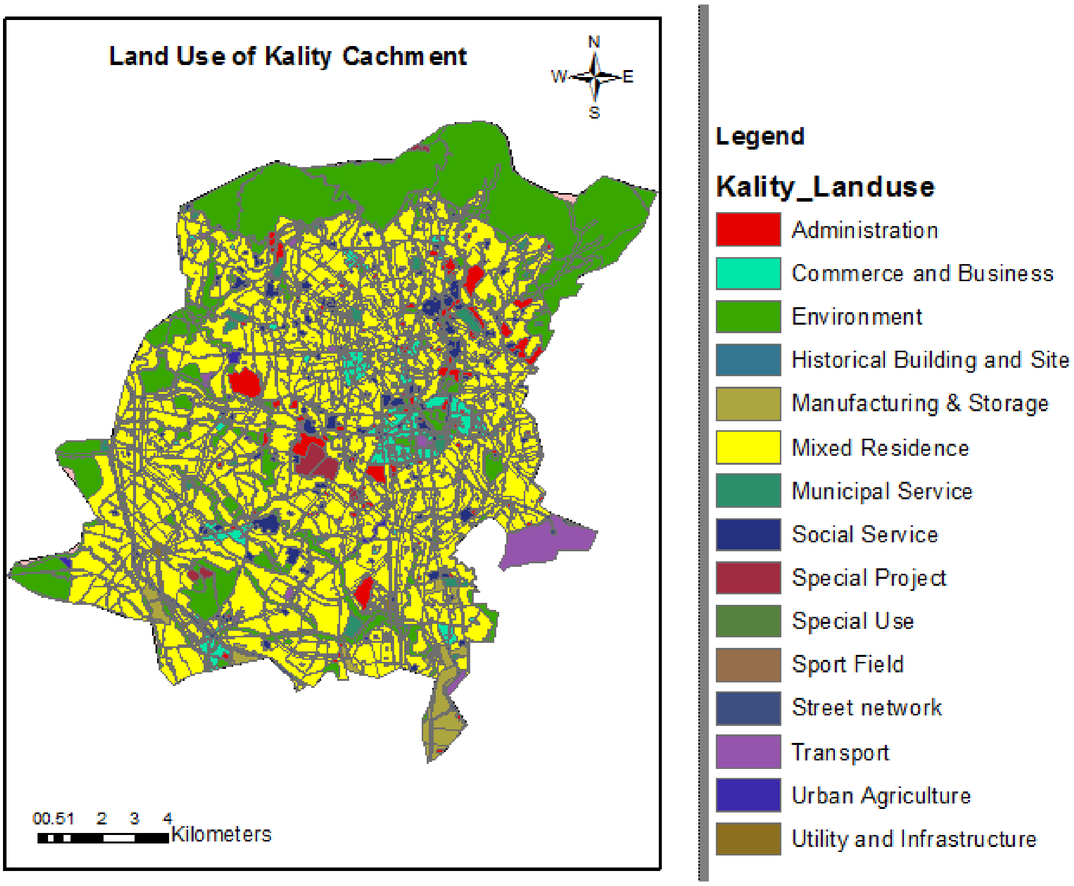

Figure 3: 8 Land use map of Kality Catchment extracted by using Arc GIS

3.2 Existing Sewerage System of Kality Catchment

The amount of domestic and other waste water outputs varies with the city of Addis Ababa's population, the availability of water, and other relevant socio economic growth. Currently a network of sewers and wastewater treatment facilities serves the Kality basin communities of Bole, Lideta, old airport, the down town area, Mekanisa, and Kera. There is currently a dearth of coverage for the city's wastewater treatment facilities.

Manure collection and drainage services are accessible to about 51% and29% of the population, respectively. The state of the city's wastewater treatment services and systems at this time often suggests a capacity restriction. The current sewage system in Addis Ababa can be classified into three groups. These are lack of access to all facilities, on-site sanitation (septic tanks, and latrines), and waterline sanitation (conventional sewage systems). In Addis Ababa, there are 31 centralized and decentralized treatment facilities (including the combined ABR and ABR and MBBR facilities). As of December 2020, Addis Ababa's wastewater treatment facilities have a combined daily capacity of 148,200 m3/day. As of December 2020, 85,232 m3/day of operational wastewater are currently collected and processed (ECDSWC, 2021).

A portion of Addis Ababa has access to conventional wastewater systems. These systems were created mostly in the Kality basin area, and Kality has a state-of-the-art wastewater treatment facility with a 100,000 m3/day capacity. The Kality wastewater treatment facility is situated at an altitude of approximately 2200 meters on the left bank of the Akaki River at coordinates (473095, 985738). However, the previous Kality wastewater treatment plant was built with three main blocking works the Lideta, West, and East interceptors—for a final population equivalent to 200,000 people. More than 40 years have passed since the first wastewater treatment facility and system were put into service (ECDSWC, 2021).

In Addis Ababa, latrines or septic tanks are used by most residents. To treat sludge from the septic tank, an independent sludge stabilization plant was established at various dates and sites in the Bole-Kotebe (Yerer region) and Kality wastewater treatment complex and the city has a collection of latrines. Both of these services are not available to certain groups of city residents. As a sanitary system, they use local rivers or deserted fields. These data on the city of Addis Ababa's current sewage system and the dearth of sanitation facilities demonstrate the need for significant improvement in the sewage system.

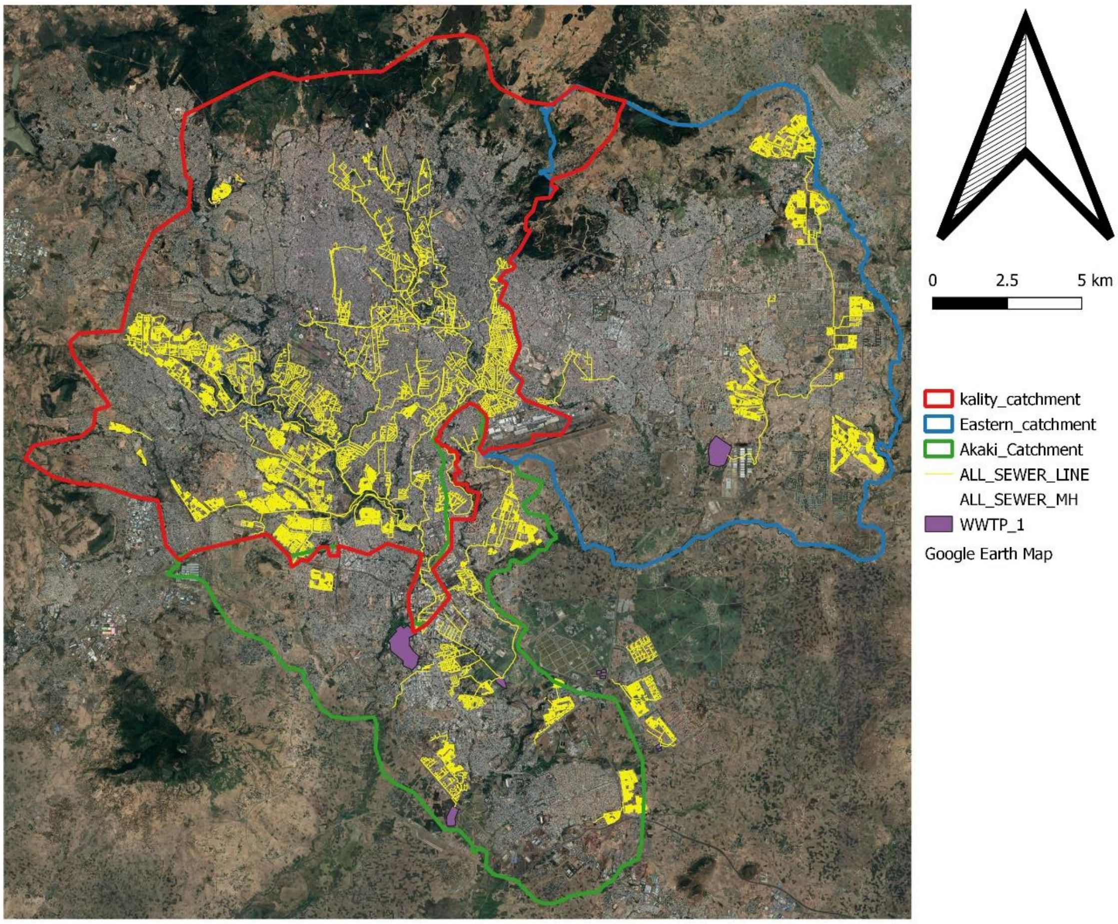

Figure 3: 9 existing sewer network of Addis Ababa with respected catchment using Qgis

The current sewage system in Kality is run by gravity. The west, Midwest, middle east and east sub basins of the Kality wastewater basin serve as the foundation for the design and implementation of the current wastewater system the first of the three main phases of development for the current sewer system was finished in 1982 the system was set up to serve the western block in particular the Lideta neighborhood(next to the military hospital the universities building site and the awash distillery and the African union neighborhood in the city center. After the systems development to serve the eastern branch and interchange network in the Bole and central regions, the second phase of development was finished in 1990 construction of 18km of truck culverts branching out into the eastern and western sub basins is part of the third major construction phase. Therefore the major intervention made in recent years, in the Kality sewerage catchment is

- Kality wastewater treatment plant with treatment capacity 100000m3/day
- 18km (1000mm-1500mm diameter) trunk sewer line

- 28km (600mm-1600mmdiameter) trunk sewer line by government funding constructed local company ASSER plc.
- 80km secondary sewer line
- 58km sewer line by government funding, constructed by local contractors
- 24km sewer line around Lebu area
- About 4okm sewer lines are under construction categorized in 15 lots in different parts of Kality catchment according to AAWSA, 2020 feasibility design report indicated.

Table 3: 1 Table existing pipe inventory at Kality Catchment

Pipe Diameter	**Length (m)**	**Remark**
1600	3,200	Existing
1500	6,000	
1400	3,891	
1300	551	
1200	585	
1000	15,094	
900	2,505	
800	853	
700	3,320	
600	33,004	
500	8,100	
400	17,188	
300	37,786	
250	33,411	
200	343,000	
Sub total	**508,488**	
300	6,250	Under construction PVC
250	7,204	
200	25,000	
Sub total	**38,454**	
Total	**546,941**	

Source: (ECDSWC, 2020)

3.2.1 Water Supply Customers Situation

To improve the sanitation situation of the city the main aspect is to improve the water supply situation in parallel with the sewerage system development. The socio economic studies indicate that most customers have yard connections. Increasing number of house connected water customs is also equally important. According to the household survey made by the project socio economic team 67% of the water customers are under the category of house connection.

Table 3: 2 Main source of drinking water for the household connection

Name of Sub city	Main source of drinking water for the household							
	Piped into Dwelling	Piped into Yard/plot	Public tap/stand pipe	Tube well/borehole	Protected dug well	Bottled water/gallon and container dispenser	Refilled bottled water	Tanker truck
Addis Ketema	68.3	20	3.3	5	0	0	3.3	0
Arada	63.3	18.3	18.3	0	0	0	0	0
Akakikality	0	82.1	17.9	0	0	0	0	0
Bole	91.7	0	5.6	0	0	0	0	2.8
Gulele	62.5	0	37.5	0	0	0	0	0
KolfeKeranyo	56	2.4	34.5	0	1.2	2.4	2.4	1.2
Kirkos	76.2	9.5	1.6	0	0	6.3	6.3	0
Lideta	68.3	24.4	4.9	2.4	0	0	0	0
Nifa Silk Lafto	85.7	1.1	4.4	0	0	7.7	1.1	0
Yeka	62.7	37.3	0	0	0	0	0	0
Total	**66.8**	**15.9**	**11.9**	**0.7**	**0.2**	**2.4**	**1.6**	**0.4**

Source: (ECDSWC, 2020)

3.2.2 Existing Sewer Network Condition

In order to handle wastewater in Kality Catchment effectively, sewer networks are a crucial piece of infrastructure. These networks do, however, confront a number of difficulties that may compromise their usefulness, efficiency, and security. Sewer network issues that are frequently encountered in the study area observed during field investigation includes:

1. Overflow: It was observed that the manholes are overflowing in different parts of the study area. The overflowing of manholes is also observed in other areas which may be due to the stormwater finding its way in to the sewers. This may overload the sewer system and the treatment plant as well.

Figure 3: 10 Photos of overflow on the existing sewer network

1. Open manholes: In some parts of the study area open manholes were observed during site investigation. Due to their potential to result in accidents and injuries, open manholes present a serious risk to public safety. Additionally, they may permit illegal access to the sewer system.

Figure 3: 11 Photos of open manholes on the existing sewer network

2. Illegal connections: During site visit, it was possible to observe unauthorized access to the sewer system. This may lower the system's ability to manage wastewater, necessitating more regular operation and maintenance.

Figure 3: 12 Photos of illegal connection on the existing sewer network

3. Missing manholes: A number of manholes were lost in the Kality catchment sewer network. Missing manholes were covered by asphalt, cobblestone and terrazzo that can make it harder to access the sewer system for operation and maintenance, which can result in delays and higher expenses.

4. Inflow: Some manholes were exposed to inflow so that the amount of wastewater that has to be cleaned increases when precipitation or groundwater enters the sewer system. This may result in backups, spills, and other issues that might be hazardous to human health and environmentally damaging.

Figure 3: 13 Photos of Inflow on the existing sewer network

5. Raised/Depressed Manhole Covers: In some parts of the study area manholes that are above or below the ground elevation were observed. This affects the traffic movement if the top of manhole is above the ground level and may cause infiltration problems if manhole top is below the ground level.

Figure 3: 14 Photos of Raised/Depressed Manhole covers s on the existing sewer network

Overall, these problems can affect the efficiency, effectiveness, and safety of sewer networks, leading to health hazards, environmental pollution, and increased costs. It is important to address these problems through regular maintenance, repair, and management practices to ensure the proper functioning of the sewer system and to protect the health and wellbeing of citizens and the environment. Some of the photos that show the existing condition of sewer networks are given in Figure 3

Figure 3:15 Photos of existing condition on the sewer network

3.2.3 Sewer Connection Rate

According to AAWSA long-term Road Map dated (2017), global connection ratio among the population was estimated to be around 13% in 2016.

Table 3: 3 projected sewer connection rate

Connection Type	**Projected year**			
	2016	**2020**	**2025**	**2030**
Domestic connection rate	13%	23%	46%	70%
Industrial connection rate	0.1%	1%	2%	2.5%
Public and Institutional connection rate	0.1%	1%	2%	2.5%
Total connection rate	**13%**	**25%**	**50%**	**75%**

Source: (AAWSA, 2016)

NRW studies indicated that customer meter inaccuracy (under registration) is about 11.54% of the total water billed as the give below table. Therefore for the first and the second scenario to estimate the wastewater generation from customer bill data 11.54% of meter inaccuracy would be added on an average water consumption bill data.

Table 3: 4 Water Balance (m3/day) based on data for the month of February 2016

<table>
<tr><td rowspan="7">Average Day system input volume for Feb 2016
395,270
100%</td><td rowspan="4">Authorized consumption
274,687
69.5%</td><td rowspan="2">Billed Authorized Consumption
217,201
69.4%</td><td>Billed metered consumption
274,173
69.4%</td><td rowspan="2">Revenue Water
274,252
69.4%</td></tr>
<tr><td>Billed unmetered Consumption*
79
0.02%</td></tr>
<tr><td rowspan="2">Unbilled Authorized* Consumption
132,097
0.11%</td><td>Unbilled metered Consumption*
277
0.07%</td><td rowspan="5">Non Revenue Water
121,018
30.6%</td></tr>
<tr><td>Unbilled Unmetered Consumption*
198
0.05%</td></tr>
<tr><td rowspan="3">Water Losses
120,583
30.5%</td><td rowspan="2">Apparent Losses*
47,749
12.08%</td><td>Unauthorized Use*
2,174
0.55%</td></tr>
<tr><td>Meter in Inaccuracies*
45,614
11.54%</td></tr>
<tr><td colspan="2">Real Losses
72,834
18.4%</td></tr>
</table>

Source: (AAWSA, 2016) Utility water and sewerage coverage report

3.2.4 Hydraulic Performance of Existing Sewer Networks

The hydraulic performance of these pipes is good enough, as far as the wastewater flow estimate is done properly and self-cleansing velocity is considered. Most of the laid centrally sewer pipes are basically designed based on the 2002 Wastewater master plan of the city. The parameters set used are indicated below:-

Minimum slope = 0.3%

Minimum velocity = 0.5 m/s

Maximum Velocity = 3 m/s

Maximum and minimum pipe cover of 0.8m and 5m above pipe

Manning's roughness coefficient

n = 0.013, concrete pipe and

n = 0.011 PVC/HDPE/GRP

The main design parameter required for sizing the sewer collection system is the quantity of wastewater to be transported. In order to estimate the maximum quantity of wastewater to be collected from each service area, local data such as population, water use, non-domestic water users, and future development plans are required.

3.2.5 Kality Catchment Sewer Network Service Area

The central Kality area was the focus of the sewerage networks building in previous years. Kirkos, Lideta, Arada and portions of bole and Yeka are among the sub cities that are already part of a core network that is served by the Kality WWTP. The network in Nifas silk is still being built. With the WWTP serving as a base the network is extended to the north and northwest. The design of the network for Addis ketema and a portion of the Kolfekeranyo sub cities was just finished and the network is currently being built in Nifas silk lafto.

3.3 Material and Equipment Used

GPS: used to collect elevation data during the flow measurement and x-y coordinate for the existing manholes in some parts of the study area. The flow measurement had be taken at specific selected manholes (points) of the sewer network.

Wooden stick: To measure flow depth of the selected manholes or points

Roll meter: To measure flow depth from the wood stick and distance from manhole to manhole some parts of the existing sewer line.

Stopwatch: To measure the flow time taken to the intended manholes.

3.3.1 Hydraulic Model Bentley Sewer GEMS Connect Edition Version10

A computer model uses mathematical equations to explain and forecast physical phenomena. A model is something that portrays things in the real world. With put needing to physically monitor the system, modeling of water distribution systems can be used to determine system pressure and flowing rate under various conditions (Rai, 2020).

Bentley Sewer GEMS Connect Edition Version 10; is selected for this study because of an extremely efficient tool for laying out a storm or sanitary sewer network. It is easy to prepare a schematic or scaled model and let sewer gems take care of the link node connectivity. Bentley sewer gemv8i is the first only fully dynamic. It is multi-platform (GIS, CAD, standalone) based sanitary and combined sewer modeling solution. With the help of sewer gems v8i we can analyze all sanitary and combined sewer system elements in one package and we also have the option of performing the analysis with the SWMM algorithm or our own implicit solution of the full saint venant equations. Sewer GEMS offers superior interoperability. It used for simulation purpose and mathematical equations to explain and predict physical events for existing and future sanitary flow (Rai, 2020).

Other Additional Software's

ArcGIS version of 10.7; Used to extract and display map of the study area, existing sewer network, topographic map and soil map, to prepare base map, thiessen polygon and parcel of land use for projection of wastewater.

Q-GIS: Used to extract and display map of the study area, existing sewer network with integrating Google earth

AutoCAD: To easy layout and viewing of the study area sewer network from Addis Ababa master plan.

Microsoft excel and Microsoft word: used for the purpose of data analysis, huge amount of data manipulating and writing manuscript.

3.4 Research Methodology

In order to achieve the objective of the intended research following specific methods and approaches is mandatory. Data collection, construction of model, hydraulic model simulation, model calibration, model validation and finally model output analysis and interpretation has been carried out to attain the objective of this research.

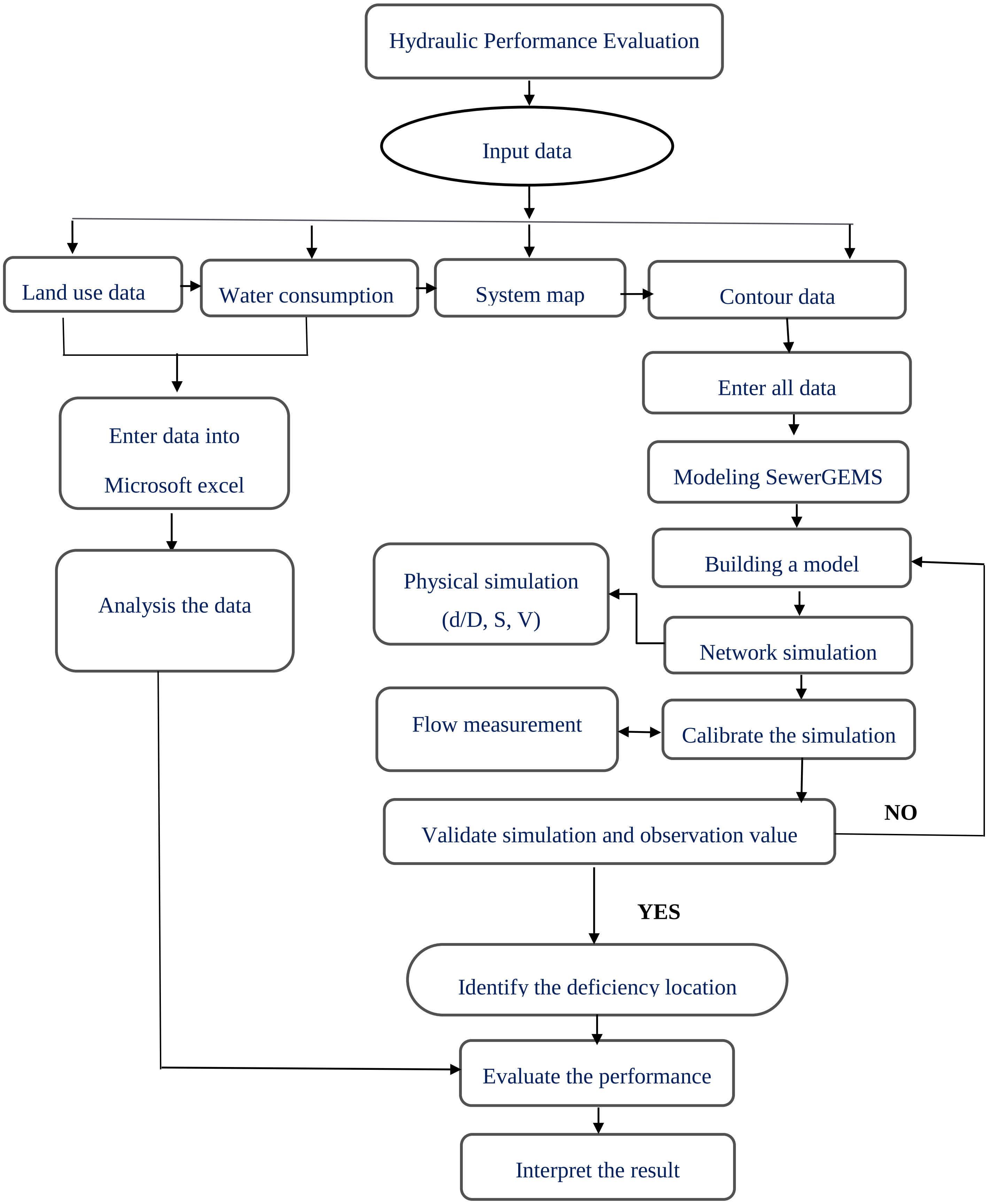

Figure 3: 16 Research framework

3.5 Data Source and Collection

To be able to achieve the stated objectives of this study, a number of relevant research instruments and methods, which included primary and secondary data, have been employed.

Primary data: Such as site observation, wastewater flow or Depth of wastewater flow measurement and manhole depth, elevation, and x, y coordinate data at some points and gathered other data from the site.

Secondary data: Relevant information were collected from study and design reports, different kinds of literature review, elevation data, Census and survey reports, and unpublished documents and exiting documents from the responsible utility organization of the city Addis Ababa Water and Sewerage Authority (AAWSA) by discussion. Water consumption data used to estimate wastewater generation and sewer system coverage of the study area, land use data used to project future wastewater generation and survey and design data of the existing sewerage system and contour map were used to construct the model using SewerGEMS software and the sewer capacity for twenty three sample manholes was measured to calibrate the model. All the necessary data type and their respective sources are listed in the table below.

Table 3: 5 Data types and sources

No.	**Data Type**	**Source**
1.	Water consumption data	Addis Ababa Water and Sewerage Authority
2.	Survey and design data of the existing sewerage system and contour map	Addis Ababa Water and Sewerage Authority
3.	Addis Ababa existing sewer network layout	Addis Ababa Water and Sewerage Authority
4.	Wastewater Contribution area and 5meter interval contour(Elevation data)	Addis Ababa Water and Sewerage Authority

5.	Land use map and summary report (2017-2027) on Addis Ababa Structural Plan	Addis Ababa city planning project office
6.	Soil type	Ministry of Agriculture

3.5.1 Water Consumption and Land Use Data

The recorded trend of water consumption for active customers (from September 2020 to August 2022) for the first scenario obtained in the form of shape files and summarized and compiled in the table below.

Table 3: 6 Compiled water consumption bill data for active customers

AAWSA Branch	Billed Water Consumption (31 months)	Number of Customers	Billed Water Consumption	
			m3/month	m3/day
NifasilK	7,336,382.00	19,014.00	236,657.48	7,888.58
Addis Ketema	574,532.00	1,518.00	18,533.29	617.78
Arada	8,851,458.00	5,850.00	368,810.75	12,293.69
Gulele	3,073,503.00	3,030.00	99,145.26	3,304.84
Megenagna	8,488,676.00	6,758.00	273,828.26	9,127.61
Mekanisa	10,018,381.00	31,047.00	323,173.58	10,772.45
Akaki	56,428.00	41.00	1,820.26	60.68
Gurdshola	-	-	-	-
Total	**38,399,360.00**	**67,258.00**	**1,321,968.88**	**44,065.63**

The water consumption data for potential customers (from September 2020 to February 2023) for the second scenario also in shape files and summarized compiled and presented in the table.

Table 3: 7 Compiled water consumption bill data for potential sewer customers

Name of Sub City	Area (Hectares) Addis Ababa	Area (Hectares) Inside Kality Catchment	Number of Household	Average Water Consumption (m3/month)	Daily Water Consumption (m3/day)
Gulele	949.07	949.07	9787	142,467.07	4,748.90
Addis Ketema	942.01	942.01	52505	623,958.13	20,798.60
Arada	517.28	517.28	8455	168,834.77	5,627.83
Lideta	659.57	659.57	33684	442,359.67	14,745.32
Kirkos	731.70	731.70	25796	475,990.70	15,866.36
Kolfekeranyo	1,159.20	1,159.20	102634	1,140,637.57	38,021.25
Nifas silk Laffto	1,266.53	1,266.53	65360	713,173.83	23,772.46
Yeka	1,402.78	882.22	8562	150,086.47	5,002.88
Bole	1,442.95	850.38	7042	331,330.90	11,044.36
Lemi Kura	889.36	-	0	0	0
Akaki Kality	1,078.48	384.12	2729	62,180.33	2,072.68
Total	**11,038.93**	**8,342.08**	**316,554.00**	**4,251,019.43**	**141,700.65**

The land use map for wastewater projection of for the third scenario was collected in shape file. Those water consumption and land use data were collected from Addis Ababa Water and Sewerage Authority and Addis Ababa Structural plan office respectively. As per the data obtained regarding water consumption, it is observed that the consumption rate varies from branch to branch and land use data show different land use type within the study area as shown in the map and table in the annex part.

3.5.2 Catchment System Maps

This is the most fundamental system map of the catchment area the gives crucial information about the study area because it obtaining number of information on the area some of them are given below

- Manhole depth and location
- Treatment plant location
- Pipe line with alignment, diameter, type of material and others.

- Manhole elevation
- Other information like roadway, drainage stream and so on.

For the purpose of this study the catchment maps were collected from Addis Ababa water and sewerage authority.

3.5.3 Catchment Topographic Maps

A topographic map uses sets of lines called contours to indicate elevations of the ground surface. Contour lines represent a contiguous set of points that are at the same elevation and can be thought of as the outline of a horizontal “slice” of the ground surface. For this study topographic maps of Addis Ababa city 5cm contour interval were used to extract the elevation of each manhole in the existing sewer network and some parts of the area especially, flow measuring points the grounds elevation and X, Y coordinates has been taken by using GPS in the field.

Figure 3: 17 measuring ground elevation and X, Y coordinates

3.5.4 Flow Measurement Sample Locations

A typical network representation of a sewer network may include hundreds or thousands of links and nodes. Ideally, during the water distribution model calibration process is adjusted for each link and each node. However, only a small percentage of representative sample measurements can be made available for the use of model calibration due to the limited financial and labor requirements for data collection. Therefore, it is of utmost importance to have a comprehensive methodology and efficient tool that can assist the engineer in achieving a highly accurate model under practical conditions (Dayessa, 2019).

The purpose of flow measurement is to give the most accurate flow rate report based on the application and to ensure clean and safe disposal of wastewater in the sewer system. Hundreds or thousands of links and nodes may require for a typical network representation. Ideally, during the sewer network model calibration process is adjusted for each link and each node. However, only some percentage of representative sample measurement is selected by the method of systematic sampling for the use of model calibration due to shortage of financial limitation, I am familiar with the study area specifically the sewer system and labor requirements for data collection and measuring because the study area cover huge area. Then representative sample manholes were selected by for the model calibration purpose. The measurements were taken at a direct connection to the upstream, middle and downstream side of the catchment in order to represent the all section of the study area.

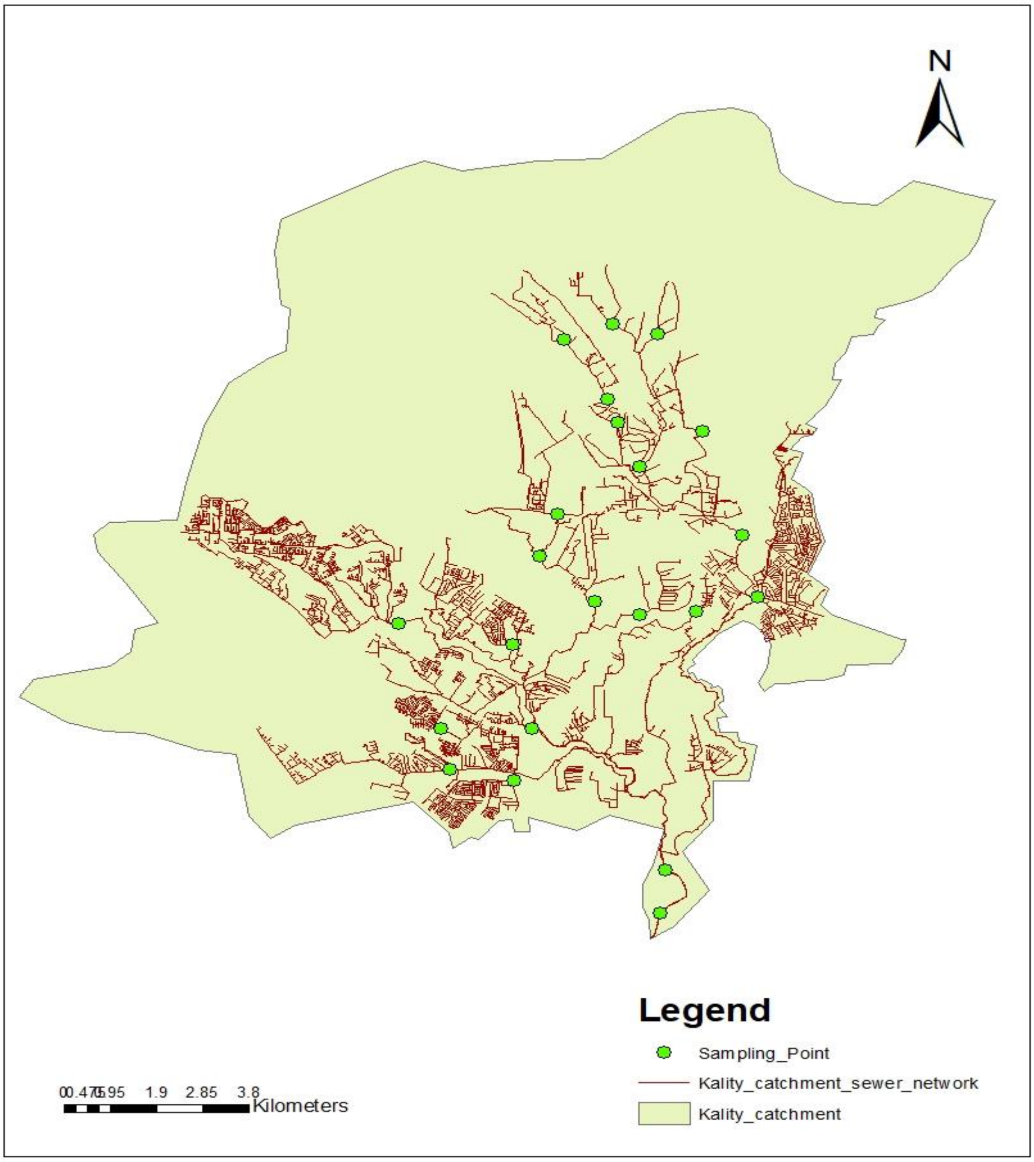

Figure 3: 18 Sample representative of flow measurement location

The main parameters of flow measurements are depth of pipe flow and velocity to load the model with the best information available, using measurements of the sewage flow at selected points in the system to calibrate. There are factors that can influence the selection of meter locations regardless of the application are area where number of sewer connection customers, areas where previous studies have indicated numerous defects, age of the collection system, areas where there have been a high number of complaints about backups or overflows and areas where there are a high number of operational and maintenance problems.

Figure 3: 19 Flow measurement at different location

3.6 Base Wastewater Flow Rate Determination

In sanitary sewers, wastewater flow can be divided into three categories: residential, non-residential, and infiltration/inflow (I/I). Residential wastewater comes from permanent residences or communal spaces like jails, dorms, and hotels as well as from dwellings like homes, apartments, and condominiums. Non-residential wastewater comes from businesses such as offices, retail stores, shopping centers, warehouses, industries, schools, jails, hospitals, churches, mosques, synagogues, and community centers; it is frequently referred to as "commercial" or "industrial. "Infiltration and inflow are both included in I/I and are described below. Groundwater infiltration occurs when it enters a sanitary sewage system through cracks, joints, and porous walls.

When additional flow enters a sanitary sewer from sources other than infiltration, it is referred to as inflow. Examples of such sources are connections from roof leaders, basement drains, land drains, and manhole covers. Typically, inflow is a direct result of rain or irrigation runoff. Form a layer of land use data, water consumption meter readings, and the combination of the land use for the current sewer system network to ascertain the potential existing flow in the sewer system.

The following steps were used to estimate the present and future wastewater flow rates of each manhole in the sewer network in order to determine the wastewater flow in the study area.

3.6.1 Estimation of Existing Wastewater Generation Rate

The existing wastewater estimation is based on the current water consumption bill recorded data obtained from AAWSA. Since the AAWSA sewage system is basically separate from the storm water system, a dry weather flow with various scenarios would be used in the hydraulic analysis of the current system. The average number of individuals for one connection is estimated to be 5, and the domestic home hold is essentially regarded as residence. Recent researchers have found a connection between water supply and wastewater produced by water end users.

Water consumption bill data obtained from utility billing records used to estimate wastewater flow rates. The consumption of water by individual residences, commercial establishments were considered, but industries not be considered in the bailing data because AAWSA has a policy not to connect any industrial waste to the central sewerage system and the industries are expected to have their own decentralized wastewater treatment plant. Since the time interval between meter readings is typically on the order of one month, these data are suitable for developing average, but not peak, flows. Recent investigations have established a relationship between the water supply and wastewater produced by water end users.

$$Q' = xQ$$

Where Q is the water consumption per person (l/c/d), Q' is the wastewater generated per person (l/c/d), and x is the return factor, given in urban drainage recent versions, Middle East: Poor Housing 85% Good Housing 75% However, utilizing the average value is more accurate than dividing the city into poor and decent housing without a well-organized study that is specific to Addis Ababa. As a result, it is assumed that 80% of the water used by those who are connected to the sewage system will end up in the sewer system when estimating the domestic wastewater flow rate (ECDSWC, 2021).

Therefore according to AAWSA sanitation master plan report, 2023 the following assumptions have been made for the estimation of wastewater discharge volumes. Wastewater flows are to be set with consideration for daily average and hourly peak flows, inflow and infiltration.

3.6.1.1 Estimation of Wastewater Flow

According to (AAWSA, 2023) wastewater flow is the part of the potable water consumption which is discharged into the sewer system3 (or other collection infrastructure) after use (including all flow components from residential, commercial, institutional and industrial usages). Since no measurements campaigns are planned on the project area, it will be assumed that 80 % of the consumed water is discharged into the sanitation systems. The formula used to calculate the daily wastewater flow is as follows:

$F_{ww} = 0.8 \times F_{pw}$---1

Where

F_{ww} = Wastewater flow (m3/d)

F_{pw} = Potable water consumption (m3/d)

3.6.1.2 Infiltration and Inflow (I & I)

As the sewer pipes are never completely watertight, infiltration of water from the underground table needs to be taken into account. As it can be easily understood, infiltration increases with the network's age and degradation state (corrosion, degradation caused by roots…). Infiltration also depends on the quality of the laying of the network (low quality materials, no laying bed, pipes fitting). These infiltrated flows may overload the pipes but also the treatment plants and lead to an increase in exploitation costs. They must therefore be taken into account during the network design stage. Inflow is related to water other than wastewater (mainly stormwater) that enters a sewer system from sources such as roof leaders, cellar/foundation drains, yard drains, area drains, drains from springs and swampy areas, manhole covers, cross connections between storm sewers and sanitary sewers, and catch basins.

Because of, the structural state of the existing sewerage network represents an additional unknown (no existing data, and no field investigation planned during the current study).

Based on that, a theoretical value will be used for I & I rate: it will be considered as 30% of the Wastewater Flow.

$I \& I = 0.15 \times F_{ww}$---2

Where:

F_{ww}= Wastewater flow (m3/d)

I & I = Infiltration and Inflow (m3/d)

3.6.1.3 Average Dry Weather Flow

The average dry weather flow includes all flow components from residential, commercial and institutional 3usages. The following formula shall be used to calculate the dry weather flow including I&I:

$\mathbf{F_{adw} = F_{ww} + I\&I}$---3

Where:

$\mathbf{F_{adw}}$: Average dry flow (m^3/d)

$F_{ww:}$ Wastewater flow (m3/d)

I & I = Infiltration and Inflow (m3/d)

3.6.1.4 Peak Wastewater Flow Factor

To design collection sewers and WWTPs, it is necessary to define the peak factor (Kap) which corresponds to the variation between day and night flows compared to the average. This peak factor is largely influenced by consumption, the number of connections and the flow time in the network which depends on its length. It decreases with total consumption and with the number of connections, the distribution of which along the network contributes to the mitigation of the peak. The peak factor, which is between 1.5 (at the end of the network) and 4 (at the head of the network), can be evaluated according to the empirical formula below:

$\boldsymbol{Kap = 1.5 + 2.5\sqrt{\frac{Fww}{86.4}}}$ ---4

Fww = Average dry flow (m^3/d) **Fww**

Kap = Peak wastewater flow factor

3.6.1.5 Dry Weather Peak Flow

The following formula shall be used to calculate the peak dry weather flow (including infiltration and inflow):

$$\mathbf{Fpdw} = \boldsymbol{Kap} \times \frac{\mathbf{Fww}}{\mathbf{24}} + \frac{\boldsymbol{I\&I}}{\mathbf{24}} \text{ --5}$$

Fww = Average dry flow (m3/d)

Kap = Peak wastewater flow factor

3.6.2 Projection of Wastewater Flow Rate Based On Land Use

The area of each land-use type within each sewer served area was assessed using the land-use and sewer served area GIS mapping. The volume of wastewater generated within each sewer served area is calculated based on the specific land use type of area and population densities for that sewer served area, the areas of and the per capita wastewater production for the study areas.

Since it refer the main spatial information of the Addis Ababa Structural plan for 2017-2027 density for different land uses, it used Area-based unit sanitary load. The product of density and the function of contributing area provided us the equivalent population. One way or another in this hydraulic analysis we can claim the method is indirectly as population based even if the population is an equivalent population which is generated from the land use and land density. The population-based method is most common way of specifying sanitary loads to a sewer system is to make them proportional to the contributing population. Population-based unit sanitary loads define loads as a function of adjusted contributing population. The population loading units were determined that will be used and the unit load per population unit. BWF criteria are based on type of land use, since different land uses contribute wastewater flows at different rates.

3.6.2.1 Population Projection

The anticipation of future growth in any community in terms of population or commercial and industrial expansion forms the basis for preparation of plan for providing the amenities including installation of sewers in the area to be served. The anticipated population, its density and its wastewater production is generally estimated for a specified planning period. The households size for the city of the city as per CSA analysis of 2007 census is 4.6-5.2. However the socioeconomic study made house hold survey made at sewered areas of Kality catchment and came up with the following article.

“The household survey within the Kality Catchment boundary as well as the whole Addis Ababa has disclosed that the mean household size found to be 5.9948 and the median value was 5 persons. The majority of households have large numbers of members ranging from 4 to 7 persons. According to the survey result the great majority or nearly 22 percent of the households in the catchment have five members. The other majority 17 percent are representing households with 4 members. Some of the sub cities like Kirkos, Bole, and Gulele have households with more than and equal to six members. It is so big number for a city way of life where the livelihood problems including shortage and poor quality of residential housing, unemployment, poor health conditions and others”. AAWSA, 2020.

