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Presented by

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MANAGEMENT OF A SEWERAGE NETWORK IN AN URBAN AREA BY COUPLING GIS AND HYDRAULIC MODELLING: CASE STUDY KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY (GHANA)

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DECLARATION

I hereby, declare that this thesis is my own work and realized to the best of my knowledge. All the material and results from other works contain in this work have been cited and referenced in accordance with the academic rules and ethics.

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ABSTRACT

The hydrological cycle is deeply modified by the high rate of urbanization and the population growth this affects the management of the hydraulic infrastructures and the soils' infiltration rate during runoff. Sewage infrastructures are very important in the socio-economic development of a country and the protection of the environment. Their deterioration is more or less rapidly over time and faces serious challenges in term of management in many developing countries. In Ghana, conventional wastewater treatment plants are underused because of the poor sewage collection system. Only the small proportion of the sewage generated from urban area generally connected to a sewer line. This work aims to simulate the existing sewerage network of KNUST and come up with the management method by coupling GIS and a hydraulic model. Primary data were obtained through the field analysis and a questionnaire while secondary data were gathered from the existing literature related to the research topic, published and non-published papers, reports and databases. ArcGIS and MOUSE were used to model and simulate the network. The results of the study showed that the sewerage network of KNUST conveys black and grey water from campus, faculty and commercial areas to its wastewater treatment plant. 99.62% of the network has the normal circulation of the sewage and 0.38% do not meet the self- cleansing condition. The major portion of the sewerage network has an open channel flow circulation during the dry period. Some manholes are flooded in the wet period. In general, the management problem of the KNUST sewerage network is due to the invert slopes that cause stagnation in the pipes, the low flowrate generation in dry and the non-coverage of some manholes. To these is added the under-sizing of some conduct and some manholes and the non-update of the master plan of the network as well. The study recommended to update the sewerage network, to apply the telemonitoring system to its good management and the implication of stronger political will in the sanitation infrastructure in general for effective management.

Keywords: GIS, MOUSE, Geodatabase, KNUST, master plan, sewerage network

RESUMÉ

Le cycle hydrologique est profondément modifié par le taux élevé d'urbanisation et la croissance démographique qui affectent la gestion des infrastructures hydrauliques et le degré d'infiltration des sols. Les infrastructures de l'assainissement jouent un rôle très important dans le développement socio-économique d'un pays et la protection de l'environnement. Leur détérioration est plus ou moins rapide dans le temps et font face à de nombreux problèmes de gestion dans les pays en voie de développement. Au Ghana, les stations de traitement conventionnelles des eaux usées sont moyennement utilisées. Seule la faible proportion des eaux usées générées par les zones urbaines est généralement raccordée à des réseaux d'assainissement. Ce travail a pour objectif de modéliser le réseau d'assainissement existant de KNUST et de proposer la méthode de gestion en couplant le SIG et un modèle hydraulique. Les données primaires ont été obtenues au moyen d'une analyse de terrain et des questionnaires, tandis que des données secondaires ont été rassemblées à partir des littératures existantes en rapport avec le thème, ainsi que de documents, rapports et bases de données publiés et non publiés. ArcGIS et Mike MOUSE ont été couplés pour modéliser et simuler le réseau. Les résultats de l'étude ont montré que le réseau d'assainissement de KNUST collecte les eaux usées d'origine domestique du campus, les zones de faculté et commerciales vers sa station de traitement d'eau usée pour être traitées. Les résultats de la simulation montrent que 99,62% du réseau collectent les eaux usées avec une vitesse inférieure ou égale à la moyenne et 0,38% ne remplit pas les conditions d'auto-curage. La majeure partie du réseau d'assainissement de KNUST a un écoulement à demi section pendant la période sèche. Certains regards sont inondés pendant la période pluviale. Les problèmes de gestion du réseau d'assainissement de KNUST sont dû généralement aux contres pentes provoquant la stagnation dans les conduites, un faible débit généré en temps sec et certains regards ne sont pas couverts. À cela s'ajoutent le sous-dimensionnement de certaines conduites et de quelques regards ainsi que la non mise à jour du réseau. Les recommandations étaient de mettre à jour le réseau d'assainissement de KNUST, de lui appliquer le système de télégestion et implications d'une volonté politique de gestion plus forte dans les infrastructures hydrauliques en général pour une gestion efficace.

Mots-clés : SIG, Mike MOUSE, base de données, KNUST, plan directeur, réseau d'assainissement

DEDICATION

"All that I am or hope to be, I owe to my Family and my surrounding, who have always Believed in me, encouraged and supported me in everything I undertake"

This work is dedicated to:
To my parents with love and gratitude,
To my Sisters and Brothers,
To my friends,

Thank you All for supporting, inspiring and encouraging me always throughout my like. Thank you for your unconditional love and always taking care of me.

May Allah rewards you!

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ABBREVIATIONS AND ACRONYMS

BMP	Best Management Practice
CSOs	Combined Sewer Overflows
SSOs	Sanitary Sewer Overflows
DHI	Danish Hydraulic Institute
EPA	Environmental Protection Agency
GIS	Geographical Information System
GPS	Global Positioning System
H&H	Hydraulic and Hydrological
HDPE	High Density Polyethylene
KNUST	Kwame Nkrumah University of sciences and Technologies
LID	Low Impact Development
MEST	Ministry of Environment, Science and Technology
MDG	Millennium Development Goals
MLGRD	Ministry of Local Government and Rural Development
MOUSE	Model for Urban Sewer
MWRWH	Ministry of Water Resources Works and Housing
NGO	Non-Governmental Organization
PVC	Polyvinyl chloride
RTC	Real Time Control
SDG	Sustainable Development Goal
SQL	Structured Query Language
SWMM	Storm Water Management Model
T5	Five years rains return period
T10	Ten years rains return period
UN	United Nations
UNICEF	United Nations Children's Fund
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

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1 Chapter one: Introduction

1.1 Background

Integrated water management in the urban area is the centre of preoccupation in many African cities. The reuse of treated wastewater is behind. The hydrological cycle is profoundly affected in different ways by urbanization. Indeed, Settlements have influenced the behaviour of the runoff as well as the drainage network and decreased the capacity of soil infiltration in many zones.

Urban areas are characterized by the dynamic change in terms of populations and the land use. The increased of the population, the water demand per capita, the leaving standard linked with the land use caused enormous change in both quantity and quality of the sewage discharge (Hussein Abed Obaid & All, 2014). As sewage collection infrastructures are buried underground, their management is somehow difficult but need to be upgrade from time to time to deal with the increased of the population and the land use. Nonetheless, increasing urbanization is not just about flow rate and the quantity of the sewage discharge only, but about pollution (Zug & Vazquez, 2014). It has to be known that with type of the sewerage network, sewage will be either rejected in the natural environment without any treatment or after being treated. Consequently, the polluted water most of time is rejected directly in the environment which is dangerous to the environment presently and in the future.

The sewer systems are inadequately designed, with the deterioration of wastewater over the years, the system is unable to handle the changing dynamics (Hussein Abed Obaid & All, 2014). The management of the sewerage network is a serious challenge. Some phenomenon such as climate change may intensify the rainfall return period in the future and can be a challenge in the management of sewerage. Urbanization affect considerably the climate of the area. According to (Sunil Thosainge, 2000), (Hall,1984) in its purpose said that it has been found that precipitation, evaporation and local temperature increase due to the urbanization. The increased in temperature and precipitation may impact the quality of the sewage and the augment the runoff since the transpiration will be less. This phenomenon can cause flood in the area due the overflow in the sewer system. Sewer overflow is a general problem around the world, for this purpose, it is necessary to have effective means to assess the consequences of urbanization on the quantitative, qualitative and economic aspects of sanitation. Urban flood is a significant socio-economic problem in the world especially in Africa. Nevertheless, the major cause of this flood in Africa is due the lack of the management of water infrastructure such as the sewer network and the drainage system.

Most of the African countries' sewage collection system is decentralized, septic tanks, pit latrines, where the rejects of the sewages are improper. Statistics have shown that about 85% of the global wastewater is discharged the environment without any treatment. The coverage in sanitation in the developing countries is about 49% which is like half of the developed world coverage (98%) (Eckart & All, 2013).

One of the major challenges in the 21st century is proving safe water and basic sanitation for all, its sustainable management by 2030 and the achievement of the agenda 2063. This research contributes to the development of decision support systems for water and sanitation facilities in urban area.

Geographic Information System (GIS) specifically ArcGIS will be linked with Model for Urban Sewer (MOUSE) in this study to understand the sewer network of Kwame Nkrumah University of Science and Technology (KNUST) and contribute to its management.

1.2 Problem statement and justification

Urban environmental sanitation is considered to be one of the most immediate and serious problems confronting urban governments in most developing countries.

Sewerages are essential sanitation infrastructures in urban area and have to be carefully maintained and managed. Currently urban sewerage problem come from the fact that most of the sewer networks are being serviced in deteriorating condition which is vulnerable to the communities and face them to unexpected catastrophic failures that perturb not the sewer system only but the environment (Ana & Bauwens, 2007). Sewer overflows impose economic costs on customers, since they are inconvenient, disruptive and may impose health and safety risks. Owing the importance of the urban sewerage, their management have to be taken as priority. Base on the fact that all sewer infrastructures are buried underground, the most challenges that sewerage networks face are: the management problems, the data accessibility, the linkage problem, the sewage overflow also mostly the sewers in Sub Saharan Africa are out of date. Sewer network requires constant hydraulic condition to ensure the performance of the network.

Most of African countries in urban area, use separate sewer system for the sewage and stormwater collection. Rainfall is drain in stormwater drainage channels and or in the normal streets. Some urban cities have their sewages which is conveyed to septic tank while others sewer network then wastewater treatment plant. The challenge that Africa faces in the purpose of sanitation is that most the of the sewages go in the environment without any treatment. The rapid urbanization impacts the stormwater flow and the rapid overflow of the sewer which conduct to the urban flooding. Sewage management becomes a serious problem due to the increase in urbanization. Numerous sewer manholes are poorly maintained, lack of the good design.

In sub-Saharan African the sewerage networks are out of date. Most of them existed since the colonial time and are not adequately operated, maintained and managed. The access to sanitation network is a big challenge. In Africa, sanitation infrastructures are marginalized and most of them are not mapped or updated.

The lack of adequate sanitation and the management of the sanitation infrastructures is the challenge that face sub Saharan Africa countries. In Ghana, treating the wastewater before its reject is behind. The septic tanks and pit latrine are commonly used for sewage collection then, the waste will be discharge into environment after septage. Ghana, in urban area, less than 15% of the population have access to sewer system (Blomberg & All, 2017).

1.3 Research questions and hypotheses

1.3.1 Research question

Based on the purpose of the research, this research addressed the below questions:

i. What is the state of the existing sewer network of the KNUST university?
ii. How the management of the network KNUST is done?
iii. What is the age of the sewer line and its components?
iv. What is the number of rooms, blocs and the population of the connected facilities to WWTP?
v. What recommendation can be offered to ensure good management of KUNST university sewerage?

1.3.2 Hypothesis

Failure in the existing sewer system of the campus to move all sewage from the KNUST university to its wastewater treatment plant.

1.4 Research objectives

1.4.1 Main objective

To analyse the management condition of KNUST sewerage network and establish a model of database of its sewerage network by coupling GIS and hydraulic modelling for its good management.

1.4.2 Specific objectives

i. Create a GIS of the sewerage network and establish its numerical model;
ii. Analyse the functioning problem of the existing sewerage network, manhole;
iii. Develop a hydraulic model of the sewer collection systems;
iv. Simulate the network operation in order to generate strategies for management and propose the management solutions.

1.5 Relevance of the research

The research has a great potential to contribute to the development of decision support systems for water and sanitation facilities in Africa especially in urban centres. It will help to understand the behaviour of the sewerage network and the forecasting flood.

1.6 Scope and limitation

As mentioned before this research carries out the management of the sewerage which deals with the protection of the environment and help in the decision making in water and sanitation area in KNUST. This study covers the evaluation of the integrated water resource management and the protection of the sanitation infrastructure. The scope of this project was limited to GIS and MOUSE engine.

Because of the time constraint and the difficulty to access to the data, this study was focused only on the sewerage network of Kwame Nkrumah University of Sciences and technologies sewerage network. It was also limited by the non-availability of the data in soft and hard copy.

1.7 Structure of the research

The thesis comprises five chapters structure as follow:

The chapter one is the introductory chapter, it introduces and states the focus of the research starting by the background information, problem statement, justification, research question, hypothesis, research objectives, relevance of the research, scope and limitation then research structure. The chapter two is the literature review, it is about the historical background of the sewerage, the sewerage management method, the institutional framework of sanitation related to the study area, the purpose of the in achievement of the Sustainable Development Goals (SDG) and the agenda 2063, overview of the sewer modelling software and flow calculation formula in the network. The chapter three represents the methodology including the study area description, research design, data collection method, data analysis, cartography of the network,

network diagnostic and network simulation. The chapter fourth is the result of the analysis and discussion. This chapter highlights the management aspects of the sewerage by doing the diagnostic of the network and its components (manhole, conduct, junction…) and the chapter five is about the conclusion and the recommendations about the study.

2 Chapter 2.0: Literature review

2.1 Introduction

The scope of sewage management has evolved throughout history with changes in socioeconomic conditions, city structures, and the environment. Today, sewage infrastructure that is well planned and operated supports urban sanitation and related activities. Effective sewage management is essential for nutrient recycling and for maintaining ecosystem integrity.

2.2 Definition of the sewerage concept

Sewage is an inevitable substance generated from the area where people exist.

Sewerage system is a sewer line (network) that conveys sewage or/and stormwater to the wastewater treatment plant or into the environment. In the 20^{th} developed world and some cities in the developing countries, sewers are pipelines that begin with pipes connected from buildings to one or more levels of larger underground horizontal mains, which terminate at sewage treatment facilities. The vertical pipes are called manholes and connected to the main surface. The sewages transport trough the sewer networks are generally done by gravity (Kumar, n.d.). Sewerage ends at the entry of the sewage treatment plant or the discharge point into the environment.

Sewage is a scientific term used for wastewater from houses, industries, stormwater from runoff and melting snow in an area.

2.3 Historical background of sewerage

Sewerage networks belong to the urban environment, therefore, in principle, they began with the urban revolution in 7000 BC when the first urban settlements were established. Numerous ancient civilizations, more precisely those situated in the Middle East, developed sewer and drainage networks for their sewage and stormwater collection in the populated area (Thorkild & All, 2013).

In the pass time sewage from houses and stormwater were easily managed. As they were considered as a reusable resource, their evacuation was far away from the agglomeration in either the sea or other water bodies until 1950 (M., Bruno And K., 2014). With global warming, the water is becoming scare, so scientists and engineers started looking the way of the reuse of water (treated sewage). At the world level, many countries have started implementing and using the centralized system in order to treat sewages before discharged them in the environment.

Nowadays with the rapid urbanization, sewage and sewerage management are becoming difficult mostly in the developing countries. (M., Bruno And K., 2014) argued that, from 1970, the rapid urbanization increased from 22% in 1950 to 75% in 1970 and influenced the sewerage. In fact, the rapid development of the cities' urbanization and their periphery has led to a sharp increase in the number of impervious surfaces. These surfaces considerably increased the volumes and the flows of the runoff thus, leading to insufficient outlets. This can lead to a progressive overload of existing networks and an increased risk of flooding.

In Africa the use of adequate sanitation and sewerage system is behind. Most of the sewer collection method is the traditional method (pit latrine, septic tank) and go through the environment after pre-treatment or none. Thus, the use of the collective sanitation which brought the subject of the sewerage network is less used in developing countries mostly in the Sub-Saharan Africa. In 2008, (WHO/UNICEF, 2008) reported that the projected coverage in improved sanitation in the western Africa was around 26% , 60% in the Southern Africa, where the Northern Africa was projected to 74%, 31% in Eastern African and 39% in Central Africa. Base on those numbers, northern African is the most developed in terms of sanitation infrastructure.

The universal safe and managed sanitation is 39%, the basic sanitation service is 29%, limited sanitation service is 8%. The unimproved sanitation service and open defecation are 12% each (WHO/UNICEF, 2017). The figure 2-1 shows the status of sanitation in the World.

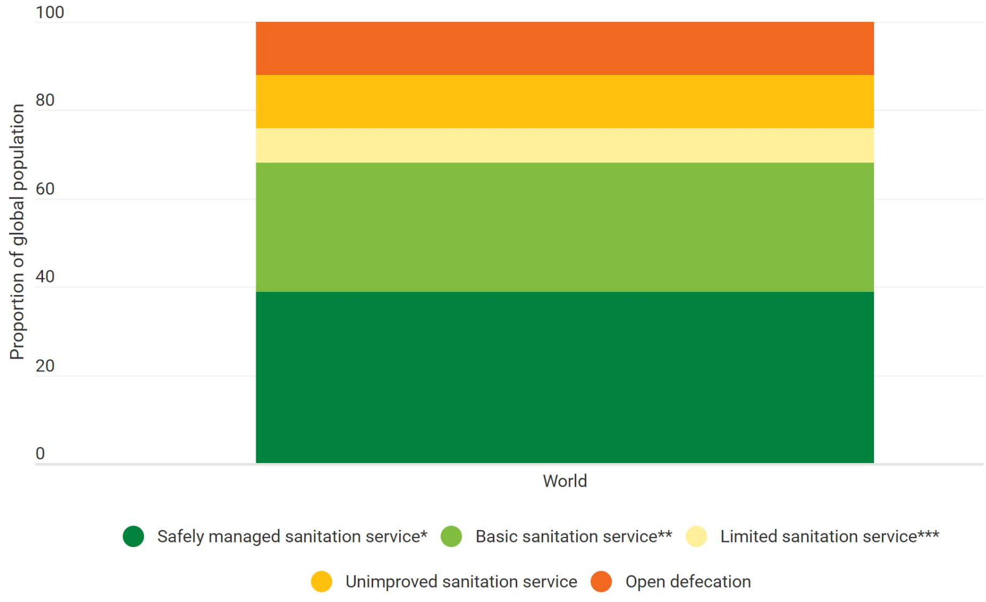

Figure 2-1: Status of sanitation in the World

Source: *WHO/UNICEF JMP Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG baseline*

2.3.1 Sanitation in Africa

Africa's sanitation is behind compare to some developed countries. In 2012, the World Bank was alarmed at the exorbitant economic impact on the continent because of the lack of sanitation: the shortcomings of this sector, which includes the evacuation of rainwater and the collection and treatment of wastewater would cost some 20 countries 1% to 2.5% of their annual GDP. That is, in total, nearly 4.2 billion euros, if taking into account only the direct health consequences on the populations (premature deaths, health expenses, etc.). And long-term effects that are more difficult to evaluate must add to this assessment, such as the appearance of epidemics, poor child development or environmental degradation (World Bank, 2012).

This poverty in adequate sanitation is a real burden for the health of the population. The lack of adequate sanitation infrastructure increases the risk of contact with excreta, which are often vectors of pathogenic organisms that are dangerous to human health.

In urban areas, most of the houses are not connected to a sewer system, but they are equipped with individual systems such as traditional latrines or pit latrines. Once filled, the pits are mechanically drained and their contents are rejected outside the city without any prior treatment. This type of management poses a health and environmental problem (Martin, 2006).

According to (WHO and UNICEF, 2000) every year, about four billion cases of diarrhoea cause 2.2 million deaths, most of them in children under five, which equals to one child dying every 15 seconds. The figure 2-2 shows the impact of sanitation on the health of the population.