Therefore, population projection should be based on land use data. Since Addis is dynamic city and the statistical better approach will be considering the proposed population density and proposed land use of the structural plan. The anticipated population, its density and its wastewater production is generally estimated for a specified planning period.

3.6.2.2 Land Use Type

In the Addis Ababa structural plan, there are above 28 different land uses and The Land Use Plan is the spatial interpretation of the Structure Plan. It contains above 28 different land uses and zones all areas of the city under 13 primary categories. But for the purpose of this study the land uses are reduced grouped in four main categories.

1. Mixed Residence / Residence

2. Mixed Commerce / Commerce

3. Office / Admin/ Institutional / Schools hospitals etc

4. Industrial

3.6.2.3 Land Use Map and Allocate Population

From watershed and the land use data, existing sewer network areas for sewerage was delineated using existing sewer served area map. Within the delineated zone, different land use types within the area was identify and mapped like residential, commercial, institutional, industrial, administration and so on.

3.6.2.4 Density Standards

The Structure Plan states that the city is running out of vacant land and notes that there is little space for horizontal development. The concept of intensive land use is promoted. The Main master plan is clipped by the service area border and the land use attribute file is extracted. The land use is categorized in four categories with maximum, medium and minimum density. High density mixed residential areas will have a minimum gross density of **150 housing units per hectare (hu/ha)**, while low and medium density residential areas will have a minimum gross density of **50 and 100 hu/ha, respectively**. The Structure Plan promotes polycentric development and proposes major sub and secondary centers within the city to relieve pressure in the busy city center.

3.6.2.5 Corrective Factors

In complex urban system the BAR (Built up Area Ratio) and the FAR (Floor Area Ratio) are used to specify the land use density: for the case of developed areas we can adopt the factors in relation with the specified densities. The land uses, factors and corresponding densities are shown in the following table below.

Table 3: 8 Land use factors in relation with the specified densities

Land use	**Density**	**Factor**	**Remark**
Mixed Residence / Residence	High	1	150
Mixed Commerce / Commerce	Medium	0.6	100
Office/Admin/Institutional	Low	0.3	50
Industrial	Low	0.3	50

3.6.2.6 Water Demand

For the design and analysis of sewer lines, Wastewater flow rate is the most important parameter and needs to be derived from the water demand of the end user. The generation of wastewater would be 80% of the proposed water supply to be supplied to the public for the domestic use. For the purpose of this typical study area (Kality

Catchment) inner city projected water consumption would be 160 l/c/day as specified by the design criteria as given referenced study below.

Table 3: 9 Water demand recommended by different consultants for Addis Ababa City

S.no	Reference Project	2015	2020	2025	2030	Remarks
		Residential Demand l/c/d				
1	Preliminary Design Report of Kality Wastewater treatment plant expansion and sewer lines in the Kality Catchment by Morrison	160	170	180	200	150 l/c/d Adopted by Morrison
2	AAWSA Business plan	110				
3	Determination of Utility Water Distribution and Sewerage Coverage percentage for the city of AA by Metaferia Consulting engineers	165	185	As per AAWSA Billing Data average consumption data ranges from 43.5lc/d to 165 l/c/d depending on the water availability and 91.4 l/c/d adopted By Metaferia		

According to the house hold survey made by the project socio economic described above table 3:2 about 67% of the water customers are under the category of house connection in the Kality Catchment. The assumption was made for this scenario at 67% of water customer house connected and from those customers all customers connected to sewer system.

3.7 Sewer System Coverage Analysis

Sewer system coverage is a critical process that helps to improve the availability, functioning and efficiency of the sewer system. There are several ways to determine sewer system coverage. Specifically, in Addis Ababa there are a number of options to determine sewer system coverage. They include coverage calculation by sewer customer verses water customer, coverage calculation by water distribution verses wastewater treated, coverage calculation by sewer customer catchment, coverage calculation by wastewater generation from offsite system, Coverage Calculation by water consumers per capita demand (as per actual treated), coverage calculation by water consumers per capita demand and coverage calculation by sewer customer verses households.

The sewer system coverage of the Kality catchment has been evaluated based on the number of water customers and number of sewer customers base on the choice of customers that customer satisfied with this options according to AAWSA. The water customers have been derived from the yearly water consumption of each customer that has been aggregated from the individual customer water meters. Besides the sewer customer, the distribution number of domestic's connection customers per family has been also evaluated and statistical analysis was used to evaluate the sewer system coverage. According to AAWSA, the sewer system coverage was derived using the following equation.

$$\textbf{Coverage of Modern Sewer System (\%)} = \frac{\textbf{Number of sewer customers}}{\textbf{number of water customers}} \times \mathbf{100} \text{ ---------------6}$$

3.8 Data Analysis

Primary and secondary data can be analyzed both qualitatively and quantitatively. Qualitatively, data was analyzed with the help of tables, charts or in words and quantitative data was analyzed with the help of Bentley SewerGEMS CONNECT Edition version 10 software. GPS and Arc map10.7 were used to collect data and to generate map of the study area, respectively. The current wastewater flow was estimated from the total current billed water consumption data and the future wastewater was estimated by projecting the current population and using unit wastewater flow of $160m^3$/day from AAWSA different feasibility study and by assuming that 80% of the water consumption becomes wastewater.

3.9 Selection of study area

According to the Addis Ababa Water and Sewerage Project Component-2 of 2004 and the 2001 NEDCO Master Plan study, the city has been divided into three main catchments for the drainage of wastewater. The major sewerage network is located in the north and northwest, with the WWTP as a base, and overflowing manholes have been seen in some areas in the Kality catchment, which is heavily inhabited and densely populated. The catchment was chosen for these reasons.

3.10 Model Representation

The model was constructed using Sewer GEMS software by giving all the necessary inputs collected from Addis Ababa Water Supply and Sewerage Authority: sewer network layout, Pipe data such as pipe diameter (mm), types of material and length (m). Inputs for nodes are elevation (m) and load (m3/d). Figure 2 shows the constructed model of the sewer network from the WWTP to service area.

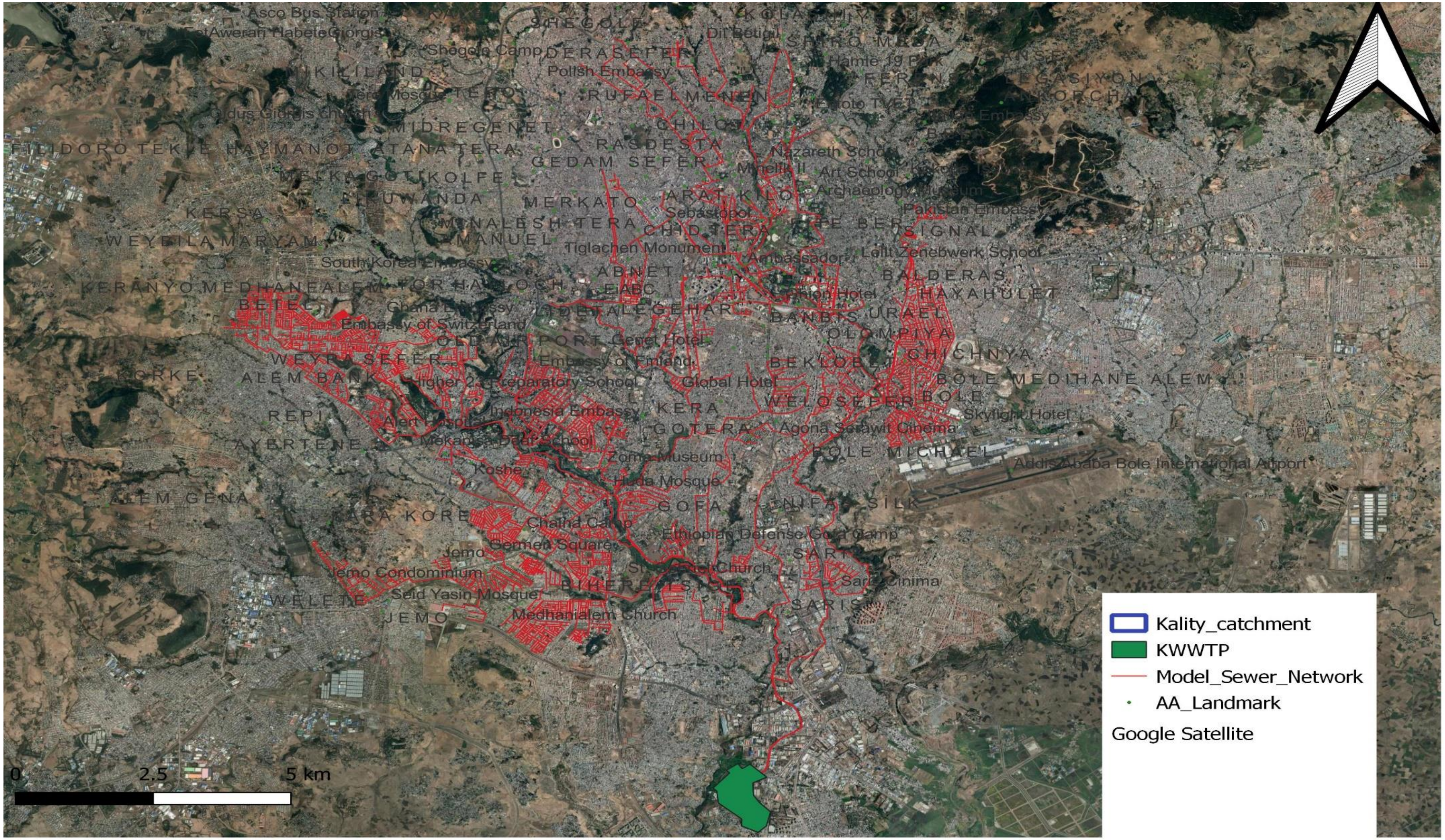

Figure 3: 20 Layout of the existing sewer network of Kality Catchment

3.11 Hydraulic Modeling of Sewer Network Using SewerGEMS

To assess the effectiveness and capacity of the current sewer network of the Kality Catchment, one of the key tasks was to develop the wastewater collection system. Therefore, using the most recent Bentley sanitary sewage hydraulic modeling software, SewerGEMS CONNECT Edition Version 10, new models for various scenarios have been created for the complete Kality Catchment wastewater collection system. The model was used to analyze the sewer lines, manhole hydraulic properties and geometric model, which had been already prepared in Arc GIS software. Many of the components that were deemed necessary in the geometric modeling stage may need to be removed from the system after hydraulic modeling. Some of the default pathways determined in geometric modeling might not satisfy the systems hydraulic design specifications. As a result, in the hydraulic study of sewerage networks, hydraulic modeling is considered to be the core component of the job.

3.11.1 Why Bentley Sewer GEMS selected?

There are several reasons why Bentley Sewer GEMS selected for modeling the performance of the sewer network for this study:

- Comprehensive Modeling Capabilities
- User-Friendly Interface
- Integration with Other Software
- Validation and Verification
- Availability of Technical Support:

Considering these factors, Bentley Sewer GEMS for modeling the performance of the sewer network is selected to conducting the research and obtaining reliable results.

3.11.2 Model Descriptions

Haestad Methods, a company based in Connecticut and best known for its WaterCAD water distribution modeling software, created SewerCAD/SewerGEMS. The most recent version is called SewerGEMS which can run from AutoCAD or ArcGIS or from a standalone Windows interface. Whether the graphical user interface or the Stand-alone graphical editor is used, projects can be finished in exactly the same way.

3.11.3 Model Capability

With the help of SewerGEMS, sanitary loads can be developed, computed, and simulated, as well as the hydraulic response of the complete system, including gravity collection pipework and pressure force mains. Algorithms for standard-step gradually varying flow are used to calculate gravity-based hydraulic grade lines. In-depth design and analysis capabilities are provided by SewerGEMS for sizing and positioning sewer system pipes on a system-wide or pipe-by-pipe basis. One project file may contain any number of different sanitary sewer networks.

3.11.4 Model Building

The construction of the current sewer network and the location of the various sewer system facilities serve as the first steps in the model development process. The GIS files of the sewer pipes, manholes, and other sewer facilities in GIS shape file format (.shp) are used to construct the sewer network. Names, installation year, material, lengths or depths, ground elevations, and other qualities of a pipeline or manhole are among the categories into which the attribute information from shape files is arranged. Shape files are imported into the model using the Model Builder tool, which then links the data in the shape file fields to the relevant Sewer GEMS model properties.

For model building the following main layers were used

- Preliminary sewer layout for the existing sewer network
- Existing sewer system layout for possible connection
- Contours DXF file to assign the ground elevation
- SewerGEMS Terrain model setup and Tyson's boundary

3.11.5 Nomenclature

The model requires a unique identification value for each element. Identification for the pipes in the model is based on its connecting upstream and downstream manhole ID. In the model, pipes are represented as links and manholes are represented as nodes. Easy identification of model elements is important as it provides for better understanding and use of the model

3.11.6 Model Data Cleanup

A complete quality assurance and quality control (QA/QC) of the entire system is carried out utilizing the pipeline and manhole data once GIS data has been entered into the model using Model Builder. This QA/QC process is crucial because it identified several places in the AAWSA's current GIS data that contained inaccurate elevation data, gaps in the data, or discrepancies between data from different sources that were provided by AAWSA. Several tools from the Sewer GEMS model were used to carry out this QA/QC process, including the TRex Wizard, Profile Manager, and the validation tool.

3.11.7 Verify and Update Existing Sewer Served Area

In order to accurately estimate the wastewater generation from the study region, it is required to validate all wastewater contributing areas after the land use of the study area has been confirmed. Although AAWSA has planned a sewer serviced region, it has to be revised due to a recent sewer line network extension. As a result, the area served by the existing sewage line was updated based on the elevation at which the manholes could receive wastewater by gravity and connect to customers.

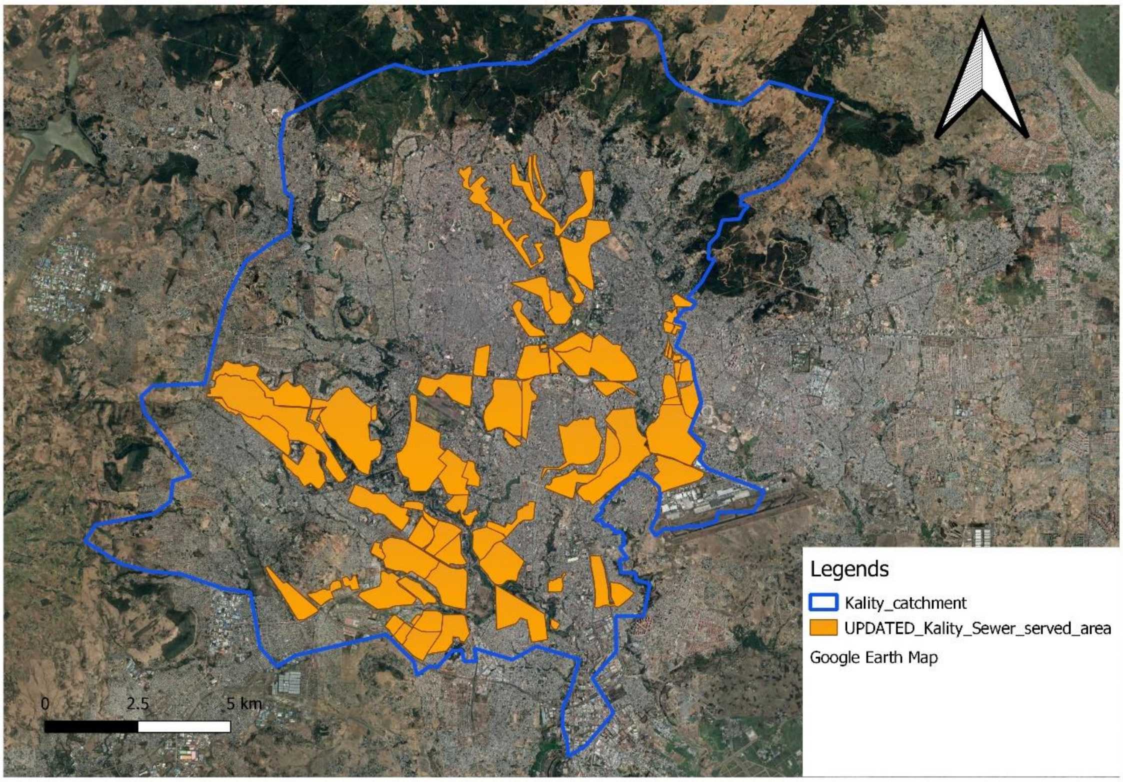

Figure 3: 21 Updated existing sewer served area of the study area

3.11.8 Review Pipes with Missing Manhole Connections

By employing a tolerance of one meter, pipes and manholes are linked spatially. Since all pipes in a model must have a connecting node, SewerGEMS creates a node for pipes that do not have a manhole within the tolerance region of one of their ends. Any nodes that SewerGEMS automatically constructed are then eliminated, leaving just the known manholes from the GIS to be represented in the model after the proper link between the pipe and manhole has been made in the model.

3.11.9 Delete Abandoned Manholes

After all pipe and manhole connections have been verified, any abandoned manholes and associated pipes are found and eliminated from the model. Using this nomenclature, it was established that 67 manholes were abandoned and taken out of the model. Additionally, pipes that were connected to manholes that were closed were removed from the model.

3.11.10 Verify Manhole and Pipe Information

Verifying all of the model's assigned altitudes is important after connection and pipe length have been confirmed. These values include the invert elevation of pipe's downstream and upstream ends, as well as the invert elevation of a manhole, manhole's rim elevation, and its ground elevation.

3.11.11 Assignment of Sanitary Load

With the help of the load builder tool in sewage GEMS, the region that the existing sewage line network is intended to serve was designated using a polygon border and sanitary loading applied at manholes. The land use methods in question are point load and load (Thiessen approach). A area load is employed in the first case (wastewater generation from water customer billing data). The projection by Land Use approach was used to allocate land use load data to the model for the second scenario. According to this method, loads are distributed across several loading nodes according to the density per land use type of each service polygon (which is specified by the Tyson's polygon; it is generated from a land use map and projected one).

3.11.12 Assignment of Roughness Coefficient

Manning's 'n' roughness coefficient is the friction factor utilized in the Manning's Equation for gravity flow to describe the roughness of a particular pipe material or condition. Manning’s roughness coefficient represent by (Morrison, 2011) Roughness coefficient with corresponding material given below

- $n = 0.013$ for concrete pipe
- $n = 0.011$ for PVC/HDPE and
- $n= 0.01$ for GRP

3.11.13 Calculation Option

In Sewer GEMS there are four different numerical solvers available. The solvers include:

- Explicit (SWMM)
- Implicit (Dynamic Wave)

- GVF-Convex (gradually varied flow with convex routing)
- GVF-Rational (gradually varied flow with ration method hydrology).

Sewer GEMS numerical solver, which exclusively runs scenarios with the GVF-convex solution, was chosen as the solver for this hydraulic analysis. Sanitary and combined sewer systems, particularly those with intricate pumping or pressure sewers, may benefit from its use. Storm CAD ran scenarios using the GVF-rational solver for the goal of doing a preliminary zero flow analysis and setting the invert design element. This aids in lowering the complexity of the dual design complicated (conduit diameter and inversion level designs).

3.11.14 Scenario Management

A limitless number of scenarios may be configured, run, evaluated, visualized, and compared using Sewer GEMS' Scenario Management Centre. By comparing countless scenarios, it is simple to compare analysis, design, operational, sanitary loads, and even network topology methods for better decision support.

3.12 Hydraulic Model Scenarios for Existing Sewer Network

In order to assess the effectiveness of the Kality Catchment Wastewater Collection System, there are three possible scenarios used by considering peak dry weather flow and including optimum infiltration/inflow under current and future conditions. The model was examined, and the possible three key scenarios are listed below.

3.12.1 Scenario I: Existing System with Active Sewer Customers

The first computer model scenario was created to evaluate the existing system using sewage generation rate data estimated from active sewerage service users lists provided by AAWSA. Regardless of whether customers are connected or not, the model includes all sewer lines linked to the main trunk sewer. It is assumed that infiltration, inflow, and unauthorized connections are inevitable once the sewer lines are built and joined to the operational trunk mains. The wastewater quantity loaded to manholes within the existing sewer lines was calculated using information from active sewer customers.

A computer model scenario was developed to assess the current sewage system using data on sewage generation rates from active sewerage service users. The model includes all sewer lines connected to the main trunk sewer, accounting for infiltration, inflow, and unauthorized connections. The amount of wastewater flowing into manholes in the existing sewer lines was determined based on information from active sewer customers.

3.12.2 Scenario II: Existing System with Potential Sewer Customers

The basic model of the current Kality catchment sewerage network served as the foundation for the development of the second scenario. The rate of wastewater development in this scenario is computed using the current potential customer's water consumption of the study area.

In accordance with the aforementioned feasibility study, sewer customer connection projection rate to be 75% of water supply customers have a house connection facility. The assumption made in this scenario is that AAWSA would be able to connect those 75% of water customers for sewer line service and assess the capacity of the current sewerage system to collect and transport sewage to the KWWTP. This analysis assumed that the present water supply situation would remain unchanged for a while. Customers for water supply were identified inside the boundaries of the current sewer network, and the wastewater quantity was calculated and allocated to each manhole based on the area proportion. If potential customers were able to connect to existing sewer lines, this scenario would serve to demonstrate the performance and capacity of the current sewer system.

3.12.3 Scenario III: Existing and Expansion Sewer System

In addition, an updated hydraulic model of the city's sanitary sewer system has been developed as a result of this study and used for sewer system evaluations. The hydraulic model includes both proposed major sewers to serve the areas of future growth and system facilities now in use. By adding recognized and existing sewer lines of the Kality catchment sewer line and using the estimated wastewater flow rates at the existing sewage network based on land use of Kality Catchment, the base computer model of this project was upgraded to the final model, which is targeting the future time of the year 2043.

Based on the anticipated wastewater generated by the proposed and existing sewerage networks, the wastewater generation rate is calculated. The proposed sewer line expansion locations with the anticipated wastewater are injected into the improved sewage system, and this model is used as a tool to assess the capacity and performance of the current sewer network. Sewer network rehabilitation and modernization requirements have been identified.

3.13 Existing Sewer Network Evaluation Approach

The model flow allocations, flow split configuration, and assumptions for the existing system study were validated using the peak dry weather sanitary load. The hydraulic requirements for d/D and acceptable surcharge were compared to the findings of the existing and build out sanitary load analyses. The places that didn't fit the bill were identified as deficiency locations.

A thorough study was then conducted to evaluate whether improvements were necessary at the deficiency areas that did not match the requirements. In order to establish the degree of surcharge (whether it gets within 15 cm of the manhole rim) and the likelihood of backflow conditions from downstream pipes, a hydraulic profile of each deficiency location was separately evaluated (Salinas, 2011).

Not all existing pipes not meeting the criteria (i.e., identified as deficiency locations) require improvement. The ultimate need for a system improvement is dictated by the level of surcharge, the possibility of diverting flow upstream to a different existing pipe, existing pipe characteristics such as slope and diameter, and whether it is impacted by backwater that will be eliminated by a downstream improvement. The depth of flow in the pipe (d) relative to the pipe diameter (D) is a typically used parameter for evaluating capacity needs. For the sewerage system analysis, the following criteria are used:

- Pipe improvements for new development: Design peak flows to be conveyed with d/D=0.80under peak flow conditions. This criterion is used for sizing all new improvements.
- Existing pipes: d/D=0.9 under estimated peak flow, which is the depth of flow providing the maximum discharge rate for circular pipes. This criterion will be used for the initial identification of capacity deficiencies in the existing system. Note: There is a lower discharge rate at d/D =1.0 (full pipe) due to friction losses, which is equivalent to the discharge rate at d/D = 0.82.
- For evaluating and prioritizing whether existing pipes require improvement, surcharge is allowed as long as the HGL remains at least 15cm below the rim elevation at the upstream manhole under peak flow conditions. Under surcharged conditions, the pipe flows at greater than full pipe flow and the HGL is above the top of the pipe (pressurized flow). This criterion is only for evaluating whether existing pipes require replacement. All new pipe improvements and replacement projects are sized to convey the peak design flow without any surcharge.
- Sensitivity analysis is done for existing pipes to determine extent of required improvements to existing pipes and whether improvements are needed due to increases in future flows due to future growth. The more stringent criteria apply to improvements needed for future growth. The less stringent criteria apply to existing pipes not affected or negligibly affected by future growth (Salinas, 2011).

3.14 Network Simulation

Steady state simulations are used to evaluate system performance. This type of analysis allows the user to model manholes filling and draining, regulating flow rates changing throughout the system in response to varying flow conditions and automatic control strategies formulated by the modeler.

3.15 Model Calibration and Validation

For model calibration and validation effort data were collected from field selected sample locations. Once sewer system model has been developed, it must be calibrated so that it precisely speaks to the genuine working genuine life sewer arrange beneath a assortment of condition. This includes making minor alteration to the input information at that point the show precisely mimicked the stream rate within the framework. Streams are measured all through the sewer arrange framework utilizing weight gage instrument to utilize the information for demonstrate calibration.

4. RESULTS AND DISCUSSION

4.1 Estimated Wastewater Generation

Estimated wastewater flow of the Kality Catchment was used for assessing the performance, checking the capacity and identifying deficient locations in the sewer network. The estimated wastewater flows based on three possible scenarios are presented and discussed below.

4.1.1 Scenario I: Wastewater Generation from Active Sewer Customers

There are water supply customers already connected with the existing Kality Catchment sewer network. The data collected from the AAWSA head office indicated that there are about 67,258 active sewer line customers within the catchment. These customers are predominantly concentrated in condominium sites. The wastewater could be generated from those active customers estimated from their water consumption billing data and 80% of the water supplied end up into sewer lines. Customer meter inaccuracy from NRW study and inflow infiltration was also considered. The total wastewater generated from all active customers was estimated as follows.

- Wastewater from active sewer customers based on the water consumption billing record
- NRW studies indicated that customer meter inaccuracy (under registration) is about 11.54% of the total water billed calculated
- Inflow infiltration considered as 0.15% of the total water billed also calculated
- Wastewater flow determination also considered as peak flow condition
- Therefore total wastewater generation rate estimated from all active sewer line service customers including is 66,451.89 m^3/day. Wastewater generation from active customer is given in Annex 4.

4.1.2 Scenario II: Wastewater Generation from Potential Sewer Customers

Wastewater generation based on water supply consumption quantity at areas where sewer lines are already constructed. Water customer within Kality Catchment at areas where sewer lines already exist is about 381,450 household, according to AAWSA long-term sewer connection projection mentioned above. It was assumed that 75% of the water customers are using sewer connection mode of service and 100% of condominium houses were sewer connected and 80% of the consumed water supply became wastewater. Based on the customers billed data the existing sewer system can receive about 140,010.64m^3/day wastewater on average depending on the water supply delivery to the city dwellers with in sewered areas of Kality Catchment. The wastewater generation rate computed based on water supply customers billing data and sewer line covered areas utilized for analysis of existing sewerage system of Scenario II and estimated wastewater generation are presented under Annex 5.

4.1.3 Scenario III: Projected Wastewater Generation from Land Use

The third scenario wastewater estimation method was based on only sewer served area prepare about 67% water customers connected to sewer system and sewer served area with respect to specific spatial distribution of the existing sewer served area. Basically this sewer served area obtained from AAWSA as a reference but this sewer served area updated according to current condition of the existing sewer network. Wastewater flow estimated based on land use of structural plan of Addis Ababa with the respected spatial distribution of the sewer served area. The wastewater to be generated could be assumed 80% of the water supply as local and international practices indicates described above. The rate of water supply shall be adopted as 160 l/pcd as per the AAWSA design water consumption rates for residential if the water supply customers to having house connection 67% and using house connection mode of service and condominium houses considered 100% house connected, all house connected customers also connected to the sewer line, at ultimate development. The non-domestic wastewater generation shall be calculated based on the percentage of estimated domestic wastewater flow. According to Addis Ababa structural plan of land use, the estimated wastewater flow rate was 244,941.39 m3/day and at design period of 2043. This data is applied for the analysis of existing sewer network for respected years. Therefore, the projected wastewater generation from land use were estimated and shown in the annex 6.

4.2 Sewer System Coverage Analysis

Considering spatial distribution of Kality catchment of existing sewer line, a huge area has been already covered. The existing sewer line is currently covering more than 4,400 hectares. Within the Kality wastewater catchment there are about 381,450 residential and commercial water supply customers and 67,258 active sewer customers according to the customer billing data. The mode of water supply service is different from customer to customer, some are enjoying house connection and others are served with yard connection and public tabs. Most of those customers with house connection are potentially expected to be connected with the existing sewer system. The wastewater to be generated could be assumed 80% of the water supply as local and international practices dictates. To improve the sanitation situation of the town the main aspect is to improve the water supply situation in parallel with the sewerage system improvement.

Different kind of AAWSA feasibility studies indicates that most customers have yard connections. Increasing number of house connected water customers is also equally important and its distribution that might also change the analysis to some extent.

According to AAWSA the sewer system coverage were calculated by contrasting the relationship of active sewer customer with water customer, therefore from customer bill recording data there are about 67,258 water customers and 381,450 sewer customers according to the customer billing data. So the sewer system coverage is the ratio of water customer to sewer customer.

$$\textbf{Coverage of Modern Sewer System (\%)} = \frac{\textbf{Number of sewer customers}}{\textbf{number of water customers}} \times 100$$

Coverage of Modern Sewer System (%) = (67,258 /381,450)*100 = 17.63%

Sewerage coverage of Kality Catchment sewer system estimated as 17.63%, the rate did not indicate how much proportion goes to residential, commercial, or industrial coverage. The coverage only shows the proportion of active sewer customer with respect to water customer in the existing sewer system of the study area.

4.3 Overcome Manhole Overflow in the Existing Sewer Network

To overcome the causes of manhole overflow in an existing sewer network, proactive measures can be taken to address the underlying issues.

Firstly, regular maintenance and cleaning of the sewer network is essential. This includes conducting routine inspections to identify potential blockages or structural issues in the pipes. By implementing a preventive maintenance program, blockages can be cleared in a timely manner, reducing the risk of manhole overflow. Regular cleaning of the sewer pipes can also remove any accumulated debris or sediment that may impede the flow of wastewater. This maintenance approach helps ensure the smooth operation of the sewer network and minimizes the chances of overflow.

Secondly, investing in infrastructure upgrades and capacity expansion is crucial. Assessing the existing sewer system's capacity and identifying areas with deficiencies can help determine where upgrades are necessary. This might involve increasing the size of pipes, by enhancing the capacity of the sewer network; it becomes better equipped to handle the demands of the community, reducing the likelihood of overflow during peak periods or heavy rainfall events. Additionally, implementing modern technologies and materials during infrastructure upgrades can improve the structural integrity of the sewer system and minimize the risk of blockages or leaks.

4.4 Model Calibration and Validation

4.4.1 Calibration of Hydraulic Sewer Network Model

The accuracy of a hydraulic model depends on how well it has been calibrated, so a calibration analysis should always be performed before a model is used for decision-making purposes. There were 23 manholes datasets were selected from field observation and from simulated results for calibrating the model. Those data's calibrated based on steady state analysis because the system is separate sewerage system and only considered the existing wastewater flow at peak flow condition. This calibration and validation result described below represent for the existing sewer network only active customer for the first scenario.

4.4.1.1 Model Performance Evaluation Criteria

There are many ways to judge on the performance of model calibration. The evaluation was made by calculating the squared relative difference between observed and simulated pressure for each test. The evaluation criteria used was statically method using correlation coefficient (R2).

$$\mathbf{R^2} = \frac{\sum(\mathbf{X}-\mathbf{X_{mean}})*(\mathbf{Y}-\mathbf{Y_{mean}})}{\sqrt{\sum(\mathbf{X}-\mathbf{X_{mean}})^2*\sum(\mathbf{Y}-\mathbf{Y_{mean}})^2}}$$

Where R^2 is Correlation Coefficient, X and Y are measured and simulated values, X_{mean} and Y_{mean} are average value of measured and simulated data respectively.

4.4.1.2 Sewer Capacity (d/D) Calibration

The model calibration process involved analyzing the steady-state simulation results since the sewer system operates separately and focuses solely on peak flow conditions. Luckily, there was no significant difference between the observed and measured values of depth/rise. To further refine the model, a sensitivity analysis was conducted by adjusting the Manning's roughness coefficient (n). After multiple iterations, it was determined that only certain pipes, specifically those made of asbestos cement with a diameter of 600mm, required a change in the roughness coefficient (n) from 0.012 to 0.013. Additionally, the pipes made of fiberglass had their roughness coefficient adjusted from 0.011 to 0.013. However, the rest of the pipes, which were made of PVC, remained constant in terms of their roughness coefficient.

To assess the effectiveness of the calibration, the differences between the modeled (d/D) and measured (d/D) values were computed using an Excel sheet. It was observed that the modeled and measured values matched to a reasonable extent, indicating a successful calibration process.

The degree of accuracy varies depending on the size of the system and the amount of field data and testing available to the modeler (Walski T. M., 2007), states that the average level is within 5% for a good data set.

Table 4: 1 Locations of samples points of sewer network manholes and the capacity of sewer Pipe (d/D) % with corresponding result

S. No.	Sample Location Points	Location				Pipe or Conduit ID	Observed Depth/ Rise (d/D)Ratio %	Simulated Depth/ Rise (d/D)Ratio%	Difference Depth/ Rise (d/D)Ratio% Error
		Elevation (Ground) (m)	Elevation (Invert) (m)	X(m)	Y(m)				
1	MH-3492	2,211.60	2,210.00	470,817.98	990,698.91	CO-3479	0.34	0.30	0.04
2	MH-4008	2,272.70	2,267.85	468,055.77	993,227.65	CO-4012	0.31	0.28	0.02
3	MH-4204	2,168.39	2,164.71	473,465.96	986,295.00	CO-4213	0.33	0.32	0.02
4	MH-4269	2,172.82	2,169.85	473,571.46	987,327.17	CO-4279	0.35	0.30	0.05
5	MH-5337	2,297.09	2,295.09	473,047.29	993,427.28	CO-5361	1.04	0.92	0.12
6	MH-3373	2,213.40	2,212.00	470,444.47	989,449.07	CO-2956	0.38	0.26	0.12
7	MH-21	2,221.06	2,218.80	469,119.09	989,715.58	CO-35	1.15	1.00	0.15
8	MH-3469	2,276.69	2,274.00	472,109.41	993,741.77	CO-3457	0.42	0.36	0.06
9	MH-55	2,302.00	2,300.90	475,474.18	993,864.53	CO-92	0.51	0.46	0.06
10	MH-212	2,280.99	2,278.49	470,433.48	992,721.27	CO-331	0.20	0.13	0.07
11	MH-5663	2,320.77	2,318.11	475,155.85	995,341.68	CO-5690	0.88	0.78	0.10
12	MH-3397	2,336.47	2,335.00	471,346.53	995,841.36	CO-3366	1.12	1.00	0.12
13	MH-4750	2,234.29	2,231.48	468,930.06	990,716.48	CO-4770	0.64	0.49	0.15
14	MH-3393	2,352.42	2,349.92	473,052.51	996,972.19	CO-3360	0.25	0.20	0.05

15	MH-223	2,315.97	2,313.47	474,218.33	993,512.57	CO-344	0.16	0.14	0.02
16	MH-4994	2,413.83	2,412.68	474,339.10	997,834.24	CO-5014	0.42	0.37	0.05
17	MH-218	2,503.28	2,500.78	471,469.22	1,000,022.59	CO-338	0.49	0.46	0.03
18	MH-117	2,301.54	2,299.04	470,985.95	994,850.14	CO-197	0.60	0.58	0.01
19	MH-3534	2,496.75	2,494.25	473,411.75	1,000,154.39	CO-3522	0.24	0.16	0.08
20	MH-5326	2,457.54	2,455.04	472,388.09	998,599.39	CO-5350	0.35	0.39	-0.04
21	MH-207	2457.54	2455.04	472388.09	998599.39	CO-323	0.29	0.23	0.05
22	MH-1396	2,424.11	2,421.61	472,586.18	998,034.90	CO-1624	0.09	0.05	0.04
23	MH-3536	2,504.15	2,501.15	472,488.98	1,000,401.71	CO-400	0.27	0.16	0.11
Average Error							10.83	9.36	1.47

As shown in table 4:1 above, computed values are within an average error of 1.47 depth/rise observed to simulated values. Hence, the model is acceptable calibrated which is satisfied the setting depth/rise calibration and validation criteria under average level is within 5% of each other, so the model considered as calibrated under peak flow condition. The agreement between the observed field data and the model result graphically sketched to show the overall relationship in between the two data sets as follow below.

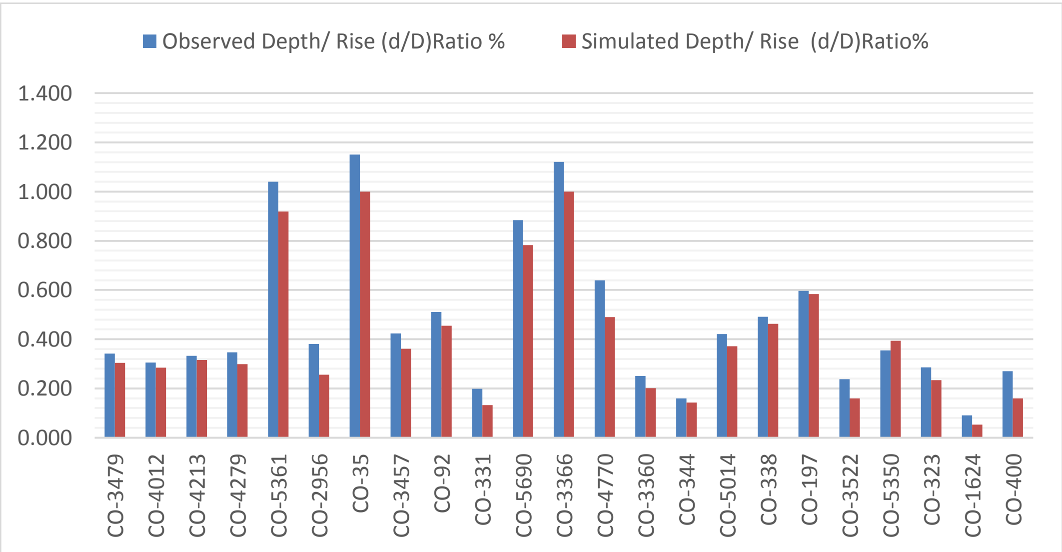

Figure 4: 1 Observed and simulated capacity of sewer Pipe (d/D) % with corresponding sewer pipe or conduit

4.4.2 Model Validation

Validation is the steps that follows calibration and uses an independent field data set to verify that the model is well calibrated. In the validation step, the calibrated model is run under conditions differing from those used for calibration and the results compared to field data. The model result is closely approximate the field results (visually) for an appropriate time period and the calibrated model is considered as validated.

Capacity of sewer (d/D) % was measured in the field in order to compare with the results of the sewer network. Figure 8 below is a comparison plot of observed d/D versus calculated d/D at various sewer lines and manholes throughout the system.

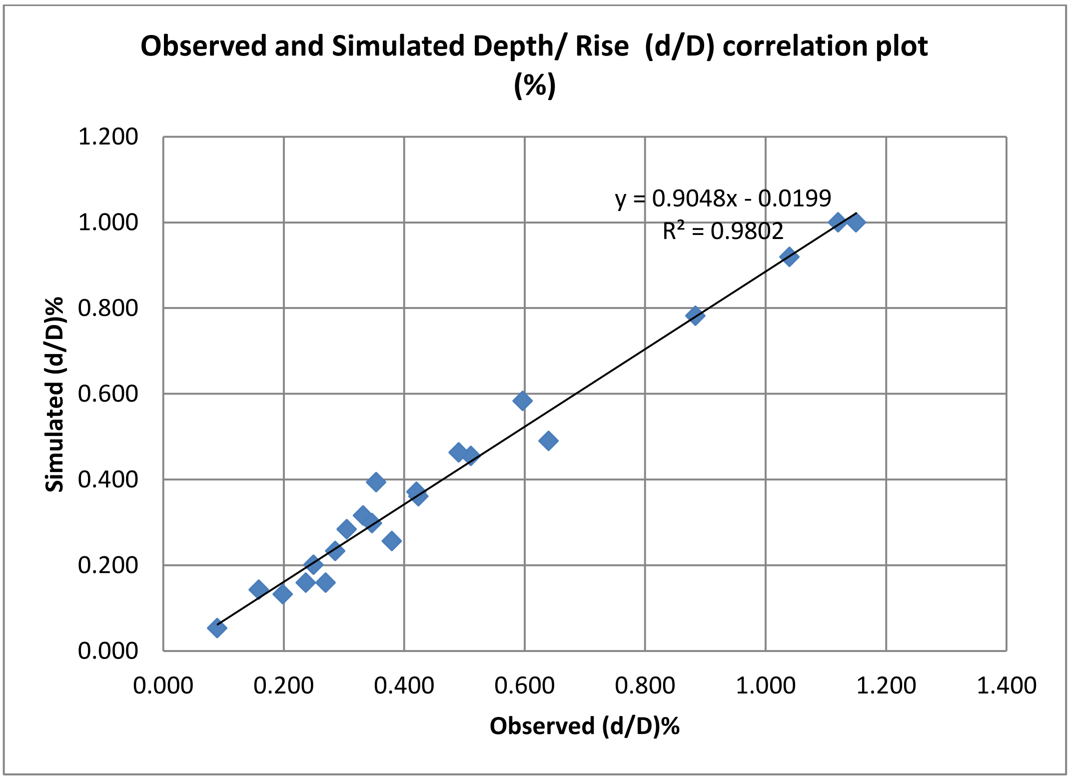

Figure 4: 2 Correlations between observed and simulated pipe capacity parameters.

The diagonal line on the plot represents the line of perfect correlation in figure 8 above. Ideally all the points should align themselves on this line; meaning that all observed capacity of pipe (depth/rise) is equal to the computed capacity of pipe (depth/rise), giving a correlation coefficient of 1 that is the best correlation between observed and simulated. The linear correlation coefficient (R^2) of observed versus computed capacity of pipe (depth/rise) is at 0.9802. The coefficient of determination (R^2) value was 98.02%, it indicates that observed and simulated relation is strongly as values tend to 1. Thus indicated that the computed capacity of sewer (depth/rise) is within the acceptable limit.

4.5 Model Analysis

The existing sewer network model analysis has been done by running the model for current year at dry weather, wet weather by considering inflow and infiltration and at peaking variations of load with different scenarios for the first and the second scenarios but the third scenario, the model analysis made at peak flow due to ultimate development of projected flow for the design horizon.

4.5.1 Steady-State Analysis

The model has been performed in steady state analysis run for the average daily demand, which is the load at every manhole. The model is simulated the capacity analysis of the existing sewer network at the peak day flow is simulated to identify the current and future problems (deficiency) of the system and to locate the critical location in existing sewer network.

4.5.1.1 Pipe (Conduit) Network

In the sewer network model, has the total number of

Table 4: 2 Length of sewer pipe network Sewer GEMS model result

No.	Sewer Pipe Length (m)	Pipe Diameter (mm)	Material Type	Percent (%) of Pipe Covered
1	368497.90	200.00	PVC	68.93
2	36399.70	250.00	PVC	6.81
3	43216.40	300.00	PVC	8.08
4	15396.00	400.00	PVC	2.88
5	7157.40	500.00	PVC	1.34
7	12730.60	600.00	Glass	2.38
6	2156.70	600.00	Asbestos Cement	0.40
8	16453.90	600.00	Asbestos Cement	3.08
9	3319.40	700.00	Asbestos Cement	0.62
10	852.70	800.00	Asbestos Cement	0.16
11	2005.50	900.00	Glass	0.38
12	15071.90	1000.00	Glass	2.82
13	584.40	1200.00	Glass	0.11
14	550.20	1300.00	Glass	0.10

15	3882.80	1400.00	Glass	0.73
16	4644.40	1500.00	Glass	0.87
17	1672.90	1600.00	Glass	0.31
Total Length of Pipe	534,592.80			100.00

The sewer network model result shows that the majority of pipes (68.93%) has a diameter of 200 mm and is made of PVC material. PVC pipes are known for their durability, resistance to corrosion, and low cost. The second most common pipe diameter is 250 mm, which accounts for 6.81% of the pipes. PVC pipes are also used for this diameter, indicating their widespread use throughout the sewer network.

The data also shows that there are other materials used in the sewer network, such as glass and asbestos cement. Glass pipes are used for diameters ranging from 600 mm to 1600 mm, while asbestos cement pipes are used for diameters ranging from 600 mm to 800 mm. The percentage of pipes made of these materials is relatively low, indicating that they are not commonly used in the sewer network.

The length of the pipes is also an important factor to consider. The data shows that the majority of pipes (68.93%) have a length greater than 200,000 m. This indicates that the sewer network is extensive and covers a large area. The remaining pipes have a length less than or equal to 200,000 m, which could be due to the location of the pipes or the design of the system. The percentage of pipe covered in each category provides an indication of the distribution of the pipes in the sewer network. The data shows that the largest percentage of pipes (68.93%) fall into the first category, which has a diameter of 200 mm and is made of PVC material. The second largest percentage of pipes (8.08%) falls into the third category, which has a diameter of 300 mm and is made of PVC material. This indicates that PVC pipes are the most commonly used pipes in the sewer network, followed by glass and asbestos cement pipes. The percentage of pipe covered in each category also provides insights into the maintenance requirements of the sewer network. Pipes with a lower percentage of coverage may require more frequent maintenance and inspection to prevent blockages and other issues. Additionally, the length of the pipes could also impact maintenance requirements, as longer pipes may be more difficult to access and maintain.

4.5.1.2 Sewer Network Elements

Table 4: 3 Elements of sewer network summary

No.	System Components	Number of element presented
1	Manholes	5867
2	Pipe	5176
3	Outfall	2
4	Treatment plant	1

According to the data give the above table, the sewer network model consists of four main system components.

1. Manholes: There are a total of 5,867 manholes in the sewer network model. Manholes are important components that provide access to the underground sewer system for inspections, maintenance, and repairs. The large number of manholes suggests that the sewer network has an extensive coverage and accessibility.

2. Pipes (conduits): The sewer network model includes 5,176 pipes or conduits. Pipes are the primary elements that transport wastewater from one location to another within the sewer network. The high number of pipes indicates a complex and interconnected network that allows for efficient movement of wastewater.

3. Outfalls: The sewer network model features two outfalls. Outfalls are the points where the wastewater is discharged from the sewer system into a receiving body of water, such as a river or ocean. The presence of outfalls suggests that the sewer network is designed to transport wastewater to a designated discharge point.

Overall, the data provided in the table gives an overview of the different components of the sewer network model. The large number of manholes and pipes indicates an extensive and interconnected network. The presence of outfalls suggests a planned discharge point for the wastewater, and the inclusion of a treatment plant indicates a focus on wastewater treatment and management.

4.6 Model Analysis Result of the Existing Sewer Network

4.6.1 Model Analysis Scenarios I Result

4.6.1.1 Sewer Capacity (Depth /Rise)

In a sewer model result, sewer capacity or depth/rise refers to the maximum volume of wastewater the sewer can hold or the highest point the water level can rise without causing any overflowing, backups and flooding.

Table 4: 4 Sewer capacities (depth/rise) in the existing sewer network at scenario I

No.	Depth/Rise (%) Value	Length of Pipe (m)	Percent of pipe, %
1	<= 90	529,166.70	98.99
2	<= 100	5426.1	1.01
3	<= 120	-	-
6	Other	-	-
	Total	534,592.80	100.00

The result provided is related to the depth/rise (%) value, length of pipes, and the percentage of pipes in a sewer network modeling that have deficiencies in their location. The result indicated that the majority of pipes (98.99%) have a Capacity or depth/rise (%) value less than or equal to 90%. This indicates that the sewer network has a relatively flat profile, which is beneficial for the flow of wastewater. The remaining 1.01% of pipes has a depth/rise (%) value greater than 90%, which could indicate that there are deficiencies in the location of these pipes. Those pipes are specifically explained as CO-10, CO-11, CO-12, CO-13, CO-14, CO-17, CO-18, CO-34, CO-35, CO-36, CO-38, CO-39, CO-40, CO-65, CO-71, CO-73, CO-75, CO-80, CO-81, CO-84, CO-85, CO-207, CO-374, CO-375, CO-1323, CO-1307, CO-1640, CO-1642, CO-1643, CO-1837, CO-1846, CO-1847, CO-2260, CO-2261, CO-3366, CO-3370, CO-3373, CO-3482, CO-3483, CO-3484, CO-4739, CO-4740, CO-4741, CO-5361, CO-5412, CO-5413, CO-5414, CO-5583, CO-5603, CO-5604, CO-5841. The result shows that the percentage of pipes with deficiencies is relatively low; these specific pipes have a slightly higher capacity, indicating a potential need for improvement or monitoring.

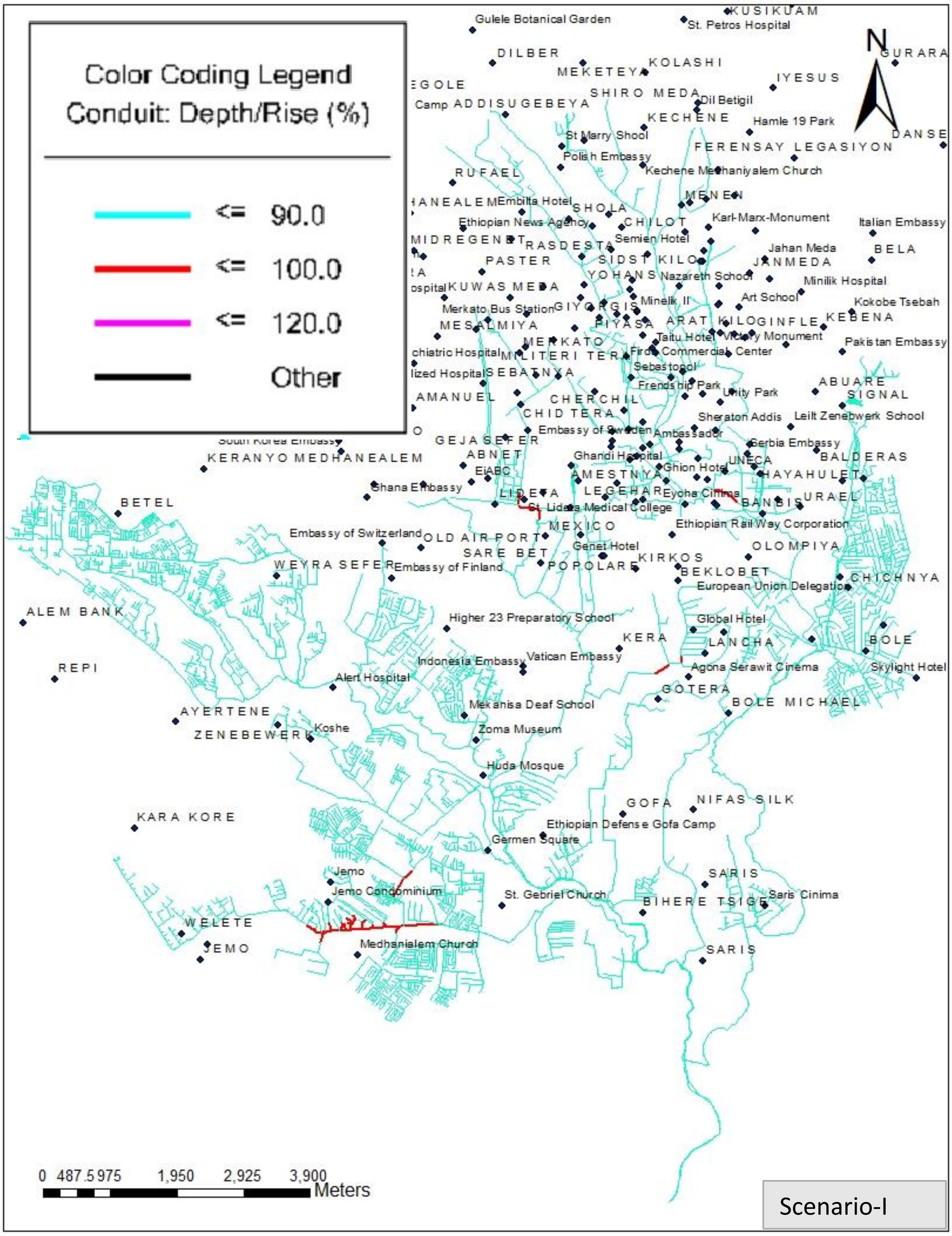

Figure 4: 3 Sewer capacities (depth/rise) in the existing sewer network at scenario I

In general, the finding provided gives insight into the depth/rise (%) value, length of pipes, and the percentage of pipes in a sewer network modeling that have deficiencies in their location. The data shows that the majority of pipes has a relatively flat profile and is functioning properly. The percentage of pipes with deficiencies is relatively low, which is a positive sign for the overall health of the sewer network. The data can be used to identify areas that need attention and to optimize the design and maintenance of the sewer network.

4.6.1.2 Surcharge

Surcharging occurs when the flow in the pipe exceeds its capacity, leading to an increase in the water level above the pipe's design level. This can result in overflow, backups, and other problems in the sewer system. The low percentage of surcharged pipes suggests that the sewer network has been designed and maintained effectively to prevent such issues.

Table 4: 5 Pipe surcharge in the existing sewer network at scenario I

No.	Is Surcharged?	Length of Pipe (m)	Percent of Pipe Surcharge
1.00	TRUE	15,372.40	2.88
2.00	FALSE	519,220.40	97.12
	Total	534,592.80	100.00

From the above table, is surcharged? TRUE: category represents pipes that are surcharged. The total length of pipes in this category is 15372.40, accounting for 2.88% of the total length of pipes. These surcharged pipes indicate that the flow in these sections of the sewer network exceeds their capacity, potentially leading to issues such as backups, overflows, and reduced performance. Is Surcharged? FALSE: This category represents pipes that are not surcharged. The total length of pipes in this category is 519220.40, accounting for 97.12% of the total length of pipes. These pipes are operating within their capacity and are not experiencing any surcharging issues.

The analysis of the provided table indicates that a small portion of the sewer network (2.88%) is experiencing surcharging, while the majority of the network (97.12%) is operating without any surcharging problems.

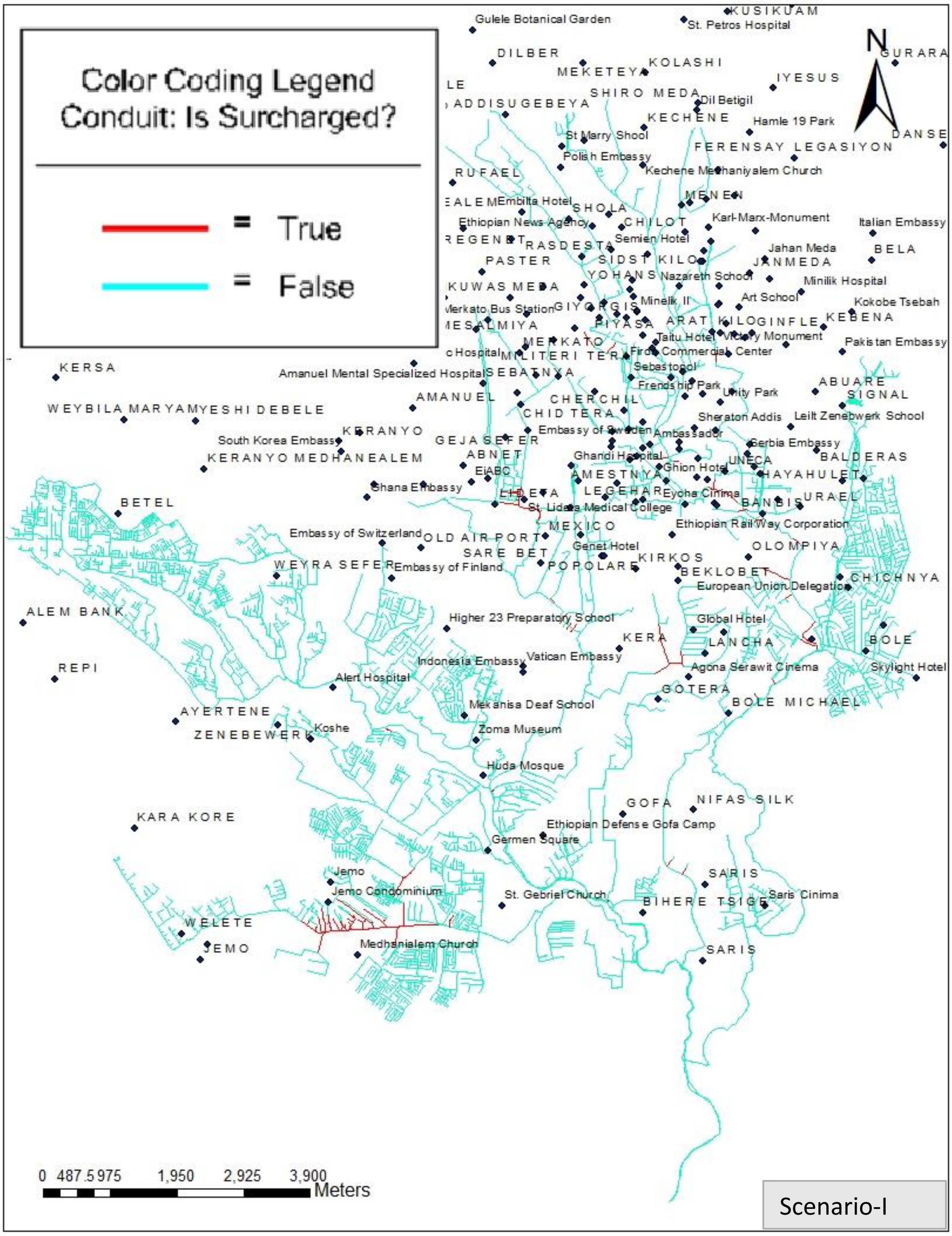

Figure 4: 4 Pipe surcharge in the existing sewer network at scenario I

Based on the findings, appropriate measures can be taken, such as pipe replacements, capacity upgrades, or maintenance activities, to alleviate the surcharging and improve the overall performance of the sewer network.

4.6.1.3 Velocity

Low velocity in the sewer network can occur due to several factors, such as inadequate slope, blockages, sedimentation, or undersized pipes. Low velocity can lead to several performance issues, including the accumulation of solids and debris, reduced self-cleaning capacity, increased risk of blockages, and potential odor problems. High velocity in the sewer network can be caused by steep slopes, oversized pipes, or significant inflows and surges. It can also result in excessive turbulence, which may lead to sediment re suspension and subsequent blockages.

Table 4: 6 Velocity distribution in existing sewer network at scenario I

No.	Velocity (m/s) Value	Length of Pipe (m)	Percent of pipe
1	<= 0.50	151,514.50	28.34
2	<= 1	169,541.00	31.71
3	<= 2	139,804.70	26.15
4	<= 3	50,554.10	9.46
6	Other	23,178.50	4.34
	Total	534,592.80	100

The above table findings indicates the velocity of the flow in the sewer pipes result, it has been found that the velocity is less than or equal to 0.50 m3/m which is not satisfy self-cleansing velocity so it leads to sedimentation for the sewer network pipe as well. The data shows that the majority of pipes 28.34% have a velocity less than or equal to 0.5 m/s. This indicates that the flow in the sewer network is generally slow, which could be due to the design of the system or the nature of the wastewater being transported which can lead to sedimentation, reduced self-cleaning ability, and potential blockages. It may also result in inadequate transport capacity and increased risk of backups and reduced system performance. The remaining 4.34% of pipes have a velocity greater than 3 m/s, which is considered to be a high velocity for sewer pipes. High velocity can cause erosion and damage to the pipes, which could lead to leaks and other problems.

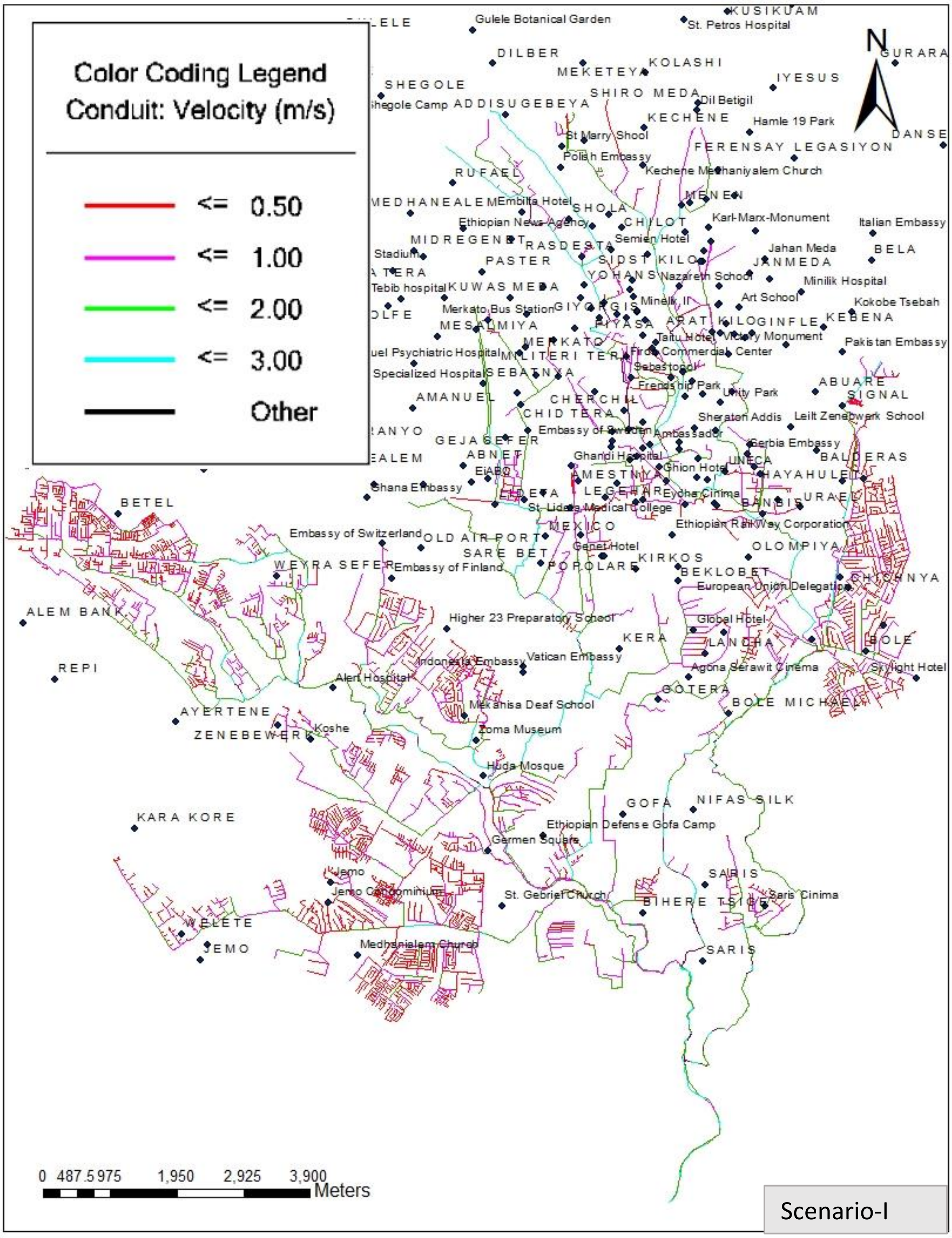

Figure 4: 5 Velocity distributions in existing sewer network at scenario I

4.6.1.4 Slope

Kality sewer network is gravity systems which primarily rely on gravity to transport wastewater from one point to another. The slope of the pipes determines the rate at which the wastewater flows. A steeper slope allows for faster and more efficient flow, minimizing the risk of blockages and backups. Carry away solids and debris. This self-cleaning velocity helps prevent the accumulation of sediment and reduces the likelihood of pipe blockages

Table 4: 7 Slope distribution in existing sewer network at scenario I

No.	Slope (%) Value	Length of Pipe (m)	Percent of pipe
1	<= 0.3	34,134.60	6.39
2	<= 3	311,211.80	58.21
3	<= 8	170,102.70	31.82
4	<= 12	17,865.30	3.34
6	Other	1,278.40	0.24
	Total	534,592.80	100.00

This result indicating that pipes with a slope value less than or equal to 0.3%. The total length of pipes in this category is 34134.60, accounting for 6.39% of the total length of pipes. Pipes with a low slope value tend to have slower flow velocities, which can result in sedimentation and potential blockages. This may impact the performance of the sewer network by reducing the flow capacity and potentially leading to backups or overflows. Pipes with a slope value less than or equal to 3%. The total length of pipes in this category is 311211.80, accounting for 58.21% of the total length of pipes. Pipes with a moderate slope value are generally considered to have good hydraulic performance, as they allow for adequate flow velocities and prevent sedimentation or blockages. Pipes with a slope value less than or equal to 8%. The total length of pipes in this category is 170102.70, accounting for 31.82% of the total length of pipes. Pipes with a higher slope value can accommodate faster flow velocities, which can help prevent sedimentation and blockages. However, extremely steep slopes may lead to excessive flow velocities, causing erosion or pipe damage.

The pipes with slope values more than 12%. The total length of pipes in this category is 1278.40, accounting for 0.24% of the total length of pipes. A high slope in the sewer network can result in faster flow velocities. The force of gravity acting on the wastewater can cause it to move rapidly through the pipes which lead erosion and potential damage.

In general, the analysis of the provided table indicates that the majority of the sewer network consists of pipes with moderate slope values (<= 3%). These pipes are expected to have good hydraulic performance and contribute to the overall efficiency of the sewer network. However, attention should be given to pipes with low slope values (<= 0.3%), as they may be prone to sedimentation and blockages. Additionally, careful consideration is needed for pipes with steep slope values (> 12%) to prevent erosion and potential damage.

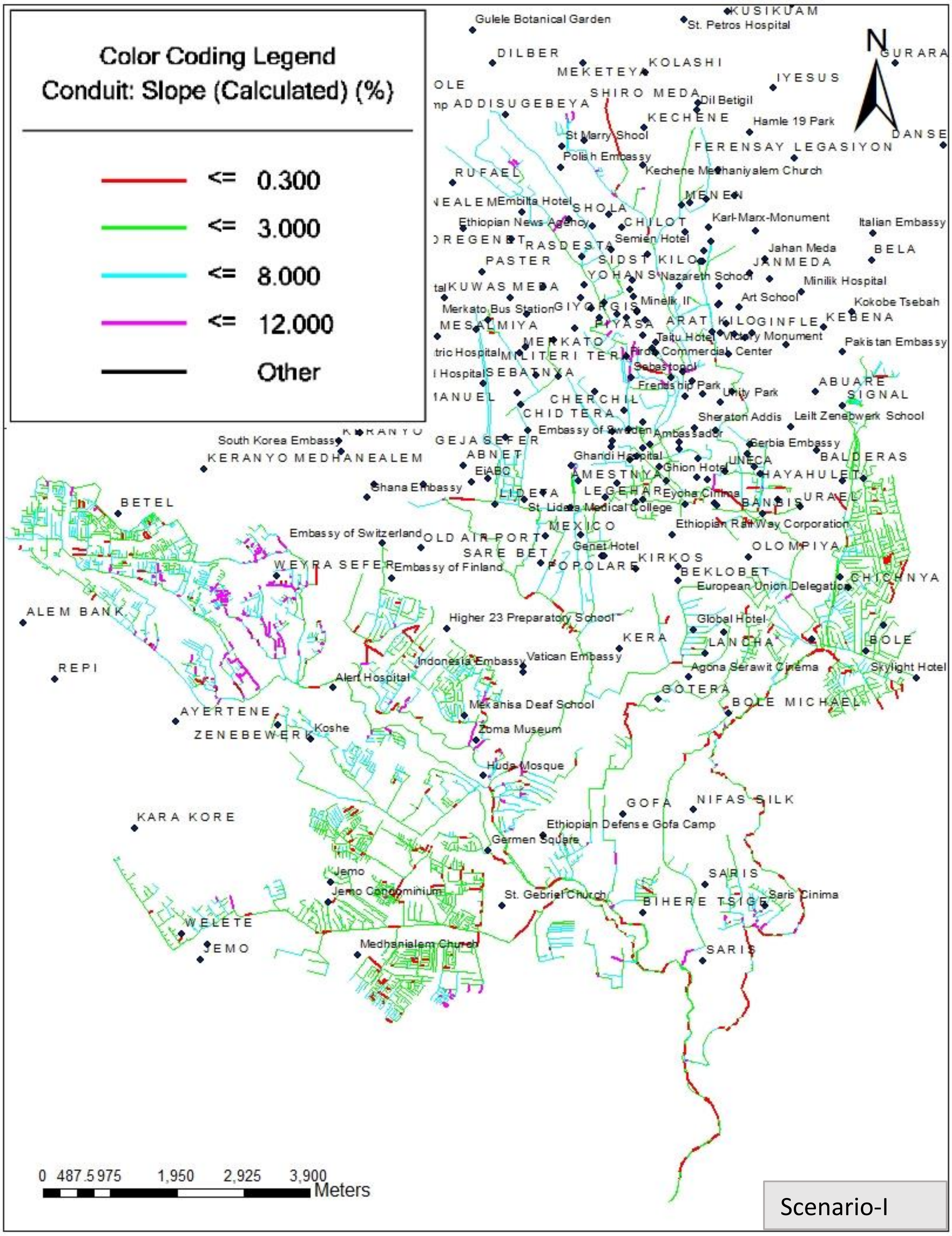

Figure 4: 6 Slope distributions in existing sewer network at scenario I

4.6.1.5 Wastewater Flow

Table 4: 8 Flow distribution in existing sewer network at scenario I

No.	Flow (m^3/day) Value	Length of Pipe (m)	Percent of pipe
1.00	<= 16613.07	508,128.60	95.05
2.00	<= 33226.02	12,875.70	2.41
3.00	<= 49838.95	8,552.50	1.60
4.00	<= 66451.89	2,402.60	0.45
6.00	Other	2,633.40	0.49
	Total	534,592.80	100.00

The table indicates that 95.05 percent of the sewer network's pipes total length of 508,128.6 have flow values that are less than or equal to 16,613.07 m3/day. This suggests that the sewer network's flow is typically modest to moderate. A flow value larger than 16,613.07m3/day is present in the remaining 4.95% of pipes, indicating a higher flow rate in those pipes. High flow rates may put greater strain on the pipes and necessitate more upkeep and monitoring.

The percentage of pipes in each category provides an indication of the distribution of the pipes in the sewer network. The data shows that the largest percentage of pipes (95.05%) fall into the first category, which has a flow value less than or equal to 16,613.07 m^3/day. The second category, which has a flow value less than or equal to 33,226.02 m^3/day, has the second-largest percentage of pipes (2.41%). This indicates that the majority of pipes in the sewer network have a relatively low to moderate flow rate.

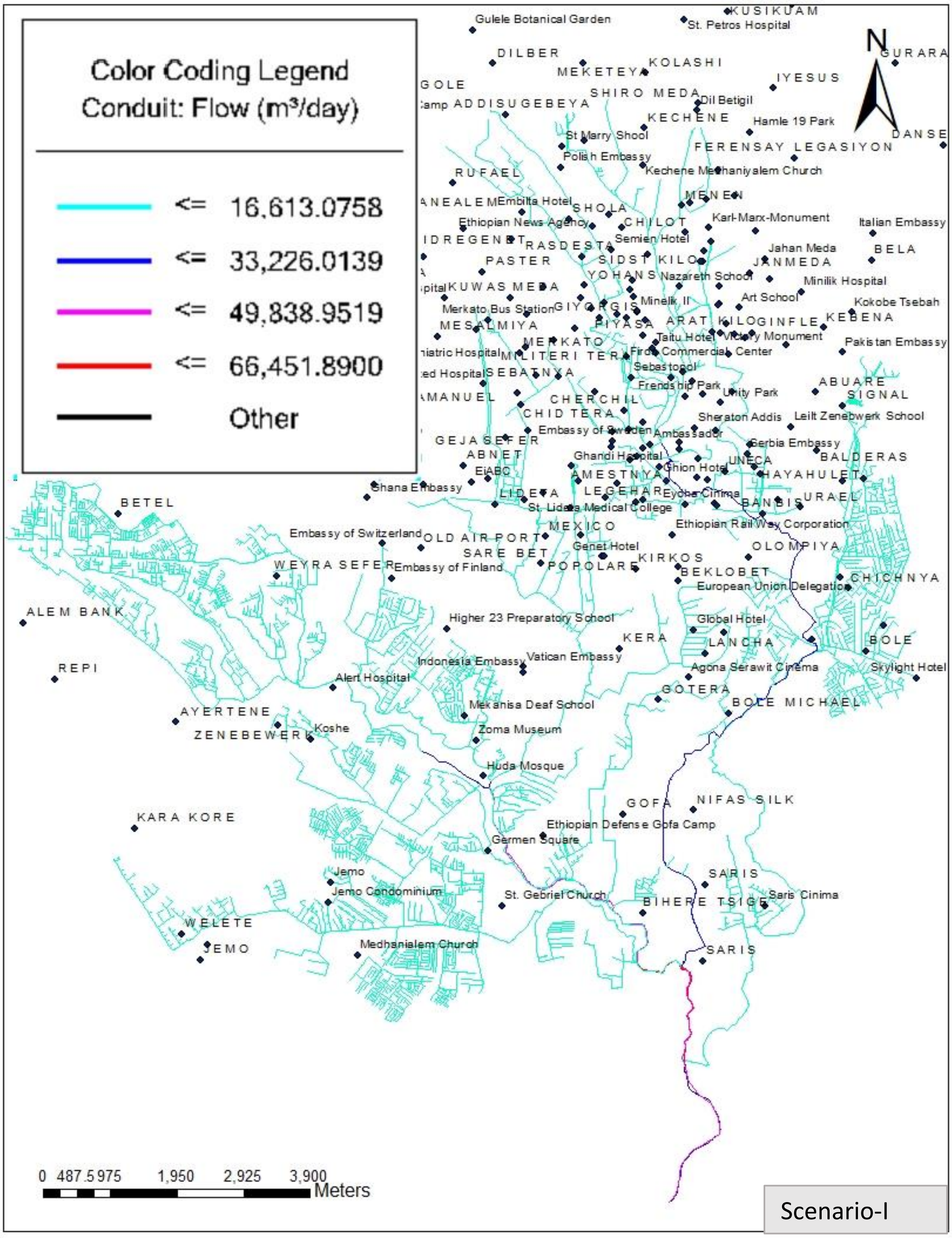

Figure 4: 7 Flow distributions in existing sewer network at scenario I

The result in the table gives insight into the flow values, length of pipes, and the percentage of pipes in a sewer network modeling. The data shows that the majority of pipes have a low to moderate flow rate and a length greater than 1 km. This indicates that the sewer network is extensive and covers a large area, but the flow rate is generally within manageable limits.

4.6.2 Model Analysis Scenarios II Result

4.6.2.1 Sewer Capacity (Depth /Rise)

Table 4: 9 Sewer capacities (depth/rise) in the existing sewer network at scenario II

Depth/Rise (%) Value	Length of Pipe (m)	Percent of pipe
<= 90	526636.60	98.51
<= 100	7,956.20	1.49
<= 120	-	0.00
Other	-	0.00
Total	534,592.80	100.00

This table represents sewer pipes that have a capacity of 90% or less. The total length of pipes in this category is 526,636.60, accounting for 98.51% of the total length of pipes. The pipe or conduit ID for these pipes is categorized as "Others." This indicates that the majority of sewer pipes has a limited capacity or acceptable range to 90% which has no any deficiency location of pipe.

The above result represents sewer pipes that have a capacity of 100% or less. The total length of pipes in this category is 7,956.20, accounting for 1.49% of the total length of pipes. The pipe or conduit ID for these pipes is specified as a list of identifiers, indicating specific pipes within the network such as CO-10, CO-11, CO-12, and so on. These pipes may have slightly higher capacity (depth/ rise) which indicating the deficiency location o f pipe within the sewer network. The pipes with higher capacity, assessing the impact of these depth/rise values on the network's overall efficiency, and identifying any potential limitations or areas for improvement. These specific pipes have a slightly higher depth or rise, indicating a potential need for improvement or monitoring.

The analysis of the model result suggests that the majority of the sewer pipes in the network have a capacity of 90% or less or within acceptable ranges. However, specific pipes listed in the second category may require further attention or need improvement due to their slightly higher capacity or depth/ rise values.

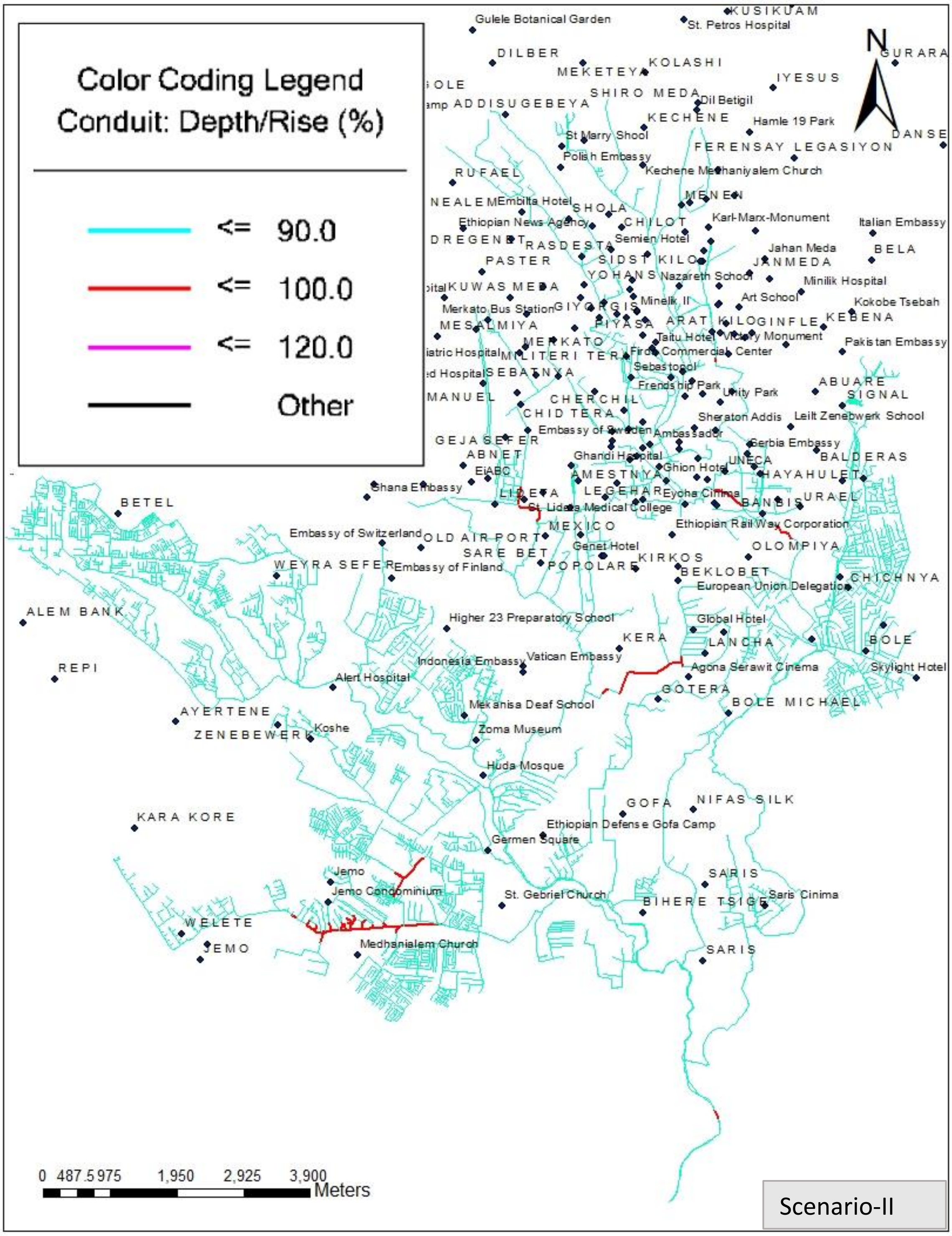

Figure 4: 8 Sewer capacities (depth/rise) in the existing sewer network at scenario II

4.6.2.2 Surcharge

Surcharging in a sewer network can occur when the flow rate exceeds the capacity of the pipes. It is important to address surcharging as it can lead to various issues such as sewer backups, overflow, and potential damage to the system.

Table 4: 10 Pipe Surcharge in the existing sewer network at scenario II

No.	Is Surcharged?	Length of Pipe (m)	Percent of Pipe Surcharge
1	TRUE	20,019.10	3.74
2	FALSE	514,573.70	96.26
	Total	534,592.80	100.00

In the provided table, it is observed that only a small portion of the sewer network, accounting for 3.74% of the total length of pipes, is surcharged. This indicates that the majority of the network, accounting for 96.26% of the total length of pipes, is able to handle the flow within their capacity. The pipes that are surcharged, totaling 20019.10 in length, need attention and remedial measures to alleviate the surcharging issue. This may involve actions such as increasing the pipe diameter, improving the hydraulic capacity of the pipes, or implementing flow control measures to prevent excessive flow. To address surcharging, it is crucial to identify the specific locations and causes of surcharging within the network. This can be done through further analysis, such as hydraulic modeling or flow monitoring, to determine the factors contributing to the surcharging and develop appropriate solutions.