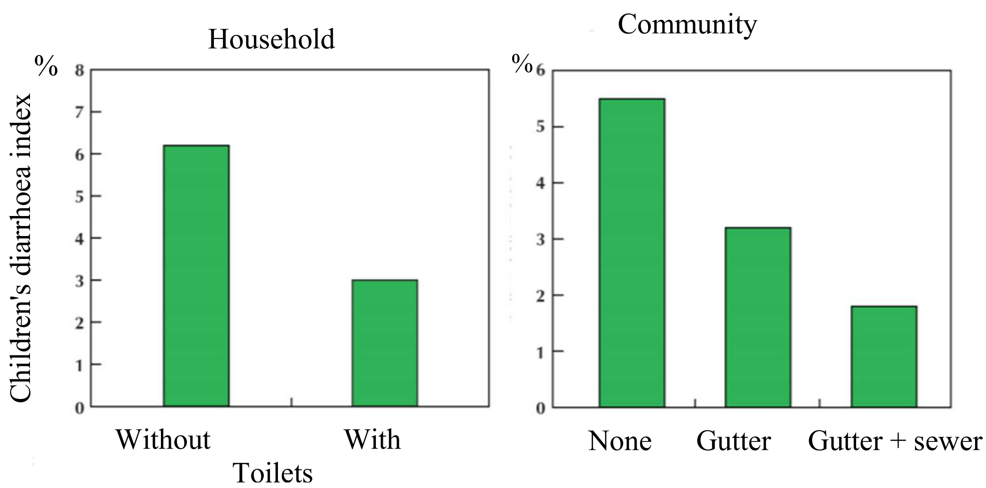

Figure 2-2: The impact of sanitation on the health of the population

Source: (Martin, 2006)

These deaths account for approximately 15% of all deaths of children under 5 in developing countries more precisely in Africa.

In sub-Saharan Africa, sanitation is essentially autonomous. The types of the said sanitation are described in the table 2-1. About half of both urban and rural population use traditional latrines. About 30% of the population use open defecation. This proportion is even higher in some countries. Improved types of latrine do not affect more than 20% of the global population. Curiously, the prevalence of improved latrines does not exceed the one of septic tanks, although there is a substantial cost difference between the two (Morella & All, 2008).

Table 2-1: Sanitation access type

	Open defecation	Traditional latrines	Improved Latrines	Septic tanks
Urban	**Percent %**			
	8	51	14	25
Rural	41	51	5	2
National	34	52	9	10

Source:(Morella & All, 2008)

2.3.2 Urban sewerage system in Ghana

Ghana like other sub-Sahara Africa countries' sanitation is one of the major developing issues. It is expected that increasing population in the rural and urban areas should be accompanied with corresponding expansion of sanitation facilities which could aptly deal with social and environment issues regarding sanitation.

A lot of efforts have been made to fight again poor sanitation in Ghana in the pass. However, the access to improved sanitation facilities at household level is about 15% (WHO/UNICEF, 2015) compared to the national target of 54%. Ghana has a very low coverage for wastewater and faecal sludge treatment (sewer systems). The national average of sewerage coverage is as low as 4.5% (UNICEF, 2016). According to (Osumanu and all, 2010), today in Ghana, around 50 percent of the population reside in the urban areas and only 18 percent have access to improved sanitation.

Shared toilet facilities considered as unimproved sanitation by JMP are actually the main sanitation facilities for Ghana populations. About 73% of urban dwellers rely on such facilities (public toilets and compounds toilets) (Mansour & Esseku, 2017). Most of the sewage collection system in Ghana are onsite technologies. Sewerage facilities serve a small fraction of urban populations. They are present only in three main cities of Ghana: Accra, Kumasi and Tema serving only a small percentage of the population.

2.4 Type and performance of urban sewerage network

There are several categories of the sewage collection systems. The classification of the sewerage refers to the types of sewage, the transport mode then the size and function of sewer (Thorkild & All, 2013). However, it is necessary relevant to consider these aspects when managing sewerage system. The sewerage collection system can be grouped in three main types citing below.

2.4.1 Combined sewer

Combined sewerages most commonly use, are buried underground and convey domestic sewage, stormwater and wastewater from industries in the same pipe to a centralized wastewater treatment plant. They are mostly in urban environment and do not require onsite pre-treatment of the wastewater. In combined sewer, manholes are installed in every change in slope.

2.4.2 Separate sewer

This type of sewage collection is in two assets, one called sanitary sewer system carries the domestique sewage and/or the industrial sewage and the second called storm collects stormwater from (rain water). The pipe of the stormwater is directly connected to the environment while the first asset pipes end in a wastewater treatment plant. The wastewater treatment plant design for type of sewer has a small size and the stormwater is carried through close or open drains.

2.4.3 Partially separate system

Here domestic sanitary sewage, industrial sewage and rain water from the roofs and back yards of the house are collected to the same pipe and the storm waters drain from streets, roads and house fronts.

2.5 Transport mode of sewage collection

According to (Thorkild & All, 2013), there are two main modes of sewage transport in the network: gravity sewers designed with sloping bottom and the flow discharge is done by gravity. Pressure sewers also named pumping sewers are carried the collection systems before treatment therefore anaerobic connection is require in this mode.

2.6 Sewerage management method

Like other water infrastructures, the sewerage system is among collective patrimony that contribute to the economic development of a city or town.

The management of the sewerage network is mostly difficult since its components are located underground. Sewerage networks management are very useful and helps to moderate the pollution of the environment. Although most of the sewerages in Africa are design as combined sewer which collect the sewage and storm water from some municipalities (hospitals, schools, industries), as mentioned before in houses individual sanitations are more applied.

The conventional and non-conventional sewer collection system are designed respectively for 30 and 15 years (Gabert, 2018).

The proper management of urban sewerage is linked with better understanding the causes of sewerage overflow. Nonetheless, the understanding of the sewer flow in the sewerage network is not simple in urban area. According to (Gabert, 2018), there are two main levels to consider when managing a sanitation service: firstly, the decision level which is under the responsibility of the actor who decides on the definition and management of sanitation service also enforces local regulations in this area, secondly, the operational level, this is under the responsibility of the actor who operates the service. It refers to the public or private operators that operate the drain service, the operation of a sewerage network or a treatment site.

2.6.1 Sanitation networks management asset

The sanitation rehabilitation / renewal policy is still sometimes a minimum policy, which is to address the most obvious failures of sanitation networks, including in large urban centres. This approach, however, takes increasingly sophisticated forms. The most elaborate and the most desirable being the patrimonial management of the network. The main aim of the approach of patrimonial management of the sanitation infrastructure is to minimize the debasement of all the asset related to the sewerage network.

Due to the its forecast nature, the patrimonial management of a sanitation network helps to fight:

- Against the presence of parasitic waters in the networks
- Against groundwater pollution due to infiltration.

All the above action goes to the regular renewal of the all dilapidated part of the infrastructures.

2.7 Sanitation management policy and institutional framework in Ghana

Ghana has a national Environmental Sanitation Policy (ESP) which was developed in May 1999 after consulting numerous stakeholders. It covers environmental sanitation broad including liquid and solid waste, stormwater drainage, environmental and hygiene education (MLGRD, 1999). A fairly document of sanitation management policy or environmental sanitation policy was set up by the Ministry of Local Government and Rural Development (MLGRD). The document highlights the basic principles and objectives, identifies roles and responsibilities, policies of environmental management and protection, legislation and funding among others. Based on (MLGRD, 1999), the purpose of the environmental sanitation is to develop and maintain clean and safe pleasant physical environment in all human settlements, to promote the social, economic and physical well-being of all sections of the population. It comprises a number of complementary activities, including the construction and maintenance of sanitary infrastructure, the provision of services, public education, community and individual action, regulation and legislation.

Ghana has a very extensive policy; institutional and legal frameworks address to waste management and environment protection. The successful management of water and sanitation infrastructures in any country depend on the effectiveness of the institutional arrangement elaborate by the government. Ghana has made efforts in dealing with sanitation problems. The table 2-2 captures some policy objectives and strategies for sanitation in Ghana.

Table 2-2: Policies and strategies for sanitation in Ghana

Policy objectives	*Strategies*
Accelerate the provision of adequate sanitation	❖ Promote the construction and use of domestic latrines ❖ Improve the treatment and disposal of waste in major towns and cities ❖ Enforce laws on the provision of sanitation facilities by landlords ❖ Promote widespread use of simplified sewerage systems in poor areas ❖ Improve the management of urban sewerage systems ❖ Improve household and institutional sanitation

	❖ Improve the treatment and disposal of waste in major towns and integrate hygiene education into water and sanitation delivery ❖ Rationalize and update District Assembly bye-laws on safe management of liquid and solid waste at the household level
Improve environmental sanitation	❖ Promote public-private partnership in the management of solid waste ❖ Build capacity of District Assemblies to better manage environmental sanitation.

Source: (Arthur & All, 2011)

2.7.1.1 Institutional structure

Ghana has in national level four ministries involve in sanitation management and environment protection. Ministry of Local Government and Rural Development (MLGRD) and Ministry of Water Resources Works and Housing (MWRWH) were the primary ministries involved in policy-making for water and sanitation, then follow up by the Ministry of Environment, Science and Technology (MEST) and the Ministry of health (Acheampong, 2010). The ministries are followed by the Metropolitan, Municipal and District Assemblies (Waste management department)

2.7.1.1.1 Ministries

- **Ministry of Local Government and Rural Development (MLGRD)**

Ministry of Local Government and Rural Development is lead as lead agency in the sector of sanitation. It has the duty of coordinating and formulating the environmental sanitation policy, issuing technical guidelines on environmental sanitation services and their management also supervising the National Environmental Sanitation Policy Coordinating Council (MLGRD, 1999).

- **Ministry of Water Resources Works and Housing (MWRWH)**

This ministry is the principal water sector ministry having in charge the overall water policy formulation, coordination, collaboration, planning, monitoring and evaluation for water supply (MLGRD, 2010).

- **Ministry of Environment, Science and Technology (MEST)**

The Ministry of Environment, Science and Technology assures the establishment of strong national scientific and technological base for accelerated sustainable development of the country. The overall objective of MEST is to ensure accelerated socio-economic development of the nation through the formulation of sound policies and a regulatory framework to promote the use of appropriate environmentally friendly, scientific and technological practices, techniques and the intensification of the application of safe and sound environmental practices.

- **Environmental Protection Agency (EPA)**

Environmental Protection Agency has been implemented as regulatory agency for environment protection and its functions are set out in the Environmental Protection Agency (EPA) Act, 1994 (Act 490) (MLGRD, 2010).

2.7.1.1.2 Metropolitan, Municipal and District Assemblies

This is the internal organization intended as a guide for the Assemblies. It is established for waste management coordination with others environmental sanitation aspects. The Assemblies carry out five distinct functions with respect to the sanitation such as:

- ✓ The waste management
- ✓ Environmental monitoring
- ✓ Provision of works related to environmental sanitation facilities
- ✓ Planning, monitoring and public relation
- ✓ Public health management

2.7.1.1.3 Private sector

Private sectors, communities and NGOs are among of environmental sanitation well-being institutional but work under the supervision of the public sectors especially the Metropolitan, Municipal and District Assemblies.

2.7.2 Status report on Ghana Sanitation (Ghana and the SDG6)

From reviews of literature, Ghana has achieved partially in 2015 the Millennium Development Goals 7 (MDG7) relative to water supply but did not meet the goal of access to improved sanitation. Proper water and sanitation are key for achieving the SDGs, including good health and gender equality.

(UN Communications Group & SDGs, 2017) argued in the Sustainable Development Goals (SDGs) in Ghana, statistics have shown that today, fewer than two in five Ghanaians drink safe water, two out of every five schools are without toilets, and three out of every five schools are without water supplies. Based on these statistics, it will be default for Ghana to achieve the SG6 in its integrality (UN Communications Group & SDGs, 2017). Ghana government and private sectors are doubling efforts for protecting the environment and the management of waste and wastewater. This study can be a support or contribution of the SDG6 more precisely in the management of the sanitation infrastructure of the KNUST campus.

2.7.3 Condition of the existing sewerage network and the wastewater treatment plant

The existing sewerage network of the institute is designed to collect all the sewage from student's campus and the university then treat it in its wastewater treatment plant. The network as well as the plant have been implementing from 1967 still toady (2019). The condition of the existing wastewater plant is not in good shape, according to (FOSU, 2009) it is not in operation. The wastewater treatment plant of the university faces some maintenance problem, but it is functioning today. These challenges do not affect the network, the network functions twenty for hours. The sewerage network of KNUST university collects only blackwater of the campus. The below figures demonstrate the WWTP and a part of it network.

Figure 2-3: KNUST's sewerage network and plant

Source: Author, April 2019

2.8 Flow calculation analysis

It is very important to know the flow of the sewer network to ensure in good management. For each type of sewers systems, there are some specific flow which are carefully taking into account. However, to better management every type of sewer system the daily average flow as well as the peak flow are obligatory to be known. The rainfall intensity has to be known to do the simulation and scenarios base on some return periods of the rain. Two methods exist to calculate the flow rate of the sewage: the superficial method called (CAQUOT method) used for the catchment with the area less than one hectare and the rational method. The runoff coefficient is an important parameter in the flow calculation, it is generally assumed as the coefficient of impermeabilization. The runoff coefficient depends from one catchment to another one depending on the type of the soil and the land use of that catchment.

2.9 Sewerage network simulation model in urban area

The simulation of the sewerage network helps to understand the behaviour of the network during certain scenarios such as the saturation of the network due the increased in the urbanization, heavy rainfall by choosing some return period etc.

Several models exist to do the simulation of the sewerage network, among them, there are MOUSE and Mike Urban for the simulation of the sewerage network in small and big city, Storm Water Management Model (SWMM), CANOE, HEC-1, HEC-RAS, Sewer CAD, Storm CAD etc.

2.9.1 CANOE

CANOE is a multifunctional software developed in France by the "Laboratoire de Génie Civil d'Ingénierie Environmentale" (LGCIE) or Civil Engineering laboratory. It is based on data management system and provide a unique tool that can be applied to a wide range of tasks such as the diagnostic studies, simulation of the pollutant discharge and the design of the sewerage network. It has GIS database interface and it uses a system of databases characterize into three types: structural data (project), libraries of hydrometric data (rainfall) and catalogue of Engineering structure (transport).

2.9.2 HEC-RAS

HEC-RAS stands Hydrologic Engineering Centres River Analysis System is US Army Corps of Engineers. It is an integrated system of software, designed for interactive use in a multi-tasking environment.

It is widely used for flood profile calculation. HEC-RAS is one dimensional hydraulic calculation for full network of constructed and natural channels use also to analyse and design the drainage system. The momentum equation is used in HEC-RAS when the surface profile is rapidly varied (Sunil Thosainge, 2000).

2.9.3 Sewer CAD

Sewer CAD developed by Bentley, is a software for designing new networks, or sections of an existing network, by taken in consideration the speeds, the slopes, the depth, and the data of the corresponding pipes and manholes.

Sewer CAD is a powerful design and analysis of flow gravity and pressure program through pipe networks and pumping stations. It is flexible and can be used in all phase of a project. Sewer CAD is a sanitary sewer modelling and design software use to model both pressurized force mains and gravity hydraulics with ease, using steady-state analysis with various standard peaking factors, and extended-period simulations.

2.9.4 SWMM or EPASWMM

The Storm Water Management Model (SWWM) has been developed by the United States Environmental Protection Agency (US-EPA). It is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas (Rossman, 2015). SWMM is among the numerous hydrological models created in 1970 and has undergone several major upgrades since then. SWMM accounts for various hydrologic processes that produce runoff from urban area. It also contains a flexible set of hydraulic modelling capabilities used to route runoff and external inflows through a drainage system network of pipes, channels, storage, treatment units and diversion structures (U. M. Shamsi, 2005). It is widely used throughout the world for planning, analysis and design linked to storm water runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well (Hussein A Obaid & All, 2014).

The Storm Water Management Model is a most recent and successful software in wastewater environment. It is a user-friendly due to its capability of hydrologic and hydraulic modelling of sewer system. Its hydraulic flexibility allows to handle the network with unlimited size. SWMM is a very good design, sizing, the drainage system for flood control. It is recommended, when designing control strategies for minimizing combined sewer overflows also when evaluating the impact of inflow and infiltration on sanitary sewer overflows.

SWMM represents catchments mathematically as spatially lumped, no linear reservoirs and the outflow are routed via channel or pipe. It subdivides the catchments into sub-catchment and generates the overflow from each of them as nonlinear reservoirs. Continuity and Manning's equations are combined to establish the nonlinear reservoir (Sunil Thosainge, 2000).

There is several sewer system modelling software but most of then take into account the quantitative aspect of the sewage while SWMM and MOUSE use both the quantitative and the qualitative aspects of the pollutant.

2.9.5 Mike MOUSE

MOUSE stands MOdel for Urban SEwer, is Danish Hydraulic Institute (DHI) software. It is a powerful and comprehensive engine for modelling complex hydrology, advanced hydraulics in both open and closed conduits, water quality and sediment transport for urban drainage systems, storm water sewers and sanitary sewers (DHI, 2017).

The hydrologic part has two methods of runoff simulation: a simple method based on time area diagram and a complex method focus on kinematic wave theory and continuity equation.

The hydraulic part of the model does the simulation of the flow routing in closed conduits or open channels. MOUSE has three option to compute the depth and the velocity of flow: the kinematic wave method mostly applied to part full flow conditions, the diffusive wave method for backwater and surcharge in the systems and the dynamic wave method, for full hydrodynamic solution. MOUSE, like SWMM, is well-suited for analysing the hydraulic performance of complex looped sewer systems including overflows, storage basins and pumping stations. Water quality modelling and prediction is also included in the MOUSE model (Sunil Thosainge, 2000).

2.10 Model Selection

The selection of the model is important in any statistical analysis which a centre of the scientific researches. Various models have been used by scientists to manage the sewerage network. In this study ArcGIS is coupled with a hydraulic model (Mike MOUSE).

2.10.1 Why MOUSE?

As highlighted early, MOUSE is a powerful hydrologic and hydrological modelling software. It has a user-friendly interface and it is adapted to all size, all type of sewerage.

MOUSE owes its exceptional power to the advanced software implementation techniques. And finally, it is the reliability of MOUSE, tested and proven in great many applications since the late 70s by more than one thousand users all around the world, which makes MOUSE the perfect choice (DHI, 2017).

Mike MOUSE is integration of MOUSE in Mike Urban software. It has the same workspace as MOUSE. As MOUSE, Mike Urban is integrated with ArcGIS 9.3. So, as in this work ArcGIS will be coupled with Mouse, and Mike Urban has both of them inside, therefore, the interchange will not be a problem.

2.10.2 GIS application in the sewer system

Geographic Information system (GIS) is used to manage, to analyse and to display a geographic information (ESRI, 2004). GIS provides a consistent environment for viewing of the display model and the input/output data results. This ability is very useful in the decision-making process (https://link.springer.com/article/10.1007%2Fs13201-016-0416-1). GIS applications have the potential to enhance the management of the water, wastewater, and stormwater systems and prepare them for the operational challenges of the 21st century (U. M. Shamsi, 2005).

ArcGIS is one of the GIS application very use in mapping. ArcGIS Desktop is an integrated suite of advance GIS application. It has a series of windows desktop application such as ArcMap, ArcCatalog, Arc Toolbox and Arc Globe with user interface components (ESRI, 2004).

The application of GIS in the sewer system is done by performing hydraulic and hydrological modelling of the sewer collection system. This process passes by the delineation of the watershed, sewer-shed, and tributary drainage areas of the study area. According to (U. M. Shamsi, 2005), three application methods are used in GIS applications in sewer system interchange, interface, and integration. These methods facilitate preparation of model-input data and mapping of model output results. GIS gives key decision capabilities in disaster management. In mapping, monitoring maintenance and modelling sewer system, GIS helps professionals.

2.10.3 Linkage of GIS with sewer system modelling (H&H) model

From the review of the literature, the coupling of GIS and H&H model are done by using three application methods: interchange, interface, and integration.

- **Interchange**

According to (U. S. Shamsi & Smith, 1969), the interchange method employs a batch process approach to transfer data between a GIS and an H&H model.

- **Interface**

The interface method provides a direct link to transfer information between the GIS and the model. The interface method can be used as

- ❖ A pre-processor: It analyses and exports the GIS data to model input files; and as
- ❖ A post-processor, which imports the model output and displays it as a GIS layer.

➢ **integration**

The integration of GIS is a combination of a model and GIS software. The combined program offers both the modelling functions and the GIS. The integration method is a closest relationship between the GIS and the model. Nowadays, the most common method used is the interface method. It was used to develop a linkage between SWMM5 and ArcGIS (U. S. Shamsi & Smith, 1969).

Data transfer between GIS and sewer model is handled by different software vendors. In some software nothing than cut and-paste approach are used for the data transfer between a GIS and the model while in others software a truly integrated package can be found. The below table highlights some sewer system modelling software and their linkage method with GIS.

Table 2-3: GIS linkage with some Sewer system modelling

Software	GIS linkage method	Vendor	Web Site
SWMM	Interchange	U.S. Environmental Protection Agency (EPA)	www.epa.gov/ceampubl/ swater/swmm/index.htm
CEDRA AVSand	Integration	CEDRA Corporation	www.cedra.com
H_2OMAP Sewer H_2OVIEW Sewer	Interface and Integration	MWH Soft	www.mwhsoft.com
Info Works CS and Info Net	Interface and Integration	Wallingford Software	www.wallingfordsoftware.com
Mouse GM and MIKE SWMM	Interface	DHI Water and Environment	www.dhisoftware.com
PCSWMM GIS	Integration	Computational Hydraulics Int.	www.computationalhydraulics.com
Storm CAD and Sewer CAD	Interface	Haestad Methods	www.haestad.com
XP-SWMM	Interchange	XP-Software	www.xpsoftware.com

	and Interface

Source: (U. M. Shamsi, 2005)

2.10.4 MOUSE selection

MOUSE has been selected for this study because of its combability with the methodology of the study. The typical applications of MOUSE include:

- Studied of combined and sanitary sewer overflows (CSOs and SSOs) and complex Real Time Control (RTC) schemes development and analysis,
- Design of new site developments, regulatory consenting procedures and analysis & diagnosis of existing storm water and sanitary sewer systems (DHI, 2017),
- Flood plain mapping of natural channel systems
- Evaluating Best Management Practice (BMP) and Low Impact Development (LID) options for sustainability goals and green infrastructure. The below table (Table 2-4) explains more the reason.

Table 2-4:Justification of MOUSE selection

	MOUSE	SWMM	Sewer CAD	HEC-RAS	CANOE
Network routing	• Kinematic wave, • Diffusive wave, • Dynamic wave • Horton infiltration model	• Kinematic wave • Green-Ampt • Saint Venant (hydraulic) • SCS method • Horton method • Steady Flow Routing (hydraulic)	-	• Saint Venant • One dimensional energy conservation equation	• Saint Venant, • Muskingum
Modelling capacity	• Modelling of water quality processes in the collectors, • Simulates in wetted and dry period	• Conducts more detailed studies in sewerage infrastructures management, • Small and big size of sewerage	• Profile of the network in gravity and pressure, • Gives a cost-effective solution for collector's sizes, • Do scenarios before given the solution	• able to model channels network, dendritic hydrographic system, • hydraulic simulation	• Contains an internal database of types of pipes and rains • Takes into account the flow (works with big flow rate)

			about the network		
Capability to analyse sewage quality	yes	Yes	No	Yes	Yes
Ability to link to databases of other software	Yes	No	Yes	Yes	Yes
Linkage with Geographic Information Systems (GIS)	Yes	Yes	No	Yes	Yes
Scenario management capabilities	No	No	No	No	No
Windows environment	Yes	Yes	Yes	Yes	Yes
Clear annotation of model components	Yes	Yes	Yes	Yes	Yes
Layout capabilities	Yes	Yes	Yes	Yes	Yes
Graphics/ Profiling System Components/ Model Results	Yes	Yes	Yes	Yes	Yes

Source: Author's construct, April, 2019

2.11 Summary of the review

As summary, sanitation infrastructures are inadequately managed in Africa. The fact that most of the sewer collection systems are individualized, the management is a lot of challenges, most of the sewage are reject in the environment without any treatment. Concerning the sewerage network most of them have to be rehabilitated and need serious operation and maintenance work. In addition, the challenge associated with achieving the environment protection, water scarcity and safe drinking water and adequate sanitation of all by the growth of the population and climate change, its implementation have to be highlighted. The cause of numerous floods occurs overall the world but more precisely in Sub Saharan Africa are the aftermath of the worst management of sewage infrastructures.

- There is gap in the collection system of sewage in developing countries. This is the result of the discharge of wastewater in the environment without any prior treatment which is creating negative impact of both the sanitary condition and the deterioration of the environment.
- The design and the management of the sewerage network are not well done. Most the network are of storm water in African countries are open and their data are not available.

3 Chapter three: Methodology

3.1 Introduction

This part of the research indicates the location of the study area and its characteristics. It covers the background of the network of Kwame Nkrumah University of Science and Technology (KNUST), the methodology of the work, some calculation and how data collection has been done.

3.2 Description of the study area

Kwame Nkrumah University of Science and Technology (KNUST) is the largest university of Kumasi Metropolis, the capital of Ashanti region. Kumasi is located in the southern central part of Ghana. It is on the latitude 6° 41′ 19″ North, and the longitude 1° 37′ 28″ West. In 2010, Kumasi had a population of 1,73 million and an area approximately 254 km^2 (United Nations Organization, 2010). Kumasi is watered by several water bodies, among them WIWI river crossing KNUST university.

KNUST university as highlighted earlier, is a largest university of the Metropolis of Kumasi having more than 42 thousand students. Thereby the university is verbally divided into zones: campus area (students' residences), faculty area (school, university and their component) and commercial area (Mall, Bank…) and so on. The university has its own wastewater treatment plant (WWTP) treating the liquid waste from some halls of the campus (campus), some bloc of the faculty area and commercial area. The plant receives all the black water generated in those halls of residence and an unknown amount of the grey water join go to the plant through the sewer line (Awuah & All, 2014).

3.2.1 Location

This research was conducted in the Kwame Nkrumah University of Science and Technology, one of the biggest universities of Ghana. KNUST lies between latitude 6°41′5.67″ N and between longitude 1°34′13.87″W. Kwame Nkrumah University of Science and Technology is a public university of Ghana. It was established in the country in 1952 years and had a population of 42,590 students in 2016 https://yen.com.gh/115713-knust-admission-list-2018-2019.html#115713. The University is situated approximately on a sixteen square-kilometre (16km^2) campus of undulating land and pleasant surroundings, about seven kilometres away from the central business district of the city of Kumasi. The campus presents a panorama of beautiful and modern buildings interspersed with verdant lawns and tropical flora. It has a lot of hostels within and in its surrounding. The map of the figure 3-1 is the study area (KNUST) location's map.

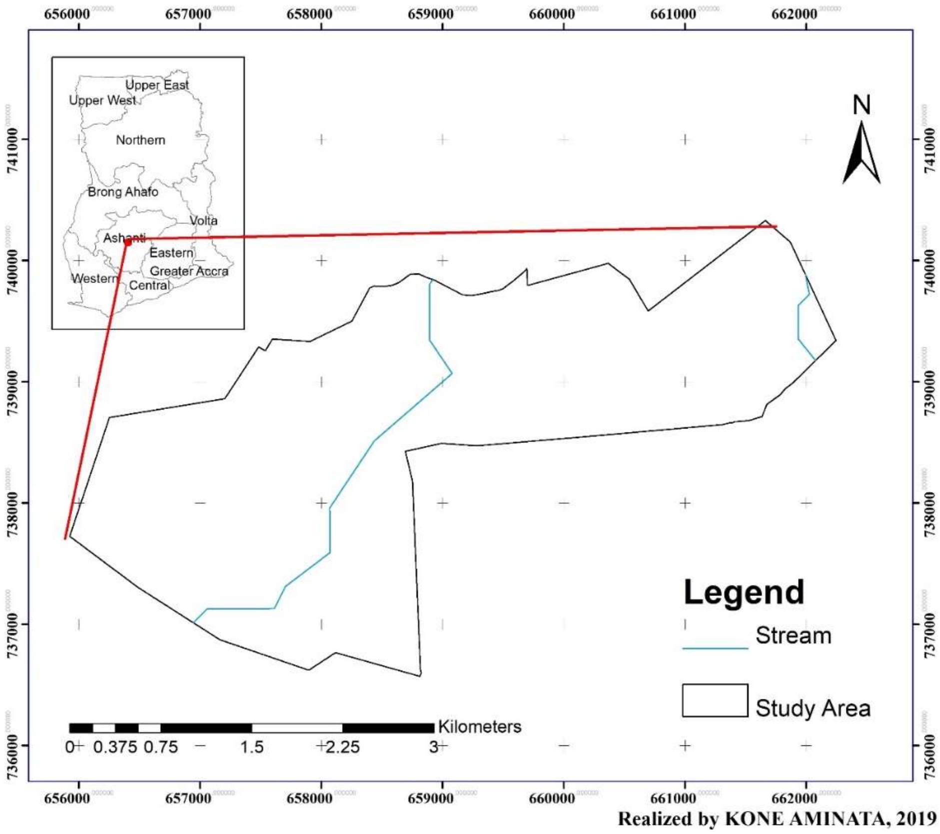

Figure 3-1: Study area Map

3.2.2 Background of the Sewage treatment plant and the sewerage network

KNUST wastewater treatment plant have been existed since 1967. From its construction period, the plant was treating the wastewater from about 700 students living in the campus area (FOSU, 2009). With the increased in urbanization, in 2009 the plant was receiving the sewage of 25 000 people from the campus including students, workers, lectures and their families. The student population living officially on campus was estimated to 30% of the 20 000 students. Unofficially, the population was rose about 60% of the 20 000 students (FOSU, 2009).
From is construction till, the sewerage network had some broken and has been rehabilitated. It is still treating the sewage of the old buildings of the university.

The wastewater treatment plan of KNUST university is a conventional type trickling filter. Its sewages are transported through pipes while the stormwater and the sullage are channelled through an open drain into the WIWI river. WIWI has within plenty streets which treatment naturally the stormwater and the grey water of the university by removing the heavy metals before it goes to the downstream. A layout of the WWTP is given by the figure 3-2.

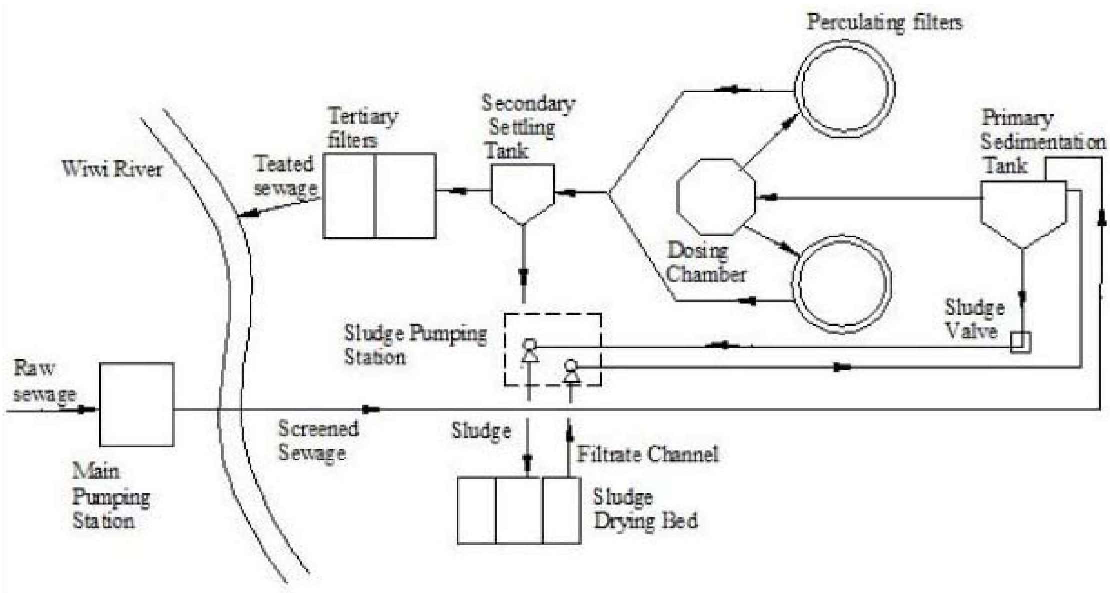

Figure 3-2: Layout of KNUST sewage treatment plant

Source:(Richard & Brew-Hammond, 2010)

Not all the facilities on campus are linked to the central sewage system (Richard & Brew-Hammond, 2010). All the sewages of the connected facilities are collected in the main pumping station then they go into the wastewater treatment plan. The sewerage collection method of the university and the facilities connected to its sewerage are as the figure 3-3 below shows.

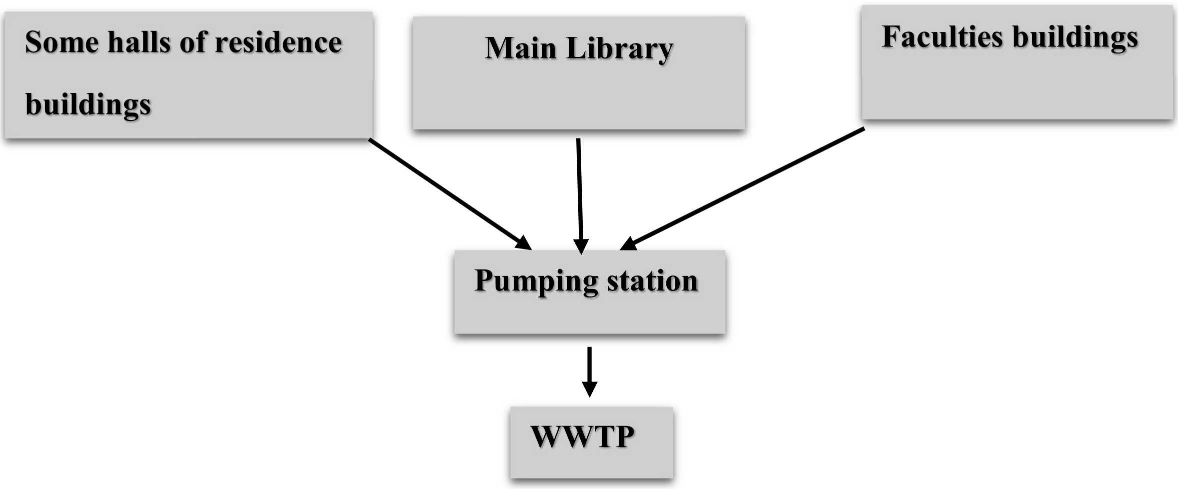

Figure 3-3: Outlook of the KNUST sewage collection system

Source:(Richard & Brew-Hammond, 2010)

The main sewage pipes connecting facilities on the university campus feed the main pumping station at the entrance of the treatment plant. KNUST's WWTP treats thus typical domestic wastewater coming from bathroom and kitchen sources. There are no large-scale industries connection systems within the catchment area of the plant.

The facilities which are not connected to the sewer line have their own septic tank for their wastewater collection. Some of them after septage are discharge into the main sewer collection point of the sewerage network then treatment by the wastewater treatment plant.

3.2.3 Climate

Kumasi Metropolis is characterized by the sub-equatorial climate type. The climate is tropical and has two seasons (wet and dry season), with relatively constant temperatures throughout the year. The average temperature of the city is 26.3°C, it becomes highest on average in March, at around 27.9 °C. The lowest average temperatures in the year occur in August, when it is around 24.4 °C. The average annual rainfall is 1448 mm. The variation in the precipitation between the driest and wettest months is 198 mm. The variation in temperatures throughout the year is 3.5 °C (Climate-Data.org). All the above interpretations are shown on the Figure 3-4.

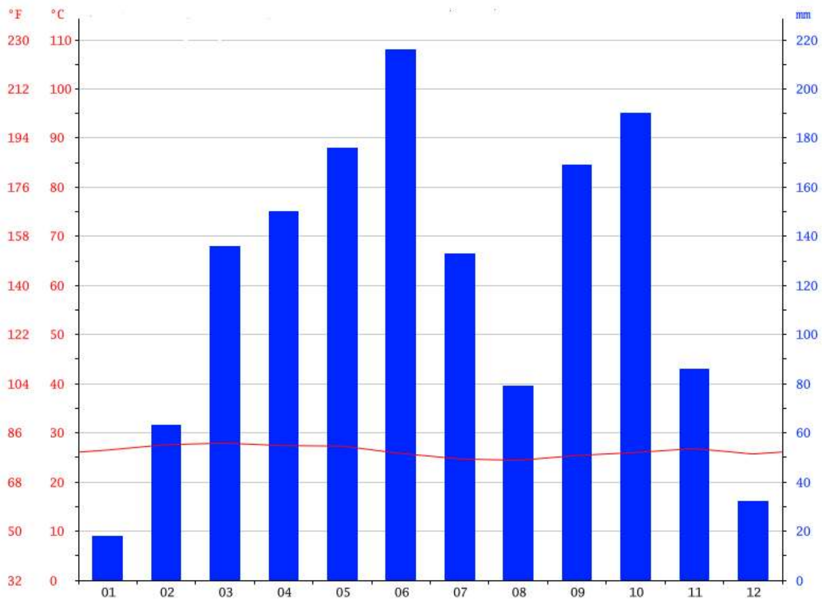

Figure 3-4: Climate variation of the Kumasi Metropol

Source: Climate-Data.org

3.3 Methodology

Planning a sanitation network requires a large amount of structural and phenomenological data. Therefore, the method use in this study is composed of several step that will be realized stepwise using different software tools and method. It is based on field visit to better understand the site, the collect of data and the use of software to achieve the research objectives. A GPS was used to collect the coordinate of the manholes connected to the sewer line and a questionnaire was used to felicitate the writing of the research. Add to all that information, the master plan of the university, spatial data of the existing network were also used for the work.

3.3.1 Data collection

To address the research objectives, both primary and secondary data were collected. Each specific objective had its key methods. The figure 3-5 represents the flowchart of each objective and their linkage to primary and/or secondary data.