By addressing the surcharging issue, the sewer network can operate more efficiently, minimize the risk of backups and overflows, and ensure the proper functioning of the system. Regular maintenance, monitoring, and upgrades of the sewer infrastructure are essential to prevent surcharging and maintain the overall performance of the network

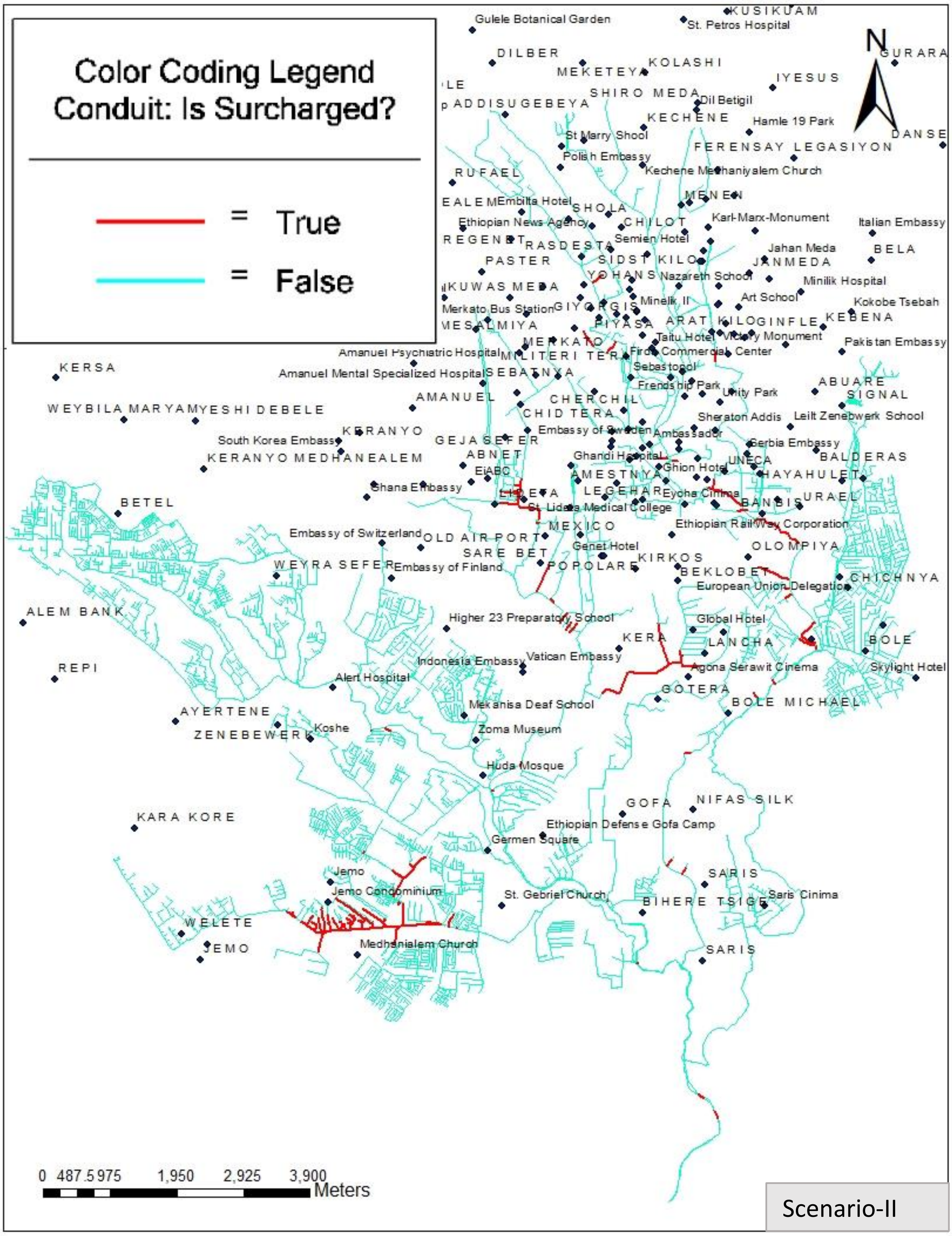

Figure 4: 9 Pipe surcharge in the existing sewer network at scenario II

4.6.2.3 Velocity

In conclusion, while a small portion of the sewer network experiences surcharging, the majority of the network is not affected. Proper identification, analysis, and remedial measures are necessary to address the surcharging issue and ensure the efficient operation of the sewer network.

Table 4: 11 Velocity distribution in existing sewer network at scenario II

No.	Velocity (m/s) Value	Length of Pipe (m)	Percent of pipe
1	<= 0.5	184,099.70	34.44
2	<= 1	170,249.90	31.85
3	<= 2	124,326.10	23.26
4	<= 3	44,562.20	8.34
6	Other	11,354.90	2.12
	Total	534,592.80	100.00

The model result of low and high velocity in the sewer network, based on the provided table, sewer pipes with a velocity of 0.5 m/s or less. The total length of pipes in this category is 184,099.70, accounting for 34.44% of the total length of pipes. This indicates that a significant portion of the sewer network has a low velocity, potentially resulting in issues such as sedimentation or blockages. Sewer pipes with a velocity of 3 m/s. The total length of pipes in this category is 11,354.90, accounting for 2.12% of the total length of pipes. This indicates that a smaller portion of the sewer network has high velocity with without acceptable range, can lead to various negative consequences, including erosion of pipe material, excessive turbulence, which may lead to damage pipe surface.

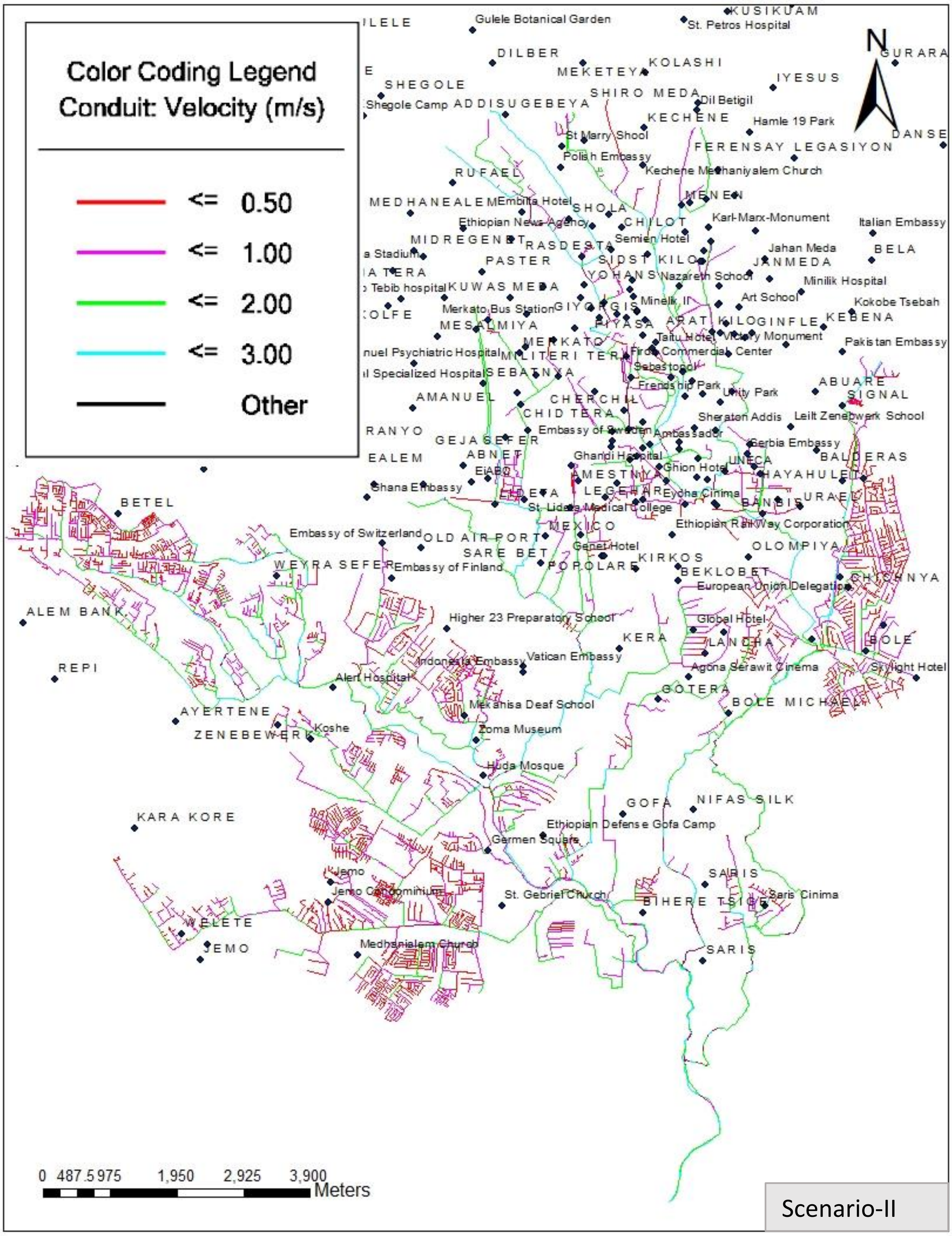

Figure 4: 10 Velocity distribution in existing sewer network at scenario II

The analysis of the model result suggests that a significant portion of the sewer network has low to moderate velocity, which may impact the flow capacity and efficiency of the system and potentially leading to flow-related issues such as sedimentation or reduced transport capacity. There is a smaller portion of the network with higher velocity, indicating bad flow conditions. Overall, the analysis of the table reveals that a significant portion of the sewer network has low to moderate velocity, which may impact the flow capacity and efficiency of the system. The absence of pipes with velocities above 3 m/s suggests potential limitations in handling higher flows.

4.6.3 Model Analysis Scenarios III Result

4.6.3.1 Sewer Capacity (Depth /Rise)

Table 4: 12 Sewer capacity (depth/rise) in the existing sewer network at scenario III

No.	Depth/Rise (%) Value	Length of Pipe (m)	Percent of pipe
1	<= 90	512343.70	95.84
2	<= 100	22,249.10	4.16
3	<= 120	-	0.00
6	Other	-	0.00
	Total	534,592.80	100.00

Based on the provided table, we can analyze the model result of the sewer network and identify the deficiency locations and improvement needs of the sewer line based on the capacity (Depth/Rise) and the length of the sewer pipes.

This table represents sewer pipes that have a capacity of 90% or less. The total length of pipes in this category is 512,343.70, accounting for 95.84% of the total length of pipes. This indicates that the majority of the sewer pipes has a capacity below or equal to 90%. The deficiency in this case is that these pipes have sufficient capacity to handle the wastewater flow. The sewer pipes that have a capacity of 100% or less. The total length of pipes in this category is 22,249.10, accounting for 4.16% of the total length of pipes. The pipe or conduit ID for these pipes is specified as a long list of identifiers, indicating specific pipes within the network. This indicates that the majority of the sewer pipes has a capacity below or equal to 100%. The deficiency in this case is that these pipes may not have sufficient capacity to handle the wastewater flow, potentially leading to blockages or overflows.

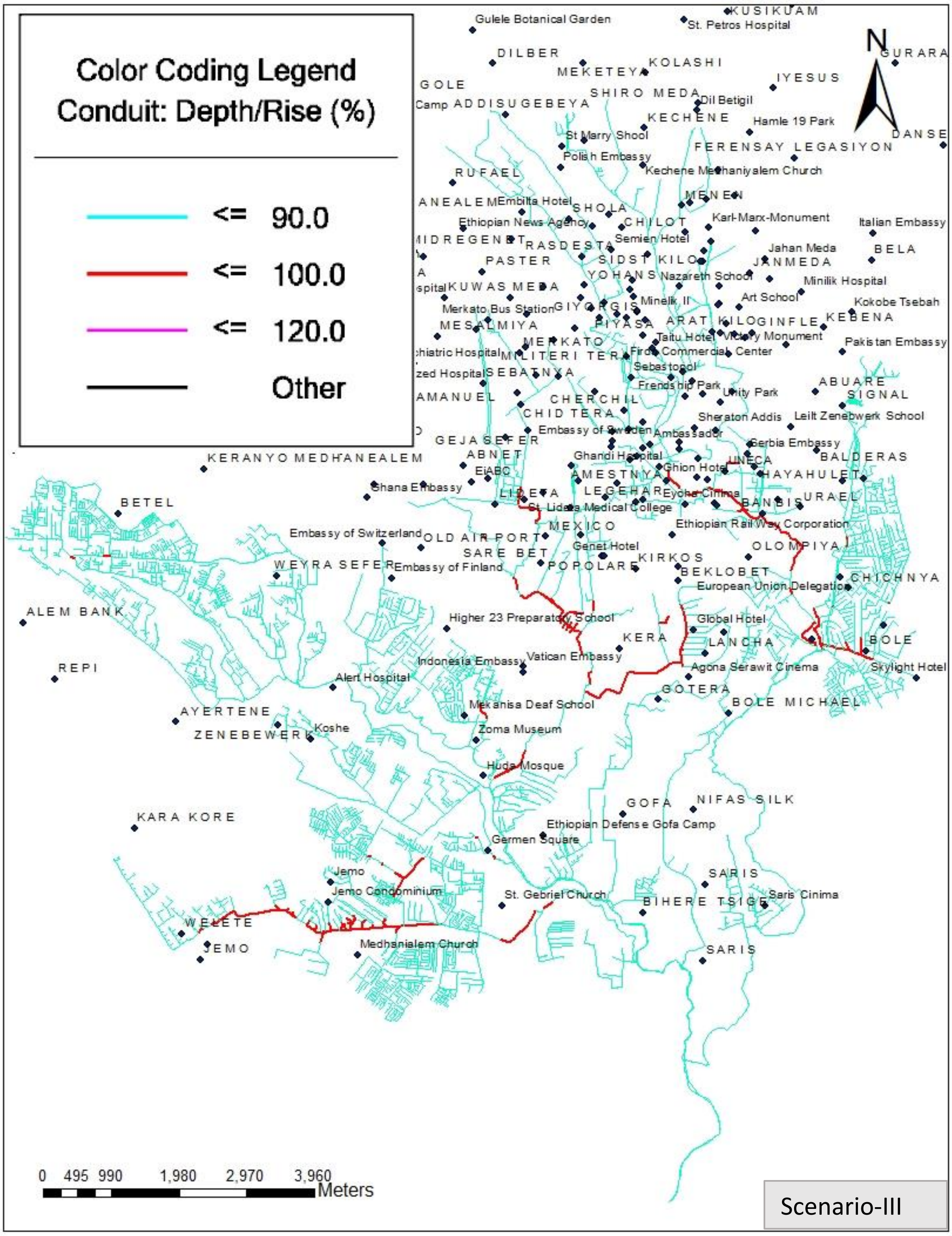

Figure 4: 11 Sewer capacity (depth/rise) in the existing sewer network at scenario III

The analysis of the capacity (depth/rise) of the sewer network model highlights deficiencies in the less of the pipes with capacities more than 90%. There is a smaller portion of pipes with slightly less capacities but still requiring improvement.

4.6.3.2 Surcharge

The provided table allows us to analyze the pipe surcharge in the sewer network model. Pipes that are labeled as "Is Surcharged? TRUE" indicates that the flow within these pipes exceeds their capacity, resulting in water levels above the design level.

Table 4: 13 Pipe Surcharge in the existing sewer network at scenario III

No.	Is Surcharged?	Length of Pipe (m)	Percent of Pipe Surcharge
1.00	TRUE	44,654.50	8.35
2.00	FALSE	489,938.30	91.65
	Total	534,592.80	100.00

The provided table allows us to analyze the pipe surcharge in the sewer network model. Pipes that are labeled as "Is Surcharged? TRUE" indicates that the flow within these pipes exceeds their capacity, resulting in water levels above the design level. These surcharged pipes account for 8.35% of the total length of pipes, with a total length of 44,654.50. This can lead to various issues such as increased risks of overflows, potential damage to the pipe structure, and reduced system performance. To address these deficiencies, it is crucial to identify the specific locations where surcharging occurs. On the other hand, pipes labeled as "Is Surcharged? FALSE" indicate that the flow within these pipes is within their design capacity. These pipes make up 91.65% of the total length of pipes, with a total length of 489,938.30. However, it is important to note that even though they are not currently experiencing surcharging, this does not guarantee optimal operation. There may still be deficiencies in terms of flow capacity, self-cleaning ability, or potential for future surcharging under different conditions.

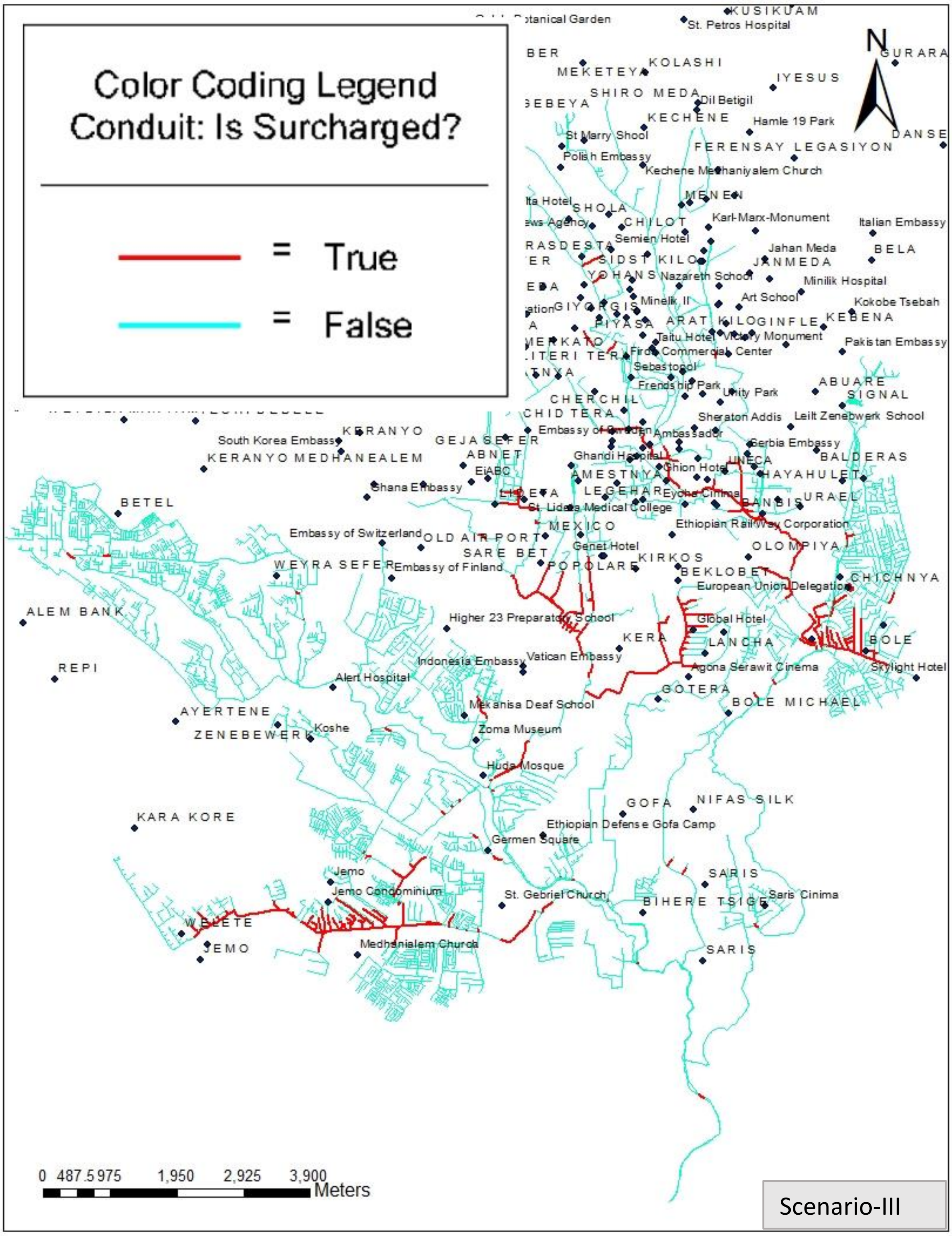

Figure 4: 12 Pipe Surcharge in the existing sewer network at scenario III

In general the analysis of the pipe surcharge in the sewer network model highlights the need for improvements in specific locations. Understanding the causes and locations of surcharging is crucial for identifying deficiencies and planning appropriate solutions.

4.6.3.3 Velocity

Table 4: 14Velocity distribution in existing sewer network at scenario III

No.	Velocity (m/s) Value	Length of Pipe (m)	Percent of pipe
1	<= 0.5	151,514.50	28.34
2	<= 1	169,541.00	31.71
3	<= 2	139,804.70	26.15
4	<= 3	50,554.10	9.46
6	Other	23,178.50	4.34
	Total	534,592.80	100.00

The result of the above table indicating that sewer pipes with a velocity of 0.5 m/s or less. The total length of pipes in this category is 151,514.50, accounting for 28.34% of the total length of pipes. A low velocity indicates slow flow within the pipes, which can lead to sedimentation and potential blockages. It may also indicate insufficient flushing and self-cleaning capability, increasing the risk of accumulation and reduced pipe capacity. But sewer pipes with a velocity of 3 m/s or more. The total length of pipes in this category is 169,541.00, accounting for 31.71% of the total length of pipes. Similar to the previous category, a low velocity suggests suboptimal flow conditions that can contribute to sedimentation and blockages. It may also indicate limited capacity to transport wastewater efficiently, potentially leading to backups and reduced system performance. The rest of the pipes are under the range of the velocity limit which is acceptable.

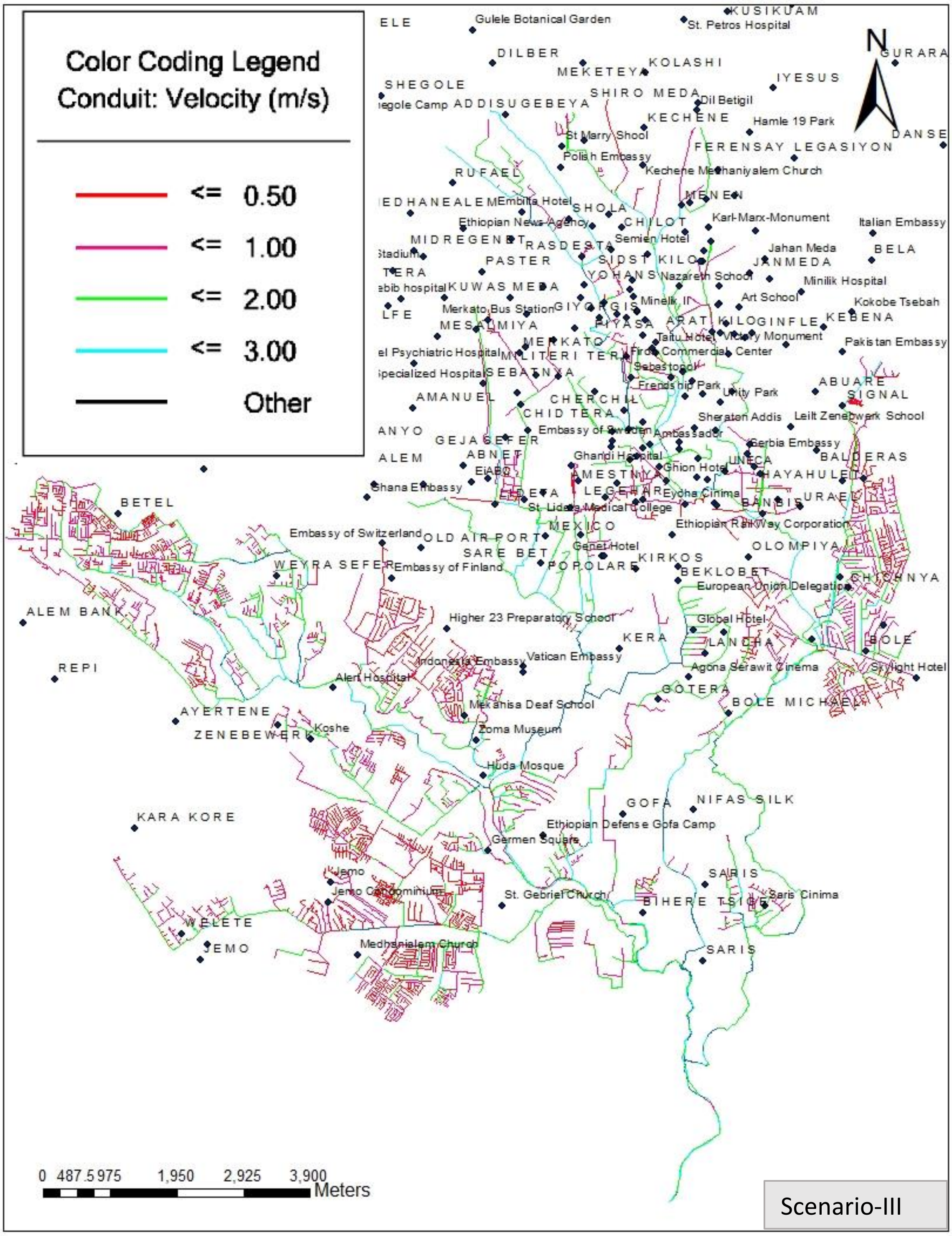

Figure 4: 13 Velocity distribution in existing sewer network at scenario III

4.7 Key Parameter in the Model Analysis (Deficient Locations)

Pipe capacity or depth/rise (d/D) and surcharge were the two key parameters to analyze the existing sewer network model to check the capacity and assess the performance of the existing sewer network. The model results summarized in this section show all the gravity sewer deficiency locations, i.e., locations where existing gravity sewers could not convey the peak flows according to the criteria established. More detailed analysis was then conducted to determine if improvements were required for the individual deficiency locations. The key criteria for identifying capacity deficiencies of existing sewers were a d/D of 0.9 under peak flow conditions, and a surcharge level that is within 15cm of the manhole rim elevation. Both criteria must be exceeded for a deficiency location to require improvement (Salinas, 2011). For evaluating and prioritizing whether existing pipes require improvement, surcharge is allowed as long as the hydraulic grade line remains at least 15cm below the rim elevation under peak flow conditions. At some locations in the system, there are shallow pipeline segments where the pipe crown is within 15cm of the ground surface, but pipes have adequate capacity to convey the peak flows with no surcharge; such locations are not identified as deficiencies (Salinas, 2011).

In the hydraulic analysis of Kality Catchment sewer network with the active sewer service customer estimated sanitary load, Scenario1, most of the network is sufficient to transport the collected sanitary load but only few areas need improvement. There is significant indication of existing sewer line deficiency in other flow scenarios. Annex 7, 8 and 9 show pipes labeled and described where the criteria of a d/D ratio=0.9 and surcharges are exceeded, for applied sanitary load for Scenario I, Scenario II, and Scenario III respectively. The deficiencies shown in Tables 7, 8 and 9 show are labeled and described well according to the loading condition first causing the deficiency, even if the severity is greater under the other loading conditions. All improvements are sized for the highest peak flow condition. The surcharge condition is checked with the hydraulic profiles of each deficiency marked pipes. Tables provide a general description for each scenarios deficiency location.

4.7.1 Deficient Location Model Analysis for Scenario I

The sewer network model results indicate several locations where are the deficiency locations in the sewer pipe system based on active customer's wastewater generation in the existing sewer network. These deficiencies are identified based on key parameters such as depth/rise and surcharge with respected criterion that has been mentioned above. . It provides the pipes that require improvement and suggests potential solutions, such as upgrading the diameter or replacing the pipe. The recommendations aim to ensure the efficient flow of wastewater and prevent surcharging, which can lead to potential issues and disruptions in the sewer system in the future.

In the first scenario model analysis, some areas, the capacity of the pipe (d/D) exceeds the criteria and exceeds the surcharge criterion. Those pipe lines labeled as CO-1323, CO-3373, CO-3366, and CO-3370 where areas include Balcha hospital, Lideta, condominiums, and commercial buildings. Improvement is recommended in these locations due to the high concentration of buildings and potential for increased wastewater flow. Similarly, pipe lines labeled CO-10, CO-11, CO-12, CO-14, CO-18, CO-36, CO-40, and CO-65 also exceed the capacity (d/D) and surcharge criteria, necessitating improvement measures.

In other areas, the capacity of the pipe (d/D) exceeds the criteria but not exceeds the surcharge criterion. These areas also mainly include Mesualekia, Beklobet and Global hotel to Gottera. No improvement is recommended for this scenario. Additionally, there are areas where the capacity of the pipe (d/D) exceeds the criteria but does not exceed the surcharge criterion. Improvement is not recommended in these locations, which include China camp near Koshe and Mekanisa Michael and other area. Annex 7 shows that the deficiency location of sewer pipes details for the first scenario.

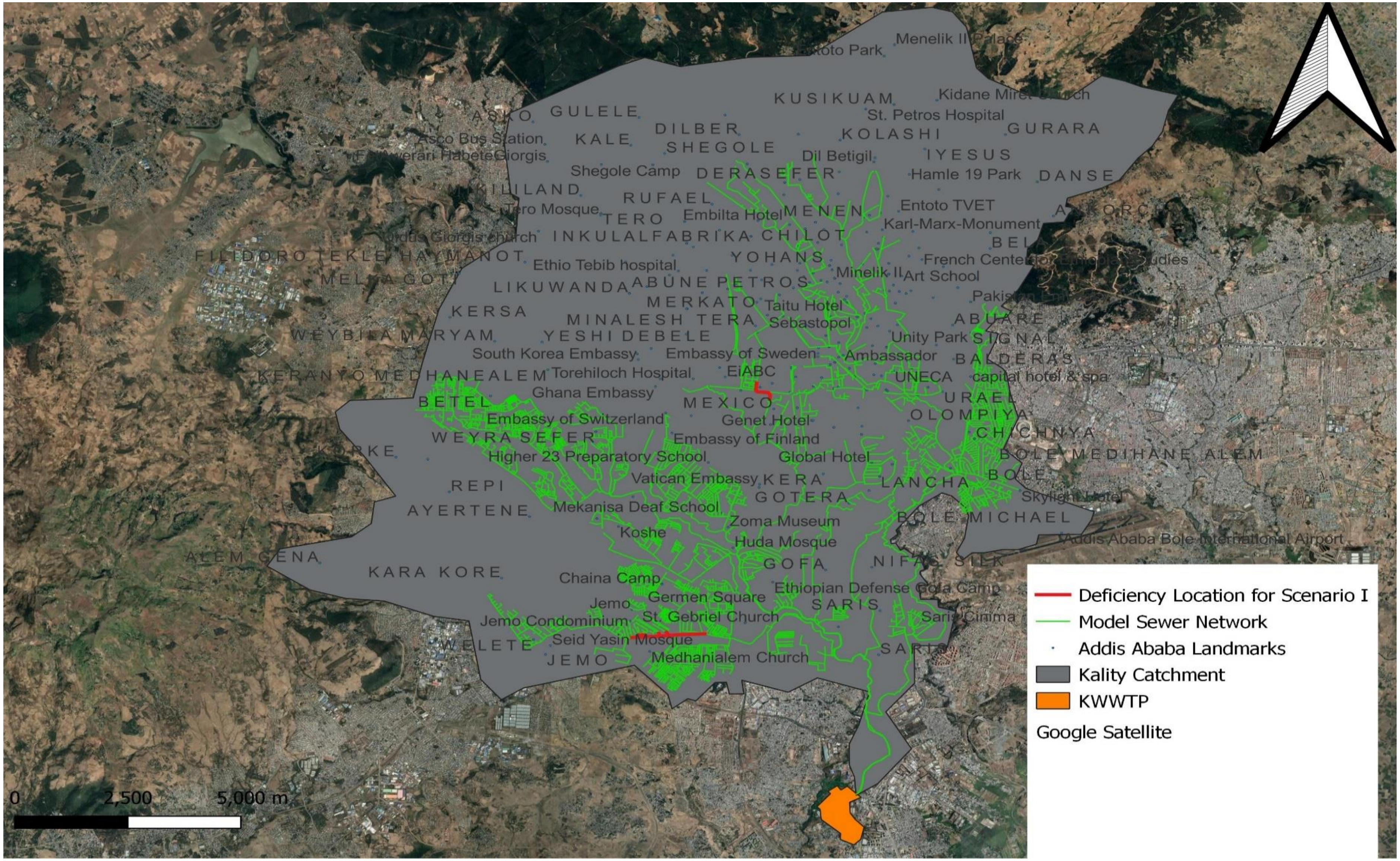

Figure 4: 14 Deficiency location of the existing sewer network at scenario I

4.7.2 Deficiency Location Model Analysis for Scenario II

In this scenario the provided sewer network model analysis, based on potential sewer customer of wastewater generation near sewer served area with analysis of the capacity and surcharge of each pipe of key parameters by specified criteria above mentioned.

The sewer network system exhibits deficiencies in pipe capacity (d/D) and surcharge criteria. Pipe lines labeled CO-3484, CO-3482, CO-103, CO-3501, CO-3483, and CO-3483, located in Sengatera condominium and Biherawi areas, have exceeded the capacity (d/D) and surcharge criteria. These pipes are also old and made of Asbestos cement, further emphasizing the need for upgrading and replacement. Similarly, pipe lines ID CO-3370, CO-3366, CO-1323, CO-3371, and CO-3373, situated around Lideta, Balcha hospital, and condominium areas, exhibit exceeded capacity (d/D) and surcharge criteria, requiring improvement measures. Furthermore, pipe lines labeled CO-3501, CO-5490, CO-1307, CO-5361, CO-5360, CO-1306, and CO-1308 located in Mesualekia, Beklobet and Global hotel to Gotera areas, also exceed the capacity (d/D) and surcharge criteria, needs improvement measures. Additionally, the pipe lines CO-3224 and CO-4741, situated near China camp and Koshe, exhibit exceeded capacity (d/D) and surcharge criteria, further emphasizing the need for improvement in these areas and pipe line labeled as CO-18, CO-11, CO-65, CO-10, CO-35, CO-40, CO-13, CO-34, CO-14, CO-39, CO-12, CO-75, CO-36, CO-1640, CO-375, CO-5841, CO-71, CO-38, CO-5604, CO-1641, CO-1846, CO-81, CO-5581, CO-1642, CO-5583, CO-80, CO-374, CO-1643 Those pipes are existing from Jemo roundabout to Lafto exhibit exceeded capacity (d/D) and surcharge criteria, further emphasizing the need for improvement. See more on annex 8 deficiency locations for the second scenario.

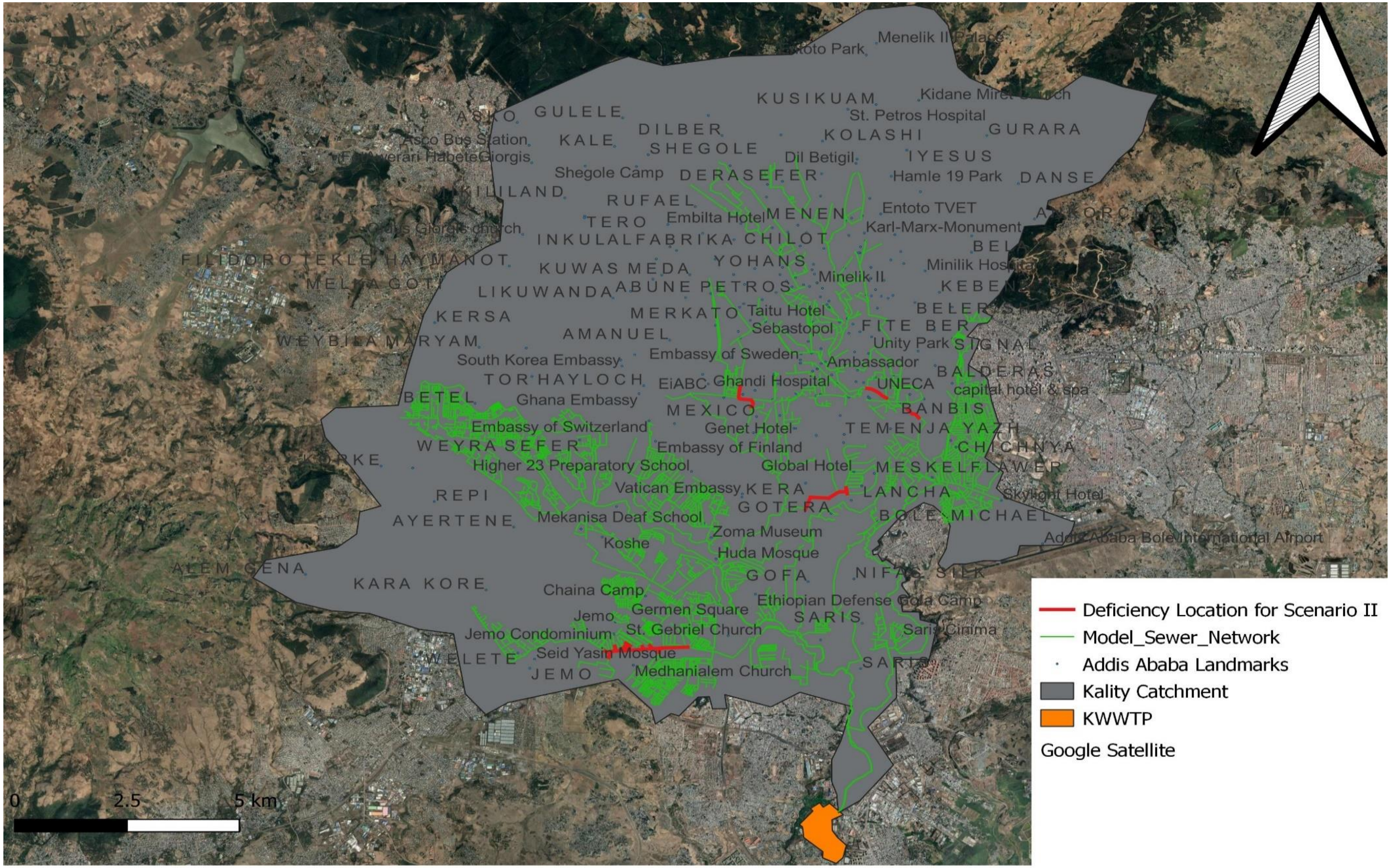

Figure 4: 15 Deficiency location of the existing sewer network at scenario II

4.7.3 Deficiency Location Model Analysis for Scenario III

The results of a sewer network model analysis, specifically focusing on deficiency locations of the projected wastewater generation from land use of spatial distribution of the existing sewer network. This analysis provides a details of capacity and surcharge of each pipe in the model sewer network with specific criteria that describe above.

The model analysis indicated that pipe capacity (d/D) and surcharge criteria exceeded in the location of Lideta, Balcha hospital, and condominium areas which pipes labeled as CO-3447, CO-3446, CO-635, CO-3450, CO-5472, CO-136, CO-135, CO-5099, CO-3456, CO-3449, CO-5502, CO-144, CO-143, CO-138, CO-5503, CO-3453, CO-1900, CO-137, CO-3448, CO-145, CO-174, CO-3363, CO-3455, CO-5492, CO-5471, CO-140, CO-140, CO-142, CO-180, CO-141, CO-3454, CO-3454, CO-134, CO-5470 CO-3370, CO-5414, CO-5415, CO-5416, CO-3366, CO-1323, CO-3371, CO-3364, CO-3364, CO-5412, CO-3373 are improvement recommended. The area located around Sengatera condominium and Biherawi areas have exceeded the capacity (d/D) and surcharge criteria. These pipes are also old and made of Asbestos cement, and lables as CO-5033, CO-5338, CO-630, CO-2754, CO-5340, CO-3422, CO-3467, CO-87, CO-5339, CO-98, CO-631, CO-102, CO-5034, CO-3484, CO-3423, CO-3482, CO-103, CO-3483, CO-4583, CO-3419, CO-3417, CO-4584, CO-79, CO-589, CO-3420, CO-101, CO-5690 so needs improvement. Similarly, pipe name CO-5490, CO-1307, CO-5361, CO-5360,CO-5360, CO-3439, CO-773, CO-1303, CO-1306, CO-752, CO-1320, CO-1170, CO-1221, CO-1308, CO-788, CO-3461, CO-744, CO-5475, CO-3460, CO-1302, CO-751, CO-731, CO-772, CO-5479, CO-5362, CO-5474

are situated around Mesualekia, Beklobet and Global hotel to Gotera areas, also exceed the capacity (d/D) and surcharge criteria, improvement recommended, and also area around near China camp and Koshe, pipes labeled as CO-4739, CO-4738, CO-4761, CO-4741, CO-4760 exceeded capacity (d/D) and surcharge criteria, need for improvement in these areas and Pipe line existing from Jemo roundabout to Lafto exhibit exceeded pipe capacity (d/D) and surcharge criteria, further need for improvement. Those pips area labeled as CO-374, CO-10, CO-13, CO-34, CO-17, CO-35, CO-40, CO-49, CO-54, CO-11, CO-71, CO-80, CO-51, CO-65, CO-84, CO-55, CO-120, CO-325, CO-342, CO-50, CO-1505, CO-1640, CO-1791, CO-1837, CO-1846, CO-1975, CO-14, CO-12, CO-2260, CO-1641, CO-1642, CO-36, CO-91, CO-2261, CO-1643, CO-81, CO-374, CO-1643, CO-311, CO-76, CO-3375, CO-3376, CO-3377, CO-3378, CO-132, CO-3379, CO-38,

CO-375, CO-39, CO-3115, CO-5581, CO-5582, CO-85, CO-5583, CO-133, CO-1847, CO-5603, CO-5604, CO-73, and CO-5841. Additionally, pipe labeled in the table given below shows that capacity (d/D) and surcharge criteria, further need for improvement for some parts of the existing sewer network. Furthermore see the deficiency location of the sewer network at annex 8 for the third scenario.