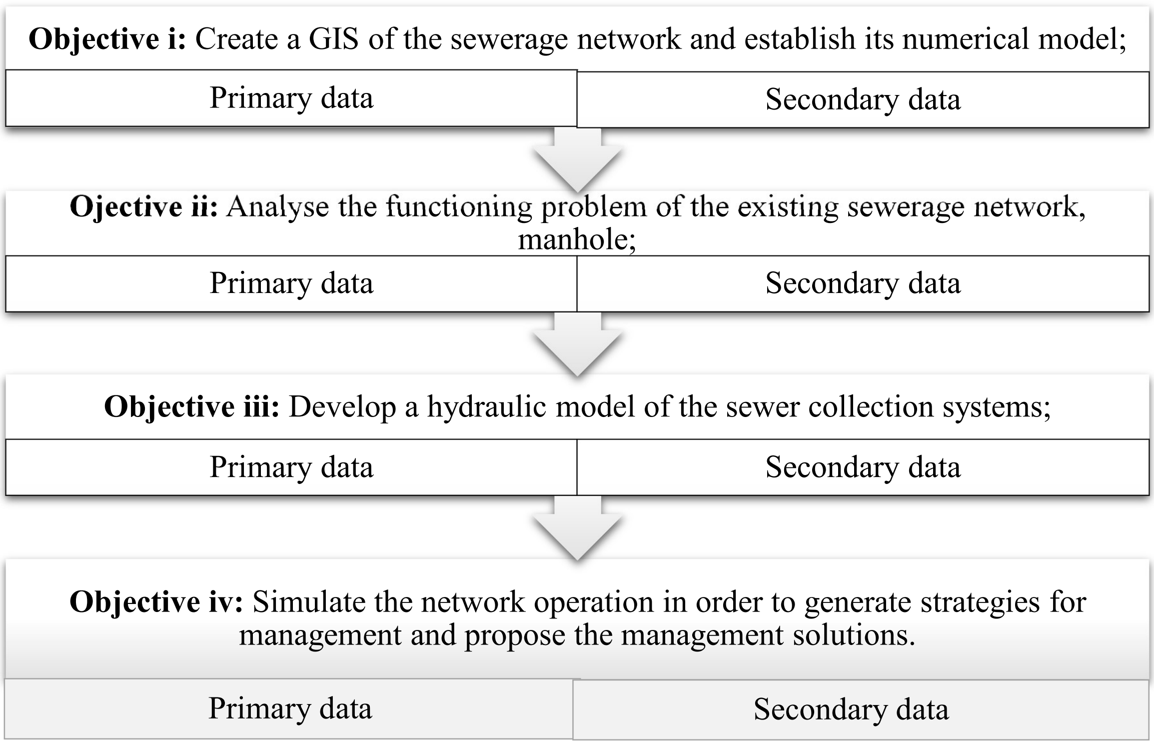

Figure 3-5: flowchart of each objective and the link with primary and/or secondary data

Source: Author's construct, May, 2019

3.3.1.1 Primary data

The present study goes through the process of the geodatabase elaboration and the management of the sewerage. This involved the necessity to compile comprehensive inventories of so many documents related to the sewerage network.

Primary data were collected from the field work. A GPS was used to take the coordinates of some manholes connected to the sewer line. A questionnaire was addressed to the to the Chief of the wastewater treatment plant about to the age, length and diameter of the pipes as well as the manholes depth and age. The primary data helped the achievement of most of the objectives of this study.

3.3.1.2 Secondary data

Secondary data were gathered from existing literature related to the research topic such as from published and non-published papers, reports and databases. These data comprise the meteorological data, the information related to the university as well as the sewerage network (the existing network of the sewerage, master plan of the university) and others parameters such as the institution in charge of the well governance of the sanitation and environment protection in Ghana. The below table summarized the overall of data collection method including the sources.

Table 3-1: Summary of primary and secondary collection system and sources

Categories	*Data*	*Method and sources*
Primary data	▪ Coordinate of the sewerage network and its components; ▪ Number of buildings linked to the sewerage network, the age of the network (pipes,) as well as the manholes also the length of the conduct and the depth of the manholes, ▪ The behaviour of the network and its components.	Field work and questionnaires

Secondary data	▪ Existing master plan of the sewerage network. ▪ Meteorological data (temperature, rainfall; ▪ Master plan of the study area as well as the topographical map; ▪ Institution structure of sanitation and environment protection in Ghana.	Document and database from the physical department and geomatic of Kwame Nkrumah University of Science and Technology, the wastewater treatment plant; Published and non-published papers;

Source: Author's construct, May, 2019

3.3.2 Data processing and analysis

The data obtained were analysed in several ways:

- The obtained GPS coordinates were analysed using Microsoft Excel.
- Microsoft Excel was used to do the calculation of the average, peak flow and the performances indicators as well as the drawing of the graph pattern and trends.
- ArcGIS software version 10.5 and the ArcGIS version 9.3 of Mike Urban were used for the mapping and the establishment of the GIS of the sewerage network as well as some calculations such as the sections of the network and the classification of the diameters and so forth.
- Finally, MOUSE software was used to establish the hydraulic model of the sewer collectors and to do the simulation of to the network.

3.3.3 Sewage flow rate estimation

The estimation of the flow rate was based on multistep analysis of the population and the connection rate to the facilities.

3.3.3.1 Population

The information of the connected facilities' population to the wastewater treatment plant was used for the determination of the sewage flow rate. The population was estimate base on the number of room and their occupancy in each building of the hostel and bloc also the lecture bungalows. The figure 3-6 shows the population of the facilities connected to the Plant. The number of populations of the faculty area was done through some estimation since it contains students staying in the residential accommodation and students staying outside. An additional 30% of the population has been added to the total population taking into account the visitors and the unknown population of certain connected facilities to the sewer line.

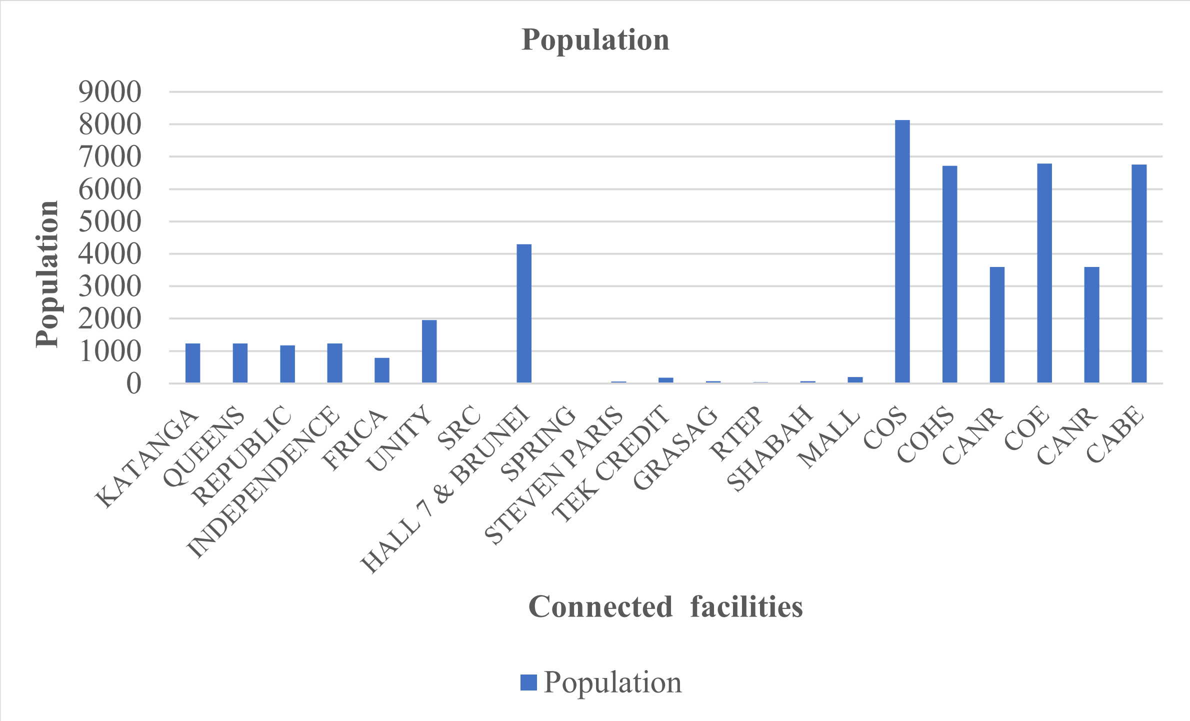

Figure 3-6: Estimate population of connected facilities to the network

Source: Author's construct, July, 2019

The flowrate was estimated by taking into account the type of the population and the location of the facilities. The average flowrate of the sewage in the campus area was calculated with 120 litre per day per inhabitant as endowment while 80 litre per day per inhabitant were taken in the faculty area. The flowrate has been calculated using the below formula.

$$\textbf{\textit{Domestic need}} = \mathbf{P} * \mathbf{E} \qquad (1)$$

Source : UA Béthune-Formulaire dule assainissement urbain

E	endowment
P	the total population

30% was added to the equation (1) for water in the supply loss assumption. Therefore, all these steps allowed to calculated the daily average flowrate, given by the equation (2).

$$Q_{average/day} = \textbf{Domestic need} * 1.3 \qquad (2)$$

Source: https://www.ssc.wisc.edu › ~ekelly › econ101

The supply peak flow was obtained using the equation (3), multiplying the daily average flowrate by the peak flow coefficient Cp.

$$Q_{P\ supply} = Q_{average/day} * C_p \qquad (3)$$

Source : UA Béthune-Formulaire dule assainissement urbain

C_p is the peak flow coefficient

$$C_p = 1.5 + \frac{2.5}{\sqrt{Q_{average}}} \qquad (4)$$

Source : UA Béthune-Formulaire dule assainissement urbain

The value of C_p is between 1.5 and 4.

The peak flow generate from KNUST has been obtained using the below formula.

$$Q_{P\ reject} = Q_{P\ supply} * 80\% \qquad (5)$$

Source: https://www.ssc.wisc.edu › ~ekelly › econ101

The quantity of wastewater generates from KNUST comes just from a section of the areas that are connected to the sewer line. The wastewater from some buildings are collected by the septic tank and are periodically discharged by septage and are discharged into the environment.

3.3.4 Cartography of the network with ArcGIS

The mapping started by looking at the spatial view of the collected manholes on google Earth as shown in the figure 3-7. The picked manholes coordinate was then imported into ArcMap to institute the drawing of the network. The mapping of the network has been done by firstly creating the geodatabase using ArcCatalog.

ArcCatalog is an ArcGIS component. It has the tools that organize, use, and manage the information in the workspaces and geodatabases. The workspaces are simply folders on the disk used to organize the work on GIS: maps, images and other data files, geoprocessing models, layers, geodatabases and so on.

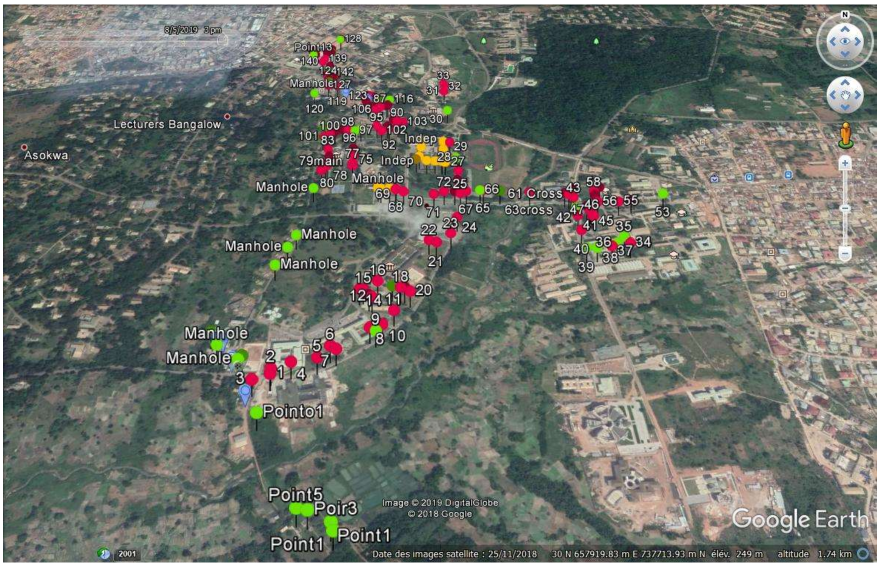

Figure 3-7: Spatial view of the manholes

Source: Author construct, May 2019

3.3.4.1 Geodatabase creation

The geodatabases are a basic geographical data set with several types. The figure 3-8 illustrates the created geodatabases related to this work. The geodatabase provides a simple way to organize and share GIS information sets.

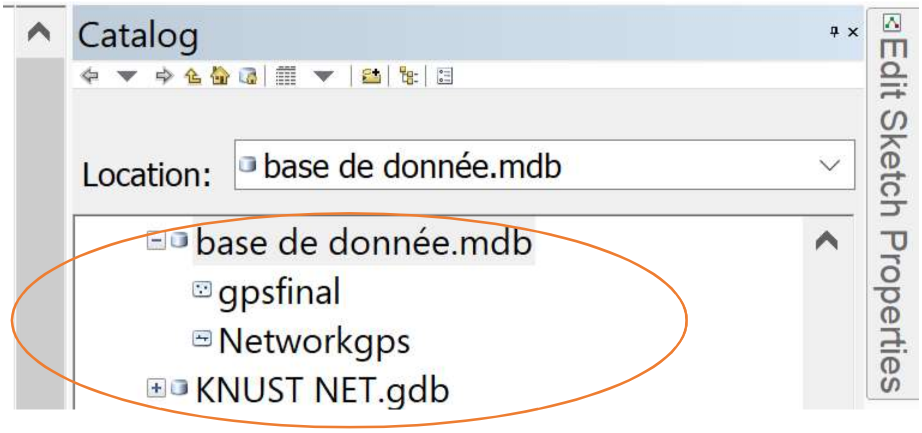

Figure 3-8: Created geodatabase

Source: Author's construct, July, 2019

3.3.4.2 Attribute table

The attribute table is composed of the rows and the columns. The tabular information is the basis for any geographic features that allows to view, query, and analyse data.

The table 3-2 represents some the KNUST sewerage network GIS tabular information. The components of some rows have been calculated using “field calculator” and some of the them have been filed manually using the editor tools.

Table 3-2: Attribute table of the network in ArcGIS

Table

Networkgps

FID	Shape *	Length	Diameter	Type_of__1
0	Polyline	85	600	PVC
1	Polyline	23	600	PVC
2	Polyline	5	600	PVC
3	Polyline	14	600	PVC
4	Polyline	128	600	Iron cast
5	Polyline	68	600	Iron cast
6	Polyline	23	600	Iron cast
7	Polyline	43	600	Iron cast
8	Polyline	138	600	Iron cast
9	Polyline	87	600	Iron cast
10	Polyline	256	600	Iron cast
11	Polyline	222	600	Iron cast
12	Polyline	232	600	Iron cast
13	Polyline	300	600	Iron cast
14	Polyline	215	600	Iron cast
15	Polyline	92	600	Iron cast
16	Polyline	77	600	Iron cast

Source: Author’s construct, July, 2019

3.3.4.3 Creation of the manholes

The creation of the manholes has been facilitated by inserting the GPS coordinates on ArcMap. This gives the latitude, longitude and altitudes (x, y, z) of the manholes or inspection chamber. The figure 3-9 shows the created manholes and pipes of the study area after the overlay with the master plant of the KNUST. The presence of the manholes on the sewer pipeline is obligatory, they assure sewage collection and convey, therefore they have to be seen on the pipeline. The manholes minimize the topographical errors.

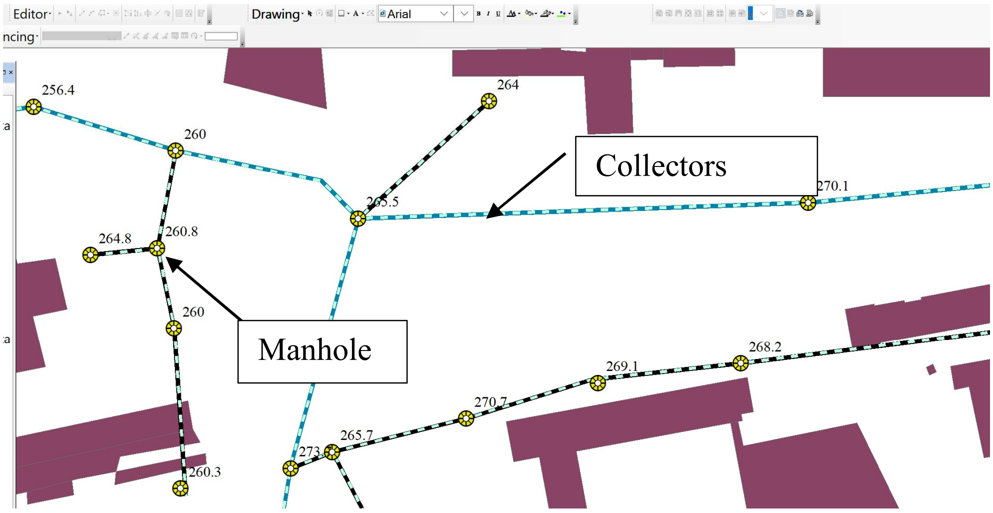

Figure 3-9: Location of the manholes on the collectors

Source: Author's construct, July, 2019

It has to be known that all the mapping has been done using ArcGIS software and his components. The network was imported to the Mike MOUSE for other planning, diagnostic and then simulation.

The network was overlay with the spatial image of the study area after planning and diagnostic. The figure 3-10 is the overlay of the network and the spatial image of KNUST.

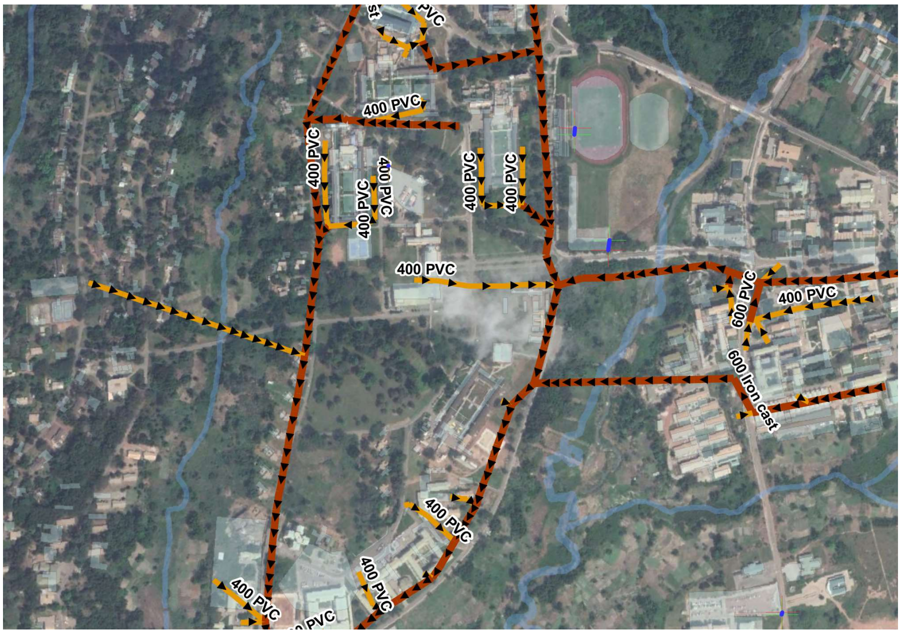

Figure 3-10: The sewerage network overlay with a spatial image

Source: Author's construct, July, 2019

3.3.5 Mike MOUSE

After the cartography with ArcGIS, an importation of the network from the ArcMap to the Mike MOUSE software was the next process. With MOUSE, a planning of the network was launched before the creation of the hydraulic profile and the simulation. The diagnostic goes to the creation of the additional manholes the tool link then split. The split tool allows to divide the conduct between two manholes by adding the additional manholes. The figure 3-11 is the picture of the split network and in beside the before network. The neighbour manholes were interpolated.

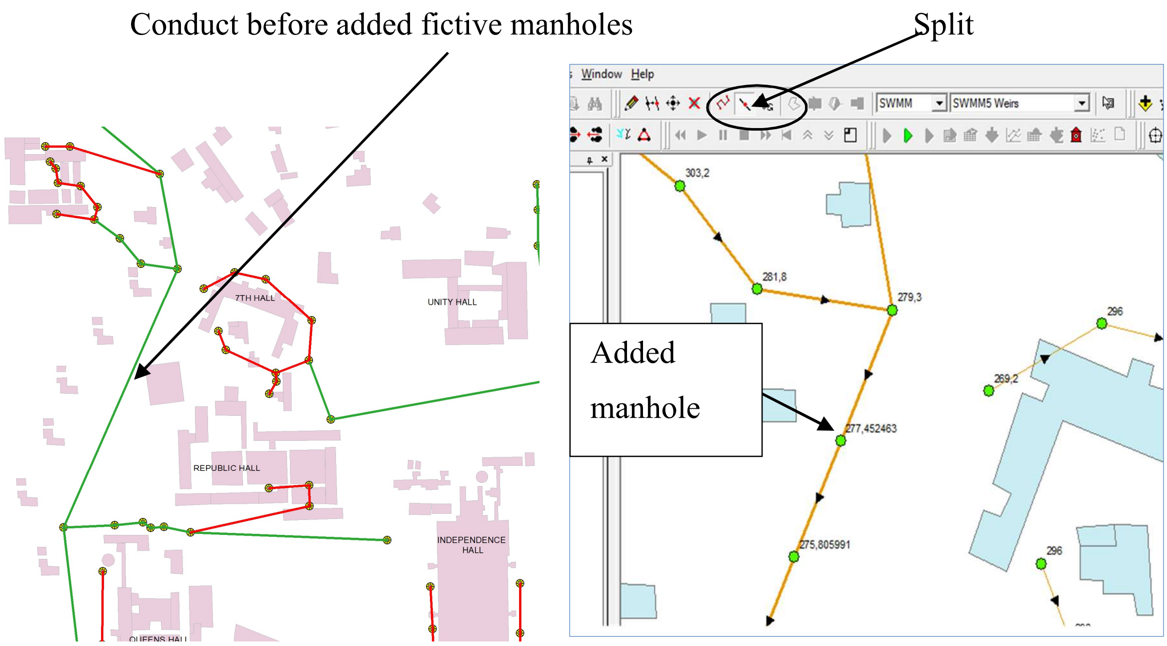

Figure 3-11: The network before and after created additional manholes

Source: Author's construct, July, 2019

3.3.5.1 Sub catchment

The hydrological function of MOUSE allows to divide the study area catchment into sub catchment to know the amount of sewage that goes to each sub catchment. The sub catchments were drawn taking into consideration the manholes. A geocoding system links the conducts to the created sub catchment. This subdivide the catchment of the study area into 47 sub catchments shown in the figure 3-12. The annex 5 represents the plant of the 47 sub catchments in the study area catchment.

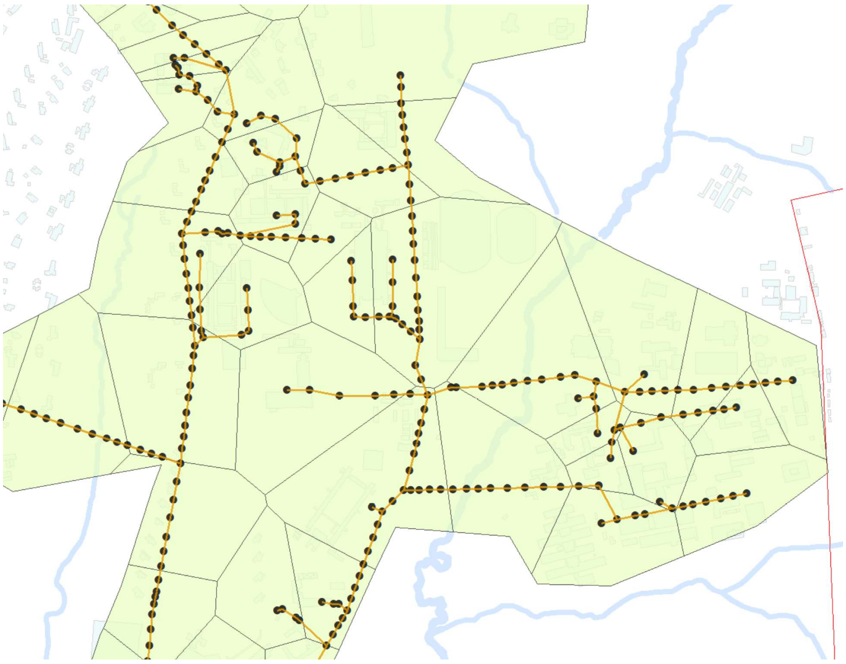

Figure 3-12: Sub catchments

Source: Author's construct, July, 2019

3.3.6 Simulation

Numerical simulation models allow to carry out detailed study of the hydraulic and hydrological of the sewerage networks (wastewater, rainwater,). Although there are several simulation models of sanitation networks, both commercial and academic but the choice is very limited depending on what the project has to carry out.

3.3.7 Simulation with MOUSE

Watersheds are essential for any hydrological model. In this work, the simulation was launched in two periods wet and dry period. To do the simulation MOUSE divides the basin into sub-basin by creating Thiessen polygon. The created sub-basins or sub-catchments allow to convey the runoff generated in the watershed to the nodes of the network. The calculated runoff is then used as a boundary condition for the network. For this, the sub catchment has to be connected with the network. This connection can be done manually with the several connection tools of MOUSE given the figure 3-13.

Figure 3-13: Catchment connection tools

After programming the sub-catchments and their connection as well as the boundary condition, the simulation was launched. It has to be known that the hydrological simulation (Watersheds) and the hydraulic simulation (network) are both different in the rainfall modelling of the network (Seor, 2010).

- **Hydrological simulation**

In MOUSE, the hydrological simulation takes into account the time step and the type of the model. The Horton Infiltration model is used to get the capacity of the le soil infiltration. Horton infiltration coefficient can be obtained using Horton infiltration formula given by the equation (6). MOUSE calculates it also automatically after filing some of the parameters.

$$f_p = f_c + (f_0 - f_c)e^{-kt} \qquad (6)$$

Source: xpswmm/xpstorm Resource Center

Where f_p is the infiltration capacity (depth/time) at some time t.

k is a constant representing the rate of decrease in f capacity

f_c is a final or equilibrium capacity f_0 is the initial infiltration capacity

Horton infiltration model indicates that if the rainfall supply exceeds the infiltration capacity. The infiltration tends to decrease in an exponential manner.

The hydrological simulation launching depends of filed all these parameters.

- **Hydraulic simulation**

In hydraulic simulation, Mouse uses the normal simulation mode and the dynamic wave.

The dynamic routing known as Saint-Venant equations which are derived from Navier-Stokes equations for shallow water flow conditions. It describes the laws of mass conservation (continuity equation) and the momentum conservation (dynamic equation).

As said before, the simulation was launched in two periods. In each period, the Time-series of the simulation was taken as followed: the study area as it contains campus, faculty and commercial areas. The time series of campus and commercial area were taken together and the faculty area alone.

3.4 Summary of the methodology

The methodology of this work is summarized by the figure 3-14.

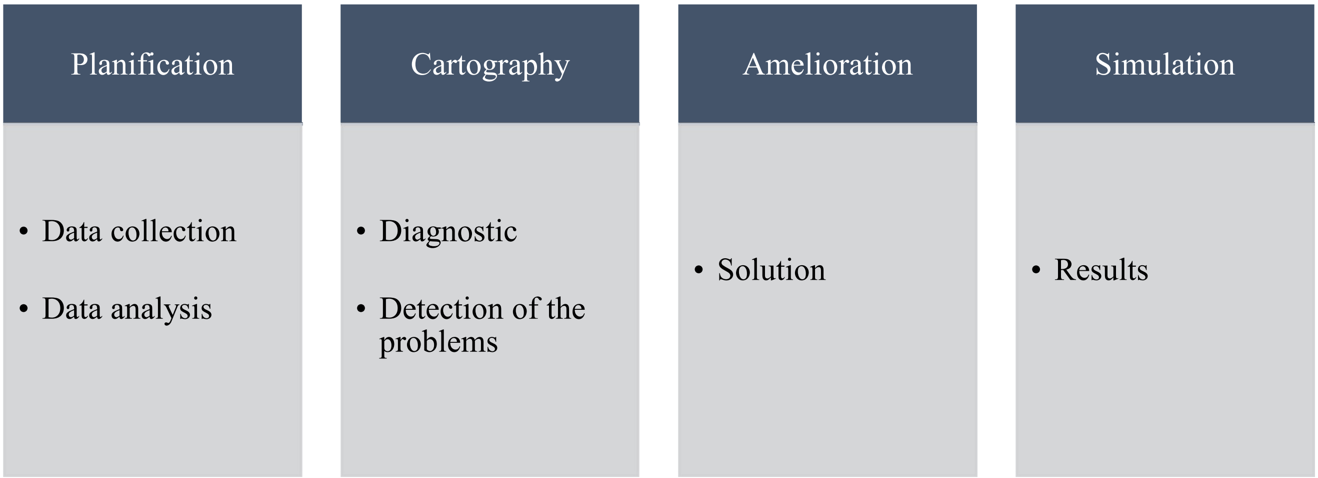

Figure 3-14: Summary of the study methodology

4 Chapter four: Result and discussion

4.1 Introduction

The durability and the easy way of the management of a sanitation network is governed by the type of materials used during the design, the maintenance and it laying of the system. Based on the type of the material, the network will have its advantage and aftermath.
The focus of this chapter is the results of the field work, the numerical analysis and calculation also the simulations result and interpretation.

4.2 Status of the existing network

The investigation on the existing sewerage network showed that the network is the separated type, old with 9500-meter linear length (for this work). It receives the sewage from eight halls of the campus and some blocs of the faculty area and commercial of KNUST.

4.2.1 Manhole

In sewer system, manhole or inspection chamber is placed to provide access for inspection to the network in case of the maintenance problems or emergency in the services. Manholes are implemented normally in each 25 meters or each change in slope or change in the direction (SEOR, 2019). The respect of this norm facilitates the resolution of maintenance problem. Manholes are very useful in flood forecasting.

The existing manholes of the study area do not cover all the criteria about manhole. However, the status of the manholes is between the average state. The figure 4-1 pictures some of manholes of the study zone. KNUST sewerage manholes are classified as shallow manholes, with 1.5 meters from invert level. These manholes are well functioning but have the management problem. On the field, only one over hundreds of the selected manholes was overfull. A part from that, the major problems that face the manhole are the covert problem, some misfunctioning problem due to the under sizing and the slope.

Figure 4-1: Status of the manholes

Source: Author's construct, May 2019

4.2.2 Pipe

The polyvinyl chloride (PVC) and the iron cast are the selected material in the piping system of KNUST. The diameters of the pipe are 400 mm to 600 mm. Management point of view, the pipes do not have a lot of issues. It has to be noted that the life-time of a PVC conduct is 70 years and 40 year for iron cast for the sewage collection network. These numbers are not applicable to the stormwater collection system. Since the network has been implemented from the year 1967, the PVC part of the network are in the norm while the iron cast part has to be rehabilitated. The figure 4-2 shows the pipe materials of used in KNUST sewerage network.

Figure 4-2: KNUST sewerage network conducts

Source: Author's construct, May, 2019

4.2.3 Performance indicators

There are several performance indicators used in water and sanitation sectors to monitors the operation and the management problems of the infrastructure as well as in quality of water. However, as the purpose of this study is based on the management of the sewerage network, the common performance indicators related to the sanitation network are eight. Only four of them were selected and calculated for study.

The performance indicators allow to know more about the status of the network. The table 4-1 summarized the selected indicators related to this work.

Performance indicators are useful for the users and well as in the sustainability of the environment and operators.

The overall aim of the performance indicators is to understand how the water or/sanitation infrastructures including the analysis and financing are working. It is very needed mostly when studying the management of water and sanitation infrastructures.

Based on the result of the below table 4-1, the WWTP has 48969 inhabitants connected. The connection rate is 88.44% which is less than 100% therefore, the network of KNUST can be extend to reach the 100% of the served population.

Table 4-1: Performance indicators

Number	Performance indicators	Index	Formula	Result
1	Connected population	D201.0	-	**48969**
2	Connection rate	P202.1	Connected inhabitants to the network / Served inhabitant	**88.44%**
3	Patrimonial policy	P202.2B		**24**
4	Obstruction index on collector		Ratio of the number of Plugs/ Linear of Collectors	**0.105** Number of plugs/Km of collectors

Source: Author's construct, June, 2019

All the information on the network are not available, so, the patrimonial policy of the sewerage network is 20%. The information about the topography of the network is updated. Only 0.105 number of plugs per kilometre of the collectors was found and one overflow has been seen from the manholes during the field analysis.

✓ Projection of the population

The known students' population of 2016 has allowed to calculate the projected population of the student as well as the population connected to the plant. The population was projected for the years: 2025, 2030, 2050 and 2060. The figure 4-3 is the trend of the projected population. From the graph, the student population as well as the population connected to the plant of KNUST, it can be said that, both cited populations of KNUST are continuously increasing following the same trend. The projected population allows to know le volume of the sewage that the sewer line will convey in the future. This volume, if it is exceeding the normal volume, it can prevent against the network overflow (flooding) in the future.

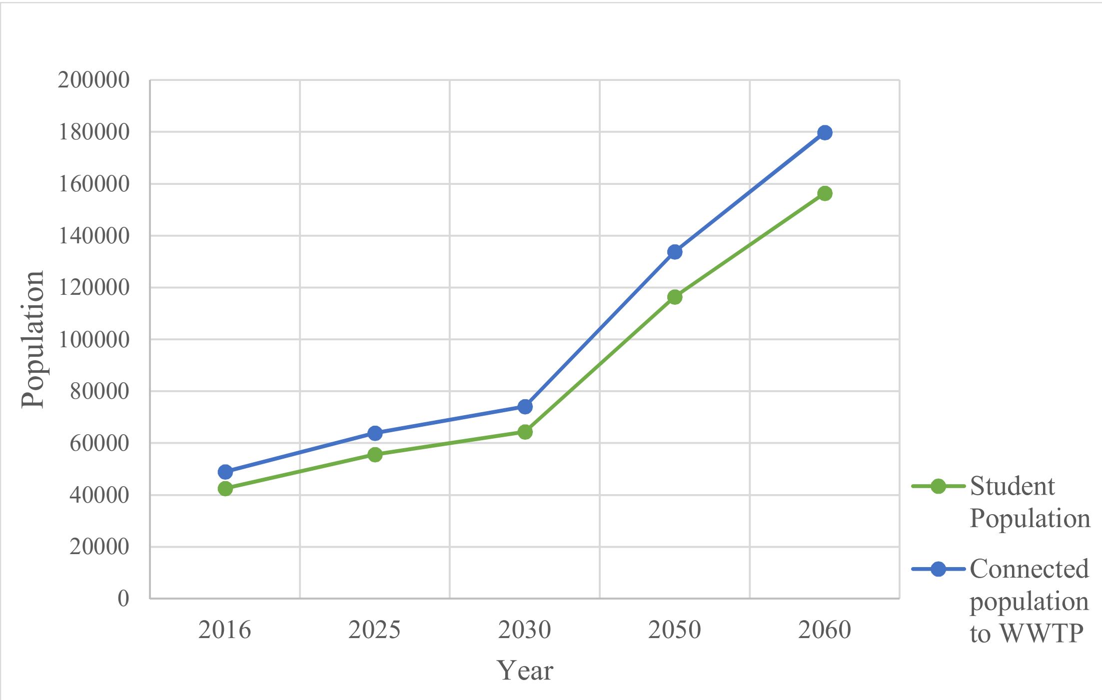

Figure 4-3:Projected Population

Source: Author's construct, June, 2019

4.2.4 Flow rate

The collective sewerage network of Kwame Nkrumah University design as the separate sewer system, conveys the sewage from domestique use to its wastewater treatment plant. The average flow generates from KNUST is estimate to 0.062 m^3/s with a connection rate of 88.44%

for 48969 inhabitants connected. This flow rate is the equivalent of 5324.67 m^3/day. The peak flow of the reject is estimated to 6777.87 m^3/s.

All the wastewater from the university are not treated by the plant. Therefore, the quantity of the sewage determined is from just a section of the university campus that is connected to the sewerage network. Some blocs inside the university and campus treat their wastewater in the septic tanks and are periodically removed by septage and discharged via the same grit chamber into the environment.

Unfortunately, the trickling of the treatment plant was broken for several days, so the wastewater trickled into an adjacent wetland which is used by farmers for taro tubers cultivations and then flows finally into the WIWI river (Awuah & All, 2014).

The present and the projected flowrate are represented in the figure 4-4 below. This chart shows that the wastewater generate from KNUST will smoothly increase by 2030. Thus from 2030 to 2050 and so on. The peak flow will increasingly rise with a margin of 80 l/s from 2030 to 2050 and will then decrease to 60l/s from 2050 to 2060. This explains that the water will be less used during his period.

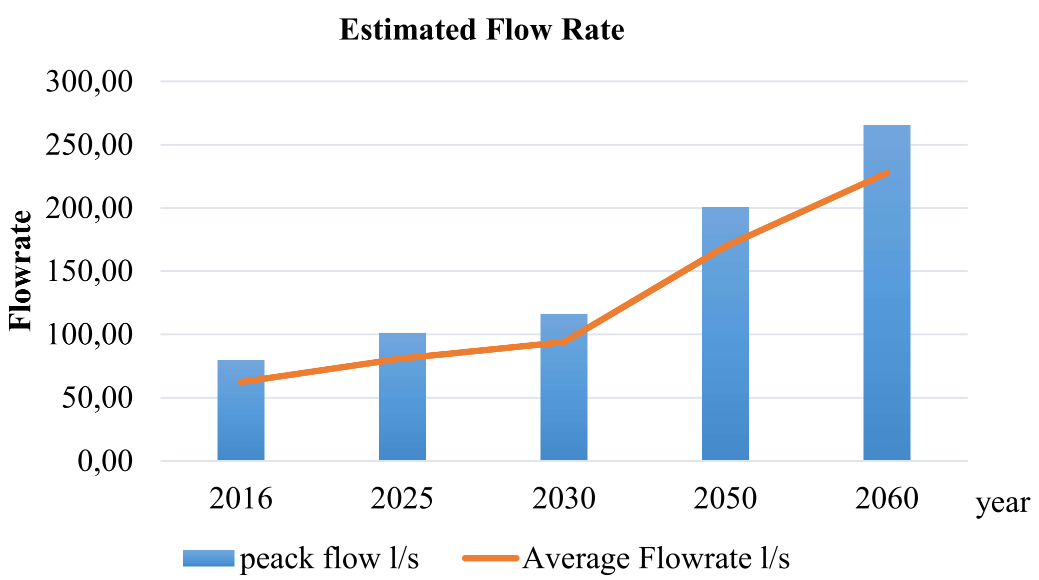

Figure 4-4: Estimated flowrate

Source: Author's construct, June, 2019

4.3 Intensity-duration-frequency curve (IDF curve)

Intensity-duration-frequency are used in the determination of rainfall of a project. The IDF curve is very useful in determination of rainwater drainage systems and are generally empirically drawn from point rainfall time series.