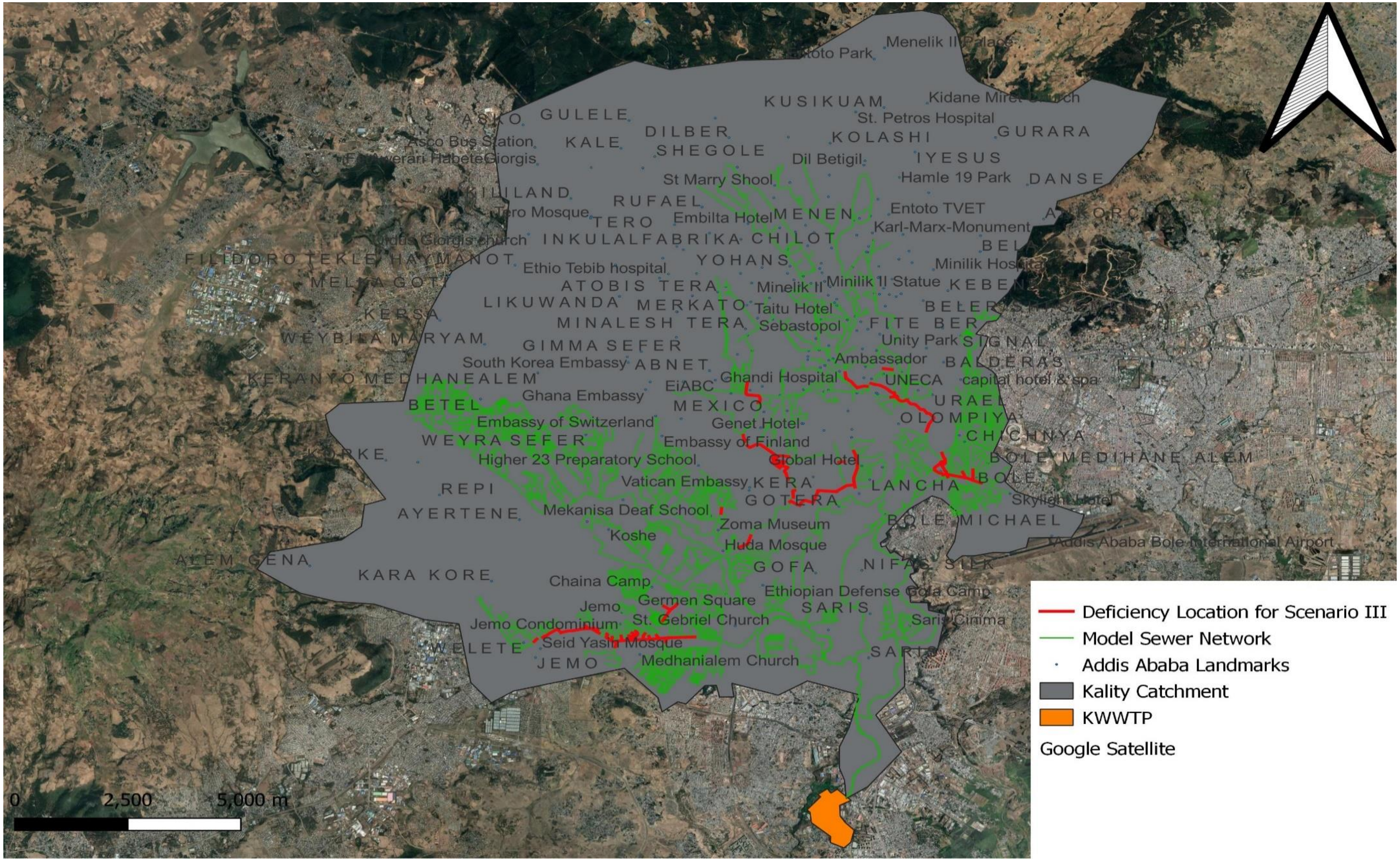

Figure 4: 16 Deficiency location of the existing sewer network at scenario III

4.8 Possible Reasons for Deficiency Locations

Deficient locations in the existing sewer system with respect to parameters such as depth/rise and pipe surcharge can occur due to various reasons identified and discussed. One common reason for deficiency locations in the existing sewer system is inadequate pipe slope. Some parts of sewer system installed with insufficient slope to ensure proper flow and prevent surcharge. The slope was too flat or misaligned, it can lead to areas where wastewater accumulates and causes deficiency locations. The lack of proper slope can impede the movement of wastewater, resulting in surcharge and potential backups. Deficiency locations can also arise due to pipe capacity issues. The existing sewer system was undersized or has insufficient capacity to handle the expected flow in some area; it can result in areas of surcharge. Inadequate pipe size or capacity can lead to deficiency locations where the flow exceeds the pipe's capacity, causing backups and potential overflows. Proper sizing and design of the sewer system are crucial to ensure adequate capacity and prevent deficiency locations. Hydraulic constraints within the sewer network can also contribute to deficiency locations. These constraints can include sharp bends, constrictions, or junctions that restrict the flow of wastewater. If the sewer system is not designed or laid out to account for these constraints, it can lead to areas where surcharge is more likely to occur. The presence of hydraulic constraints can cause turbulence and hinder the smooth flow of wastewater, leading to deficiency locations. Excessive inflow and infiltration of water into the sewer system is another factor that can contribute to deficiency locations especially in the study area is clearly observed during site observation. Cracks, leaks, manholes below ground elevation, or improper connections in the pipe can allow groundwater or stormwater to enter the sewer system, increasing the flow volume and potentially causing surcharge in certain areas. The presence of I&I can overload the sewer system, leading to deficiency locations where the system is unable to handle the increased flow.

4.9 Feasible Improvement Measures for Deficiency Locations

If the sewer line is consistently experiencing deficient due to inadequate pipe capacity, one of the best solutions is to upsize the pipes. This involves replacing sections of the sewer line with larger diameter pipes to accommodate higher flow volumes and reduce the risk of surcharge. For deficiency locations were caused by improper pipe alignment or inadequate slope, correcting these issues is crucial. Adjusting the alignment and slope of the pipes can help ensure proper flow and prevent surcharge. This may require excavation and realignment of sections of the sewer line. Identify and address any hydraulic constraints within the sewer network that contribute to deficiency locations. This may involve modifying or optimizing areas with sharp bends, constrictions, or Manholes to improve flow capacity and reduce the risk of surcharge. Implement measures to control excessive inflow and infiltration of water into the sewer line. This can include repairing cracks, sealing pipe joints, and addressing improper connections to minimize the entry of groundwater or stormwater. By reducing I&I, the risk of surcharge can be significantly reduced. Regular maintenance practices should be implemented to prevent and remove blockages within the sewer line. This can include proactive cleaning, inspection, and root control programs to ensure smooth flow and prevent surcharge caused by obstructions. For deficiency locations arise due to pipe capacity issues, enhancing the capacity of the sewer line is necessary. This can be achieved by upsizing the pipes or increasing their capacity to handle the anticipated flows. Replacing sections of the sewer line with larger diameter pipes or implementing storage or diversion structures can help alleviate surcharge and prevent deficiency locations. Proper sizing and design of the sewer system should consider future growth and increased demands to avoid capacity-related deficiencies.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Considering spatial distribution of Kality Catchment existing sewer line, a huge area has been already covered. Kality Catchment is suffering from the overflow of manhole in different parts of the study area in the sewer network. Sewer capacity in the sewer network fail at peak flow condition in some parts of the study area and surcharge occurs during when wastewater generation increase. Deficient hydraulic performances (pipe capacity (d/D) and surcharge) occurred due to random connection of manholes and improper pipe slope without any scientific method/mathematical calculation for capacity flow and slope of the pipe. Therefore this study is used to assess the performance of sewer network of Kality Catchment by using Bentley SewerGEMS Connection 10.

The wastewater generation for the first and second scenarios was determined based on water consumption bill data, considering both active and potential sewer customers. The sewer system coverage in Kality Catchment is estimated to be 17.63% which is very low as compared to the potential customers can be served. Regarding the performance of the sewer network in relation to pipe capacity (d/D), the analysis indicates that 1.01%, 1.49%, and 4.16% of pipes have a pipe capacity or depth/rise (%) value greater than 90%. This accounts for lengths of 5,415.10m, 7,956.20m, and 22,249.10m for the first, second, and third scenarios respectively, under peak flow conditions. Furthermore, the findings from the pipe surcharge simulation show that the total length of surcharged pipes were 15,372.40m, 20,019.10m, and 44,654.50m, accounting for 2.88%, 3.74%, and 8.35% of the respective total lengths of pipes for the first, second, and third scenarios. The result shows that the majority of pipes 28.34% have a velocity less than or equal to 0.5 m/s. which is not satisfy self-cleansing velocity so it leads to sedimentation for the sewer network pipe as well.

The findings suggest that the current sewer network in the area is sufficient for the existing sewage load, mainly due to low active customers or service connections. However, the analysis reveals that the overall technical performance of the existing system is poor, indicated by inadequate velocity and slope within permissible limit. This indicates that the potential cause of overflow is pipe blockage caused by sedimentation and deposition of materials due to insufficient self-cleansing velocity. Additionally, the sewer system's capacity is expected to be inadequate in the near future due to an increase in service connections and improper addition of another system. For the future, increasing of wastewater generation the sewer system may render it incapable of handling changing hydraulic parameters effectively. Blockages resulting in reduced pipe capacity worsen surcharging and backups by causing the accumulation of debris like wood logs, plastic bags, household waste, and solidified grease. Furthermore, the investigation of the study area and measurement of flow depth indicate that sanitary sewer overflows (SSOs) occur during wet weather due to factors such as rain-derived inflow and infiltration, blockages, cracked pipes and manholes.

The analysis of the model reveals that, under peak flow conditions, the deficiency locations exhibit exceeding pipe capacity (d/D) and surcharge criteria as mentioned earlier. This encompasses a total distance of 1,691.90m, 5,334.80m, and 17,577.50m for the first, second, and third scenarios respectively. These exceedances have the potential to cause issues such as backups, overflows, and reduced performance. The deficient locations are primarily identified around Lideta condominium, Balcha hospital, Sengatera, Biherawi, Mesualekia, Beklobet, Global hotel to Gotera, China camp near Koshe, Jemo condominium, and Lafto. It is crucial to address these deficiencies in the study area through improvement measures.

5.2 Recommendation

To improve the sanitation situation of the study area the main aspect is to improve the water supply situation in parallel with the sewerage system development. Considering spatial distribution of Kality Catchment existing sewer line, huge areas have been already covered. The main drawback of the system is few number of customers connected to the network with respect to sewer system coverage. Tremendous effort is more crucial to connect water customers with house connection that could easily be accessed for sewer connection.

The projected wastewater generation rate could surpass the capacity of Kality wastewater treatment plant capacity in short period of time. Therefore, AAWSA should plan the expansion of the treatment plant along with expansion of sewer line network in the Kality Catchment. Due to high pipe capacity (d/D) value and surcharging the following recommendation addressed for the respected scenarios give below.

Scenario I: The existing sewer network in this scenario exhibits deficiencies in hydraulic performances, specifically pipe capacity (d/D) and surcharge. Pipe lines labeled in the table 4:14 located around Balcha hospital, Lideta, and condominium areas, have exceeded the capacity (d/D) and surcharge criteria. Therefore, it is recommended to improve these pipes to ensure efficient sewer system operation. Additionally, pipe lines labeled table 4:14 also exceed the capacity (d/D) and surcharge criteria, necessitating improvement measures.

Scenario II: In the second scenario, the sewer network system displays deficiencies in pipe capacity (d/D) and surcharge criteria. Pipe lines listed in table 4:15, located in Sengatera condominium and Biherawi areas, have exceeded the capacity (d/D) and surcharge criteria. Furthermore, these pipes are old and made of asbestos cement, highlighting the urgency for upgrading and replacement. Similarly, pipe lines listed in table 4:15, situated around Lideta, Balcha hospital, and condominium areas, also exceed the capacity (d/D) and surcharge criteria, need improvement measures. Additionally, the pipe lines depicted in table 4:15, located in Mesualekia, Beklobet and Global hotel to Gotera areas, surpass the capacity (d/D) and surcharge criteria, requiring improvement measures. Moreover, the pipe lines listed table 4:15, situated near China camp and Koshe, exhibit exceeded capacity (d/D) and surcharge criteria, emphasizing the need for improvement in these areas. The pipe line listed in table 4:15, which extends from Jemo roundabout to Lafto, also exceeds the capacity (d/D) and surcharge criteria, further highlighting the necessity for improvement.

Scenario III: In this scenario, the existing sewer network system displays deficiencies in hydraulic parameters, specifically pipe capacity (d/D) and surcharge. Multiple pipe lines, spanning from Jemo roundabout to Lafto, exhibit shortcomings in pipe capacity (d/D) and surcharge, necessitating improvement measures. Pipe CO-207, located near Mekanisa Mikael and connected to the Jemo sewer line, surpasses the d/D and surcharge criteria, thus requiring improvement. Similarly, pipes labeled in Table 4:16, situated near China camp close to Koshe, exceeded the capacity (d/D) and surcharge criteria, indicating the need for improvement. Additionally, the capacity (d/D) and surcharge criteria are exceeded in the Mesualekia, Beklobet, Global hotel to Gotera area, as well as in Lideta, Balcha hospital, and the condominium areas. These areas are densely populated with condominium houses and commercial buildings, indicating the necessity for improvement. Moreover, the capacity (d/D) and surcharge criteria are exceeded in Sengatera, Biherawi, and Stadium areas, where the sewer pipes are old and made of asbestos cement. Therefore, it is crucial to upgrade or replace these pipes to ensure improvement.

Based on the identified deficiency locations, develop strategies to mitigate the surcharge and exceedance of sewer capacity. This may involve upsizing pipes, optimizing slope gradients, implementing flow control measures, or constructing additional storage capacity. Consider both short-term and long-term solutions that address the specific deficiencies and ensure the resilience of the sewer network.

General, It is recommended that the utility upgrade or replace the existing sewer network that have to be found deficient location, regular maintenance and cleaning of the sewer network is also essential, as well as expand a new sewer system especially, the area where potential water customers occurred and connect unserved sewer system areas into the system.

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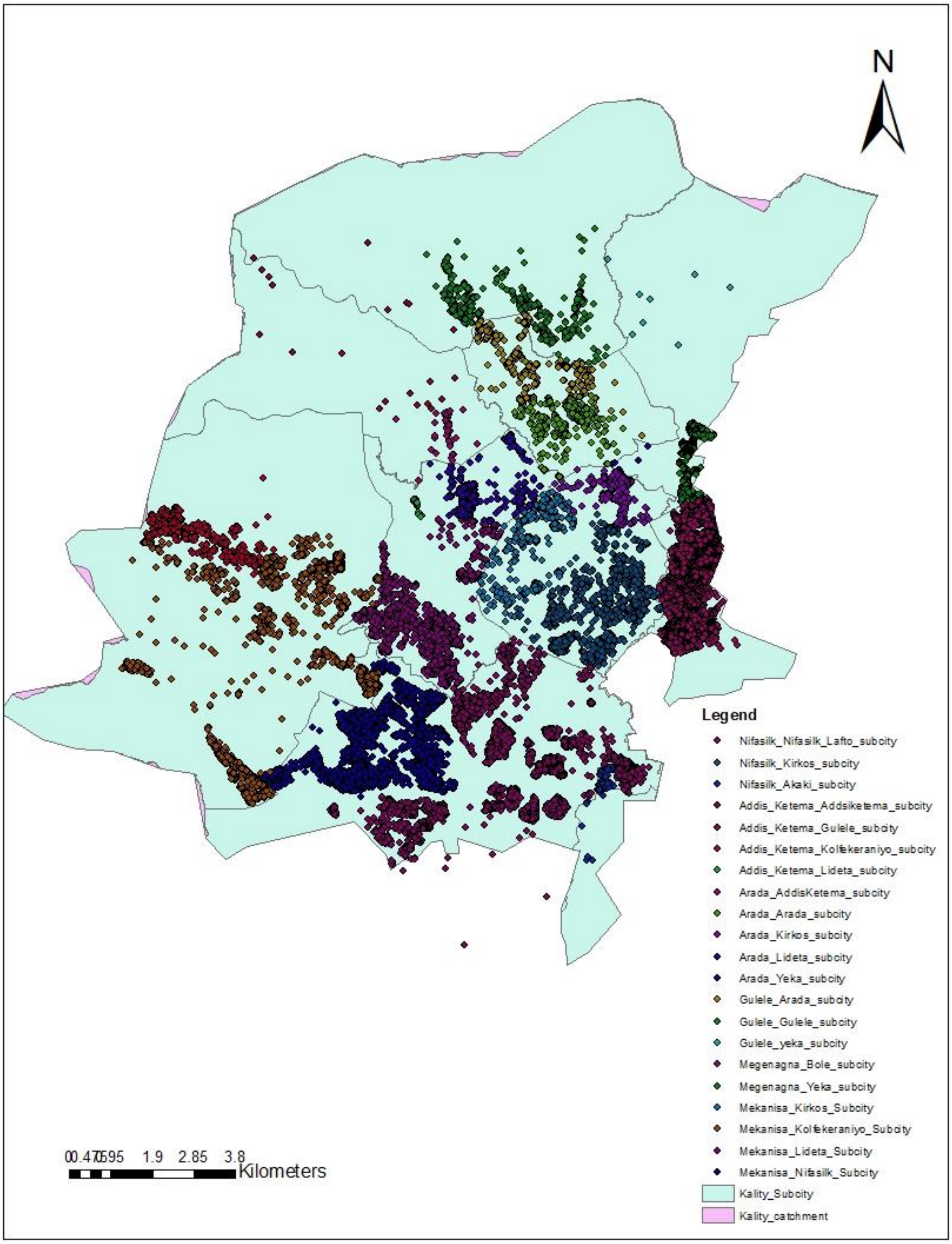
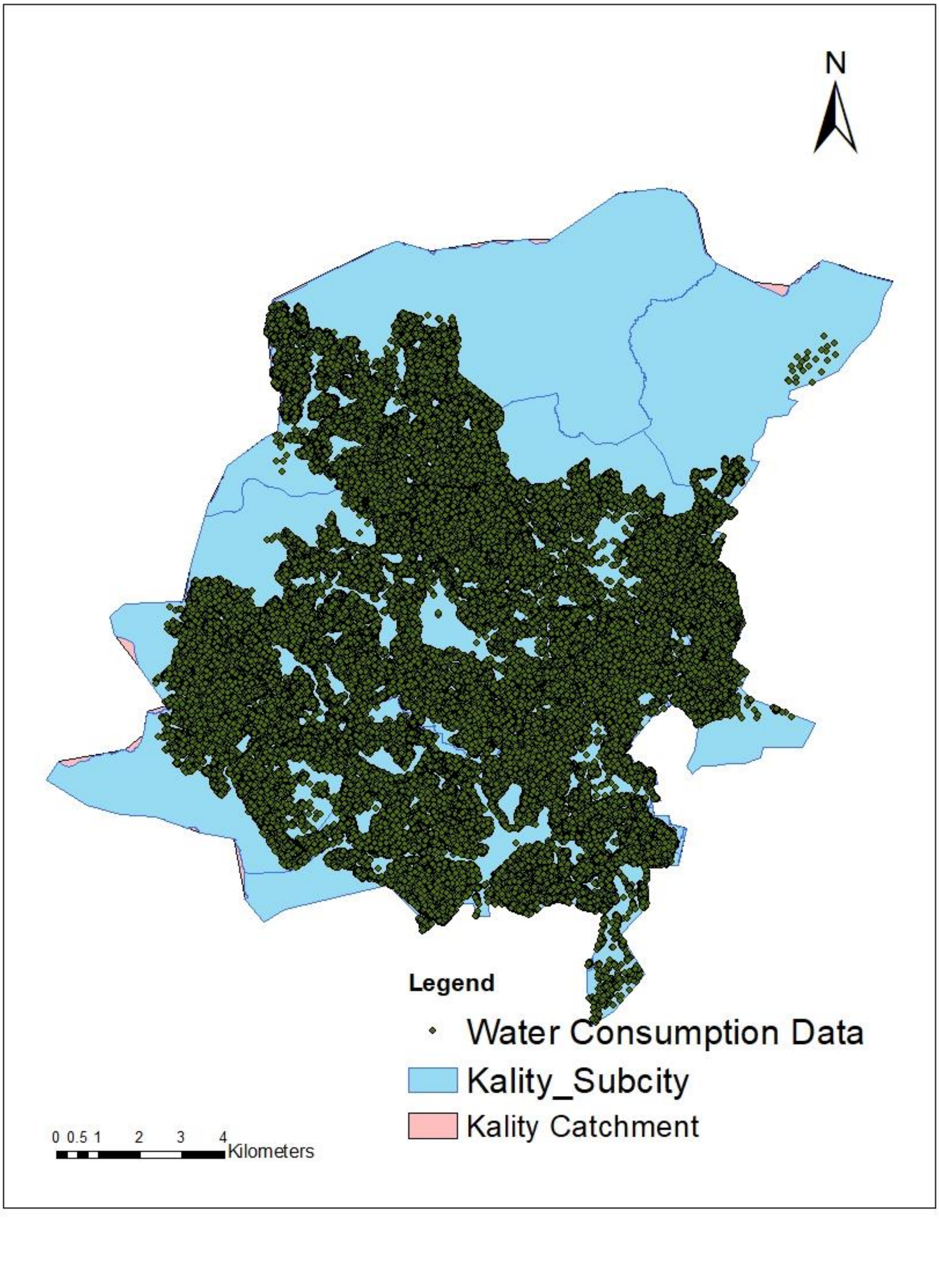
APPENDICES

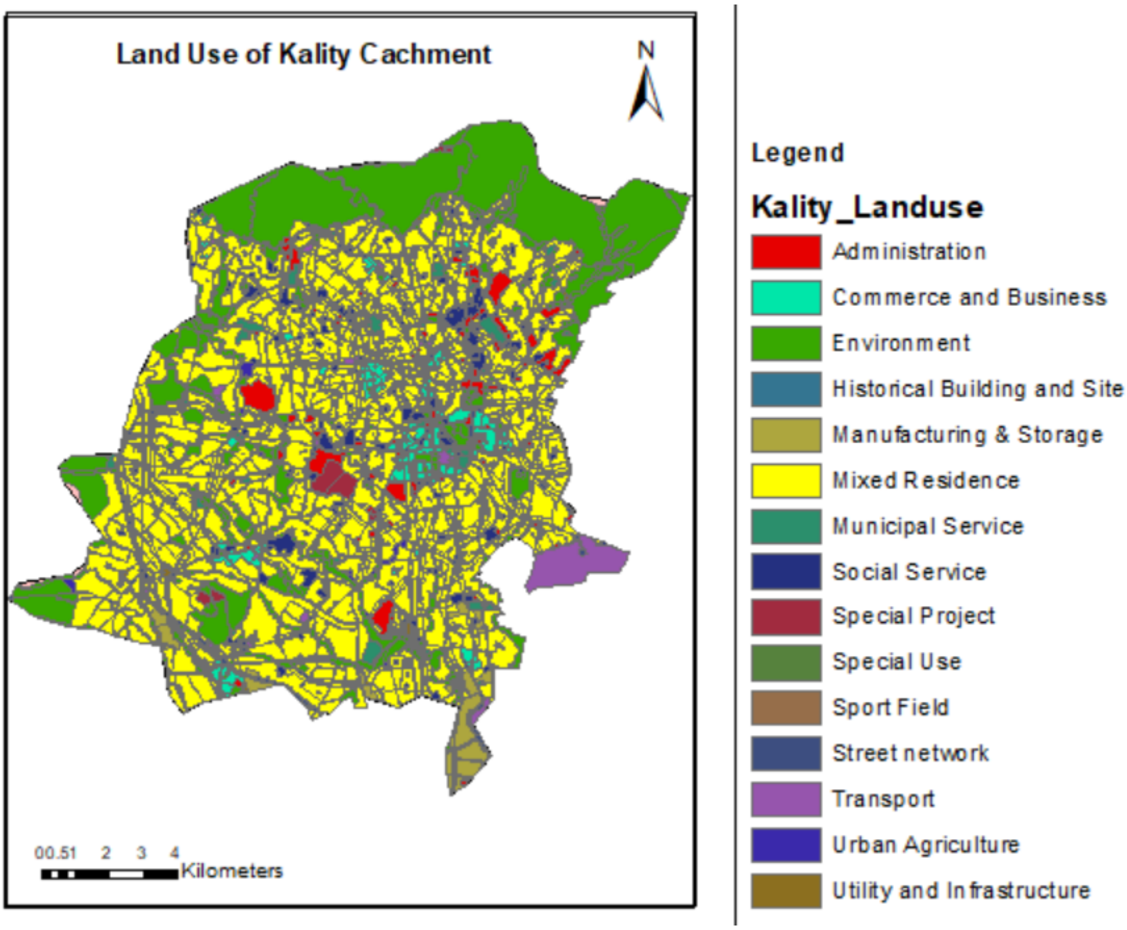
Annex: 1 Active sewer customers of water consumption distribution for scenario I



Annex: 2 Potential customers of water consumption distribution for scenario II



Annex: 3 Land use spatial distribution of Kality Catchment for scenario III



Annex: 4 estimated wastewater generation from active sewer customers for scenario I

AAWSA Branch	Administrative Sub city	Contributing Weredas	Billed Water Consumption	Number of Customers	Billed Water Consumption	
					m3/month	m3/day
NifasilK	Akaki	Only 0.6	106,420.85	130.14	3,432.93	114.43
	Kirkos	01, 02, 03, 04, 06, 09, 10 and 11	2,682,437.14	5,323.43	86,530.23	2,884.34
	Nifa Silk Lafto	01, 02, 03, 04, 05, 06, 07, 08, 09, 10 and 12	4,547,524.01	13,560.43	146,694.32	4,889.81
			7,336,382.00	**19,014.00**	**236,657.48**	**7,888.58**
Addis Ketema	Addis Ketema	04, 09 and 14	7,554.03	33.34	243.68	8.12
	Gulele	Only0.9	2,952.64	15.56	95.25	3.17
	Kolfekeraniyo	Only0.7	539,490.44	1,406.87	17,402.92	580.10

	Lideta	Only0.2	24,534.88	62.23	791.45	26.38
			574,532.00	**1,518.00**	**18,533.29**	**617.78**
Arada	Arada	01, 05, 08 and 09	2,146,227.33	1,780.28	89,426.14	2,980.87
	Yeka	Only 0.6	13,193.52	31.31	549.73	18.32
	Lideta	03, 05, 08 and 09	2,658,471.23	3,797.16	110,769.63	3,692.32
	Addis ketema	01, 03 and 08	102,420.81	68.43	4,267.53	142.25
	Kirkos	07 and 08	3,931,145.12	172.81	163,797.71	5,459.92
			8,851,458.00	**5,850.00**	**368,810.75**	**12,293.69**
Gulele	Yeka	01, 02 and 03	8,622.00	9.69	278.13	9.27
	Arada	02, 04, 05, 06, 07 and 09	2,114,828.53	1,373.31	68,220.28	2,274.01

	Gulele	01, 02, 03, 04, 06, 07 and 08	950,052.47	1,647.00	30,646.85	1,021.56
			3,073,503.00	**3,030.00**	**99,145.26**	**3,304.84**
Megenagna	Bole	01, 02, 03 and 04	5,157,895.00	4,279.00	166,383.71	5,546.12
	Yeka	07 and 08	3,330,781.00	2,479.00	107,444.55	3,581.48
			8,488,676.00	**6,758.00**	**273,828.26**	**9,127.61**
Mekanisa	Kolfekeraniyo	01, 02, 03, 04, 05, 06, 07, 09 and 11	1,799,863.34	7,372.03	58,060.11	1,935.34
	Kirkos	05, 07, 10 and 11	987,997.89	855.18	31,870.90	1,062.36
	Lideta	01, 04, 06 and 08	1,939,642.72	2,657.23	62,569.12	2,085.64
	Nifasilk Lafto	01, 02, and 13	5,290,877.05	20,162.57	170,673.45	5,689.12
			10,018,381.00	**31,047.00**	**323,173.58**	**10,772.45**

Akaki	Akaki		56,428.00	41.00	1,820.26	60.68
			56,428.00	**41.00**	**1,820.26**	**60.68**
Gurdshola	-	-	-	-	-	-
Lemikura	-	-	-	-	-	-
Total			**38,399,360.00**	**67,258.00**	**1,321,968.88**	**44,065.63**
80% of water consumption						**35,252.50**
Meter Inaccuracies 11.5%						4,068.14
						39,320.64
Inflow and Infiltration (15%)						11,796.19
						51,116.84
Wastewater Generation from Active Customers at Peak Flow						**66,451.89**

Annex: 5 estimated wastewater generation from potential water customers for scenario II

Name of Sub City	Contribute Weredas	Number of Household	Average Water Consumption (m3/month)	Daily Water Consumption (m3/day)	Wastewater Generation Rate (m3/day) at 75% Sewer Connection Rate
Gulele	W1				-
	W2				-
	W3				-
	W4				-
	W5	2447	26,546.07	884.87	530.92
	W6				-
	W7				-
	W8				-
	W9	4419	69,553.97	2,318.47	1,391.08
	W10	2921	46,367.03	1,545.57	927.34
		9787	**142,467.07**	**4,748.90**	**2,849.34**
Addis Ketema	W1	3464	97,269.00	3,242.30	1,945.38
	W3	7591	46,809.97	1,560.33	936.20
	W4	3855	55,686.07	1,856.20	1,113.72
	W5	2124	36,042.53	1,201.42	720.85
	W6	6062	51,298.03	1,709.93	1,025.96
	W8	4624	54,463.50	1,815.45	1,089.27

	W9	4648	44,680.47	1,489.35	893.61
	W10	1609	37,933.27	1,264.44	758.67
	W11	2329	51,581.03	1,719.37	1,031.62
	W12	4881	58,984.27	1,966.14	1,179.69
	W13	7285	48,099.93	1,603.33	962.00
	W14	4033	41,110.07	1,370.34	822.20
		52,505.00	**623,958.13**	**20,798.60**	**12,479.16**
Arada	W1	2476	58,399.27	1,946.64	1,167.99
	W2				-
	W4				-
	W5	2134	25,374.83	845.83	507.50
	W6	6	433.83	14.46	8.68
	W7	206	2,959.23	98.64	59.18
	W8	1542	38,724.40	1,290.81	774.49
	W9	2091	42,943.20	1,431.44	858.86
		8455	**168,834.77**	**5,627.83**	**3,376.70**
Lideta	W1	2923	27,491.07	916.37	549.82
	W2	1745			821.71

			41,085.47	1,369.52	
	W3	4848	31,015.60	1,033.85	620.31
	W4	1859	13,873.47	462.45	277.47
	W5	4348	23,368.37	778.95	467.37
	W6	2431	42,514.93	1,417.16	850.30
	W7	3526	97,736.13	3,257.87	1,954.72
	W8	3970	67,730.13	2,257.67	1,354.60
	W9	5503	57,617.50	1,920.58	1,152.35
	W10	2531	39,927.00	1,330.90	798.54
		33684	**442,359.67**	**14,745.32**	**8,847.19**
Kirkos	W1				-
	W2	3870	74,767.33	2,492.24	1,495.35
	W3	1732	50,332.63	1,677.75	1,006.65
	W4	5810	58,468.80	1,948.96	1,169.38
	W5	3016	33,441.90	1,114.73	668.84
	W7	559	118,318.43	3,943.95	2,366.37
	W8	3433	93,816.27	3,127.21	1,876.33
	W9				-

	W10	2977	22,521.90	750.73	450.44
	W11	4399	24,323.43	810.78	486.47
		25796	**475,990.70**	**15,866.36**	**9,519.81**
Kolfe keranyo	W1	8090	79,570.00	2,652.33	1,591.40
	W2	7749	66,769.67	2,225.66	1,335.39
	W3	13336	121,757.67	4,058.59	2,435.15
	W4	14614	156,021.73	5,200.72	3,120.43
	W5	10210	112,237.67	3,741.26	2,244.75
	W6	12420	136,197.27	4,539.91	2,723.95
	W7	16590	204,595.80	6,819.86	4,091.92
	W8	6446	93,461.27	3,115.38	1,869.23
	W9	2678	48,720.50	1,624.02	974.41
	W10	3115	51,193.33	1,706.44	1,023.87
	W11	7386	70,112.67	2,337.09	1,402.25
		102634	**1,140,637.57**	**38,021.25**	**22,812.75**
Nifas silk Laffto	W1	21610	204,385.43	6,812.85	4,087.71
	W2	6590			930.82

			46,541.07	1,551.37	
	W5	3752	46,495.63	1,549.85	929.91
	W6	8449	99,869.43	3,328.98	1,997.39
	W7	1801	23,030.30	767.68	460.61
	W8	2087	27,691.83	923.06	553.84
	W9	3153	46,739.97	1,558.00	934.80
	W10	3138	48,006.07	1,600.20	960.12
	W11	384	5,362.17	178.74	107.24
	W12	8834	101,076.80	3,369.23	2,021.54
	W13	5448	62,272.83	2,075.76	1,245.46
	W14	114	1,702.30	56.74	34.05
	W15				-
		65360	**713,173.83**	**23,772.46**	**14,263.48**
Yeka	W1				-
	W2				-
	W3				-
	W4				-
	W5	726	12,862.37	428.75	229.81
	W6	3745	48,199.07	1,606.64	861.16
	W7	4066			1,577.76

			88,307.20	2,943.57	
	W8	3	35.47	1.18	0.63
	W9				-
	W10	22	682.37	22.75	12.19
	W11				-
	W12				-
		8562	**150,086.47**	**5,002.88**	**2,681.54**
Bole	W1	9	79,335.37	2,644.51	1,417.46
	W2	1816	61,435.83	2,047.86	1,097.65
	W3				-
	W4	3180	80,689.23	2,689.64	1,441.65
	W5	2037	109,357.37	3,645.25	1,953.85
	W6				-
	W7				-
	W11				-
	W12				-
	W13		513.10	17.10	9.17
	W14				-
		7042	**331,330.90**	**11,044.36**	**5,919.78**
Lemi kura	W2				-
	W3				-
	W4				-
	W5				-
	W6				-

	W8				-
	W9				-
	W10				-
	W13				-
	W14				-
		0	**0**	**0**	**0**
Akaki Kality	W1				-
	W2				-
	W3				-
	W4				-
	W5	234	9,510.07	317.00	190.20
	W6	2462	51,360.50	1,712.02	1,027.21
	W7	33	1,309.77	43.66	26.20
	W8				-
	W9				-
	W10				-
	W11				-
	W12				-
	W13				-
		2729	**62,180.33**	**2,072.68**	**1,243.61**
Total		**316,554.00**	**4,251,019.43**	**141,700.65**	**83,993.36**
Meter Inaccuracies 11.5%					9,659.24
					93,652.60
Inflow and Infiltration (15%)					14,047.89
					107,700.49
Wastewater Generation from Potential Customers					**140,010.64**

Annex: 6 projected wastewater generation from land use data for scenario III

No.	Name of sewer Served Area	Area Served (Hectares)	Population Equivalent(House)	Population in Served Area	Population Density at Year 2043	Estimated Wastewater Quantity (m3/d) for year 2043
1	Piaza	42.65	6169	28376	665	3632.11
2	Neway challenge No.2	35.52	2424	11152	314	1427.43
3	Muzika Sefer 1	15.00	3436	15804	1054	2022.96
4	Saris addis Sefer GW2	74.03	7890	36294	490	4645.61
5	22 Mazoria	7.13	1657	7621	1069	975.50
6	Weyra sefer condominium	5.65	4502	20711	3668	2650.96
7	Kirkos1 Global	120.00	20170	92782	773	11876.16
8	Unknown_Area_Type	116.49	12851	59115	507	7566.74
9	Sengatera 40 60 commerce Mexico	62.08	3499	16096	259	2060.33
10	Dekemehari-Immigration	27.94	1691	7780	279	995.87
11	Nifasilk St Mechael	109.75	13732	63169	576	8085.68
12	Bambis	22.64	15525	71414	3154	9140.96
13	Kerchele micaeal	10.26	834	3834	374	490.81

14	bashawelde	16.33	1829	8414	515	1076.99
15	Gofa 15	37.22	3075	14146	380	1810.69
16	Mekanisa gebriel- Future school	93.00	3647	16775	180	2147.21
17	Bole medahnalem	160.39	15112	69515	433	8897.88
18	Infront of Belgium Em	12.33	1110	5108	414	653.77
19	Lideta Condominium	29.32	3304	15198	518	1945.37
20	Bihertige	14.08	3525	16217	1152	2075.74
21	Bole karamara welosefer	186.72	13486	62037	332	7940.74
22	Jemo2-2	25.04	2166	9963	398	1275.32
23	Jemo2-1	11.60	3601	16564	1428	2120.14
24	Balders Condominium	8.09	2470	11362	1404	1454.37
25	Landemark	38.34	4193	19290	503	2469.11
26	Meskelflower Gottera	87.68	9899	45535	519	5828.48
27	Germen Adebabay Condo site1	38.49	2757	12681	329	1623.19
28	Jemo1	84.54	7866	36186	428	4631.76
29	China Camp	105.16	5216	23994	228	3071.22
30	Jemo3	59.47	1658	7627	128	976.28
31	Betel1	71.06	5409	24879	350	3184.55
32	Atlas Hotel	8.27	638	2933	354	375.38
33	Sheraton	33.32	1526	7018	211	898.32

34	Africa Union	123.42	14671	67485	547	8638.12
35	Kore Mekanisa1 Donbosco shool	35.74	7733	35574	995	4553.43
36	Sost kutr mazoria Bisrate Gebre	180.16	20585	94690	526	12120.34
37	Biheretsige1	4.51	1446	6650	1473	851.19
38	Jemo Local	31.85	519	2388	75	305.68
39	Kore mekanisa Condo site Michae	45.49	7733	35574	782	4553.43
40	Betel2	249.11	907	4173	17	534.10
41	Sheger Menafesha	86.76	17700	81419	938	10421.57
42	Batel5 Alembank+UC	71.83	4825	22197	309	2841.18
43	mazegaja	39.95	3683	16943	424	2168.70
44	Adwa to 22	2.99	1195	5495	1839	703.39
45	Mowr Chichinia	21.43	2977	13696	639	1753.07
46	Old air port	79.76	7121	32756	411	4192.82
47	Betel4+Anfo UC	102.59	9712	44677	436	5718.68
48	Lebu Muzika sefer	51.44	4793	22047	429	2822.08
49	Kechene Road 2	12.77	4964	22832	1788	2922.52
50	Areke Fabrica Mekanisa	32.83	3968	18254	556	2336.54
51	Bole Dildy	83.20	6868	31595	380	4044.15
52	Betel7 zenebework	225.90	4957	22804	101	2918.87
53	Rasdesta	11.10	2437	11208	1010	1434.66

54	Adwa dildy Mekelakeya betoch	6.63	4891	22499	3393	2879.86
55	Adwa Dildy	3.47	1419	6527	1878	835.42
56	Lubu condo1	3.70	574	2640	714	337.96
57	Gofa condominium	88.39	4576	21047	238	2694.07
58	Varnero real estate+Lebu B1+B2	63.75	4842	22273	349	2850.93
59	ECA kazanchis	148.85	7142	32853	221	4205.16
60	Kore mekanisa condo2	18.04	8179	37624	2086	4815.94
61	Around Jemo	10.62	3523	16206	1526	2074.37
62	Adwa to 22 A	2.92	2105	9682	3316	1239.27
63	Gofa Area	46.70	7568	34811	745	4455.85
64	Stadium	15.98	1065	4901	307	627.28
65	Awraris 22	33.53	6980	32108	958	4109.87
66	Zire Embassy	21.00	6018	27682	1318	3543.32
67	Megenagna Addis Amba School	18.46	6265	28819	1561	3688.84
68	Spain Embassy	7.71	2679	12322	1598	1577.20
69	post office	1.84	257	1181	643	151.20
70	Koshe	84.08	5770	26543	316	3397.48
71	Bisrate Gebreal2 Abomazoria	68.96	5573	25637	372	3281.55
72	Kechene Road 3	9.00	2653	12205	1356	1562.27
73	kechene	90.73	9553	43944	484	5624.88

74	22 Akababi	3.62	2105	9682	2674	1239.27
75	Hope university-Lebu2 -UC	15.28	6602	30369	1987	3887.26
	Projected Wastewater Generation Using Land Use Method					**244,941.39**

Annex: 7 Critical or deficiency location of scenario I

Label	Length (Scaled) (m)	Diameter (mm)	Depth/Rise (%)	Description on deficiency location of the existing sewer network
CO-5413	56.8	300	100	Capacity of pipe (d/D) exceeded the criteria and exceeded the surcharge criterion; area is located around Balcha hospital, Lideta, condominium and covered with condominium houses and commercial building thus it improvement recommended.
CO-5414	99.6	300	94.7	
CO-5412	18.6	200	100	
CO-3366	326.5	200	100	
CO-3370	96.5	200	100	
CO-1323	62.3	200	100	
CO-3373	21.2	200	100	
CO-5361	248.9	200	91.9	The area is located around Mesualekia, Beklobet, and Global hotel to Gotera. D/d exceeded the criteria but not exceeded the surcharge criterion, therefore no improvement recommended.
CO-1307	93.9	200	6.41	
CO-4740	53.5	200	100	Capacity of pipe (d/D) exceeded the criteria but not exceeded the surcharge criterion, this area is located around China camp near Koshe and Mekanisa Michael no improvement recommended
CO-207	326.1	200	92.4	
CO-4741	32.8	200	100	
CO-4739	67.3	200	100	
CO-3484	98.9	600	100	
CO-3482	209.2	600	96.5	
CO-3483	93.6	600	100	
CO-71	64.4	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.

CO-73	55	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-38	200.9	400	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-5583	50.7	400	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-80	78.1	400	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-374	125.4	300	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-84	153.5	400	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-18	53.3	200	100	Capacity of pipe (d/D) exceeded the criteria and also exceeded the surcharge criterion, thus it improvement recommended.
CO-5604	32	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.

CO-11	52.5	200	100	Capacity of pipe (d/D) exceeded the criteria and also exceeded the surcharge criterion, thus it improvement recommended.
CO-65	116.2	400	100	Capacity of pipe (d/D) exceeded the criteria and also exceeded the surcharge criterion, thus it improvement recommended.
CO-1846	44.8	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-10	55	200	100	Capacity of pipe (d/D) exceeded the criteria and also exceeded the surcharge criterion, thus it improvement recommended.
CO-1642	98.1	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-35	191.7	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-2260	65.1	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-1640	38	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.

CO-375	55.3	400	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-40	538	200	99.7	Capacity of pipe (d/D) exceeded the criteria and also exceeded the surcharge criterion, thus it improvement recommended.
CO-13	60.1	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-34	160.1	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-5841	122.8	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-5603	66.5	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-14	55.5	200	100	Capacity of pipe (d/D) exceeded the criteria and also exceeded the surcharge criterion, thus it improvement recommended.
CO-81	120.1	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.