In this study, the IDF curves was drawn for the return period of 5 years, 10 years, 15 years, 25 years, 50 years and 100 years as shown the graph below based on Montana coefficients and an interval of times.

The data from this curve were used in the simulation for the decadal rainfall simulation. The IDF curve is given by the figure 4-5.

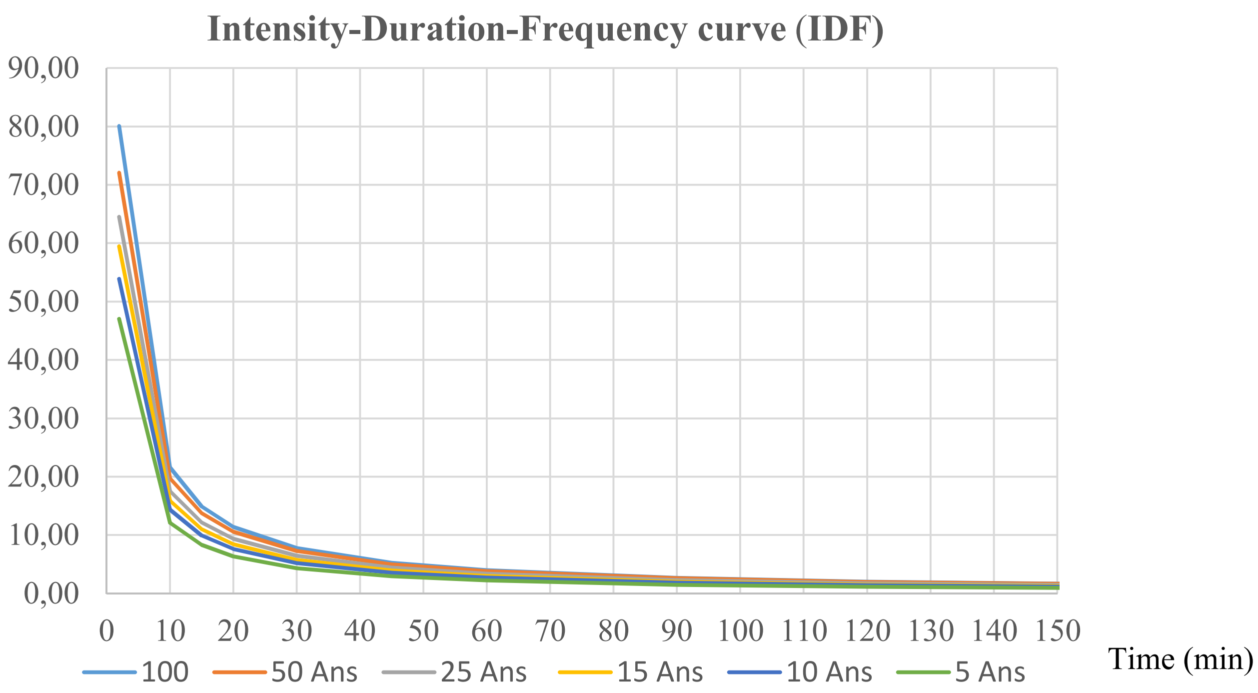

Figure 4-5: IDF curve

Source: Author's construct, July, 2019

Rainfall intensity is given by the figure 4-6 below which shows the variation of the rainfall during the time. This curve is the variation of the rainfall intensity of two period: 5 years (T5) and 10 years (T10). The result of this analysis was obtained from the IDF curve and used for the simulations.

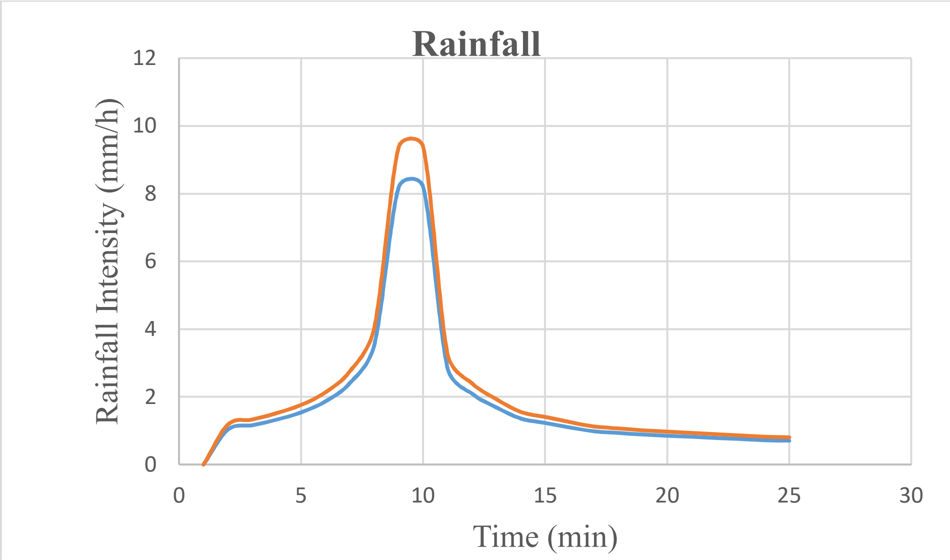

Figure 4-6:Rainfall intensity

Source: Author's construct, July, 2019

4.4 Functioning diagnostic of the network

4.4.1 Query and analysis

The Structure Query Language (SQL) is a tool on ArcGIS which is used to formulate the queries that reflect the concerns of data managers by univariate layers or multivariate layers (Madani Yousifi & Nahari Sisi, 2017). It ensures the independence between the program and the data.

The example of query below was to classify all the diameters less than 600 mm that the network contains. This process helps to classify the connection type of each pipe. The figure 4-7 shows the SQL applied to all the diameter less than 600 mm. The same process is applied to the manholes.

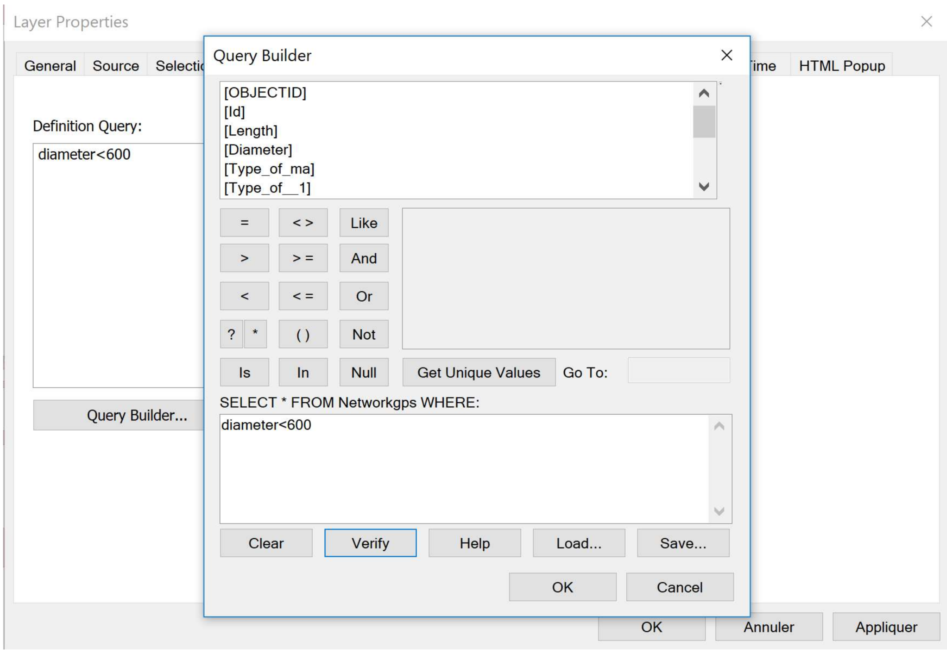

Figure 4-7: SQL showing all the diameter less than 600 mm

Source: Author's construct, July, 2019

4.4.2 Analysis

The results of the analysis can be argued that, the study was carried on 5.34 km^2 over 16 km^2 total area of KNUST. The non-availability of the updated sewerage network in hard or soft copy conducts to lead the study on 9.501 Km length of the total sewerage network. This length of pipe conveys the wastewater from domestique consumption. The stormwater and the grey water from some building of campus are drained through an open channel with unknown dimension.

The studied sewerage network had:

- ✓ One hundred and forty-one (141) manholes on the 9.501 Km of the sewer line. This comprise all the sewers and the inspection chambers.

After the diagnostics with MOUSE Engine Software, some additional manholes were added in each Twenty-five meter, and the simulation was launched with a total manhole of 307.

- ✓ The network has only one reject point.

The collectors (pipes) are classified into two types depending on the size of the conducts' diameter. The figure 4-8 shows the repartition of the collectors' base on the dimension of the conduct diameter. It shows that 62.5 % of the of the diameter are 600 mm and 37.5 are 400 mm.

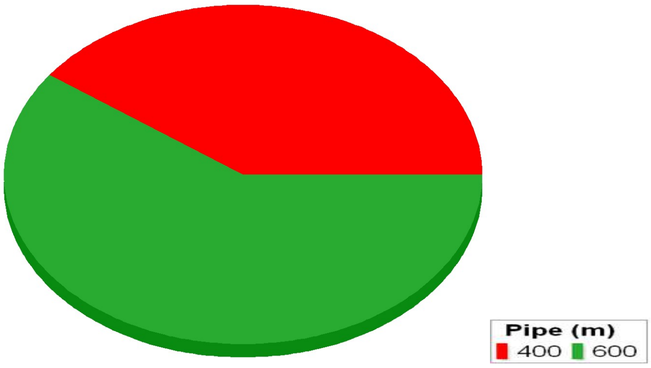

Figure 4-8: The classification of the pipe base on the size

Source: Author's construct, July, 2019

This analysis classifies the network into three tributaries:

- ✓ Primary collectors
- ✓ Secondary collectors
- ✓ Tertiary collectors

The network of KNUST is built with two type of material the Iron cast and the PVC. The below figure, figure 4-9 shows that the large part of the sewerage network are built with PVC material.

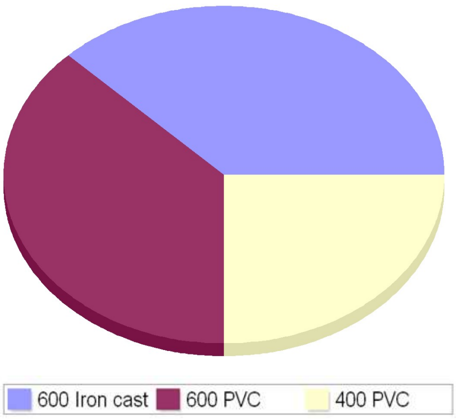

Figure 4-9: Repartition of the conduct base on the type of the Material

Source: Author's construct, July, 2019

To understand the behaviour of the stormwater flow in the basin, the contour line of KNUST has been converted in a digital elevation model (DEM) to come out with the highest and lowest elevation of the zone. The classification was in two classes, 235 meters was the lowest elevation and 290 was the highest. The digital elevation model of KNUST is represented by the figure 4- 10. The yellow colour represents all the elevation between 230 and 255 meters while the green is between 256 and 290 meters.

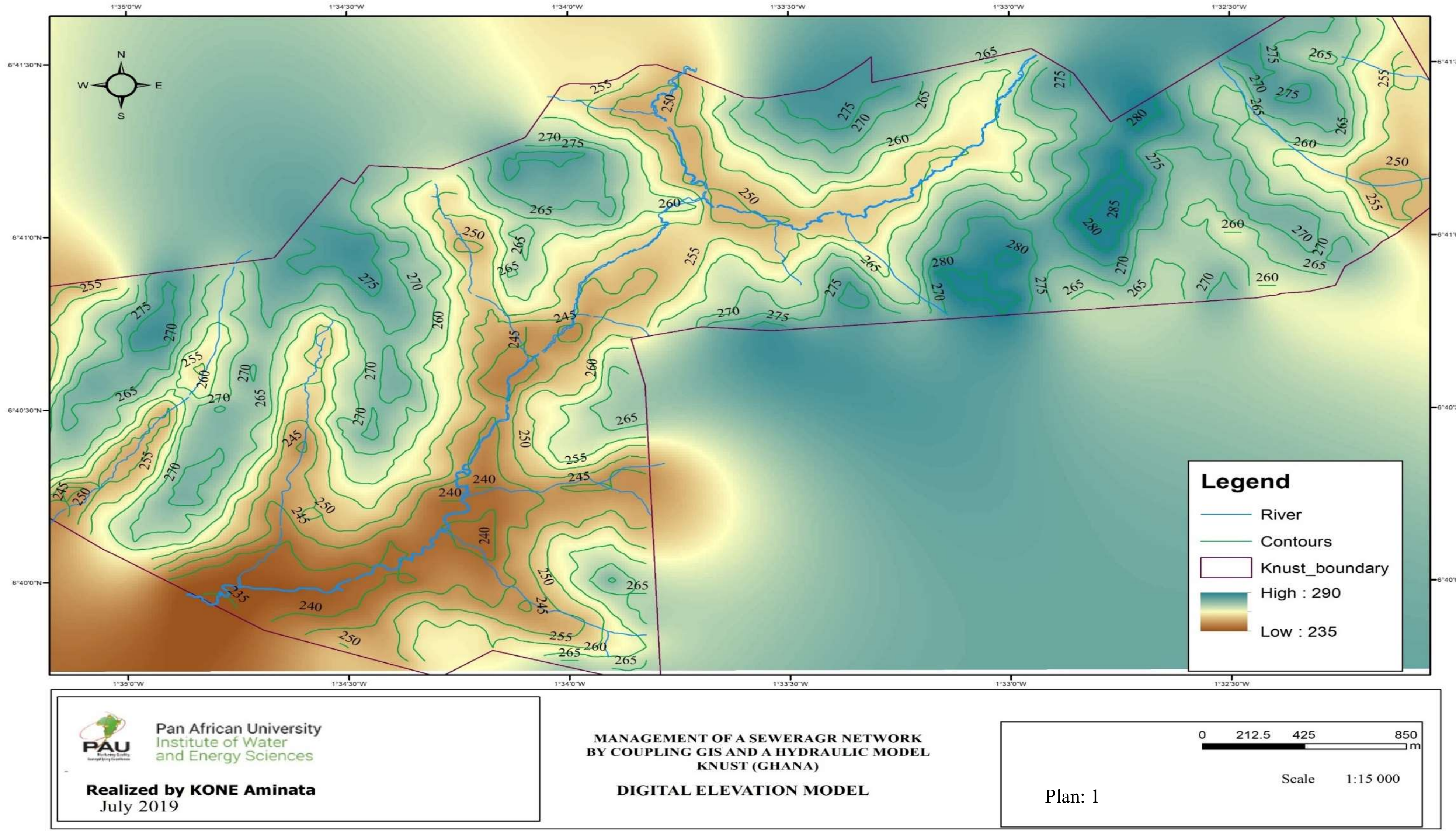

Figure 4-10:Digital Elevation Model of KNUST

4.5 Result of the simulations

The aim of the simulation was to know the hydraulic and hydrological behaviour of the sewerage network in dry and rain periods.

4.5.1 Dry period

The hydraulic simulation was launched for a duration of 24 hours. This simulation allowed knowing the maximum cumulated volume of wastewater generate from KNUST during dry period. The continuity balance of the simulation result shows that, the start volume in the manholes, pipe and structure is 2.5m^3 and end 141.4 m^3. The total inflow volume was estimated at 5287.4 m^3 and 5168.7m^3 in the outlet. The figure 4-12 gives more detail about the results this simulation. The minimum and maximum discharge of the simulation are respectively 0.044 m^3/s and 0.076 m^3/s.

The dry period simulation results show that major part of network conveying the wastewater behaves like an open channel flow water distribution, meaning that the distribution of the wastewater inside the pipe is not the full distribution and the none overflow occurs.

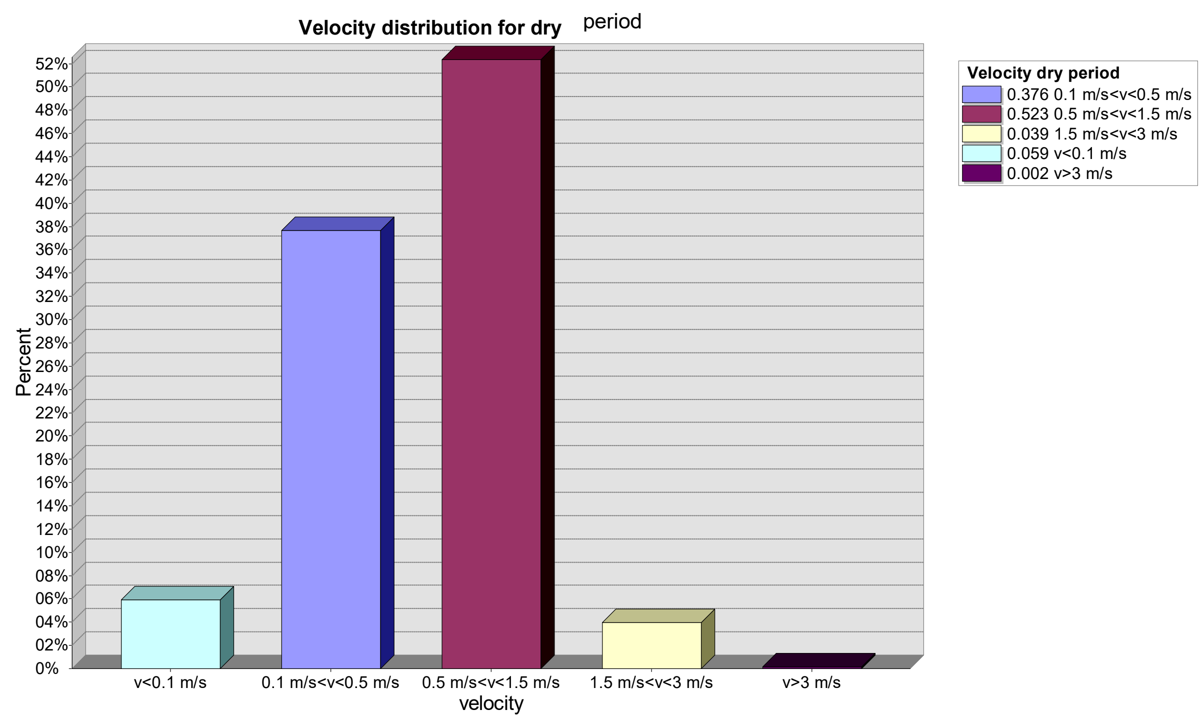

Figure 4-11: Velocity distribution in the network for dry period

However, 99.62% of the total length of the network have an open channel flow distribution behaviour and 0.38% behave like a closed conduit flow distribution. The velocity of the flux inside the network was classified into five classes within an interval of 0.1m/s to 3 m/s. About 89.99 % of the network's total length have the normal velocity variation of the sewage, 37.64% of the 89.99% have a velocity between 0.1 m/s and 0.5 m/s and the rest were between 0.5m/s and 1.5 m/s. The figure 4-11 represents the distribution of the velocity in the network. in this study, this repartition can be explained as follow:

All the sewer lines having a velocity between 0.1 and 0.5 meter per second are near to the normal distribution of the sewage inside the pipe, but it can cause rapid corrosion of the pipeline. The velocities between the intervals]0.5m/s, 1.5 m/s [and [1.5 m/s; 3 m/s [have the normal circulation of the wastewater inside the pipe, and the velocities greater than 3m/s mean that the pipe is at full section and the overflow can occur at any time.

Thus, based on these results, the sewage speed distribution in the pipe can be classified as normal in the dry period. The velocity greater than 3m/s is observed toward a small part of the network. The level of the sewage inside the pipes and manholes depend on the depth of manholes. The less the depth, the more risk of the network overflow.

However, the network faces a self-cleansing problem due the low slope between four manholes. The self-cleansing condition is the ability of a sewer line to carry the flow that it receives without crushing. In practice, the good self-cleansing condition requires the ability to transport solids inside the sewerage without any sedimentation. This problem is generally due the low slopes when the wastewater is conveying by gravity. The slopes do not allow the pipes to have optimum velocity to achieve the self-cleansing state. The section of the network which didn't respond to the self-cleansing condition had the slope less than 0.007m/m. To avoid the problem self-cleaning, the velocity of the wastewater in full or half section of the circular conduct, the velocity has to not be less than 0.7m/s and 0.6 m/s when the conduct filling is about two over then (2/10) of the diameter. The table 4-2 below represents the sections of the network that do not meet the self-cleansing condition.

Table 4-2: Self-cleansing problem of the sewerage network

N°	**1**	**2**	**3**	**4**
Slope (%)	**0.002**	**0.002**	**0.002**	**0.002**
Velocity (m/s)	**0.010**	**0.010**	**0.020**	**0.330**
Length (m)	**22.350**	**84.950**	**19.840**	**32.070**
Diameter (m)	**0.400**	**0.400**	**0.400**	**0.400**
Area (m^2)	0.126	0.126	0.126	0.126
Q (m^3/s)	0.001	0.001	0.003	0.041
Vps (m/s)	0.876	0.876	0.876	0.876
Qps (m^3/s)	0.110	0.110	0.110	0.110
Q/Qps	0.011	0.011	0.023	0.376
V/Vps	0.011	0.011	0.023	0.377

To meet the self-cleansing condition, a lifting station can be installed in this part of the network or a cleaning of the pipe can be schedule to avoid the overflow in the network.

The network has a normal distribution of the pression. The velocity map in the figure 4-12 gives the repartition of the velocity with colour as follow:

- ✓ Purple for all the velocity les 0.1 m/s and it is more seen int the tertiary tributaries of the network.
- ✓ Blue for the velocity between 0.1 m/s and 0.5 m/s,
- ✓ Green for the velocity between 0.5 m/s and 1.5 m/s
- ✓ Yellow for the velocity between 1.5 m/s and 3 m/s, at this state, the network has a closed conduct flow and as highlighted before, it is the part of the network that do not meet the self- cleansing condition. This can be followed by the network overflow.
- ✓ Red for the velocity greater than 3m/s is observed in the outlet of the network.

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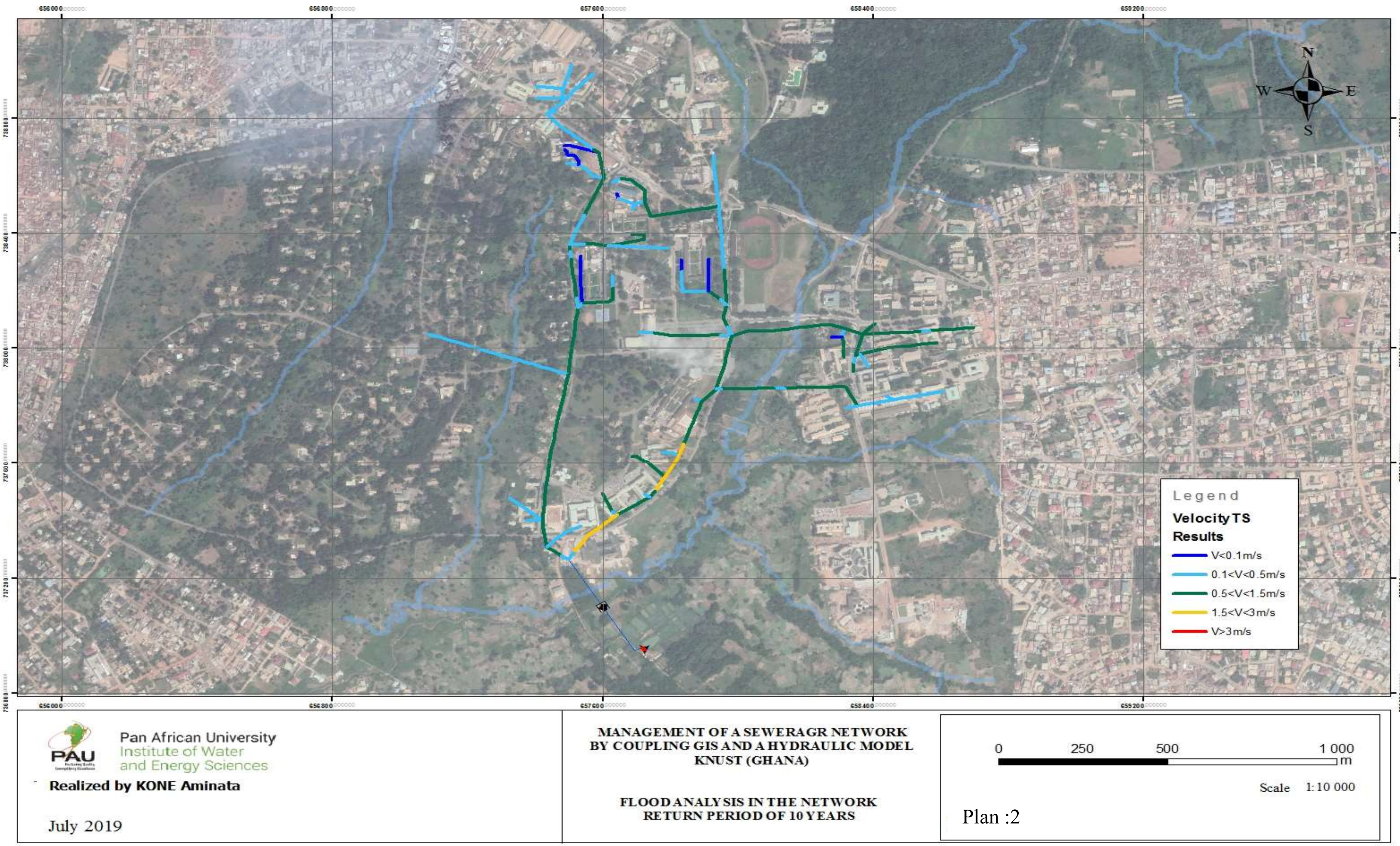

Figure 4-12: Flood analysis with the velocity dry Period

4.5.1.1 Time series

The simulation was launched for duration of 24 hours as said above. The time series given by the figure 4-13 is the time series of the discharge in the outlet of the sewer line. This figure shows how the flow is distributed from the outlet to the wastewater plant. From the curve, it can be seen that the curve is ascending and descending forming a wave. The peack discharge is observed at 65l/s at 1pm 40 minutes. The discharge in dry period is done correctly, no flood of the manholes or the pipe was observed.

During dry period simulation, the disfonctioning analysis saw on the overall of the network was that; certain setions of the network do not meet the sef-cleansing condition because of the low slope.

The simulated maximum discharge value (peak discharge) is close to the theorical peak discharge.

$$Q_{\mathrm{max}\,simulated} \simeq Q_{\mathrm{ma\,x}\,theoric}$$

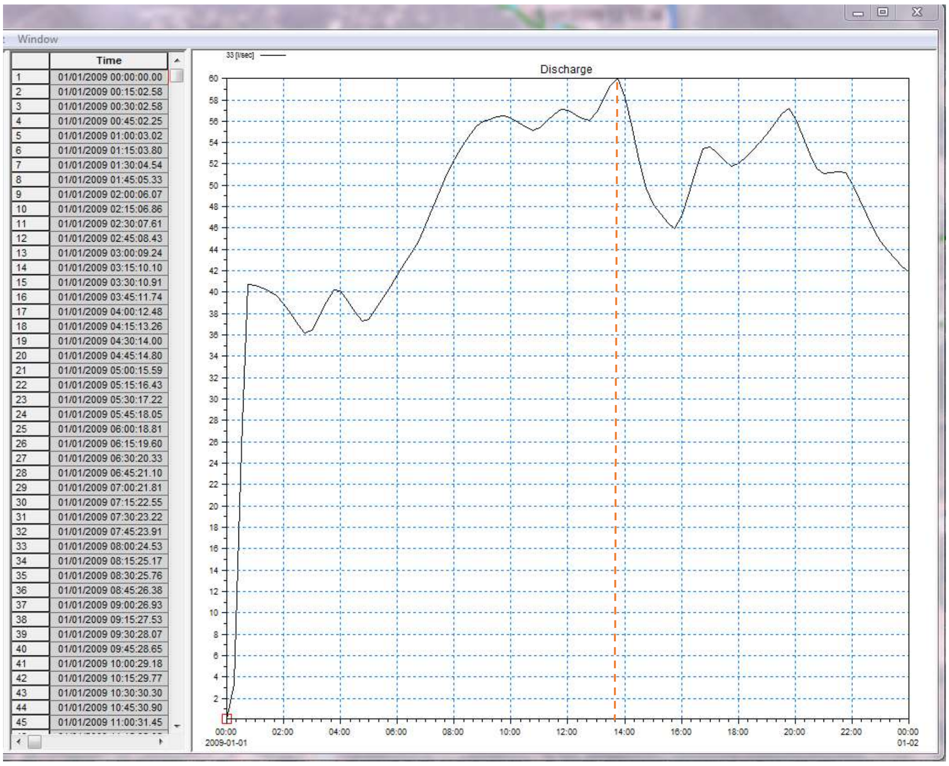

Figure 4-13: Time series for dry period discharge

4.5.1.2 Hydraulic profil with MOUSE

A longitudinal profile of a part of the main pipe before and after the simulation is given by the figures 4-14 and 4-15. They are indexing respectively by a and b. This was to view the water level inside the pipe during the simulation. The blue line represents the level of water in the pipe, the green line is the top level of the manholes (matrix part) and the piezometric line is represented with the blue line dotted with red. All this these colours can be seen on the (b) which is the hydraulic profile of the network when the simulation was launched

When the piezometric line surpasses the matrixial part of the pipe, it means that there is an overflow in the network. From the longitudinal profile, the pipes don't have any overflow and it can be seen that the distribution of the sewage is like an open channel flow.

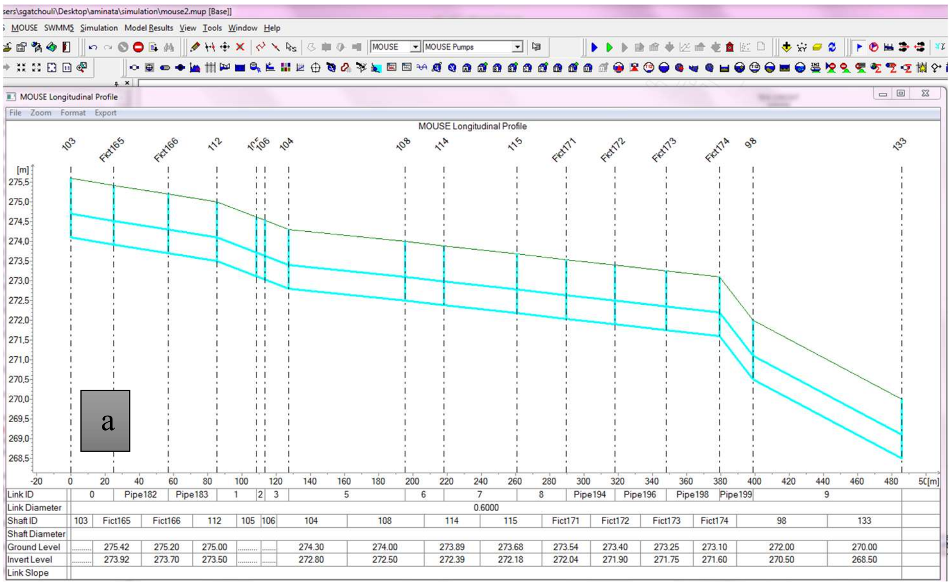

Figure 4-14: Longitudinal profile before the simulation

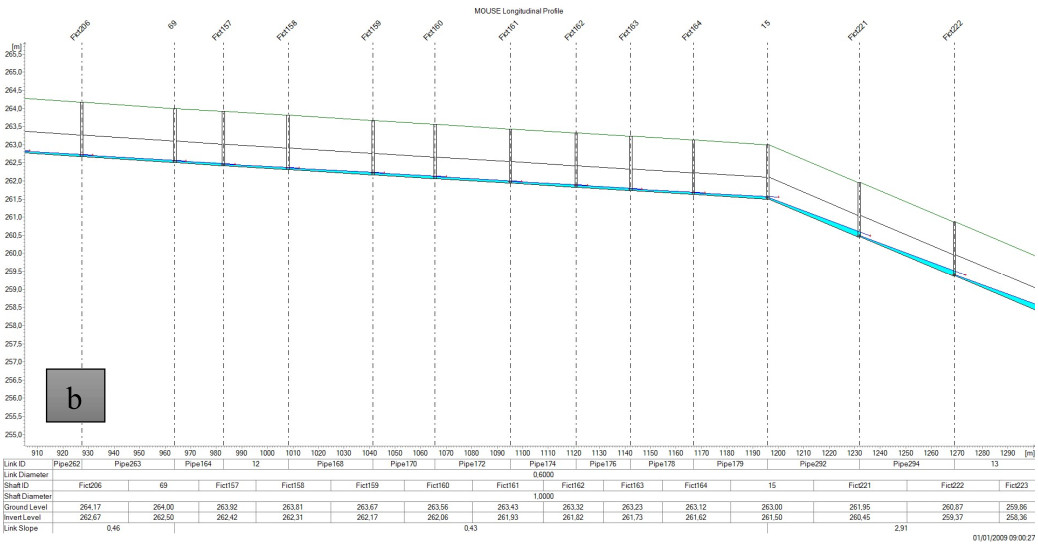

Figure 4-15: Longitudinal profile during the simulation

It is clear that the sewer collection system of KNUST is the separate sewer system, so knowing that some buildings have their grey and stormwater (from the roof) go illegally to the plant, therefore, the wet period simulation was launched to view the phenomenon.

4.5.2 Wet period

The modelling of the effect of stormwater on the network was carried out for 10 years rains return period. The 10 years return period are generally used for flood forecasting and are also selected when doing an explicit analysis of a model. Maps showing the results of these modelisations are reperesenting with the figures 17 and 18. The results of the velocity distribution are represented as followed:

- ✓ Purple for all the velocity les 0.1 m/s
- ✓ Blue for the velocity between 0.1 m/s and 0.5 m/s
- ✓ Green for the velocity between 0.5 m/s and 1.5 m/s
- ✓ Yellow for the velocity between 1.5 m/s and 3 m/s
- ✓ Red for the velocity greater than 3m/s

The distribution of the modelled velocity is given by the figure 4-16. It has to be known that all the velocity above 3m/s are considered as the network overflow and have to be resized. The explanation of the velocity intervals is the same as highlighted earlier in the dry period simulation.

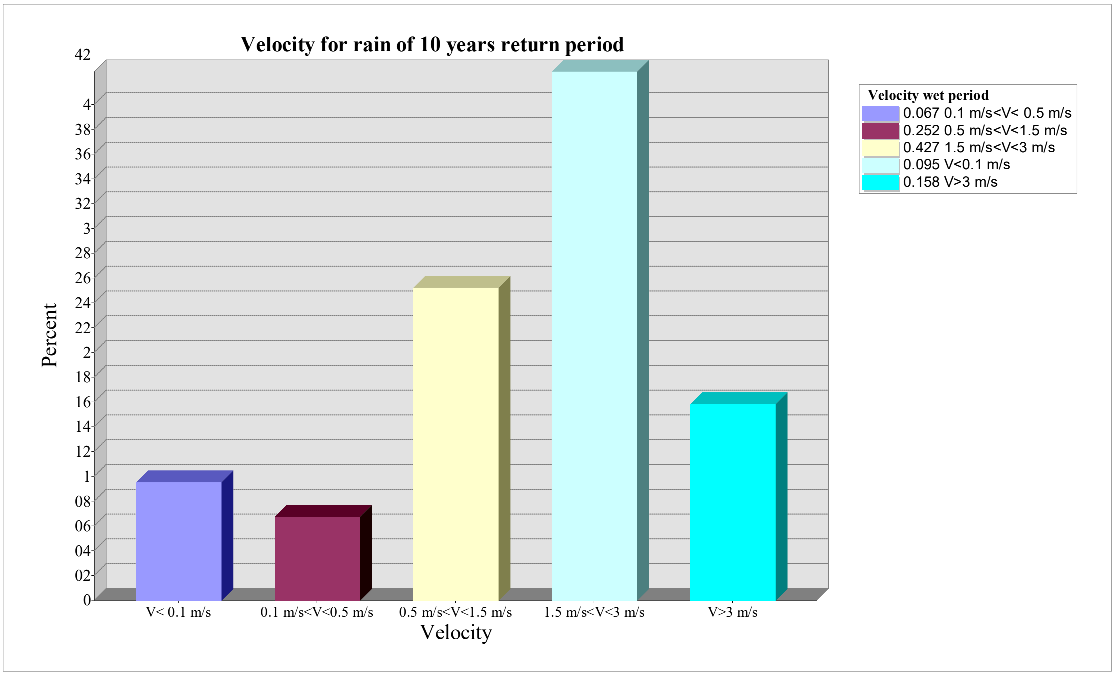

Figure 4-16: Velocity for rains 10 years return period

This histogram shows that 9.53% of the network have the velocity less than 0.1 m/s, 74.64% have are closed to the optimum velocity while 15.83% of the network have the velocity greater than the normal.

In the figure 4- 17 below, the red and yellow colour are very visible in almost all the network. This shown, the inability of the network to carry the stormwater and domestique wastewater. This high velocity can break the pipe and cause inundation.