CO-39	96.6	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-17	180.1	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-1837	52.8	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-12	61	200	100	Capacity of pipe (d/D) exceeded the criteria and also exceeded the surcharge criterion, thus it improvement recommended.
CO-2261	91.8	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-1643	116.1	200	96.8	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-1641	65.8	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-85	41.5	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.

CO-75	52.9	400	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
CO-36	78.9	200	100	Capacity of pipe (d/D) exceeded the criteria and also exceeded the surcharge criterion, thus it improvement recommended.
CO-1847	29.8	200	100	Only Capacity of pipe (d/D) exceeded but not surcharge criterion for this scenario, therefore, no improvement recommended.
Total Length (m) improvement recommended				**1,691.90**

Annex 8 Critical or deficiency location of scenario II

Label	Length (Scaled) (m)	Diameter (mm)	Depth/Rise (%)	Description and comments
CO-3484	98.9	600	100	Capacity of pipe (d/D) and the surcharge exceeded the criteria. The area is located Sengatera condominium and Biherawi and also the pipe is old and asbestos cement, therefore it is important to upgrade and replace this pipe. Improvement recommended.
CO-3482	209.2	600	100	
CO-103	98.1	600	93.6	
CO-3501	47.4	200	90.7	
CO-3483	93.6	600	100	
CO-3419	348.6	600	91.7	
CO-3370	96.5	200	100	Capacity of pipe d/D exceeded the criteria and exceeded the surcharge criterion; this area is located around Lideta, condominium, Balcha hospital. Thus, improvement recommended.
CO-3366	326.5	200	100	
CO-1323	62.3	200	100	
CO-3371	91.1	200	100	
CO-3373	21.2	200	100	
CO-5413	56.8	301	100	Capacity of pipe d/D exceeded the criteria but not exceeded the surcharge criterion; this area is located around Lideta, condominium, Balcha hospital. No improvement recommended.
CO-5414	99.6	300	98.1	
CO-5415	32.9	301	90.8	
CO-5412	18.6	200	100	
CO-3501	47.4	200	90.7	The area is located around Mesualekia, Beklobet, and Global hotel to Gotera. Capacity of pipe (d/D) and the surcharge criterion exceeded the criteria thus improvement recommended.
CO-5490	155.3	200	100	
CO-1307	93.9	200	100	
CO-5361	248.9	200	100	
CO-5360	319.7	200	95.4	
CO-1306	40.8	200	100	
CO-1308	54.1	200	100	
CO-3145	55.1	250	64.5	The area is located around

CO-5478	103.8	200	95.5	Mesualekia, Beklobet, and Global hotel to Gotera. Capacity of pipe (d/D) but not the surcharge criterion exceeded the criteria thus no improvement recommended.
CO-3439	407	200	100	
CO-4748	52.7	200	100	Capacity of pipe (d/D) exceeded the criteria but not exceeded the surcharge criterion, this area is located around China camp near Koshe, no improvement recommended
CO-207	326.1	200	95.5	
CO-4740	53.5	200	100	
CO-4746	58.3	200	100	
CO-4747	94.8	200	100	
CO-4739	67.3	200	100	
CO-4738	57.2	200	100	
CO-4761	61.4	200	100	
CO-4760	69.4	200	100	
CO-3224	42.9	200	100	Capacity of pipe (d/D) exceeded the criteria and exceeded the surcharge criterion, this area is located around China camp near Koshe, therefore improvement recommended
CO-4741	32.8	200	100	
CO-18	53.3	200	100	Capacity of pipe (d/D) exceeded the criteria and exceeded the surcharge criterion, this area is located around Jemo condominium and lafto, therefore improvement recommended
CO-11	52.5	200	100	
CO-65	116.2	400	100	
CO-10	55	200	100	
CO-35	191.7	200	100	
CO-40	538	200	100	
CO-13	60.1	200	100	
CO-34	160.1	200	100	
CO-14	55.5	200	100	
CO-39	96.6	200	100	
CO-12	61	200	100	
CO-75	52.9	400	100	
CO-36	78.9	200	100	

CO-1640	38	200	100	
CO-375	55.3	400	100	
CO-5841	122.8	200	100	
CO-71	64.4	200	100	
CO-38	200.9	400	100	
CO-5604	32	200	100	
CO-1641	65.8	200	100	
CO-1846	44.8	200	100	
CO-81	120.1	200	100	
CO-5581	21.3	200	100	
CO-1642	98.1	200	100	
CO-5583	50.7	400	100	
CO-80	78.1	400	100	
CO-374	125.4	301	100	
CO-1643	116.1	200	100	
CO-1847	29.8	200	100	Capacity of pipe (d/D) exceeded the criteria but not exceeded the surcharge criterion; this area is located around from Jemo roundabout to Lafto. No improvement recommended
CO-73	55	200	100	
CO-1505	29.1	200	90.9	
CO-84	153.5	400	100	
CO-49	28.9	200	100	
CO-2261	91.8	200	100	
CO-85	41.5	200	100	
CO-17	180.1	200	100	
CO-1837	52.8	200	100	
CO-76	66	200	95.5	
CO-2260	65.1	200	100	
CO-5603	66.5	200	100	
CO-5582	32.7	200	100	
CO-91	83.3	200	100	
Total Length (m) improvement recommended				**5,334.80**

Annex: 9 Critical or deficiency location of scenario III

Label	Length (Scaled) (m)	Diameter (mm)	Depth/Rise (%)	Description and comments
CO-207	55	200	95.2	This pipe connecting newly construct around Mekanisa Mikael connects to the Jemo sewer line. The d/D and the surcharge criterion exceeded the criteria thus improvement recommended.
CO-311	52.5	200	96.5	Capacity of pipe (d/D) exceeded the criteria and exceeded the surcharge criterion, this area is located around Jemo condominium and lafto, therefore improvement recommended
CO-76	53.3	200	99.1	
CO-374	28.9	301	100	
CO-10	116.2	200	100	
CO-13	66	200	100	
CO-34	32	200	100	
CO-17	78.1	200	100	
CO-35	153.5	200	100	
CO-40	67	200	100	
CO-49	102.5	200	100	
CO-54	74.6	200	100	
CO-11	149.9	200	100	
CO-71	68.6	200	100	
CO-80	79.1	400	100	
CO-51	68.9	200	100	
CO-65	81.3	400	100	
CO-84	79.7	400	100	
CO-55	326.1	200	100	
CO-120	89.3	200	100	
CO-325	146.8	200	100	
CO-342	125.4	200	100	
CO-50	33.2	200	100	

CO-1505	93.9	200	100
CO-1640	29.1	200	100
CO-1791	44.8	200	100
CO-1837	216.2	200	100
CO-1846	47.3	200	100
CO-1975	48.1	200	100
CO-14	106.4	200	100
CO-12	110.9	200	100
CO-2260	100.8	200	100
CO-1641	81.9	200	100
CO-1642	96.5	200	100
CO-36	99.8	200	100
CO-91	224.8	200	100
CO-2261	121.8	200	100
CO-1643	348.6	200	100
CO-81	222.1	200	100
CO-3375	99.9	200	100
CO-3376	252.9	200	100
CO-3377	50.4	200	100
CO-3378	76.1	200	100
CO-132	66.5	200	100
CO-3379	189.6	200	100
CO-38	67.3	400	100
CO-375	53.5	400	100
CO-39	58.3	200	100
CO-3115	94.8	200	100
CO-5581	39.8	200	100
CO-85	67.9	200	100
CO-5582	93.6	200	100
CO-75	63.4	400	100
CO-5583	92.5	400	100
CO-133	14.2	200	100

CO-1847	9.7	200	100	
CO-5603	103	200	100	
CO-18	248.9	200	100	
CO-5604	51.1	200	100	
CO-73	14.7	200	100	
CO-5841	79.5	200	100	
CO-4740	52.3	200	100	Capacity of pipe (d/D) exceeded the criteria but not exceeded the surcharge criterion, this area is located around China camp near Koshe, no improvement recommended
CO-4746	48.7	200	100	
CO-1916	64.4	200	91.4	
CO-4766	44.8	200	91.5	
CO-4747	30.8	200	100	
CO-4739	50	200	100	
CO-4738	48.9	200	100	
CO-4761	50.8	200	100	
CO-4741	50.7	200	100	Capacity of pipe (d/D) exceeded the criteria and exceeded the surcharge criterion, this area is located around China camp near Koshe, therefore improvement recommended
CO-4760	32	200	100	
CO-3224	47	200	100	
CO-4553	32.2	600	91.2	Capacity of pipe (d/D) exceeded the criteria but not exceeded the surcharge criterion, therefore no improvement recommended
CO-3052	60.1	200	92.1	
CO-4551	191.7	600	100	
CO-4552	538	600	100	
CO-4993	60.5	200	100	
CO-4548	225.8	600	100	
CO-3478	83.3	300	90.2	
CO-227	30.1	600	100	
CO-4997	109.4	200	91.5	
CO-3086	105.2	200	98.6	
CO-226	31.2	600	100	
CO-224	65.5	600	100	

CO-223	88	600	98.2	
CO-4661	145.5	200	95	
CO-4549	55.3	600	100	
CO-225	155.2	600	100	
CO-42	120.4	600	98.2	Capacity of pipe (d/D) exceeded the criteria and exceeded the surcharge criterion, therefore improvement recommended
CO-43	38	600	97.2	
CO-4992	98.1	200	100	
CO-5490	65.1	200	100	The capacity of pip (d/D) and the surcharge criterion exceeded the criteria, the area is located around Mesualekia, Beklobet, Global hotel to Gotera, thus improvement recommended.
CO-1307	108	200	100	
CO-5361	36	200	100	
CO-5360	249.5	200	100	
CO-5478	34.6	200	100	
CO-732	160.2	200	100	
CO-3439	73.7	200	100	
CO-773	74.7	200	100	
CO-1303	77	200	100	
CO-1306	57.2	200	100	
CO-752	32.8	200	100	
CO-1320	125.3	200	100	
CO-1170	14.7	200	100	
CO-1221	51	200	100	
CO-1308	21.3	200	100	
CO-788	32.7	200	100	
CO-3461	200.9	200	100	
CO-744	64.4	200	100	
CO-5475	55	600	98.1	The capacity of pip (d/D) but not the surcharge criterion exceeded the criteria, the area is located around Mesualekia, Beklobet, Global hotel to Gotera which is developed area thus improvement
CO-3460	98.1	600	92.3	
CO-1302	48	200	93.2	
CO-751	39	200	100	
CO-731	99.5	200	100	
CO-772	269.5	200	100	

CO-5479	165.2	200	100	recommended.
CO-5362	187.9	200	100	
CO-5474	250.9	600	100	
CO-5502	209.2	500	100	Capacity of sewer pipe (d/D) and the surcharge exceeded the criteria, this area is located arounnd Lideta, condominium, Balcha hospital and covered with condominium houses and commercial building thus it improvement is recommended.
CO-144	93.6	200	100	
CO-143	98.9	500	100	
CO-138	65.2	200	100	
CO-5503	50.7	500	100	
CO-3453	49	200	100	
CO-1900	72.9	200	100	
CO-5501	52.7	400	100	
CO-137	91.3	400	100	
CO-3448	64.6	400	95.9	
CO-145	97.5	200	100	
CO-174	45.1	400	100	
CO-3363	155.3	400	100	
CO-3455	34	400	100	
CO-5492	42.8	400	100	
CO-5471	124.5	400	100	
CO-140	61	400	100	
CO-142	55.5	400	100	
CO-180	180.1	400	100	
CO-141	160.1	200	100	
CO-3454	78.9	400	100	
CO-134	96.6	400	100	
CO-5470	196.7	400	100	
CO-3370	96.5	200	100	
CO-5413	56.8	250	95.6	
CO-5414	99.6	250	98	
CO-5415	32.9	250	98.4	
CO-5416	14.7	301	94.2	
CO-3366	326.5	200	100	

CO-1323	62.3	200	100	
CO-3371	91.1	150	94.4	
CO-3364	26.7	240	93.3	
CO-5412	18.6	200	100	
CO-3373	21.2	200	100	
CO-3447	160.2	400	95.6	Capacity of sewer pipe (d/D) but not the surcharge exceeded the criteria, due to this area is located around Lideta, condominium, Balcha hospital and covered with condominium houses and commercial building thus it improvement is recommended.
CO-3446	34.6	400	100	
CO-635	155.2	200	97.1	
CO-3450	187.9	500	100	
CO-5472	52.3	400	99.8	
CO-136	84.1	200	100	
CO-135	71.8	200	100	
CO-5099	94.2	200	100	
CO-3456	63.4	400	100	
CO-3449	165.2	500	100	
CO-3484	45.1	600	100	Capacity of sewer pipe (d/D) and the surcharge exceeded the criteria. The area is located Sengatera, Biherawi, and Stadium area and the pipe is old and asbestos cement, therefore it is important to upgrade or replace this pipe so improvement recommended.
CO-3423	158.5	700	91.4	
CO-3482	99	600	100	
CO-103	156.8	600	100	
CO-3483	123.1	600	100	
CO-4583	61.3	700	100	
CO-3419	21.4	600	100	
CO-3417	59.5	600	100	
CO-4584	24.2	600	100	
CO-79	173.6	600	93.4	
CO-589	24.7	251	100	
CO-3420	27.5	500	98.3	
CO-101	111.7	500	100	
CO-5690	89.9	500	100	
CO-5033	85.1	600	100	
CO-5338	181.1	600	100	
CO-630	153.4	600	100	

CO-2754	15	600	94.8	
CO-5340	74.4	500	96.1	
CO-3422	40.8	600	100	
CO-3467	54.1	500	100	
CO-87	87	500	96.1	
CO-5339	62.3	500	100	
CO-98	65.8	500	100	
CO-631		200	100	
CO-102	116.1	200	100	
CO-5034	42.7	251	100	
CO-1912	52.8	300	100	Capacity of sewer pipe (d/D) and the surcharge exceeded the criteria, therefore it is important to upgrade or replace this pipe, thus improvement recommended.
CO-5125	29.8	251	100	
CO-5126	46.9	251	100	
CO-5124	84.9	251	100	
CO-93	50.8	251	100	
CO-588	91.8	251	100	
CO-1887	73.3	300	100	
CO-5123	105.9	251	100	
CO-2388	89.3	300	100	
CO-3002	92.4	300	100	
CO-92	111.6	300	100	
CO-589	63.8	251	100	
CO-1884	42.9	300	100	
CO-1885	326.5	300	100	
CO-2389	21.2	300	100	
CO-2571	118.3	200	100	
CO-2572	50	300	100	
CO-2537	385.3	300	100	
CO-2387	407	300	100	
CO-200	119.6	500	95.4	Capacity of sewer pipe (d/D) but not the surcharge exceeded the criteria, thus No improvement
CO-5136	27.1	200	100	
CO-5135	63.4	200	96.5	

CO-453	183.7	300	93.9	recommended.
CO-2494	55.9	300	100	
Total Length (m) improvement recommended				**17,577.50**

Annex 10: SewerGEMS model pipe report of the existing sewer network

Label	Start Node	Stop Node	Length (Scaled) (m)	Slope (Calculated) (%)	Diameter (mm)	Material	Velocity (m/s)	Flow / Capacity (Design) (%)	Depth/Rise (%)	Is Surcharged?
CO-4553	MH-4535	MH-4536	49	0	600	Asbestos Cement	0.56	2,570.20	74	FALSE
CO-5734	MH-5716	MH-5717	74.2	0	200	PVC	0.17	1,667.10	70.2	FALSE
CO-5769	MH-5752	MH-5753	65	0	200	PVC	0.02	222.2	55.5	FALSE
CO-4800	MH-4780	MH-4781	68.2	0.015	200	PVC	0.1	20	30.3	FALSE
CO-4964	MH-4944	MH-4943	65.2	0.015	200	PVC	0.1	18.6	29.3	FALSE
CO-4758	MH-4738	MH-4737	59.7	0.017	200	PVC	0.05	1.5	8.5	FALSE
CO-1427	MH-1234	MH-3212	220.7	0.027	200	PVC	0.14	21.6	31.6	FALSE
CO-2650	MH-2412	MH-4877	71.4	0.028	200	PVC	0.07	1.8	9.4	FALSE
CO-3484	MH-3496	MH-59	98.9	0.03	600	PVC	1.01	206.4	100	TRUE
CO-2242	MH-1934	MH-5079	31.7	0.032	200	PVC	0.14	17.9	28.6	FALSE
CO-629	MH-430	MH-5016	59.9	0.033	251	PVC	0.33	96.7	79.1	FALSE
CO-1446	MH-1253	MH-1841	58.9	0.034	200	PVC	0.11	6.7	17.6	FALSE
CO-3280	MH-3320	MH-3316	58.8	0.034	300	PVC	0.22	11.4	22.8	FALSE
CO-2827	MH-2656	MH-2109	28.6	0.035	200	PVC	0.1	5.4	15.7	FALSE
CO-3423	MH-3436	MH-3435	269.5	0.037	700	PVC	0.84	181.3	87.7	TRUE
CO-3286	MH-3326	MH-3275	121.6	0.041	900	Asbestos Cement	0.62	108	70.7	FALSE
CO-639	MH-443	MH-3389	182.1	0.044	251	PVC	0.14	6.3	17	FALSE
CO-3482	MH-3494	MH-3495	209.2	0.046	600	PVC	1.02	168.2	96.5	TRUE
CO-103	MH-61	MH-3494	98.1	0.046	600	PVC	1.02	168.4	86.1	FALSE

CO-3501	MH-3513	MH-4993	47.4	0.049	200	PVC	0.47	204.1	88	TRUE
CO-5396	MH-5370	MH-5369	39.6	0.051	400	PVC	0.43	30.5	37.9	FALSE
CO-2146	MH-1839	MH-1609	58.3	0.051	200	PVC	0.08	1.2	7.6	FALSE
CO-5397	MH-5371	MH-5370	35.2	0.057	400	PVC	0.44	29	36.9	FALSE
CO-5709	MH-5684	MH-5685	175.1	0.057	200	PVC	0.16	10.2	21.3	FALSE
CO-4581	MH-4563	MH-4465	87.3	0.057	700	PVC	0.04	0	73.4	FALSE
CO-2769	MH-2579	MH-4650	86.8	0.058	200	PVC	0.07	0.7	6	FALSE
CO-3157	MH-3198	MH-3189	101.8	0.059	200	PVC	0.09	1.3	8	FALSE
CO-1406	MH-1218	MH-1219	16.9	0.059	300	PVC	0.36	65.8	59.2	FALSE
CO-2289	MH-1983	MH-320	66.9	0.06	200	PVC	0.07	0.6	5.4	FALSE
CO-1818	MH-1547	MH-2632	130.1	0.062	200	PVC	0.1	1.6	10.2	FALSE
CO-2563	MH-2301	MH-2302	97	0.062	200	PVC	0.11	2.6	11.2	FALSE
CO-3483	MH-3495	MH-3496	93.6	0.063	600	PVC	1.02	143.9	100	TRUE
CO-1880	MH-1607	MH-1608	46.8	0.064	200	PVC	0.1	1.6	9.6	FALSE
CO-2157	MH-1855	MH-1856	60	0.067	200	PVC	0.08	0.7	6	FALSE
CO-5725	MH-5705	MH-5706	146.3	0.068	200	PVC	0.15	6.5	18.4	FALSE
CO-1151	MH-919	MH-849	86.9	0.069	200	PVC	0.16	7.1	18	FALSE
CO-5713	MH-5690	MH-5691	142.9	0.07	200	PVC	0.24	31.1	37.8	FALSE
CO-1287	MH-1094	MH-873	28.5	0.07	200	PVC	0.07	0.6	5.4	FALSE
CO-59	MH-37	MH-2873	110.5	0.072	200	PVC	0.19	11.9	26.4	FALSE
CO-627	MH-429	MH-1768	55	0.073	200	PVC	0.11	1.6	8.9	FALSE
CO-4748	MH-4728	MH-4718	52.7	0.076	200	PVC	0.19	10.6	27.6	FALSE
CO-71	MH-45	MH-46	64.4	0.078	200	PVC	0.99	261.2	100	TRUE
CO-88	MH-53	MH-77	51.2	0.078	400	PVC	0.16	0.6	11.3	FALSE
CO-4491	MH-4474	MH-4464	63.3	0.079	700	Asbestos Cement	0.86	126.8	77.7	FALSE
CO-3028	MH-2962	MH-3192	122.9	0.081	200	PVC	0.07	0.4	4.8	FALSE

CO-2264	MH-1959	MH-1771	36.7	0.082	200	PVC	0.12	2.1	10	FALSE
CO-3282	MH-3322	MH-3326	122.3	0.082	900	Asbestos Cement	0.9	76.6	65.6	FALSE
CO-5701	MH-5675	MH-5676	121.6	0.082	200	PVC	0.25	26.1	34.5	FALSE
CO-208	MH-123	MH-287	36.3	0.083	251	PVC	0.16	1.3	14.5	FALSE
CO-5138	MH-5115	MH-2172	70.7	0.085	200	PVC	0.11	1.3	8.1	FALSE
CO-833	MH-618	MH-619	35.3	0.085	200	PVC	0.18	7.4	18.5	FALSE
CO-3449	MH-3461	MH-3460	165.2	0.086	500	PVC	0.64	103.5	73.8	FALSE
CO-5017	MH-4997	MH-3518	103.3	0.087	300	PVC	0.44	73.4	63.7	FALSE
CO-4820	MH-4800	MH-2127	34	0.088	200	PVC	0.08	0.4	4.8	FALSE
CO-2871	MH-2721	MH-1203	167	0.09	200	PVC	0.09	0.7	7.3	FALSE
CO-3103	MH-3098	MH-3107	132.9	0.09	200	PVC	0.13	2.5	10.8	FALSE
CO-73	MH-45	MH-5830	55	0.091	200	PVC	0.22	70.6	100	TRUE
CO-5272	MH-5249	MH-409	64.4	0.093	251	PVC	0.1	0.3	3.8	FALSE
CO-1774	MH-1514	MH-1525	42.7	0.094	200	PVC	0.11	1.4	8.3	FALSE
CO-1789	MH-1523	MH-1524	42.6	0.094	200	PVC	0.28	31.1	38.3	FALSE
CO-2600	MH-2342	MH-1865	95.4	0.094	200	PVC	0.15	3.9	15	FALSE
CO-2920	MH-2784	MH-2719	41.9	0.095	200	PVC	0.19	7.1	18.1	FALSE
CO-2366	MH-2063	MH-2064	71.3	0.098	200	PVC	0.11	1.3	9.2	FALSE
CO-5299	MH-5275	MH-2433	50.7	0.099	200	PVC	0.08	0.5	4.9	FALSE
CO-2352	MH-2051	MH-1895	70.4	0.099	200	PVC	0.1	0.9	6.8	FALSE
CO-38	MH-21	MH-246	200.9	0.1	400	PVC	0.42	80.3	100	TRUE
CO-4216	MH-4207	MH-4208	29.7	0.101	1,500.00	Glass	1.35	32.9	39.5	FALSE
CO-5710	MH-5685	MH-5686	194.6	0.103	200	PVC	0.13	1.8	15.3	FALSE
CO-1501	MH-1294	MH-1295	28.8	0.104	200	PVC	0.08	0.4	5	FALSE
CO-1912	MH-1629	MH-1630	48	0.104	200	PVC	0.26	20.4	30.7	FALSE
CO-5012	MH-4992	MH-4991	57.5	0.104	200	PVC	0.25	17.6	28.4	FALSE

CO-2025	MH-1737	MH-1192	76.7	0.104	200	PVC	0.11	0.9	6.9	FALSE
CO-4544	MH-4526	MH-4527	94.7	0.106	600	Asbestos Cement	0.29	2.4	10.6	FALSE
CO-749	MH-547	MH-1006	193.4	0.109	200	PVC	0.23	10.9	22.3	FALSE
CO-4729	MH-4709	MH-4706	36.8	0.109	200	PVC	0.3	31	38.2	FALSE
CO-5697	MH-5670	MH-5671	90.1	0.111	250	PVC	0.27	12.4	23.5	FALSE
CO-3339	MH-3380	MH-2352	89.8	0.111	200	PVC	0.19	5.7	17.9	FALSE
CO-4440	MH-4425	MH-4426	97	0.113	700	Asbestos Cement	0.91	111.8	78.3	FALSE
CO-1784	MH-1519	MH-2593	149	0.114	200	PVC	0.31	29.3	37.1	FALSE
CO-5609	MH-5583	MH-3139	52.4	0.115	200	PVC	0.14	2.1	9.9	FALSE
CO-4608	MH-4590	MH-3821	52.2	0.115	1,500.00	Glass	1.2	17.4	28.3	FALSE
CO-5502	MH-5476	MH-5477	34	0.118	500	PVC	0.95	80.3	67.9	FALSE
CO-4367	MH-4355	MH-3268	252.5	0.119	900	Asbestos Cement	1.04	63.5	57.8	FALSE
CO-2490	MH-2211	MH-1557	84.2	0.119	200	PVC	0.1	0.5	13.5	FALSE
CO-2488	MH-2208	MH-1238	83.9	0.119	200	PVC	0.1	0.7	11.5	FALSE
CO-3926	MH-3930	MH-3931	50.3	0.119	600	Glass	0.57	17.7	28.5	FALSE
CO-2144	MH-1837	MH-2832	166.5	0.12	200	PVC	0.33	34.6	40.5	FALSE
CO-1763	MH-1505	MH-336	41.6	0.12	200	PVC	0.23	9.5	20.8	FALSE
CO-1545	MH-1336	MH-429	32.3	0.124	200	PVC	0.13	1.4	8.3	FALSE
CO-698	MH-506	MH-507	15.9	0.126	200	PVC	0.3	8.8	20	FALSE
CO-1603	MH-1382	MH-457	46.9	0.128	251	PVC	0.09	0.2	3.3	FALSE
CO-3348	MH-3386	MH-3387	148.4	0.128	251	PVC	0.27	8.8	20	FALSE
CO-3052	MH-3010	MH-3078	39	0.128	200	PVC	0.41	72.9	63.4	FALSE
CO-4972	MH-4952	MH-2794	92.6	0.13	200	PVC	0.17	3.3	12.5	FALSE
CO-5504	MH-5478	MH-1990	22.4	0.134	200	PVC	0.14	1.6	8.8	FALSE

CO-5748	MH-5729	MH-5730	74.5	0.134	200	PVC	0.31	24	32.9	FALSE
CO-3250	MH-3288	MH-3292	156.1	0.135	200	PVC	0.21	5.7	16.2	FALSE
CO-2112	MH-1808	MH-2094	74.2	0.135	200	PVC	0.12	0.9	6.6	FALSE
CO-3636	MH-3645	MH-3646	51.4	0.136	1,000.00	Glass	0.89	11.7	23.1	FALSE
CO-3658	MH-3667	MH-3668	72.6	0.138	1,000.00	Glass	0.95	14.5	25.7	FALSE
CO-4047	MH-4042	MH-2488	111.9	0.143	200	PVC	0.13	1.2	12.1	FALSE
CO-3328	MH-3373	MH-20	195.7	0.143	500	PVC	0.75	20.8	39.2	FALSE
CO-4481	MH-4464	MH-4465	34.7	0.144	700	Asbestos Cement	1.04	93.8	78.4	FALSE
CO-4830	MH-4810	MH-4609	89.7	0.145	200	PVC	0.29	15.6	26.7	FALSE
CO-4580	MH-4562	MH-203	137.2	0.146	301	PVC	0.66	44.8	46.9	FALSE
CO-2377	MH-2071	MH-2046	271.8	0.147	200	PVC	0.4	47.7	48.6	FALSE
CO-4545	MH-4527	MH-4528	67.7	0.148	600	Asbestos Cement	0.33	2	10.2	FALSE
CO-4962	MH-4942	MH-2553	54.1	0.148	200	PVC	0.07	0.1	2.8	FALSE
CO-4583	MH-4565	MH-5663	72.9	0.148	700	PVC	1.04	87.4	72.4	FALSE
CO-3230	MH-3272	MH-3274	87.5	0.149	300	PVC	0.34	4.4	14.4	FALSE
CO-2506	MH-2236	MH-2237	86.9	0.15	200	PVC	0.15	1.7	11	FALSE
CO-3336	MH-3378	MH-3261	133.3	0.15	800	Asbestos Cement	1.13	77.8	66.3	FALSE
CO-3267	MH-3308	MH-3250	93.1	0.15	200	PVC	0.12	0.9	6.8	FALSE
CO-3463	MH-3475	MH-3474	250.9	0.151	600	Asbestos Cement	0.89	61.4	56.6	FALSE
CO-2649	MH-2411	MH-4865	99.3	0.151	200	PVC	0.2	4	14	FALSE
CO-262	MH-167	MH-114	329.9	0.152	301	PVC	0.63	35	40.8	FALSE
CO-4524	MH-4507	MH-4508	131.4	0.152	600	Asbestos Cement	0.52	8.7	19.9	FALSE
CO-5868	MH-5865	MH-5866	853.4	0.152	250	PVC	0.27	2.8	11.5	FALSE

CO-4551	MH-4533	MH-4534	65.2	0.153	600	Asbestos Cement	0.91	65.2	59.4	FALSE
CO-5490	MH-5464	MH-1119	155.3	0.155	200	PVC	0.61	147.7	89.8	TRUE
CO-5125	MH-5102	MH-5103	64.6	0.155	251	PVC	0.62	49.8	49.9	FALSE
CO-2597	MH-2336	MH-2999	237.8	0.156	200	PVC	0.15	1.5	10.1	FALSE
CO-5716	MH-5692	MH-5697	126.8	0.158	200	PVC	0.24	7.5	18.3	FALSE
CO-3266	MH-3308	MH-3309	87.9	0.159	200	PVC	0.12	0.7	6.4	FALSE
CO-3596	MH-3605	MH-3606	49.8	0.161	1,000.00	PVC	0.84	13	24.3	FALSE
CO-2028	MH-1739	MH-5089	43.5	0.161	200	PVC	0.12	0.7	5.9	FALSE
CO-4522	MH-4505	MH-4506	123	0.163	600	Asbestos Cement	0.54	8.9	20.1	FALSE
CO-3662	MH-3671	MH-3672	55.1	0.163	1,000.00	Glass	1.01	13.3	24.6	FALSE
CO-1413	MH-1224	MH-2665	618.1	0.163	200	PVC	0.18	2.5	13.7	FALSE
CO-453	MH-303	MH-304	42.8	0.163	251	PVC	0.57	33.3	39.8	FALSE
CO-3262	MH-3304	MH-3322	122.3	0.164	700	Asbestos Cement	1.1	105.9	79.9	FALSE
CO-5732	MH-5713	MH-5714	303.8	0.165	200	PVC	0.3	15.2	26	FALSE
CO-4449	MH-4434	MH-4435	121	0.165	700	Asbestos Cement	1.11	91.5	75.2	FALSE
CO-1348	MH-1177	MH-1970	84.6	0.165	200	PVC	0.17	1.9	18.9	FALSE
CO-257	MH-161	MH-162	48.2	0.166	301	PVC	0.24	1.1	9.1	FALSE
CO-27	MH-13	MH-14	120.4	0.166	600	Asbestos Cement	0.94	33	39.5	FALSE
CO-3634	MH-3643	MH-3644	54.2	0.166	1,000.00	Glass	0.96	10.6	22	FALSE
CO-1193	MH-980	MH-1070	95.6	0.167	200	PVC	0.13	0.8	12.6	FALSE
CO-5543	MH-5517	MH-3379	52.7	0.171	301	PVC	0.62	75.9	65.2	FALSE
CO-2693	MH-2470	MH-2471	110	0.173	200	PVC	0.12	0.6	5.5	FALSE
CO-4370	MH-4358	MH-4359	115.7	0.173	700	Asbestos	1.14	102.8	78.9	FALSE

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CO-4556	MH-4538	MH-4539	52	0.173	600	Asbestos Cement	0.95	62.1	57	FALSE
CO-4292	MH-4282	MH-4285	40.4	0.173	1,400.00	Glass	1.55	24.5	33.7	FALSE
CO-2223	MH-1914	MH-1350	62.9	0.175	200	PVC	0.26	7.5	18.5	FALSE
CO-318	MH-203	MH-195	114.1	0.175	301	PVC	0.71	40.2	45.5	FALSE
CO-3245	MH-3284	MH-3285	51.3	0.176	200	PVC	0.21	3.6	12.9	FALSE
CO-2067	MH-1771	MH-1960	28.4	0.176	200	PVC	0.1	0.3	7	FALSE
CO-1879	MH-1605	MH-1699	51	0.176	200	PVC	0.11	0.5	5.4	FALSE
CO-4365	MH-4353	MH-4354	113	0.177	700	Asbestos Cement	1.15	101.9	78.7	FALSE
CO-1611	MH-1388	MH-2146	78.6	0.178	200	PVC	0.21	4	13.6	FALSE
CO-3697	MH-3706	MH-3707	16.7	0.179	1,000.00	Glass	1.01	11.1	22.5	FALSE
CO-4248	MH-4238	MH-4239	55.5	0.18	1,400.00	Glass	1.58	24.2	33.5	FALSE
CO-3142	MH-3170	MH-3167	204.6	0.181	200	PVC	0.14	1	18	FALSE
CO-187	MH-110	MH-111	259.7	0.181	400	PVC	0.45	4	14	FALSE
CO-3833	MH-3839	MH-3374	77.2	0.181	600	Glass	0.68	16.1	27.1	FALSE
CO-358	MH-234	MH-2863	226	0.181	251	PVC	0.34	10.8	22.2	FALSE
CO-3223	MH-3266	MH-4722	44.1	0.181	200	PVC	0.11	0.4	4.8	FALSE
CO-3218	MH-3261	MH-4350	110.1	0.182	800	Asbestos Cement	1.22	70.7	64.2	FALSE
CO-4234	MH-4225	MH-4226	76.9	0.182	1,500.00	Glass	1.67	24.4	33.6	FALSE
CO-2170	MH-1864	MH-1865	60.4	0.182	200	PVC	0.17	1.7	12.8	FALSE
CO-4212	MH-4203	MH-4204	54.8	0.182	1,500.00	Glass	1.67	24.5	33.7	FALSE
CO-3686	MH-3695	MH-3696	86.1	0.186	1,000.00	Glass	1.05	12.2	23.6	FALSE
CO-1373	MH-1197	MH-1617	53.7	0.186	200	PVC	0.31	13.3	35.6	FALSE
CO-270	MH-174	MH-4913	106.8	0.187	301	PVC	0.74	41.6	45	FALSE

CO-5767	MH-5750	MH-5751	53.3	0.187	200	PVC	0.25	6.4	17	FALSE
CO-3682	MH-3691	MH-3692	31.8	0.188	1,000.00	Glass	1.06	12.1	23.5	FALSE
CO-3684	MH-3693	MH-3694	26.5	0.189	1,000.00	Glass	1.06	12.1	23.5	FALSE
CO-624	MH-427	MH-1919	63.2	0.19	200	PVC	0.18	2.1	15.3	FALSE
CO-3555	MH-3564	MH-3565	110.4	0.19	1,000.00	Glass	1.02	10.4	21.8	FALSE
CO-3479	MH-3491	MH-3492	105	0.19	300	PVC	0.47	20.1	30.4	FALSE
CO-258	MH-162	MH-144	110.3	0.19	301	PVC	0.33	2.5	11.1	FALSE
CO-4012	MH-4008	MH-4009	88.8	0.191	1,000.00	Glass	1.01	17.6	28.4	FALSE
CO-3168	MH-3210	MH-4884	291.8	0.192	304.8	PVC	0.34	6.6	17.4	FALSE
CO-4509	MH-4492	MH-4493	78	0.192	600	Asbestos Cement	0.63	11.1	22.5	FALSE
CO-3683	MH-3692	MH-3693	36.4	0.192	1,000.00	Glass	1.07	12	23.4	FALSE
CO-3169	MH-3211	MH-463	101.6	0.197	251	PVC	0.56	58.6	55.7	FALSE
CO-2276	MH-1973	MH-1945	65.9	0.197	200	PVC	0.3	10	21.3	FALSE
CO-4552	MH-4534	MH-4535	50.7	0.197	600	Asbestos Cement	1	57.7	68.3	FALSE
CO-3685	MH-3694	MH-3695	50.5	0.198	1,000.00	Glass	1.08	11.8	23.4	FALSE
CO-3377	MH-3405	MH-3404	99.5	0.201	300	PVC	0.62	51.6	51	FALSE
CO-335	MH-216	MH-3046	271.9	0.202	200	PVC	0.27	7.3	31.4	FALSE
CO-1077	MH-834	MH-835	54.1	0.203	200	PVC	0.35	16.1	27.1	FALSE
CO-5545	MH-5519	MH-3339	19.6	0.204	200	PVC	0.16	1.1	7.4	FALSE
CO-4457	MH-4441	MH-4442	63.6	0.205	700	Asbestos Cement	1.21	80.6	68.1	FALSE
CO-4510	MH-4493	MH-4494	97.7	0.205	600	Asbestos Cement	0.64	10.8	22.3	FALSE
CO-5126	MH-5103	MH-402	97.5	0.205	251	PVC	0.69	43.1	47.9	FALSE
CO-5097	MH-5075	MH-2505	106.2	0.207	200	PVC	0.19	2	9.7	FALSE

CO-3450	MH-3462	MH-106	187.9	0.208	500	PVC	1.17	56.1	53.6	FALSE
CO-4011	MH-4007	MH-4008	76.4	0.209	1,000.00	Glass	1.04	16.9	27.8	FALSE
CO-4312	MH-4302	MH-4303	23.9	0.21	1,400.00	Glass	1.08	5	15.3	FALSE
CO-3687	MH-3696	MH-3697	94.9	0.211	1,000.00	Glass	1.1	11.4	23.2	FALSE
CO-3688	MH-3697	MH-3698	85.2	0.211	1,000.00	Glass	1.1	11.4	22.8	FALSE
CO-4936	MH-4916	MH-4915	141.7	0.212	301	PVC	0.87	64.8	58.6	FALSE
CO-2360	MH-2057	MH-2052	150.5	0.213	200	PVC	0.22	3.5	14.2	FALSE
CO-4217	MH-4208	MH-4209	79.2	0.215	1,500.00	Glass	1.77	22.5	35.9	FALSE
CO-4704	MH-4684	MH-4685	46.4	0.215	300	PVC	0.27	2.5	10.9	FALSE
CO-2524	MH-2253	MH-2254	88	0.216	200	PVC	0.19	1.8	10.2	FALSE
CO-3337	MH-3379	MH-1301	13.8	0.218	300	PVC	0.4	9.3	60.4	FALSE
CO-3667	MH-3676	MH-3677	82.3	0.219	1,000.00	Glass	1.12	11.4	22.8	FALSE
CO-2608	MH-2354	MH-38	95.9	0.219	200	PVC	0.12	0.4	15.6	FALSE
CO-4993	MH-4973	MH-4972	91.3	0.219	200	PVC	0.47	42.7	45.6	FALSE
CO-4486	MH-4469	MH-4470	91.1	0.22	600	Asbestos Cement	0.67	10.9	22.3	FALSE
CO-4614	MH-4595	MH-4596	49.9	0.221	600	PVC	0.11	0	1.3	FALSE
CO-3635	MH-3644	MH-3645	27.2	0.221	1,000.00	Glass	1.06	9.2	21.2	FALSE
CO-5479	MH-5453	MH-1111	45.1	0.222	200	PVC	0.29	7.9	19.5	FALSE
CO-1021	MH-778	MH-779	49.6	0.222	200	PVC	0.29	7.3	18.3	FALSE
CO-1191	MH-979	MH-980	85.6	0.222	200	PVC	0.29	7.7	18.8	FALSE
CO-1790	MH-1524	MH-1534	45	0.222	200	PVC	0.38	19.5	34.1	FALSE
CO-1882	MH-1609	MH-2384	98.6	0.223	200	PVC	0.17	1.3	8	FALSE
CO-2218	MH-1907	MH-1908	62.5	0.224	200	PVC	0.34	13.2	24.5	FALSE
CO-3672	MH-3681	MH-3682	40.2	0.224	1,000.00	Glass	1.13	11.2	22.6	FALSE
CO-4743	MH-4723	MH-4724	35.5	0.226	200	PVC	0.16	1	7.1	FALSE
CO-4548	MH-4530	MH-4531	66.5	0.226	600	Asbestos	1.1	64.3	58.4	FALSE

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CO-1646	MH-1413	MH-1558	44.1	0.227	200	PVC	0.14	0.7	6	FALSE
CO-1430	MH-1238	MH-1557	44	0.228	200	PVC	0.32	10.5	21.8	FALSE
CO-2535	MH-2268	MH-2269	109.6	0.228	200	PVC	0.13	0.6	5.8	FALSE
CO-2271	MH-1966	MH-1967	65.6	0.229	200	PVC	0.15	0.9	7.5	FALSE
CO-3587	MH-3596	MH-3597	56.7	0.229	1,000.00	PVC	0.96	10.9	22.3	FALSE
CO-3572	MH-3581	MH-3582	34.8	0.23	1,000.00	PVC	0.96	11.1	22.4	FALSE
CO-3668	MH-3677	MH-3678	69.4	0.231	1,000.00	Glass	1.14	11.1	22.7	FALSE
CO-4395	MH-4382	MH-4381	86.4	0.231	900	Asbestos Cement	1.34	45.5	47.3	FALSE
CO-4363	MH-4351	MH-4352	116.6	0.231	700	Asbestos Cement	1.31	89.2	73.6	FALSE
CO-1381	MH-1202	MH-2550	125.2	0.232	200	PVC	0.21	2.4	10.6	FALSE
CO-3225	MH-3268	MH-4356	129.2	0.232	900	Asbestos Cement	1.34	45.4	52.5	FALSE
CO-4468	MH-4451	MH-4452	85.4	0.234	700	Asbestos Cement	1.28	74.8	64.5	FALSE
CO-5362	MH-5338	MH-5453	51.1	0.235	200	PVC	0.31	8.9	20.1	FALSE
CO-234	MH-144	MH-94	34	0.235	301	PVC	0.37	2.7	11.3	FALSE
CO-4446	MH-4431	MH-4430	85	0.235	700	Asbestos Cement	1.29	77.4	66.1	FALSE
CO-4315	MH-4305	MH-4306	29.7	0.236	1,400.00	Glass	1.12	4.7	14.8	FALSE
CO-3673	MH-3682	MH-3683	29.6	0.236	1,000.00	Glass	1.15	10.9	22.4	FALSE
CO-3607	MH-3616	MH-3617	8.5	0.237	1,000.00	PVC	0.97	10.6	22	FALSE
CO-3464	MH-3476	MH-3475	252.9	0.237	600	Asbestos Cement	1.05	48.7	52.9	FALSE
CO-4299	MH-4289	MH-4337	58.9	0.238	1,400.00	Glass	1.74	20.9	31	FALSE
CO-3645	MH-3654	MH-3655	33.5	0.239	1,000.00	Glass	1.08	8.8	20	FALSE

CO-2479	MH-2194	MH-2703	58.3	0.24	200	PVC	0.33	10.1	21.4	FALSE
CO-4298	MH-4288	MH-4289	37.5	0.24	1,400.00	Glass	1.75	20.8	30.9	FALSE
CO-1505	MH-1298	MH-1299	29.1	0.241	200	PVC	0.16	0.9	6.9	FALSE
CO-4328	MH-4318	MH-4319	24.9	0.241	1,300.00	Glass	1.14	5.7	16.2	FALSE
CO-4357	MH-4346	MH-1502	41.5	0.241	200	PVC	0.2	1.9	12.9	FALSE
CO-3609	MH-3618	MH-3619	33.2	0.241	1,000.00	PVC	0.97	10.5	21.9	FALSE
CO-3669	MH-3678	MH-3679	91	0.242	1,000.00	Glass	1.16	10.8	22.4	FALSE
CO-3424	MH-3437	MH-2781	82.3	0.243	251	PVC	0.26	2.7	11.2	FALSE
CO-4240	MH-4231	MH-4232	45.2	0.244	1,500.00	Glass	1.85	21.2	31.2	FALSE
CO-2338	MH-2038	MH-231	69.6	0.244	200	PVC	0.13	0.5	5.9	FALSE
CO-465	MH-310	MH-2955	204.1	0.245	200	PVC	0.17	1.1	7.8	FALSE
CO-69	MH-43	MH-2851	175.1	0.246	500	PVC	0.87	13.7	25	FALSE
CO-3661	MH-3670	MH-3671	52.8	0.246	1,000.00	Glass	1.17	10.8	22.2	FALSE
CO-144	MH-85	MH-2181	81.3	0.246	200	PVC	0.14	0.5	61.3	TRUE
CO-2322	MH-2022	MH-2023	68.9	0.247	200	PVC	0.15	0.8	12.7	FALSE
CO-3614	MH-3623	MH-3624	68.8	0.247	1,000.00	PVC	0.98	10.4	21.8	FALSE
CO-4273	MH-4263	MH-4264	8.1	0.247	1,400.00	Glass	1.77	20.6	30.8	FALSE
CO-3727	MH-3736	MH-3737	40.5	0.247	1,000.00	Glass	1.12	9.2	20.5	FALSE
CO-4093	MH-4085	MH-4343	80.8	0.247	600	Glass	0.66	8.8	20	FALSE
CO-3040	MH-2986	MH-2987	221.6	0.248	200	PVC	0.22	2.5	15.1	FALSE
CO-3656	MH-3665	MH-3666	28.1	0.249	1,000.00	Glass	1.18	10.8	22.2	FALSE
CO-944	MH-713	MH-954	76.3	0.249	200	PVC	0.24	3.4	20.7	FALSE
CO-193	MH-114	MH-92	361.1	0.249	400	PVC	0.75	13.2	24.5	FALSE
CO-2456	MH-2166	MH-2167	80.2	0.249	200	PVC	0.23	2.8	11.5	FALSE
CO-5510	MH-5484	MH-5483	80.2	0.249	400	PVC	0.78	38.9	43.3	FALSE
CO-3671	MH-3680	MH-3681	103.6	0.251	1,000.00	Glass	1.18	10.6	22	FALSE

CO-4220	MH-4211	MH-4212	51.8	0.251	1,500.00	Glass	1.87	20.8	31	FALSE
CO-3714	MH-3723	MH-3724	71.3	0.253	1,000.00	Glass	1.13	9.2	20.5	FALSE
CO-3585	MH-3594	MH-3595	43.5	0.253	1,000.00	PVC	0.99	10.4	21.8	FALSE
CO-4386	MH-4374	MH-4375	78.7	0.254	700	Asbestos Cement	1.36	84.1	70.2	FALSE
CO-4302	MH-4292	MH-4294	55	0.255	1,400.00	Glass	1.16	4.6	14.6	FALSE
CO-3701	MH-3710	MH-3711	58.7	0.256	1,000.00	Glass	1.14	9.3	20.6	FALSE
CO-5583	MH-5557	MH-51	50.7	0.256	400	PVC	0.24	22.1	100	TRUE
CO-4808	MH-4788	MH-2817	54.5	0.257	200	PVC	0.11	0.3	4.1	FALSE
CO-3229	MH-3271	MH-4690	77.7	0.257	300	PVC	0.41	7.9	19.1	FALSE
CO-4345	MH-4335	MH-3727	58.1	0.258	1,000.00	Glass	1.14	9.1	20.4	FALSE
CO-2209	MH-1899	MH-1372	61.9	0.258	200	PVC	0.14	0.5	5.3	FALSE
CO-4375	MH-4363	MH-4364	77.2	0.259	700	Asbestos Cement	1.37	83.6	69.9	FALSE
CO-2432	MH-2140	MH-1682	92.2	0.26	200	PVC	0.29	5.7	16.3	FALSE
CO-3713	MH-3722	MH-3723	34.5	0.261	1,000.00	Glass	1.15	9.1	20.4	FALSE
CO-4306	MH-4296	MH-4297	61.2	0.261	1,400.00	Glass	1.17	4.5	14.5	FALSE
CO-3665	MH-3674	MH-3675	53.5	0.262	1,000.00	Glass	1.2	10.5	21.8	FALSE
CO-4321	MH-4311	MH-4312	45.8	0.262	1,300.00	Glass	1.18	5.5	15.9	FALSE
CO-2724	MH-2510	MH-2030	114.4	0.262	200	PVC	0.2	1.6	8.9	FALSE
CO-2403	MH-2098	MH-2541	122.1	0.262	200	PVC	0.15	0.7	8.9	FALSE
CO-3651	MH-3660	MH-4202	53.3	0.263	1,000.00	Glass	1.12	8.3	19.5	FALSE
CO-3478	MH-3490	MH-3491	76.1	0.263	300	PVC	0.52	16.8	29.1	FALSE
CO-3681	MH-3690	MH-3691	11.4	0.263	1,000.00	Glass	1.19	10.3	21.6	FALSE
CO-648	MH-463	MH-3103	76	0.263	200	PVC	0.52	44.5	57.9	FALSE
CO-3709	MH-3718	MH-3719	45.6	0.263	1,000.00	Glass	1.15	9.1	20.4	FALSE
CO-4507	MH-4490	MH-4491	114	0.263	600	Asbestos	0.7	9.5	20.8	FALSE

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CO-2870	MH-2719	MH-3091	91.2	0.263	200	PVC	0.16	0.9	12.4	FALSE
CO-4323	MH-4313	MH-4314	64.5	0.263	1,300.00	Glass	1.18	5.4	15.9	FALSE
CO-5440	MH-5414	MH-3442	79.5	0.264	300	PVC	0.74	61.4	56.6	FALSE
CO-2655	MH-2418	MH-1418	102.1	0.264	200	PVC	0.14	0.5	6.6	FALSE
CO-3728	MH-3737	MH-3738	68.1	0.264	1,000.00	Glass	1.15	8.9	20.4	FALSE
CO-1996	MH-1713	MH-5626	45.2	0.266	200	PVC	0.13	0.4	6.5	FALSE
CO-4720	MH-4700	MH-4698	48.9	0.266	200	PVC	0.15	0.7	12.3	FALSE
CO-3664	MH-3673	MH-3674	90	0.267	1,000.00	Glass	1.2	10.4	21.7	FALSE
CO-4238	MH-4229	MH-4230	63.6	0.267	1,500.00	Glass	1.91	20.2	30.5	FALSE
CO-5033	MH-5013	MH-61	63.4	0.268	600	PVC	1.27	91	74.9	FALSE
CO-3711	MH-3720	MH-3721	70.9	0.268	1,000.00	Glass	1.16	9	20.3	FALSE
CO-3731	MH-3740	MH-3741	41	0.268	1,000.00	Glass	1.15	8.8	20.1	FALSE
CO-4221	MH-4212	MH-4214	74.5	0.269	1,500.00	Glass	1.92	20.1	30.7	FALSE
CO-3674	MH-3683	MH-3684	67	0.269	1,000.00	Glass	1.2	10.2	21.9	FALSE
CO-1993	MH-1711	MH-1712	51.9	0.27	200	PVC	0.12	0.3	13.7	FALSE
CO-5137	MH-5114	MH-2171	174	0.27	200	PVC	0.52	41.8	45.1	FALSE
CO-3666	MH-3675	MH-3676	55.5	0.27	1,000.00	Glass	1.21	10.3	21.7	FALSE
CO-3566	MH-3575	MH-3576	55.4	0.271	1,000.00	Glass	1.15	8.7	19.9	FALSE
CO-3642	MH-3651	MH-3652	18.4	0.271	1,000.00	Glass	1.14	8.3	19.4	FALSE
CO-277	MH-178	MH-1222	18.4	0.271	200	PVC	0.11	0.2	3.7	FALSE
CO-4539	MH-4522	MH-4523	73.6	0.272	600	Asbestos Cement	0.46	2.3	10.4	FALSE
CO-2013	MH-1727	MH-2178	80.8	0.272	200	PVC	0.22	2.1	14.4	FALSE
CO-720	MH-520	MH-521	18.4	0.272	200	PVC	0.16	0.8	6.5	FALSE
CO-307	MH-197	MH-220	146.8	0.273	301	PVC	1	68.8	61	FALSE
CO-3655	MH-3664	MH-3665	69.7	0.273	1,000.00	Glass	1.22	10.3	21.7	FALSE

CO-3565	MH-3574	MH-3575	55	0.273	1,000.00	Glass	1.15	8.6	19.9	FALSE
CO-2536	MH-2268	MH-2297	91.3	0.274	200	PVC	0.13	0.4	5.3	FALSE
CO-3716	MH-3725	MH-3726	62	0.274	1,000.00	Glass	1.17	8.9	20.1	FALSE
CO-3612	MH-3621	MH-3622	91.1	0.275	1,000.00	PVC	1.02	9.9	21.2	FALSE
CO-4274	MH-4264	MH-4265	32.7	0.275	1,400.00	Glass	1.84	19.5	30.3	FALSE
CO-5724	MH-5703	MH-5704	360.9	0.277	200	PVC	0.25	3.2	14.9	FALSE
CO-203	MH-120	MH-4505	108.2	0.277	600	Asbestos Cement	0.65	6.8	17.7	FALSE
CO-3718	MH-3727	MH-3728	28.8	0.278	1,000.00	Glass	1.17	8.8	20.2	FALSE
CO-3660	MH-3669	MH-3670	32.3	0.279	1,000.00	Glass	1.22	10.2	21.5	FALSE
CO-3551	MH-3560	MH-3561	50.1	0.279	1,000.00	Glass	1.17	8.6	19.9	FALSE
CO-3698	MH-3707	MH-3708	35.8	0.279	1,000.00	Glass	1.18	8.9	21.3	FALSE
CO-227	MH-139	MH-4530	89.3	0.28	600	Asbestos Cement	1.19	57.8	54.6	FALSE
CO-3646	MH-3655	MH-3657	7.1	0.28	1,000.00	Glass	1.15	8.1	19.6	FALSE
CO-3650	MH-3659	MH-3660	42.8	0.28	1,000.00	Glass	1.15	8.1	19.2	FALSE
CO-2150	MH-1842	MH-1869	60.6	0.281	200	PVC	0.18	1.2	16.2	FALSE
CO-3562	MH-3571	MH-3572	92.6	0.281	1,000.00	Glass	1.17	8.5	19.7	FALSE
CO-4531	MH-4515	MH-4516	71.2	0.281	600	Asbestos Cement	0.54	3.4	12.6	FALSE
CO-3699	MH-3708	MH-3709	42.7	0.281	1,000.00	Glass	1.18	8.9	20.1	FALSE
CO-207	MH-122	MH-3267	326.1	0.282	200	PVC	0.83	149	92.4	TRUE
CO-3568	MH-3577	MH-3578	63.8	0.282	1,000.00	Glass	1.17	8.5	19.7	FALSE
CO-2450	MH-2157	MH-2182	81.3	0.283	200	PVC	0.58	57.9	54.6	FALSE
CO-2358	MH-2056	MH-2057	70.7	0.283	200	PVC	0.3	5.4	29.7	FALSE
CO-599	MH-410	MH-3211	282.4	0.283	251	PVC	0.68	61	56.4	FALSE
CO-2900	MH-2760	MH-2597	151.8	0.283	200	PVC	0.17	0.8	7.8	FALSE

CO-4385	MH-4373	MH-4372	70.6	0.283	700	Asbestos Cement	1.42	79.7	67.5	FALSE
CO-4726	MH-4706	MH-4712	56.4	0.284	200	PVC	0.48	29.4	37.1	FALSE
CO-2108	MH-1806	MH-2351	105.5	0.284	200	PVC	0.25	3.1	12.1	FALSE
CO-1860	MH-1589	MH-1590	45.7	0.285	200	PVC	0.12	0.2	4.7	FALSE
CO-2095	MH-1797	MH-1346	77.2	0.285	200	PVC	0.22	1.9	9.6	FALSE
CO-4487	MH-4470	MH-4471	70.1	0.285	600	Asbestos Cement	0.73	9.5	21.6	FALSE
CO-2830	MH-2660	MH-1479	70	0.286	200	PVC	0.5	32.4	39.1	FALSE
CO-5658	MH-5632	MH-5631	112	0.286	200	PVC	0.38	12.7	24.1	FALSE
CO-3759	MH-3767	MH-3766	70	0.286	1,600.00	Glass	1.69	10	21.4	FALSE
CO-4289	MH-4279	MH-4280	55.9	0.286	1,400.00	Glass	1.86	19.1	29.6	FALSE
CO-3618	MH-3627	MH-3628	41.9	0.286	1,000.00	PVC	1.03	9.6	21	FALSE
CO-5805	MH-5792	MH-5793	34.8	0.288	200	PVC	0.51	36.8	41.4	FALSE
CO-4247	MH-4237	MH-4238	62.4	0.288	1,400.00	Glass	1.87	19.1	29.6	FALSE
CO-481	MH-320	MH-1320	31.1	0.289	200	PVC	0.1	0.2	3.1	FALSE
CO-1779	MH-1516	MH-5106	72.7	0.289	200	PVC	0.3	5.4	15.8	FALSE
CO-280	MH-180	MH-3380	162.3	0.29	301	PVC	0.45	3.6	13	FALSE
CO-4712	MH-4692	MH-4693	34.5	0.29	300	PVC	0.44	8.2	19.3	FALSE
CO-255	MH-159	MH-160	44.9	0.29	301	PVC	0.27	0.7	6.9	FALSE
CO-3751	MH-3759	MH-3760	72.5	0.29	1,600.00	Glass	1.7	10	21.4	FALSE
CO-3729	MH-3738	MH-3739	31	0.29	1,000.00	Glass	1.19	8.5	19.9	FALSE
CO-143	MH-85	MH-81	68.9	0.29	500	PVC	1.35	51	50.6	FALSE
CO-4514	MH-4497	MH-4498	68.9	0.29	600	Asbestos Cement	0.7	7.9	19.1	FALSE
CO-138	MH-82	MH-2151	79.1	0.291	200	PVC	0.15	0.6	41.8	FALSE
CO-4445	MH-4430	MH-4432	68.7	0.291	700	Asbestos	1.4	69.6	63.7	FALSE

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CO-1474	MH-1270	MH-1285	34.3	0.291	200	PVC	0.23	2.3	12.5	FALSE
CO-4256	MH-4246	MH-4247	65.1	0.292	1,400.00	Glass	1.88	18.9	29.5	FALSE
CO-3480	MH-3492	MH-3493	68.5	0.292	300	PVC	0.54	16.3	27.3	FALSE
CO-4450	MH-4435	MH-4436	68.5	0.292	700	Asbestos Cement	1.4	68.8	68.1	FALSE
CO-3641	MH-3650	MH-3651	23.9	0.292	1,000.00	Glass	1.17	7.9	19.1	FALSE
CO-3809	MH-3816	MH-3817	54.5	0.293	1,500.00	Glass	1.68	11	22.3	FALSE
CO-3648	MH-3657	MH-3658	75	0.293	1,000.00	Glass	1.17	7.9	19.1	FALSE
CO-3692	MH-3701	MH-3702	71.4	0.294	1,000.00	Glass	1.21	9	20.3	FALSE
CO-3619	MH-3628	MH-3629	74.8	0.294	1,000.00	Glass	1.17	8	20.1	FALSE
CO-2532	MH-2262	MH-2263	88.4	0.294	200	PVC	0.14	0.4	4.5	FALSE
CO-3112	MH-3111	MH-3353	54.4	0.294	200	PVC	0.28	4.5	14.4	FALSE
CO-80	MH-49	MH-45	78.1	0.294	400	PVC	0.31	26.4	100	TRUE
CO-4296	MH-4286	MH-4287	61	0.295	1,400.00	Glass	1.88	18.8	29.3	FALSE
CO-4716	MH-4696	MH-4697	50.7	0.296	300	PVC	0.46	8.8	20.1	FALSE
CO-4989	MH-4969	MH-2147	37.2	0.296	200	PVC	0.48	26.1	34.9	FALSE
CO-4318	MH-4308	MH-4309	57.4	0.296	1,300.00	Glass	1.23	5.1	15.4	FALSE
CO-2930	MH-2799	MH-1614	158.6	0.296	200	PVC	0.15	0.5	13.6	FALSE
CO-2429	MH-2136	MH-2251	33.8	0.296	200	PVC	0.15	0.6	6.3	FALSE
CO-3620	MH-3629	MH-3630	117.9	0.297	1,000.00	Glass	1.18	8	19.2	FALSE
CO-4226	MH-4217	MH-4218	47.1	0.297	1,500.00	Glass	1.99	19.1	29.6	FALSE
CO-3580	MH-3589	MH-3591	43.7	0.297	1,000.00	PVC	1.05	9.7	21	FALSE
CO-3722	MH-3731	MH-3446	97.5	0.297	1,000.00	Glass	1.2	8.4	19.6	FALSE
CO-2120	MH-1813	MH-3560	60.5	0.298	1,000.00	Glass	1.19	8.4	19.6	FALSE
CO-4388	MH-4376	MH-4377	67.1	0.298	700	Asbestos Cement	1.45	77.7	66.2	FALSE

CO-3758	MH-3766	MH-3768	36.9	0.298	1,600.00	Glass	1.71	9.8	21.3	FALSE
CO-3583	MH-3592	MH-3593	50.1	0.299	1,000.00	PVC	1.06	9.6	20.9	FALSE
CO-3695	MH-3704	MH-3705	106.9	0.299	1,000.00	Glass	1.21	8.6	19.8	FALSE
CO-1556	MH-1344	MH-2116	76.7	0.3	200	PVC	0.15	0.6	5.5	FALSE
CO-4223	MH-4214	MH-4215	43.3	0.3	1,500.00	Glass	1.99	19	30	FALSE
CO-5681	MH-5654	MH-5703	359.6	0.3	200	PVC	0.33	7	34.6	FALSE
CO-3376	MH-3404	MH-3403	99.8	0.3	300	PVC	0.71	41.4	47.9	FALSE
CO-4305	MH-4295	MH-4296	43.3	0.3	1,400.00	Glass	1.23	4.2	14	FALSE
CO-3724	MH-3733	MH-3734	23.3	0.3	1,000.00	Glass	1.2	8.4	19.6	FALSE
CO-3696	MH-3705	MH-3706	26.5	0.302	1,000.00	Glass	1.21	8.6	19.8	FALSE
CO-4272	MH-4262	MH-4263	79.4	0.302	1,400.00	Glass	1.9	18.6	29.2	FALSE
CO-3570	MH-3579	MH-3580	76	0.303	1,000.00	Glass	1.2	8.2	19.3	FALSE
CO-4213	MH-4204	MH-4205	79.2	0.303	1,500.00	Glass	2	19	31.6	FALSE
CO-4224	MH-4215	MH-4216	62.6	0.303	1,500.00	Glass	2	18.9	29.5	FALSE
CO-4320	MH-4310	MH-4311	26.4	0.304	1,300.00	Glass	1.24	5.1	15.3	FALSE
CO-25	MH-12	MH-5842	65.8	0.304	200	PVC	0.31	5.7	52.3	FALSE
CO-3574	MH-3583	MH-3584	52.6	0.304	1,000.00	PVC	1.06	9.6	20.9	FALSE
CO-3643	MH-3652	MH-3653	82.1	0.305	1,000.00	Glass	1.18	7.8	19.1	FALSE
CO-3560	MH-3569	MH-3571	52.5	0.305	1,000.00	Glass	1.2	8.2	19.4	FALSE
CO-4308	MH-4298	MH-4299	42.6	0.305	1,400.00	Glass	1.23	4.2	13.9	FALSE
CO-2192	MH-1884	MH-2378	98.2	0.306	200	PVC	0.17	0.8	6.8	FALSE
CO-4297	MH-4287	MH-4288	22.8	0.307	1,400.00	Glass	1.91	18.4	29.2	FALSE
CO-4228	MH-4219	MH-4220	48.9	0.307	1,500.00	Glass	2.01	18.8	29.4	FALSE
CO-3601	MH-3610	MH-3611	9.8	0.307	1,000.00	PVC	1.06	9.4	20.7	FALSE
CO-2370	MH-2067	MH-2068	71.7	0.307	200	PVC	0.49	26.2	38.7	FALSE
CO-4369	MH-4357	MH-4358	65.1	0.307	700	Asbestos Cement	1.47	77.1	65.9	FALSE

CO-3640	MH-3649	MH-3650	26	0.308	1,000.00	Glass	1.19	7.7	18.8	FALSE
CO-4309	MH-4299	MH-4300	55.2	0.308	1,400.00	Glass	1.24	4.2	13.9	FALSE
CO-105	MH-63	MH-64	74.6	0.308	500	PVC	1.56	85	71.7	FALSE
CO-4316	MH-4306	MH-4307	38.9	0.309	1,400.00	Glass	1.24	4.1	14.4	FALSE
CO-4324	MH-4314	MH-4316	58.3	0.309	1,300.00	Glass	1.25	5	15.6	FALSE
CO-3904	MH-3909	MH-3910	38.8	0.309	600	Glass	0.85	13.7	25	FALSE
CO-3730	MH-3739	MH-3740	113.2	0.309	1,000.00	Glass	1.21	8.2	19.6	FALSE
CO-3694	MH-3703	MH-3704	42	0.309	1,000.00	Glass	1.22	8.5	19.7	FALSE
CO-4960	MH-4940	MH-1341	48.3	0.31	200	PVC	0.34	7.3	18.3	FALSE
CO-5474	MH-5448	MH-3471	48.7	0.31	600	PVC	1.17	43.3	46	FALSE
CO-1465	MH-1263	MH-1209	64.4	0.311	200	PVC	0.14	0.4	5.2	FALSE
CO-3909	MH-3914	MH-3915	70.8	0.311	600	Glass	0.82	12.1	23.5	FALSE
CO-306	MH-196	MH-2056	128.7	0.311	200	PVC	0.55	39.4	46.9	FALSE
CO-5401	MH-5375	MH-376	51.5	0.311	251	PVC	0.51	7	17.9	FALSE
CO-5394	MH-5368	MH-2157	35.4	0.311	200	PVC	0.6	56.9	54	FALSE
CO-5336	MH-5312	MH-63	77.1	0.311	600	PVC	1.3	68.2	60.6	FALSE
CO-5578	MH-5552	MH-2477	89.8	0.312	200	PVC	0.17	0.8	6.3	FALSE
CO-3693	MH-3702	MH-3703	38.3	0.313	1,000.00	Glass	1.23	8.4	20	FALSE
CO-3552	MH-3561	MH-3562	22.4	0.313	1,000.00	Glass	1.22	8.2	19.6	FALSE
CO-4330	MH-4320	MH-4321	57.4	0.314	1,300.00	Glass	1.25	5	15.2	FALSE
CO-3712	MH-3721	MH-3722	60.5	0.314	1,000.00	Glass	1.22	8.3	19.9	FALSE
CO-2491	MH-2217	MH-1642	120.9	0.314	200	PVC	0.2	1.3	7.9	FALSE
CO-4311	MH-4301	MH-4302	25.4	0.315	1,400.00	Glass	1.25	4.1	13.8	FALSE
CO-3355	MH-3390	MH-3490	63.5	0.315	300	PVC	0.55	15.2	27	FALSE
CO-4290	MH-4280	MH-4283	50.7	0.315	1,400.00	Glass	1.93	18.2	29.2	FALSE
CO-4790	MH-4770	MH-4769	44.4	0.315	200	PVC	0.14	0.4	4.7	FALSE

CO-3419	MH-3432	MH-4566	348.6	0.316	600	PVC	1.38	90.2	74.3	FALSE
CO-3613	MH-3622	MH-3623	19	0.316	1,000.00	PVC	1.07	9.2	20.9	FALSE
CO-4322	MH-4312	MH-4313	41.1	0.316	1,300.00	Glass	1.26	5	15.5	FALSE
CO-3569	MH-3578	MH-3579	69.5	0.316	1,000.00	Glass	1.22	8	19.4	FALSE
CO-4294	MH-4284	MH-4286	85.3	0.316	1,400.00	Glass	1.93	18.1	29.1	FALSE
CO-3616	MH-3625	MH-3627	78.9	0.317	1,000.00	PVC	1.07	9.2	20.5	FALSE
CO-4616	MH-4597	MH-4598	47.2	0.318	600	PVC	0.15	0	1.6	FALSE
CO-425	MH-284	MH-2646	132.1	0.318	200	PVC	0.17	0.8	12	FALSE
CO-4214	MH-4205	MH-4206	59.7	0.318	1,500.00	Glass	2.04	18.5	29.3	FALSE
CO-3700	MH-3709	MH-3710	84.9	0.318	1,000.00	Glass	1.23	8.3	19.8	FALSE
CO-2591	MH-2330	MH-2331	94.3	0.318	200	PVC	0.16	0.6	7.2	FALSE
CO-5134	MH-5111	MH-1981	100.5	0.318	200	PVC	0.55	37.5	42.4	FALSE
CO-4461	MH-4445	MH-4446	125.7	0.318	700	Asbestos Cement	1.44	64.6	58.5	FALSE
CO-374	MH-246	MH-3269	125.4	0.319	301	PVC	0.01	1.2	100	TRUE
CO-5661	MH-5635	MH-5634	47	0.319	200	PVC	0.45	17.8	28.5	FALSE
CO-4538	MH-4521	MH-4522	62.6	0.319	600	Asbestos Cement	0.49	2.1	10	FALSE
CO-3265	MH-3306	MH-4705	50	0.32	200	PVC	0.37	9.3	20.6	FALSE
CO-2828	MH-2658	MH-2358	62.4	0.32	200	PVC	0.25	2.3	18.9	FALSE
CO-4535	MH-4519	MH-4520	62.4	0.321	600	Asbestos Cement	0.56	3.1	12.1	FALSE
CO-1326	MH-1145	MH-5134	249.4	0.321	200	PVC	0.4	12	23.4	FALSE
CO-3649	MH-3658	MH-3659	40.5	0.321	1,000.00	Glass	1.2	7.6	18.8	FALSE
CO-4326	MH-4316	MH-4317	68.2	0.323	1,300.00	Glass	1.27	4.9	15.2	FALSE
CO-3592	MH-3601	MH-3603	43.3	0.323	1,000.00	PVC	1.08	9.2	20.5	FALSE
CO-3749	MH-3757	MH-3758	43.3	0.323	1,600.00	Glass	1.77	9.5	20.8	FALSE

CO-4364	MH-4352	MH-3249	123.7	0.323	700	Asbestos Cement	1.5	75.4	69.2	FALSE
CO-5652	MH-5626	MH-2300	46.4	0.323	200	PVC	0.11	0.1	3.8	FALSE
CO-2420	MH-2123	MH-1641	77.2	0.324	200	PVC	0.18	0.8	7.8	FALSE
CO-5599	MH-5573	MH-2972	80.2	0.324	200	PVC	0.15	0.4	5.1	FALSE
CO-5124	MH-5101	MH-5102	92.5	0.324	251	PVC	0.82	34.6	40.6	FALSE
CO-3557	MH-3566	MH-3567	40.1	0.325	1,000.00	Glass	1.23	8	19.1	FALSE
CO-5503	MH-5477	MH-85	30.8	0.325	500	PVC	1.41	48.3	58.4	FALSE
CO-5705	MH-5679	MH-5680	246.4	0.325	200	PVC	0.32	5.8	16.2	FALSE
CO-4451	MH-4436	MH-4437	61.4	0.326	700	Asbestos Cement	1.46	65.2	59.9	FALSE
CO-84	MH-51	MH-54	153.5	0.326	400	PVC	0.24	19.1	100	TRUE
CO-4307	MH-4297	MH-4298	58.3	0.326	1,400.00	Glass	1.26	4	14.1	FALSE
CO-1559	MH-1346	MH-1347	33.6	0.327	200	PVC	0.17	0.7	7.8	FALSE
CO-4338	MH-4328	MH-4329	48.9	0.328	1,200.00	Glass	1.28	6	16.7	FALSE
CO-3777	MH-3784	MH-3785	64.1	0.328	1,500.00	Glass	1.75	10.4	21.8	FALSE
CO-3417	MH-3430	MH-5313	121.8	0.328	600	PVC	1.33	66.6	59.7	FALSE
CO-3721	MH-3730	MH-3731	66.9	0.329	1,000.00	Glass	1.24	8	19.2	FALSE
CO-3256	MH-3295	MH-3296	69.9	0.329	200	PVC	0.15	0.5	4.9	FALSE
CO-1602	MH-1382	MH-1383	36.3	0.33	200	PVC	0.1	0.1	2.9	FALSE
CO-1588	MH-1370	MH-1926	63.5	0.331	200	PVC	0.24	2.1	14.3	FALSE
CO-2972	MH-2871	MH-3178	374.9	0.331	200	PVC	0.24	2.2	10.3	FALSE
CO-3584	MH-3593	MH-3594	45.3	0.331	1,000.00	PVC	1.09	9.1	20.7	FALSE
CO-29	MH-14	MH-17	150.7	0.332	600	Asbestos Cement	1.21	23.7	33.1	FALSE
CO-3691	MH-3700	MH-3701	42.1	0.332	1,000.00	Glass	1.27	8.5	19.7	FALSE
CO-3567	MH-3576	MH-3577	72.1	0.333	1,000.00	Glass	1.24	7.8	19.4	FALSE

CO-4225	MH-4216	MH-4217	105.2	0.333	1,500.00	Glass	2.07	18.1	29.1	FALSE
CO-3582	MH-3591	MH-3592	36	0.333	1,000.00	PVC	1.1	9.1	20.7	FALSE
CO-3717	MH-3726	MH-4335	48.1	0.333	1,000.00	Glass	1.25	8	19.6	FALSE
CO-4887	MH-4867	MH-4868	9	0.334	200	PVC	0.35	7.4	18.5	FALSE
CO-1394	MH-1212	MH-1837	59.9	0.334	200	PVC	0.25	2.4	15.9	FALSE
CO-3258	MH-3299	MH-3300	74.9	0.334	200	PVC	0.12	0.2	4.8	FALSE
CO-3745	MH-3753	MH-3754	47.8	0.335	1,600.00	Glass	1.79	9.3	20.7	FALSE
CO-3564	MH-3573	MH-3574	32.8	0.335	1,000.00	Glass	1.24	7.8	18.9	FALSE
CO-3626	MH-3635	MH-3647	50.7	0.335	1,000.00	Glass	1.31	9.4	20.7	FALSE
CO-602	MH-413	MH-414	148.7	0.336	251	PVC	0.8	29.6	37.3	FALSE
CO-1820	MH-1548	MH-2704	142.6	0.337	200	PVC	0.18	0.9	7.8	FALSE
CO-4319	MH-4309	MH-4310	32.7	0.337	1,300.00	Glass	1.29	4.8	15.2	FALSE
CO-2045	MH-1752	MH-1738	53.3	0.338	200	PVC	0.33	5.9	16.5	FALSE
CO-4997	MH-4977	MH-4973	67.9	0.339	200	PVC	0.55	35	40.8	FALSE
CO-3571	MH-3580	MH-3581	53.1	0.339	1,000.00	Glass	1.24	7.7	19	FALSE
CO-2215	MH-1903	MH-2757	150.4	0.339	200	PVC	0.28	3.2	12.7	FALSE
CO-469	MH-313	MH-2685	147.4	0.339	251	PVC	0.36	4.5	14.5	FALSE
CO-5743	MH-5724	MH-5725	58.9	0.339	200	PVC	0.5	24.3	33.2	FALSE

HYDRAULIC MODELING OF KALITY CATCHMENT SEWER NETWORK -BY GETYE FEKADU. wtg 8/28/2023	Bentley Systems, Inc. Haestad Methods Solution Center 27 Siemon Company Drive S uite 200 W Watertown, CT 06795 USA +1-203-755-1666	SewerGEMS CONNECT Edition [10.02.01.04] Page 1 of 1

The above annex shows the sample pipe report of scenario I, computed in Bentley Sewer GEMS CONNECT Edition Version 10 and the left pipe report (about 5367 pipes or conduits from first scenario), the whole of the second and third scenario are not listed here in order to minimize the page.

Annex 11: SewerGEMS model manhole report of the existing sewer network

Label	Elevation (Rim) (m)	Elevation (Invert) (m)	Hydraulic Grade Line (m)	X (m)	Y (m)	Flow (System Sanitary) (m³/day)
MH-1	2,273.85	2,271.35	2,271.48	467,822.51	993,278.39	15,328.99
MH-2	2,302.00	2,301.40	2,301.46	475,508.79	993,783.68	1,795.91
MH-3	2,279.73	2,276.21	2,276.34	467,655.25	993,356.45	8,603.37
MH-4	2,289.00	2,287.00	2,287.03	473,822.07	992,568.13	224.06
MH-5	2,227.53	2,225.03	2,227.53	468,473.88	989,671.49	3,387.80
MH-6	2,227.27	2,224.77	2,227.27	468,528.83	989,674.25	3,459.86
MH-7	2,297.20	2,296.00	2,296.01	473,994.09	992,699.36	14.28
MH-8	2,297.82	2,295.32	2,295.35	474,033.38	992,738.54	542.87
MH-9	2,226.71	2,224.21	2,226.61	468,588.84	989,677.92	3,579.40
MH-10	2,300.26	2,297.76	2,297.79	474,106.64	992,809.79	510.88
MH-11	2,217.80	2,216.80	2,217.02	470,656.06	991,859.58	21,620.18
MH-12	2,215.79	2,213.80	2,213.98	469,911.63	989,757.01	8,037.82
MH-13	2,215.00	2,213.20	2,213.44	470,028.17	989,728.31	8,064.54
MH-14	2,215.00	2,213.00	2,213.20	470,144.90	989,698.74	8,178.75
MH-15	2,302.68	2,300.18	2,300.19	474,197.76	992,894.51	41.18
MH-16	2,292.65	2,290.15	2,290.16	473,680.65	992,529.16	58.89
MH-17	2,215.00	2,212.50	2,212.69	470,293.42	989,673.02	8,266.19
MH-18	2,224.41	2,221.91	2,224.41	468,768.67	989,688.51	3,638.11
MH-19	2,222.65	2,220.15	2,222.65	468,928.49	989,698.05	3,828.49
MH-20	2,214.22	2,211.72	2,211.96	470,472.22	989,642.45	11,839.16
MH-21	2,221.06	2,218.80	2,220.86	469,119.09	989,715.58	4,399.30
MH-22	2,297.33	2,294.83	2,294.84	473,980.49	992,685.81	40.83
MH-23	2,220.69	2,218.19	2,220.69	469,374.43	989,736.21	6,984.70
MH-24	2,225.41	2,225.00	2,225.15	471,085.82	992,122.98	15,337.64
MH-25	2,272.12	2,269.62	2,269.66	468,208.97	992,510.61	764.39
MH-26	2,277.31	2,274.81	2,275.03	472,002.14	993,723.96	12,492.92
MH-27	2,220.00	2,218.00	2,218.07	469,589.05	989,449.63	1,823.51
MH-28	2,220.00	2,218.50	2,218.56	469,587.31	989,421.53	1,672.21
MH-29	2,231.61	2,229.11	2,229.27	467,742.18	989,889.45	2,322.27
MH-30	2,231.72	2,229.22	2,229.40	467,718.38	989,905.88	2,316.85
MH-31	2,219.14	2,216.64	2,216.71	469,793.86	989,447.29	2,021.30
MH-32	2,219.30	2,216.80	2,216.81	469,792.93	989,418.35	21.53
MH-33	2,232.56	2,230.06	2,230.14	467,653.66	989,951.97	2,298.28
MH-34	2,233.02	2,230.52	2,230.63	467,625.13	989,970.54	2,266.37
MH-35	2,219.02	2,217.00	2,217.08	469,754.64	989,448.58	1,971.41
MH-36	2,220.82	2,219.00	2,219.07	469,590.16	989,381.86	1,668.29
MH-37	2,223.93	2,221.43	2,221.49	469,576.04	989,248.76	1,589.06
MH-38	2,224.91	2,222.41	2,222.46	469,572.57	989,208.92	1,498.58

MH-39	2,225.75	2,223.25	2,223.31	469,569.81	989,164.01	1,489.24
MH-40	2,220.01	2,217.51	2,217.60	469,635.44	989,450.48	1,873.15
MH-41	2,226.84	2,224.34	2,224.39	469,567.12	989,114.08	1,479.53
MH-42	2,227.73	2,225.23	2,227.73	468,421.48	989,668.15	3,370.86
MH-43	2,215.54	2,213.04	2,213.17	470,172.07	989,472.66	2,713.46
MH-44	2,216.09	2,213.59	2,213.67	470,111.72	989,474.92	2,057.41
MH-45	2,228.45	2,225.95	2,227.77	468,228.12	989,651.03	3,247.30
MH-46	2,228.45	2,226.00	2,228.11	468,164.97	989,638.52	2,583.23
MH-47	2,230.87	2,228.80	2,228.91	467,796.77	989,852.37	2,406.70
MH-48	2,302.33	2,301.70	2,301.93	475,398.96	993,843.24	27,972.33
MH-49	2,228.22	2,225.72	2,227.75	468,305.43	989,662.25	3,346.89
MH-50	2,230.00	2,228.50	2,228.59	467,860.94	989,805.46	2,436.46
MH-51	2,229.28	2,227.00	2,228.12	468,071.00	989,659.16	2,522.17
MH-52	2,335.00	2,332.50	2,332.74	473,725.62	996,081.65	21,840.90
MH-53	2,336.17	2,333.67	2,333.73	473,704.24	995,986.71	1,623.07
MH-54	2,230.00	2,227.50	2,228.14	467,945.19	989,747.12	2,464.92
MH-55	2,302.00	2,301.40	2,301.54	475,474.18	993,864.53	4,008.33
MH-56	2,312.05	2,311.05	2,311.41	475,024.99	994,692.17	27,120.09
MH-57	2,315.03	2,312.53	2,312.79	475,026.51	994,798.65	26,679.45
MH-58	2,229.42	2,225.00	2,225.07	469,564.46	989,002.48	1,454.69
MH-59	2,332.40	2,329.90	2,330.79	473,899.52	996,127.52	24,389.26
MH-60	2,325.00	2,322.50	2,322.88	474,639.77	995,693.00	26,394.28
MH-61	2,332.17	2,329.67	2,330.12	474,329.60	995,892.38	24,583.94
MH-62	2,369.44	2,364.87	2,364.96	474,084.20	996,529.49	2,340.82
MH-63	2,343.21	2,340.71	2,341.07	473,297.46	996,544.13	19,889.87
MH-64	2,343.44	2,340.94	2,341.29	473,238.92	996,590.38	19,729.24
MH-65	2,344.43	2,341.93	2,342.11	473,233.86	996,616.34	19,169.82
MH-66	2,206.70	2,204.20	2,204.27	471,830.57	990,428.94	2,641.39
MH-67	2,217.58	2,216.00	2,216.08	471,760.36	990,749.45	2,394.46
MH-68	2,217.96	2,215.46	2,215.53	471,733.92	990,729.84	2,521.73
MH-69	2,219.35	2,216.85	2,216.92	471,795.01	990,765.41	2,165.28
MH-70	2,235.74	2,233.24	2,233.27	469,239.41	988,787.81	444.6
MH-71	2,237.00	2,234.50	2,234.53	469,216.83	988,756.68	319.41
MH-72	2,239.10	2,236.60	2,236.68	466,890.70	989,964.46	1,804.74
MH-73	2,241.29	2,238.79	2,238.81	466,879.10	990,003.07	163.17
MH-74	2,232.76	2,230.26	2,230.30	469,332.80	988,909.07	513.86
MH-75	2,233.59	2,231.09	2,231.13	469,303.72	988,868.52	488.36
MH-76	2,231.90	2,229.40	2,229.48	469,360.33	988,952.18	530.49
MH-77	2,336.21	2,333.71	2,333.73	473,754.88	995,979.13	36.08
MH-78	2,230.44	2,227.94	2,227.98	469,365.21	989,016.58	689.69
MH-79	2,231.80	2,229.30	2,229.30	469,360.67	988,956.63	6.18
MH-80	2,233.44	2,230.94	2,231.04	467,564.83	989,965.37	2,263.46
MH-81	2,285.76	2,284.00	2,284.25	471,786.55	994,131.34	11,465.28

MH-82	2,286.57	2,285.57	2,285.73	471,733.82	994,171.28	11,439.66
MH-83	2,287.27	2,286.00	2,286.23	471,680.77	994,214.77	11,410.15
MH-84	2,288.00	2,287.00	2,287.17	471,627.62	994,255.01	10,729.85
MH-85	2,285.00	2,283.80	2,284.05	471,841.13	994,089.28	11,489.70
MH-86	2,276.06	2,275.06	2,275.13	472,458.84	992,042.08	1,772.98
MH-87	2,276.73	2,274.23	2,274.29	472,386.17	992,042.93	1,819.36
MH-88	2,220.76	2,218.26	2,218.36	470,608.31	991,917.60	5,673.18
MH-89	2,242.99	2,240.49	2,240.59	470,389.84	992,315.47	5,494.35
MH-90	2,243.70	2,241.20	2,241.34	470,316.80	992,372.94	4,736.75
MH-91	2,226.36	2,223.86	2,223.91	471,879.36	990,816.47	2,119.31
MH-92	2,280.48	2,278.60	2,278.68	472,692.32	992,480.81	1,556.91
MH-93	2,279.00	2,278.00	2,278.08	472,696.26	992,365.64	1,699.72
MH-94	2,240.82	2,238.32	2,238.34	469,144.65	988,665.30	300.96
MH-95	2,372.21	2,369.71	2,369.75	473,239.40	997,505.27	623.27
MH-96	2,381.36	2,378.86	2,378.88	473,223.77	997,627.87	307.49
MH-97	2,213.44	2,210.94	2,211.01	471,800.48	990,616.78	2,588.61
MH-98	2,328.02	2,325.52	2,325.62	475,713.40	995,042.31	4,198.39
MH-99	2,334.51	2,332.01	2,332.10	475,787.90	995,155.32	3,956.12
MH-100	2,234.57	2,232.07	2,232.12	471,996.99	990,887.59	2,034.70
MH-101	2,285.72	2,283.22	2,283.39	471,966.85	994,032.79	12,392.86
MH-102	2,232.10	2,229.60	2,229.65	469,189.00	989,039.69	657.74
MH-103	2,233.43	2,230.93	2,230.97	469,063.39	989,114.75	562.62
MH-104	2,425.89	2,423.39	2,423.69	472,339.39	998,130.35	12,702.59
MH-105	2,428.11	2,425.61	2,425.82	472,143.52	998,234.56	12,519.26
MH-106	2,290.39	2,289.39	2,289.66	471,554.50	994,465.20	10,675.15
MH-107	2,425.06	2,422.56	2,422.69	472,549.63	998,052.28	12,723.83
MH-108	2,348.97	2,346.47	2,346.67	473,129.85	996,824.21	18,584.56
MH-109	2,439.57	2,437.07	2,437.21	472,342.00	998,372.80	12,376.01
MH-110	2,233.33	2,231.00	2,231.06	469,048.15	989,123.40	496.68
MH-111	2,233.97	2,231.47	2,231.52	468,842.58	989,282.17	383.11
MH-112	2,336.34	2,335.00	2,335.09	473,441.51	995,992.07	1,532.60
MH-113	2,443.47	2,440.97	2,441.16	472,093.32	998,476.05	12,243.46
MH-114	2,280.90	2,279.50	2,279.60	472,641.34	992,822.90	1,497.60
MH-115	2,390.00	2,387.50	2,387.64	473,488.28	997,852.99	4,507.46
MH-116	2,398.16	2,395.66	2,395.81	472,647.76	997,669.96	12,752.06
MH-117	2,301.54	2,299.04	2,299.26	470,985.95	994,850.14	9,624.78
MH-118	2,260.90	2,257.40	2,257.52	469,422.20	992,863.71	3,331.58
MH-119	2,302.99	2,301.00	2,301.15	475,505.54	993,791.25	10,035.73
MH-120	2,208.00	2,205.70	2,205.80	471,665.17	990,437.73	2,156.54
MH-121	2,207.20	2,205.70	2,205.91	471,385.74	989,927.74	12,928.03
MH-122	2,226.62	2,224.12	2,224.22	469,203.14	990,159.14	2,159.03
MH-123	2,226.67	2,224.17	2,224.22	469,199.73	990,160.91	27.86
MH-124	2,438.69	2,436.19	2,436.30	473,340.96	998,643.33	3,999.93

MH-125	2,438.56	2,436.06	2,436.14	473,346.45	998,638.00	4,065.30
MH-126	2,303.28	2,300.78	2,300.80	469,508.51	993,436.00	181.73
MH-127	2,304.03	2,301.53	2,301.55	469,518.19	993,444.41	176.5
MH-128	2,390.00	2,388.50	2,388.58	473,487.95	997,865.81	4,443.10
MH-129	2,409.69	2,405.69	2,405.70	473,648.76	997,931.22	42.14
MH-130	2,410.00	2,407.00	2,407.01	473,663.63	997,932.58	40.96
MH-131	2,444.25	2,441.75	2,441.91	472,093.10	998,495.05	12,234.62
MH-132	2,405.00	2,401.00	2,401.01	473,624.60	997,892.49	53.1
MH-133	2,216.00	2,215.00	2,215.15	470,628.22	991,787.50	21,622.65
MH-134	2,216.00	2,215.20	2,215.40	470,626.17	991,794.10	21,621.92
MH-135	2,225.90	2,219.50	2,219.65	470,686.24	991,908.71	15,942.47
MH-136	2,225.50	2,220.00	2,220.25	470,746.48	991,934.51	15,940.46
MH-137	2,226.00	2,221.00	2,221.16	470,768.61	991,946.74	15,938.00
MH-138	2,226.00	2,222.00	2,222.22	470,848.39	991,988.95	15,934.61
MH-139	2,228.00	2,223.00	2,223.16	470,888.52	992,009.59	15,929.47
MH-140	2,225.20	2,224.00	2,224.22	471,079.04	992,101.65	15,909.97
MH-141	2,217.73	2,216.00	2,216.05	469,997.56	989,444.29	557.31
MH-142	2,397.74	2,393.00	2,393.01	473,543.88	997,863.79	62.55
MH-143	2,401.59	2,396.00	2,396.01	473,576.27	997,872.44	59.46
MH-144	2,240.61	2,238.40	2,238.43	469,117.63	988,685.95	129.39
MH-145	2,412.11	2,409.61	2,409.62	473,686.16	997,986.82	17.47
MH-146	2,413.66	2,411.16	2,411.17	473,698.98	998,021.10	15.59
MH-147	2,216.44	2,213.94	2,213.98	470,170.92	989,434.53	648.5
MH-148	2,216.71	2,214.21	2,214.26	470,135.00	989,436.04	628.57
MH-149	2,243.96	2,241.46	2,241.49	474,148.06	989,974.11	609.82
MH-150	2,291.80	2,286.80	2,286.81	468,116.36	993,778.97	35.1
MH-151	2,300.98	2,298.48	2,298.51	469,479.57	993,408.72	338.6
MH-152	2,217.86	2,216.50	2,216.54	469,957.60	989,446.07	457.83
MH-153	2,226.84	2,224.34	2,224.34	469,580.37	989,115.86	2.97
MH-154	2,226.65	2,224.15	2,224.16	469,620.23	989,112.46	11.92
MH-155	2,217.28	2,214.78	2,214.82	470,094.66	989,437.50	577.15
MH-156	2,241.19	2,238.69	2,238.72	469,208.90	988,617.64	163.9
MH-157	2,241.69	2,239.19	2,239.21	469,243.05	988,591.52	122.67
MH-158	2,221.09	2,218.59	2,218.63	474,335.01	989,798.47	774.63
MH-159	2,231.78	2,229.50	2,229.52	469,473.40	988,906.62	37.65
MH-160	2,231.87	2,229.37	2,229.39	469,518.19	988,903.80	85.64
MH-161	2,241.19	2,238.69	2,238.71	468,991.32	988,781.59	43.91
MH-162	2,241.11	2,238.61	2,238.64	469,030.27	988,753.20	107.12
MH-163	2,242.92	2,240.42	2,240.44	469,214.47	988,550.50	95.09
MH-164	2,347.15	2,344.65	2,344.74	475,817.84	995,717.96	3,597.43
MH-165	2,345.78	2,343.28	2,343.40	475,808.25	995,668.76	3,716.27
MH-166	2,282.13	2,281.13	2,281.19	472,814.42	992,973.58	1,414.63
MH-167	2,281.00	2,280.00	2,280.12	472,763.68	992,972.54	1,448.27

MH-168	2,290.25	2,287.75	2,287.78	469,052.22	993,271.60	510.27
MH-169	2,294.00	2,291.50	2,291.53	469,079.61	993,315.23	409.16
MH-170	2,336.08	2,335.00	2,335.01	473,740.48	995,928.20	8.82
MH-171	2,227.20	2,224.70	2,224.74	474,530.90	989,871.91	283.15
MH-172	2,398.67	2,395.50	2,395.62	473,449.57	998,006.54	4,262.23
MH-173	2,398.81	2,394.81	2,394.91	473,484.35	997,962.43	4,270.67
MH-174	2,262.00	2,260.80	2,260.93	469,045.68	992,846.34	3,106.88
MH-175	2,263.26	2,262.00	2,262.06	469,088.88	992,883.29	1,203.41
MH-176	2,397.97	2,396.00	2,396.14	473,417.46	998,055.39	4,247.87
MH-177	2,230.00	2,227.50	2,227.51	474,082.88	989,752.14	41.52
MH-178	2,230.23	2,227.73	2,227.74	474,132.40	989,787.80	7.26
MH-179	2,223.29	2,220.79	2,220.82	470,216.85	990,342.05	256.59
MH-180	2,223.93	2,221.43	2,221.46	470,212.47	990,404.24	228.3
MH-181	2,283.68	2,281.18	2,281.24	470,315.60	992,720.62	1,080.35
MH-182	2,284.44	2,281.68	2,281.75	470,250.63	992,717.72	988.74
MH-183	2,292.49	2,289.99	2,290.02	469,323.43	993,247.49	526.27
MH-184	2,295.00	2,292.50	2,292.53	469,355.28	993,306.88	478.13
MH-185	2,285.24	2,282.74	2,282.77	469,242.76	993,115.71	583.47
MH-186	2,288.43	2,285.93	2,285.96	469,281.33	993,173.96	556.73
MH-187	2,319.75	2,317.25	2,317.29	474,330.57	993,609.58	612.48
MH-188	2,321.27	2,319.00	2,319.01	474,297.05	993,671.54	7.52
MH-189	2,273.44	2,270.94	2,270.97	469,153.36	992,981.07	631.23
MH-190	2,279.37	2,276.87	2,276.90	469,192.67	993,040.61	606.97
MH-191	2,338.07	2,335.57	2,335.65	475,821.20	995,222.35	3,948.96
MH-192	2,235.00	2,232.50	2,232.51	474,081.80	989,827.94	25.57
MH-193	2,391.19	2,388.69	2,388.85	473,493.00	997,887.00	4,442.32
MH-194	2,297.60	2,295.10	2,295.13	469,408.55	993,381.37	410.15
MH-195	2,304.19	2,302.00	2,302.13	475,736.09	993,614.87	1,762.16
MH-196	2,304.99	2,303.00	2,303.10	475,749.34	993,539.51	1,590.88
MH-197	2,341.15	2,338.65	2,338.74	475,854.89	995,293.75	3,934.12
MH-198	2,465.00	2,463.80	2,463.88	473,010.00	999,718.03	3,352.55
MH-199	2,246.82	2,244.32	2,244.37	466,420.59	989,703.22	1,174.98
MH-200	2,248.23	2,245.00	2,245.07	466,361.44	989,638.04	1,146.91
MH-201	2,221.44	2,218.94	2,218.95	470,116.06	989,201.17	47.04
MH-202	2,223.96	2,221.46	2,221.47	470,054.03	989,124.71	8.84
MH-203	2,303.00	2,301.80	2,301.94	475,666.92	993,692.90	1,790.92
MH-204	2,305.69	2,303.19	2,303.20	475,691.07	993,789.18	14.61
MH-205	2,232.22	2,228.90	2,228.93	469,620.27	988,898.42	147.01
MH-206	2,448.65	2,446.15	2,446.36	472,297.12	998,542.29	12,218.61
MH-207	2,457.54	2,455.04	2,455.17	472,388.09	998,599.39	12,188.03
MH-208	2,239.10	2,237.60	2,237.68	466,796.80	989,908.80	1,630.80
MH-209	2,290.20	2,286.00	2,286.01	469,460.29	993,085.06	24.6
MH-210	2,278.02	2,277.02	2,277.03	469,406.10	992,989.10	129.12

MH-211	2,470.00	2,465.80	2,465.87	472,903.46	999,765.98	1,859.76
MH-212	2,280.99	2,278.49	2,278.53	470,433.48	992,721.27	1,133.10
MH-213	2,260.00	2,258.30	2,258.43	469,298.76	992,871.08	3,321.24
MH-214	2,223.41	2,222.00	2,222.00	469,529.17	989,271.88	5.05
MH-215	2,466.83	2,464.33	2,464.34	472,512.21	998,627.94	50.02
MH-216	2,350.99	2,348.49	2,348.58	475,844.71	995,842.90	3,558.60
MH-217	2,499.75	2,497.25	2,497.42	471,554.93	999,918.80	8,645.11
MH-218	2,503.28	2,500.78	2,500.93	471,469.22	1,000,022.59	8,526.92
MH-219	2,242.59	2,240.09	2,240.16	466,551.90	989,749.61	1,273.45
MH-220	2,341.55	2,339.05	2,339.23	475,862.15	995,438.64	3,849.35
MH-221	2,449.22	2,446.72	2,446.73	472,203.49	998,589.67	21.75
MH-222	2,241.05	2,238.55	2,238.63	466,675.43	989,828.52	1,378.42
MH-223	2,315.97	2,313.47	2,313.52	474,218.33	993,512.57	732.08
MH-224	2,239.26	2,236.76	2,236.79	468,653.99	989,043.43	266.59
MH-225	2,244.12	2,241.62	2,241.63	468,553.54	988,932.50	50.53
MH-226	2,217.42	2,214.92	2,214.98	470,020.35	989,889.28	790.75
MH-227	2,220.00	2,216.00	2,216.06	470,105.67	990,012.49	691.11
MH-228	2,221.77	2,219.27	2,219.30	470,174.18	990,197.39	293.93
MH-229	2,303.96	2,302.96	2,302.98	475,858.78	993,525.81	51.74
MH-230	2,244.39	2,241.89	2,241.90	473,994.20	989,944.92	11.19
MH-231	2,235.97	2,233.47	2,233.48	469,111.05	988,903.80	53.84
MH-232	2,420.00	2,417.50	2,417.58	473,261.42	998,443.45	4,176.38
MH-233	2,406.82	2,404.32	2,404.42	473,324.00	998,299.00	4,198.44
MH-234	2,327.44	2,324.94	2,324.97	474,486.17	995,632.27	300.37
MH-235	2,359.33	2,356.83	2,356.94	475,923.57	996,271.56	3,425.41
MH-236	2,356.96	2,354.46	2,354.55	475,907.69	996,092.90	3,453.24
MH-237	2,237.13	2,234.63	2,234.63	469,543.22	988,738.56	4.16
MH-238	2,330.04	2,327.54	2,327.56	466,581.73	993,243.19	234.07
MH-239	2,239.21	2,236.71	2,236.73	474,608.19	989,965.47	136.38
MH-240	2,254.04	2,251.54	2,251.55	474,727.22	990,141.91	105.2
MH-241	2,459.56	2,457.06	2,457.08	473,719.55	998,823.45	82.26
MH-242	2,463.87	2,461.49	2,461.50	473,548.19	998,959.49	55.45
MH-243	2,226.22	2,223.72	2,223.73	469,310.79	989,320.62	4.92
MH-244	2,222.54	2,221.00	2,221.01	469,530.93	989,304.33	16.53
MH-245	2,337.58	2,335.08	2,335.09	475,774.10	995,297.14	32.42
MH-246	2,221.09	2,218.60	2,220.73	469,319.34	989,731.41	4,463.33
MH-247	2,225.68	2,223.18	2,223.19	469,185.38	989,495.52	42.23
MH-248	2,472.68	2,470.18	2,470.37	472,129.94	999,152.87	11,920.49
MH-249	2,479.70	2,477.20	2,477.39	471,970.06	999,394.49	11,833.72
MH-250	2,466.40	2,463.90	2,464.08	472,235.96	998,879.08	12,124.28
MH-251	2,305.77	2,303.27	2,303.30	469,199.50	993,588.52	357.41
MH-252	2,225.70	2,223.20	2,223.21	469,673.48	989,148.80	10.35
MH-253	2,456.89	2,454.39	2,454.40	473,674.52	998,794.82	63.56

MH-254	2,232.52	2,230.02	2,230.02	469,063.52	989,153.28	2.25
MH-255	2,224.01	2,221.51	2,221.54	469,325.89	989,461.81	115.52
MH-256	2,273.32	2,270.82	2,270.89	468,884.70	993,234.75	1,858.59
MH-257	2,224.54	2,222.04	2,222.06	470,150.71	989,069.55	96.4
MH-258	2,526.95	2,524.45	2,524.58	471,198.66	1,000,385.21	8,354.56
MH-259	2,420.90	2,418.40	2,418.42	473,428.92	998,316.06	104.18
MH-260	2,250.04	2,247.54	2,247.56	474,924.34	989,980.94	93.88
MH-261	2,290.29	2,287.79	2,287.86	473,248.24	993,238.30	953.36
MH-262	2,268.29	2,265.79	2,265.81	474,244.80	990,494.08	320.51
MH-263	2,278.41	2,275.91	2,275.92	474,098.44	991,077.84	27.45
MH-264	2,506.33	2,503.83	2,503.88	473,441.85	1,000,317.53	1,347.49
MH-265	2,550.40	2,547.90	2,547.93	473,826.88	1,000,956.08	356.37
MH-266	2,513.74	2,511.24	2,511.28	472,413.28	1,000,478.87	1,178.01
MH-267	2,363.77	2,361.27	2,361.28	471,841.66	996,283.02	24.46
MH-268	2,221.29	2,218.79	2,218.82	470,781.38	991,624.93	370.26
MH-269	2,222.05	2,219.55	2,219.57	470,783.44	991,637.04	288.05
MH-270	2,218.44	2,217.00	2,217.01	469,811.16	989,446.73	24.01
MH-271	2,351.83	2,349.33	2,349.34	474,534.16	996,205.78	60.9
MH-272	2,352.78	2,350.28	2,350.29	474,532.66	996,225.78	56.71
MH-273	2,480.59	2,478.09	2,478.11	471,980.41	999,418.67	123.13
MH-274	2,479.67	2,477.67	2,477.85	471,961.15	999,412.04	8,796.34
MH-275	2,217.42	2,214.92	2,214.94	470,795.97	991,115.83	298.47
MH-276	2,226.64	2,224.64	2,224.65	469,232.48	990,223.90	18.2
MH-277	2,226.88	2,225.00	2,225.01	469,244.00	990,245.95	14.17
MH-278	2,330.47	2,327.97	2,327.98	476,030.51	994,861.14	44.93
MH-279	2,330.97	2,328.47	2,328.48	476,053.35	994,873.51	20.12
MH-280	2,371.13	2,368.63	2,368.65	471,861.20	996,502.72	92.54
MH-281	2,370.19	2,369.00	2,369.02	471,850.39	996,526.51	80.44
MH-282	2,297.00	2,295.00	2,295.06	467,035.34	993,061.47	2,876.27
MH-283	2,221.88	2,219.38	2,219.41	469,989.72	990,189.72	199.48
MH-284	2,222.08	2,219.58	2,219.62	469,973.83	990,218.94	189.86
MH-285	2,364.04	2,361.54	2,361.55	474,653.38	996,563.28	42.96
MH-286	2,365.12	2,362.62	2,362.63	474,655.09	996,597.24	26.74
MH-287	2,226.70	2,224.20	2,224.22	469,216.49	990,193.08	24.47
MH-288	2,340.29	2,337.79	2,337.83	469,929.07	995,988.60	1,289.48
MH-289	2,335.90	2,334.00	2,334.09	469,964.45	995,979.70	1,424.83
MH-290	2,239.52	2,237.02	2,237.03	469,377.23	988,634.78	60.21
MH-291	2,238.36	2,235.86	2,235.88	469,399.44	988,665.00	96.2
MH-292	2,266.16	2,263.66	2,263.67	474,087.60	990,452.58	27.59
MH-293	2,265.16	2,262.66	2,262.67	474,094.28	990,414.22	49.58
MH-294	2,257.83	2,255.33	2,255.34	474,623.97	990,257.27	10.15
MH-295	2,259.38	2,256.88	2,256.88	474,645.28	990,290.73	5.05
MH-296	2,360.13	2,357.63	2,357.67	474,639.49	996,459.41	431.13

MH-297	2,361.51	2,359.01	2,359.02	474,644.40	996,499.41	66.92
MH-298	2,219.85	2,217.35	2,217.37	469,993.30	989,357.54	94.34
MH-299	2,220.68	2,218.18	2,218.20	469,990.59	989,316.93	74.24
MH-300	2,219.96	2,217.60	2,217.64	470,017.08	990,046.70	365.05
MH-301	2,220.00	2,218.00	2,218.04	469,977.70	990,061.44	350.49
MH-302	2,219.95	2,217.00	2,217.04	470,057.24	990,032.63	382.27
MH-303	2,317.92	2,315.42	2,315.47	475,652.84	994,410.50	969.54
MH-304	2,317.99	2,315.49	2,315.59	475,662.30	994,452.26	842.17
MH-305	2,243.48	2,240.98	2,241.00	469,247.35	988,522.33	85.92
MH-306	2,349.54	2,347.04	2,347.05	474,528.35	996,162.43	68.08
MH-307	2,237.83	2,235.33	2,235.34	474,500.76	989,954.82	94.4
MH-308	2,240.50	2,238.00	2,238.01	474,455.32	989,958.33	21.18
MH-309	2,222.73	2,221.00	2,221.02	469,771.61	990,269.05	84.89
MH-310	2,223.41	2,221.50	2,221.52	469,755.11	990,311.54	56.88
MH-311	2,255.82	2,253.32	2,253.34	474,641.38	990,197.07	84
MH-312	2,256.08	2,253.58	2,253.60	474,602.62	990,221.61	60.94
MH-313	2,220.05	2,218.50	2,218.53	469,937.77	990,084.27	144.93
MH-314	2,277.45	2,276.00	2,276.01	472,487.03	992,083.11	39.56
MH-315	2,222.39	2,219.89	2,219.91	470,859.47	991,134.23	265.32
MH-316	2,225.74	2,223.24	2,223.26	470,909.55	991,137.61	222.39
MH-317	2,332.92	2,330.42	2,330.44	476,059.08	994,717.59	34.28
MH-318	2,335.36	2,332.86	2,332.87	476,104.90	994,696.92	27.86
MH-319	2,329.60	2,327.10	2,327.12	475,997.65	994,821.36	69.06
MH-320	2,251.11	2,248.61	2,248.61	469,163.17	988,342.86	8.13
MH-321	2,248.65	2,246.15	2,246.16	469,193.53	988,384.65	19.87
MH-322	2,329.79	2,327.29	2,327.30	475,907.89	994,568.31	80.42
MH-323	2,331.43	2,328.93	2,328.93	475,942.38	994,529.21	7.43
MH-324	2,222.00	2,219.50	2,219.53	469,798.37	990,223.28	107.78
MH-325	2,320.00	2,317.50	2,317.55	475,675.77	994,560.58	818.73
MH-326	2,321.30	2,318.80	2,318.85	475,725.90	994,579.66	703.68
MH-327	2,261.51	2,259.01	2,259.02	474,458.93	990,297.50	28.21
MH-328	2,261.25	2,260.00	2,260.01	474,405.46	990,302.12	6.55
MH-329	2,279.61	2,277.11	2,277.12	465,146.65	990,682.99	20.93
MH-330	2,280.89	2,278.39	2,278.39	465,116.69	990,728.33	3.1
MH-331	2,340.03	2,337.53	2,337.54	474,501.23	995,958.73	18.02
MH-332	2,345.99	2,343.49	2,343.51	474,520.28	996,103.52	76.51
MH-333	2,350.06	2,347.56	2,347.58	475,917.85	995,724.28	98.19
MH-334	2,348.76	2,346.26	2,346.28	475,902.50	995,666.51	113.2
MH-335	2,337.07	2,334.57	2,334.57	476,152.89	994,661.27	7.11
MH-336	2,234.63	2,232.13	2,232.15	469,011.49	989,074.39	109.77
MH-337	2,351.90	2,349.40	2,349.41	475,929.69	995,786.81	73.55
MH-338	2,376.19	2,373.69	2,373.69	471,924.76	996,497.12	9.69
MH-339	2,355.00	2,354.50	2,354.51	475,021.55	996,078.15	17.94

MH-340	2,331.20	2,328.70	2,328.71	475,986.24	994,908.29	19.68
MH-341	2,231.67	2,229.17	2,229.19	470,880.47	991,715.55	168.27
MH-342	2,234.76	2,232.26	2,232.28	470,944.44	991,725.71	147.82
MH-343	2,320.24	2,317.74	2,317.76	474,847.80	993,662.11	176.02
MH-344	2,322.32	2,319.82	2,319.84	474,809.40	993,714.43	105.07
MH-345	2,240.42	2,237.92	2,237.93	469,428.18	988,593.30	48.84
MH-346	2,234.90	2,232.40	2,232.41	469,022.71	989,062.78	54.85
MH-347	2,254.26	2,251.76	2,251.81	465,849.20	989,581.79	742.75
MH-348	2,255.75	2,253.25	2,253.30	465,813.48	989,637.38	727.89
MH-349	2,334.88	2,332.38	2,332.39	474,719.36	994,538.99	14.05
MH-350	2,334.19	2,331.69	2,331.71	474,687.76	994,597.54	274.11
MH-351	2,351.78	2,350.80	2,350.81	474,465.54	996,233.99	39.17
MH-352	2,500.68	2,498.18	2,498.19	472,106.63	999,680.71	24.73
MH-353	2,500.51	2,499.00	2,499.01	472,173.05	999,662.59	6.52
MH-354	2,484.92	2,482.42	2,482.44	471,982.04	999,489.10	119.45
MH-355	2,345.55	2,343.05	2,343.09	474,591.46	996,093.35	650.97
MH-356	2,354.68	2,352.18	2,352.19	474,541.36	996,297.71	11.29
MH-357	2,355.87	2,353.37	2,353.38	476,010.33	995,924.06	5.47
MH-358	2,354.73	2,352.23	2,352.24	475,946.25	995,889.54	32.38
MH-359	2,269.11	2,266.61	2,266.63	465,395.92	990,270.87	146.84
MH-360	2,270.72	2,268.22	2,268.24	465,354.74	990,333.33	121.1
MH-361	2,368.54	2,366.04	2,366.06	471,861.04	996,427.32	103.14
MH-362	2,333.86	2,332.36	2,332.39	474,653.29	994,664.69	223.71
MH-363	2,355.00	2,352.50	2,352.51	476,013.43	995,855.10	9.73
MH-364	2,283.71	2,281.21	2,281.22	472,619.44	992,378.60	77.73
MH-365	2,355.00	2,354.00	2,354.01	474,995.34	996,076.08	27.85
MH-366	2,375.45	2,372.95	2,372.95	471,926.72	996,471.09	7.33
MH-367	2,259.24	2,256.74	2,256.75	474,531.90	990,266.28	45.83
MH-368	2,278.27	2,275.77	2,275.78	465,189.52	990,615.77	34.94
MH-369	2,252.55	2,250.05	2,250.10	465,892.18	989,514.33	758.87
MH-370	2,275.53	2,273.03	2,273.04	465,219.21	990,541.32	54.37
MH-371	2,272.35	2,269.85	2,269.87	465,310.83	990,400.64	96.46
MH-372	2,273.90	2,271.40	2,271.42	465,263.47	990,473.25	72.21
MH-373	2,250.81	2,248.31	2,248.38	465,936.30	989,445.68	785.35
MH-374	2,368.01	2,365.51	2,365.52	474,666.59	996,681.47	12.39
MH-375	2,347.17	2,346.50	2,346.51	474,643.09	996,102.84	12.02
MH-376	2,359.16	2,358.16	2,358.21	471,862.07	996,040.71	256.86
MH-377	2,361.92	2,359.42	2,359.44	471,899.77	996,118.69	85.22
MH-378	2,316.82	2,314.32	2,314.35	474,938.08	994,696.21	421.86
MH-379	2,356.59	2,354.09	2,354.10	474,475.04	996,320.85	17.69
MH-380	2,320.26	2,317.76	2,317.79	474,859.15	994,738.99	384.78
MH-381	2,332.19	2,329.69	2,329.70	475,985.85	994,627.64	66.56
MH-382	2,335.17	2,332.67	2,332.68	476,078.15	994,635.30	17.12

MH-383	2,302.22	2,299.72	2,299.75	474,754.35	993,354.05	343.46
MH-384	2,236.99	2,234.49	2,234.51	471,041.59	991,729.67	131.67
MH-385	2,248.43	2,245.93	2,246.00	466,293.95	989,561.33	985.76
MH-386	2,249.08	2,246.58	2,246.65	466,203.50	989,523.83	946.3
MH-387	2,354.76	2,352.26	2,352.27	476,050.85	995,799.24	26.39
MH-388	2,356.16	2,353.66	2,353.66	476,083.74	995,892.06	3.19
MH-389	2,257.53	2,255.03	2,255.08	465,759.44	989,722.62	711.1
MH-390	2,340.26	2,337.76	2,337.81	474,577.86	995,982.35	676.51
MH-391	2,344.08	2,341.58	2,341.59	474,514.46	996,062.21	15.06
MH-392	2,241.91	2,239.41	2,239.42	468,890.67	988,802.38	28.27
MH-393	2,337.57	2,335.07	2,335.08	476,200.95	994,736.31	12.77
MH-394	2,284.35	2,281.85	2,281.86	472,599.31	992,527.53	15.89
MH-395	2,308.31	2,305.81	2,305.82	475,550.57	993,415.54	34.56
MH-396	2,311.14	2,308.64	2,308.65	475,507.94	993,312.55	19.34
MH-397	2,313.00	2,310.50	2,310.51	474,818.47	993,447.41	38.52
MH-398	2,355.99	2,353.49	2,353.50	476,031.74	995,911.69	4.82
MH-399	2,249.38	2,246.88	2,246.90	474,146.50	990,065.73	209.66
MH-400	2,252.81	2,250.31	2,250.32	474,043.82	990,120.25	23.32
MH-401	2,337.26	2,334.76	2,334.76	476,147.59	994,641.41	2.33
MH-402	2,305.30	2,302.50	2,302.62	475,456.42	994,136.95	1,230.57
MH-403	2,305.56	2,303.06	2,303.15	475,441.88	994,255.55	1,146.91
MH-404	2,241.36	2,238.86	2,238.87	469,312.61	988,562.83	8.17
MH-405	2,325.46	2,322.96	2,323.00	475,826.75	994,658.56	653.18
MH-406	2,249.47	2,247.20	2,247.28	466,094.78	989,462.19	911.27
MH-407	2,260.58	2,258.08	2,258.10	474,141.81	990,294.96	113.71
MH-408	2,255.64	2,253.14	2,253.16	474,150.15	990,194.89	145.61
MH-409	2,256.59	2,254.09	2,254.10	474,279.83	990,221.58	5.18
MH-410	2,298.75	2,295.00	2,295.05	468,841.56	993,568.90	1,686.56
MH-411	2,302.07	2,299.57	2,299.58	468,978.72	993,562.59	12.51
MH-412	2,249.02	2,246.52	2,246.52	468,803.66	988,688.20	2.53
MH-413	2,340.00	2,338.50	2,338.56	473,195.96	996,230.48	1,148.05
MH-414	2,340.51	2,339.00	2,339.09	473,099.67	996,342.58	1,126.57
MH-415	2,360.16	2,359.00	2,359.03	471,853.30	996,188.56	159.28
MH-416	2,308.60	2,306.10	2,306.11	475,673.73	993,382.11	23.08
MH-417	2,312.97	2,310.47	2,310.48	475,561.90	993,280.38	11.16
MH-418	2,307.09	2,304.59	2,304.62	475,377.29	994,392.29	150.49
MH-419	2,224.27	2,221.77	2,221.80	469,967.34	990,369.51	174.8
MH-420	2,233.68	2,231.18	2,231.19	470,914.58	991,532.30	41.4
MH-421	2,314.61	2,312.11	2,312.13	474,852.36	993,470.84	245.27
MH-422	2,307.56	2,305.06	2,305.12	475,902.79	993,520.86	993.17
MH-423	2,285.00	2,282.50	2,282.51	472,464.63	992,438.17	17.46
MH-424	2,332.88	2,330.38	2,330.40	474,324.40	995,920.84	71.43
MH-425	2,292.03	2,289.53	2,289.57	472,057.86	994,176.59	873.26

MH-426	2,241.78	2,239.28	2,239.29	470,969.16	991,303.26	62.94
MH-427	2,261.99	2,259.49	2,259.53	465,629.84	989,924.49	522.38
MH-428	2,266.04	2,263.54	2,263.58	465,533.07	990,076.01	483.52
MH-429	2,224.46	2,221.96	2,221.97	469,978.97	989,127.01	34.59
MH-430	2,335.71	2,333.21	2,333.41	474,561.99	995,856.68	1,156.20
MH-431	2,331.80	2,329.30	2,329.58	474,371.57	995,830.00	26,059.69
MH-432	2,351.88	2,349.38	2,349.40	472,683.13	996,722.11	60.33
MH-433	2,365.35	2,362.85	2,362.86	472,488.36	996,766.47	13.7
MH-434	2,278.70	2,276.20	2,276.26	468,713.62	993,409.84	1,807.30
MH-435	2,357.26	2,354.76	2,354.77	474,915.37	996,177.44	46.07
MH-436	2,365.26	2,362.76	2,362.77	471,825.36	996,391.11	30.95
MH-437	2,298.11	2,295.61	2,295.65	472,152.01	994,359.86	623.03
MH-438	2,250.06	2,247.56	2,247.56	468,941.39	988,548.64	5.63
MH-439	2,233.51	2,231.01	2,231.03	471,006.90	991,626.05	74.99
MH-440	2,240.71	2,238.21	2,238.21	468,884.75	988,882.71	4.71
MH-441	2,230.31	2,227.81	2,227.82	470,813.14	991,356.45	8.94
MH-442	2,327.04	2,326.00	2,326.03	474,283.38	995,742.01	134.32
MH-443	2,347.27	2,346.00	2,346.04	474,384.42	996,141.50	66.98
MH-444	2,349.71	2,345.00	2,345.04	474,617.07	996,147.97	433.47
MH-445	2,358.36	2,355.86	2,355.87	474,645.63	996,379.80	37.04
MH-446	2,240.85	2,238.35	2,238.36	468,869.03	988,886.52	18.79
MH-447	2,285.00	2,282.50	2,282.52	472,437.84	992,529.96	51.12
MH-448	2,326.92	2,324.42	2,324.43	474,854.86	993,947.17	25.48
MH-449	2,345.00	2,343.00	2,343.06	473,002.87	996,616.29	536.43
MH-450	2,282.91	2,280.41	2,280.42	472,484.44	992,265.15	26.06
MH-451	2,224.80	2,222.30	2,222.30	470,754.69	991,358.15	6.65
MH-452	2,328.64	2,326.14	2,326.15	474,701.32	993,942.21	21.47
MH-453	2,250.90	2,248.40	2,248.41	471,290.27	991,687.62	54.94
MH-454	2,248.98	2,246.48	2,246.49	469,270.94	988,340.47	23.38
MH-455	2,504.05	2,501.55	2,501.55	472,090.34	999,734.19	4.74
MH-456	2,328.08	2,325.58	2,325.59	474,674.98	993,877.11	27.61
MH-457	2,225.82	2,223.32	2,223.33	469,657.98	989,150.91	3.43
MH-458	2,319.84	2,317.34	2,317.35	474,997.29	993,741.30	43.72
MH-459	2,399.28	2,396.78	2,396.80	473,291.93	997,818.16	124.68
MH-460	2,219.42	2,216.92	2,216.93	470,189.71	989,982.08	20.7
MH-461	2,229.58	2,227.08	2,227.09	469,236.40	989,139.93	15.43
MH-462	2,383.39	2,380.89	2,380.97	473,963.06	996,855.58	2,094.90
MH-463	2,299.00	2,296.00	2,296.14	468,840.74	993,935.72	1,300.27
MH-464	2,227.12	2,224.62	2,224.63	469,797.22	989,061.98	19.14
MH-465	2,232.53	2,230.03	2,230.03	469,084.10	989,156.53	1.76
MH-466	2,436.01	2,433.51	2,433.52	473,073.70	998,175.15	30.97
MH-467	2,355.00	2,354.00	2,354.02	475,050.76	996,152.41	90.25
MH-468	2,246.30	2,243.80	2,243.82	471,120.64	991,426.58	144.73

MH-469	2,378.73	2,376.23	2,376.24	474,415.20	996,876.84	27.41
MH-470	2,565.68	2,563.17	2,563.19	473,703.80	1,001,435.69	138.25
MH-471	2,351.51	2,350.00	2,350.01	472,686.41	996,673.22	8.81
MH-472	2,336.09	2,334.50	2,334.53	469,971.28	996,021.43	133.83
MH-473	2,347.12	2,344.62	2,344.66	476,720.79	995,410.96	289.35
MH-474	2,349.40	2,346.90	2,346.93	476,695.11	995,526.06	223.62
MH-475	2,352.78	2,350.28	2,350.31	476,627.81	995,781.27	184.11
MH-476	2,386.21	2,383.71	2,383.81	475,907.77	997,473.68	2,924.10
MH-477	2,386.69	2,384.19	2,384.20	475,935.61	997,475.79	3.12
MH-478	2,386.88	2,384.38	2,384.38	475,938.63	997,479.66	0.1
MH-479	2,387.17	2,384.67	2,384.67	475,940.33	997,485.51	0.72
MH-480	2,387.14	2,384.64	2,384.64	475,944.11	997,482.21	2.46
MH-481	2,379.56	2,377.00	2,377.02	476,104.58	997,055.18	57.46
MH-482	2,379.54	2,378.00	2,378.00	476,111.03	997,053.45	6.54
MH-483	2,271.54	2,269.80	2,269.81	469,184.21	992,538.46	20.04
MH-484	2,271.74	2,269.27	2,269.28	469,176.77	992,538.80	73
MH-485	2,388.70	2,386.20	2,386.20	476,060.72	997,366.87	2.55
MH-486	2,388.35	2,387.00	2,387.00	476,053.36	997,373.53	0.57
MH-487	2,387.20	2,384.70	2,384.70	475,951.85	997,475.32	1.24
MH-488	2,388.17	2,385.67	2,385.68	476,052.16	997,355.83	16.02
MH-489	2,387.76	2,386.00	2,386.01	476,047.69	997,345.09	12.78
MH-490	2,413.99	2,411.49	2,411.50	476,539.04	997,816.81	24.53
MH-491	2,413.31	2,410.81	2,410.82	476,536.57	997,805.26	34.35
MH-492	2,343.68	2,341.18	2,341.20	467,659.06	994,551.55	110.81
MH-493	2,343.03	2,340.53	2,340.55	467,670.40	994,546.33	126.36
MH-494	2,359.19	2,356.69	2,356.72	467,270.73	994,262.27	431.2
MH-495	2,357.97	2,355.47	2,355.50	467,280.98	994,254.93	439.79
MH-496	2,393.66	2,391.16	2,391.16	466,594.30	994,679.70	9.91
MH-497	2,392.02	2,389.52	2,389.53	466,600.25	994,667.76	17.46
MH-498	2,232.77	2,230.27	2,230.29	470,048.33	991,499.59	196.35
MH-499	2,233.16	2,230.66	2,230.68	470,039.68	991,510.24	184.13
MH-500	2,385.53	2,383.03	2,383.03	475,950.73	997,408.74	0.78

HYDRAULIC MODELING OF KALITY CATCHMENT SEWER NETWORK -BY GETYE FEKADU. wtg 8/28/2023	Bentley Systems, Inc. Haestad Methods Solution Center 27 Siemon Company Drive S uite 200 W Watertown, CT 06795 USA +1-203-755-1666	SewerGEMS CONNECT Edition [10.02.01.04] Page 1 of 1

The above annex shows the sample manhole report of scenario I, computed in Bentley Sewer GEMS CONNECT Edition Version 10 and the left manhole report (about 5367 manhole from first scenario), the whole of the second and third scenario are not listed here in order to minimize the page.