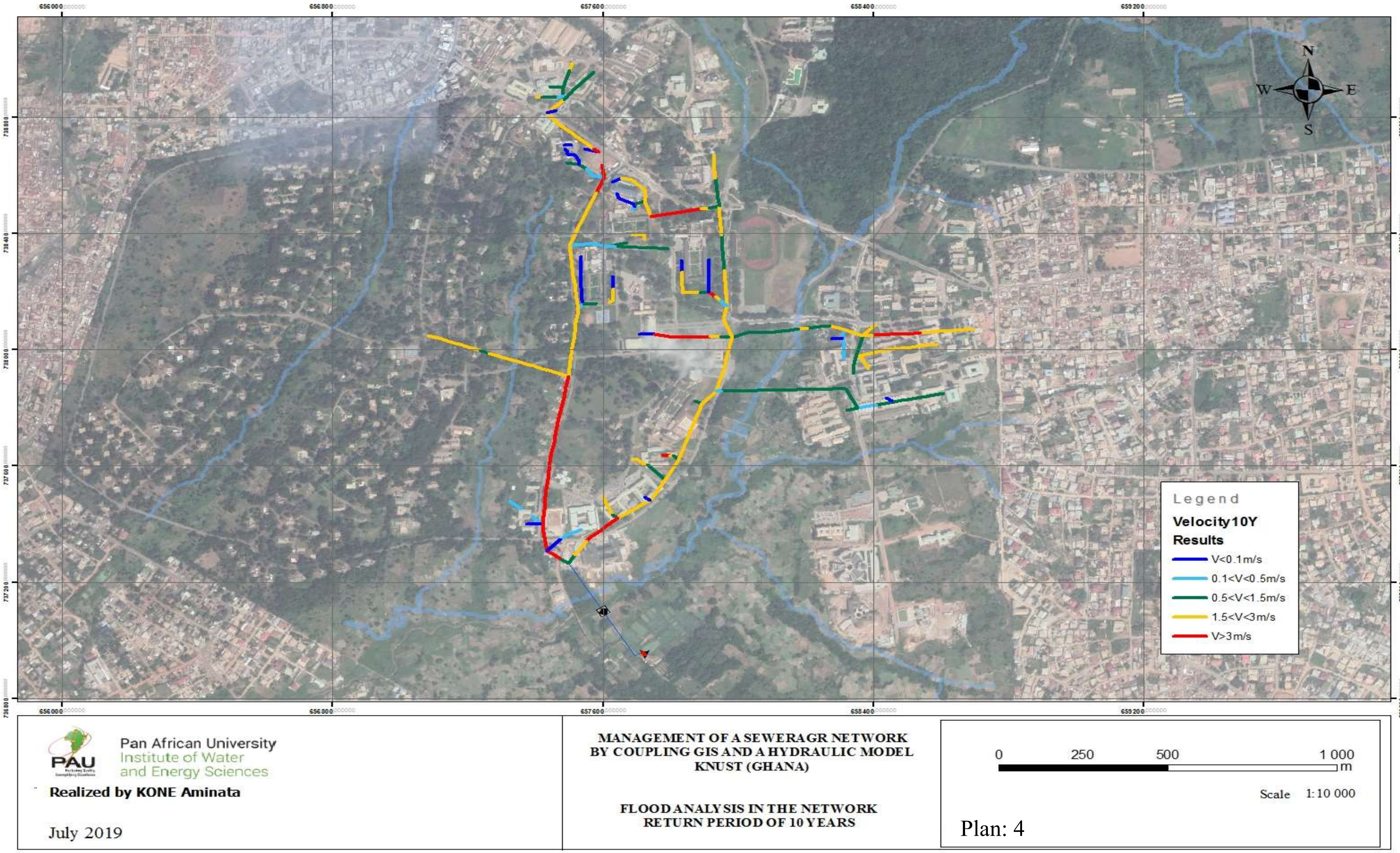

Figure 4-17:Flood analysis with the velocity wet Period

Based on this result, even though, the wastewater treatment plant has been designed separated sewer system and receives water which is not from domestique uses, it cannot convey the stormwater from the rain less than 10 years of return period. It can be said that the rain water that infiltrates in the network does not impact the network but the damage can occur if the amount of stormwater going through the network is high. From the result, 15.83% of the network in red have to be resized to avoid flooding problem.

The modelling of water pressure and water discharge for 10 years return period represented in the figure 4-18 is described as:

- ✓ Green colour represents the pipes conveying the wastewater like the flow in an open channel flow
- ✓ Yellow pipes with close conduit flow

Theses colours were used for the modelling of the wastewater pressure and below colour to check the flooding.

- ✓ Orange represents all pipes that have the water flowing at -30 cm from ground level. This number is used as the forecast threshold informing that flood can occur in the network.
- ✓ Red pipes are flooded pipes.

Base on this modelling, the distribution of the wastewater is with high pressure. Almost the totality of the network has high pressure distribution and the major part of the network was flooded.

These results conduct, to do a last simulation for the projected network (future network). The results of the projected network's simulation are represented by the figure 5-1 and 5-2 show that, by resizing some pipes and the type of material of network, the wastewater treatment plant be used as a combined plant.

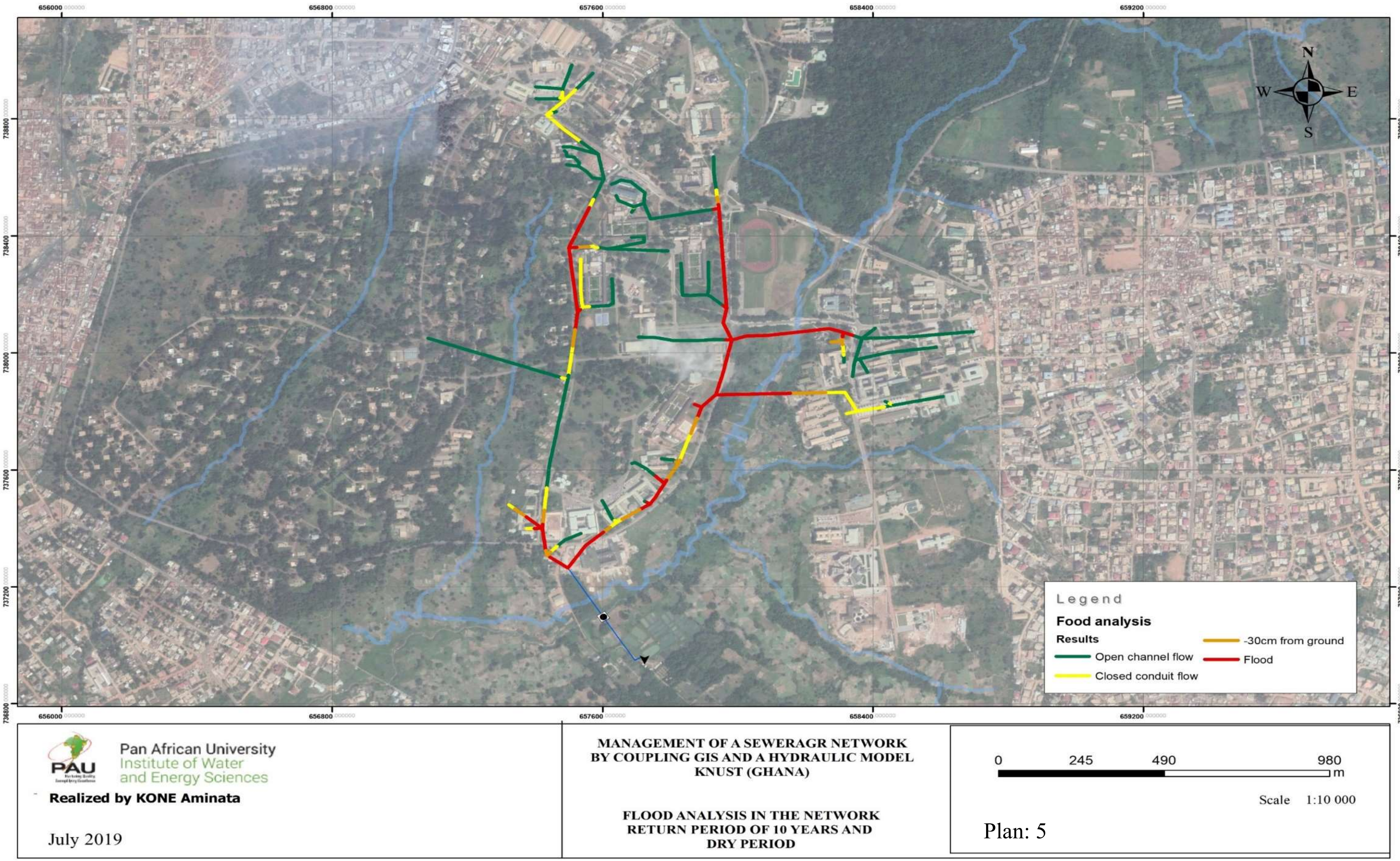

Figure 4-18: Flood analysis with the pressure and the discharge wet period

4.5.2.1 Time series for rain period

Like the dry period simulation, the rain period simulation was also launched for 24 hours rainfall with 10 years rains return period. The times series curve of the outlet (figure 4-19) obtained from the simulation shows that the peak discharge was already observed at 30 minutes of rain and remains constant until 5h of rain then decreased. It has to be noted that during this period the wastewater level has surpassed the piezometric level, so, the pipes were unable to covey all the sewage.

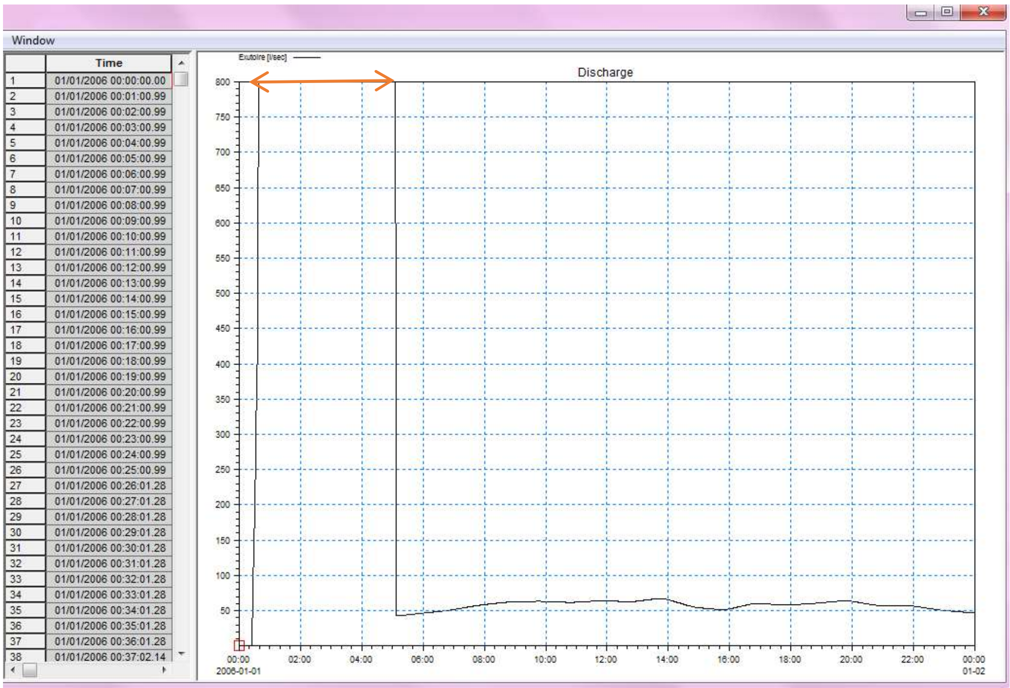

Figure 4-19: Time series for rain period

4.5.2.2 Longitudinal profile wet period

The component of the 10 years rains return period's longitudinal profile is the same as decribed above in the dry period. Here, the overflow is observed from the node "Fict311" to the the pomape station "bache", this overflow flow is explained by the presence of a high slope from the "Fict314" to the pumaping station observed on the figure 4-20.

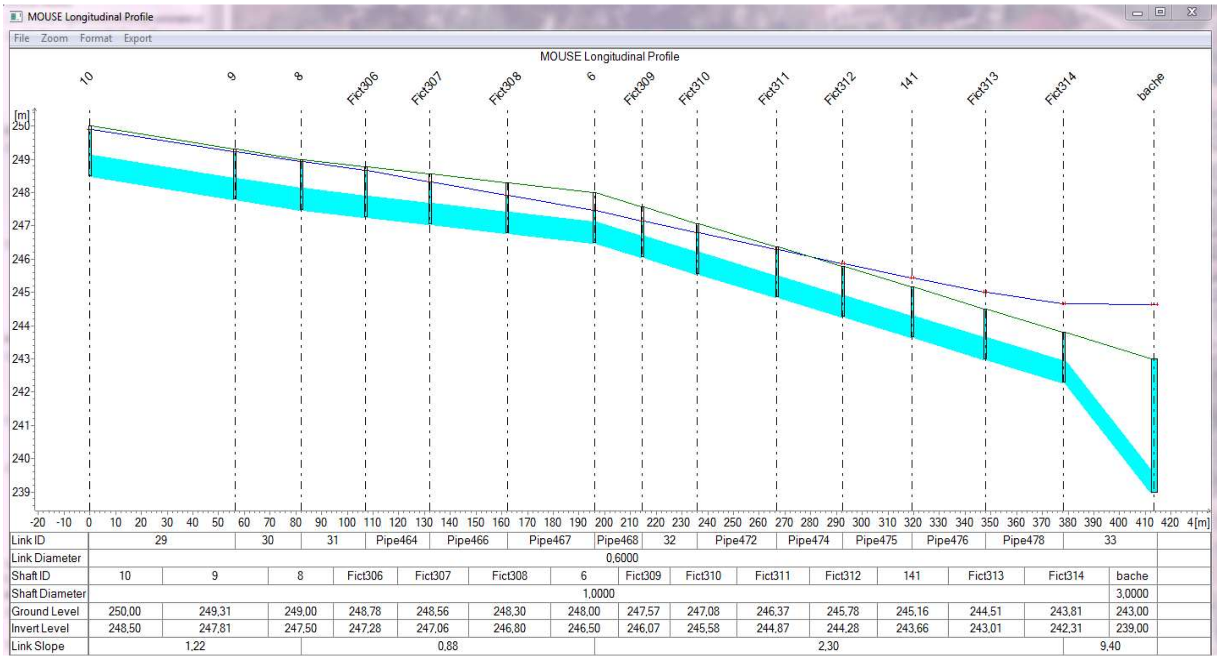

Figure 4-20: Longitudinal profile T10

4.6 Management strategy

Sanitaion recognized as a complex sector, faces of course the management issue whetever in collective or individuel collection system of the wastewater. Therfore, all progress in the sanitation sector must be backed by an appropriate institutional framework and strong political will at the local and national levels (Inter-ministerial Committee for International Cooperation and Development, 2008). The sustainable strategies for improving the management system of sanitation infrastructure include the implication of the institution in charge of its management as well as the population participation.

5 Chapter six: Conclusion and Recommendations

5.1 Conclusion

This study, titled the management of the sewerage network of Kwame Nkrumah University of science and technology by coupling GIS and a hydraulic model come out with the statistic of the problem facing the network and some improvement solutions.

The management of any water infrastructure contributes to the good governance of water, protect the environment and improves the socio-economic development of the city or country.
In general, the management problem of the KNUST sewerage network is due to the invert slopes that cause stagnation in the pipes, the low flowrate generation in dry, and the non-coverage of certain manholes. To these, it is added the under-sizing of some conduct and some manholes as well.
The study shows that, 0.38 percent of the pipes do not meet the self-cleansing condition due to shallow slopes. The results of the simulation showed that at 99.62% of the flow in the pipes have the normal speeds and no overflow has been observed during dry period.

5.2 Recommendations

This study thus recommends that:

- A lifting station must be installed in all sub-basins with slopes lower than 0.007m / m or a manual cleaning must be scheduled for them. (Self-cleansing condition)
- The KNUST plant and the network need to be expanded to efficiently convey and treat the sewage.
- Some manholes, and pumping station should be redesigned to facilitated the inspection of the network.
- Since the life time of the iron cast pipe is short, the study recommends to renew all the pipe with iron cast with PVC or with high-density polyethylene (HDPE)
- Even though, the sewer is the separate system, taking into account the hydrological impact, the study recommended to resign the WWPT as a combine sewer system, due to the fact that, during the rain period, the first runoff that occurs are more charge in pollutant and affects the quality of the water from the river. The material and the diameter of about 5.408 Km of pipe should be changed during the rehabilitation of the wastewater treatment plant. The plan of the projected network is represented in the figure 5-1below.

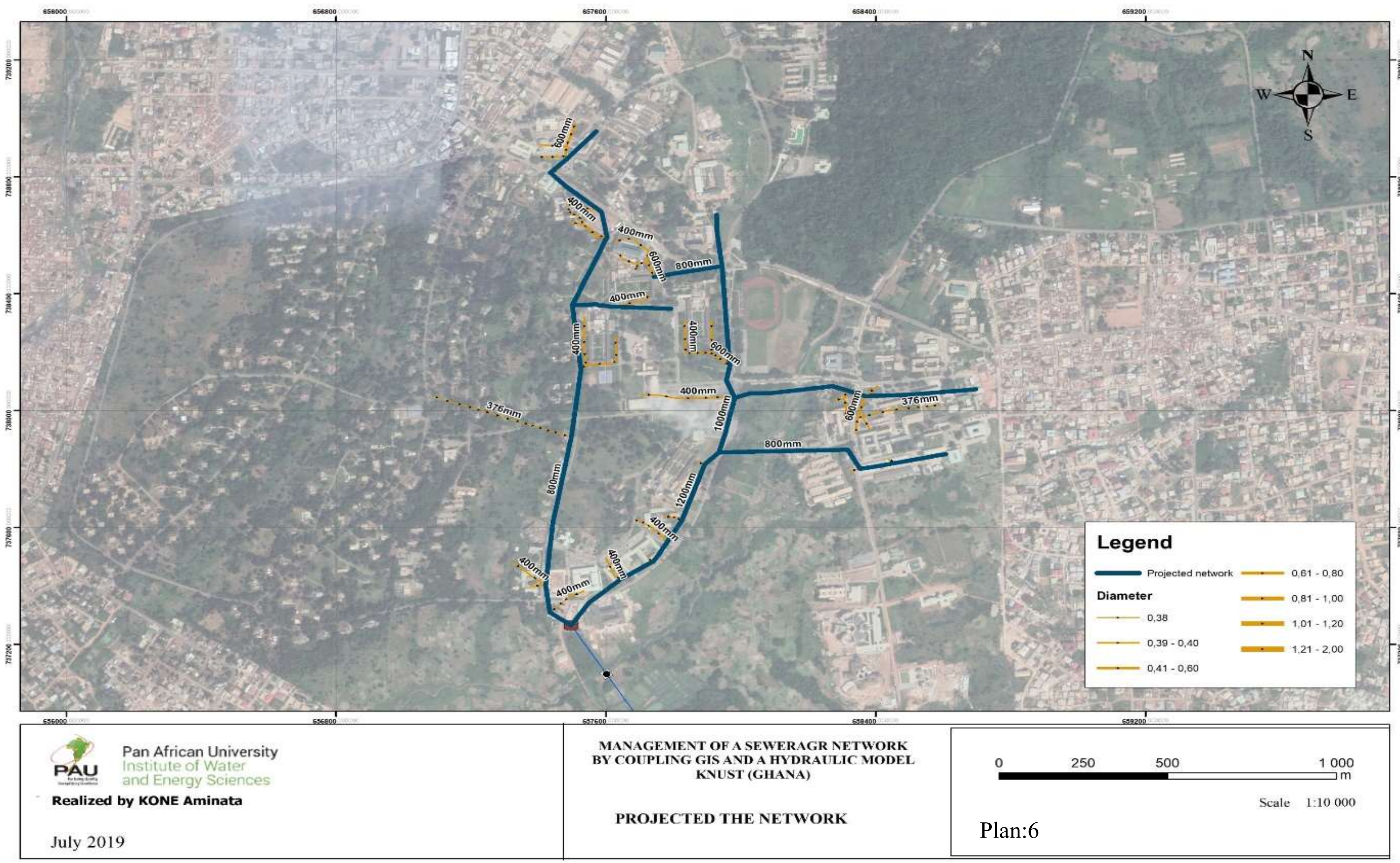

Figure 5-1: Projected sewerage network

The results show that after resizing the diameter of the 5.408 km of the network, the pipeline can carry all the wastewater and storm water generate in KNUST with no flooding problem. The plan of the simulation of the projected network is given by the figure 5-2. From this it can be seen that no overflow is observed from the network.

- A reservoir should be built to collect the extra stormwater after the first pumping during the heavy rain. This will reduce pumping time, protect the river against the pollution, avoid the flooding and the water can be used for irrigation without risk.
- The overall sewerage network of KNUST should be mapped and register in hard and soft copy.
- The implication of stronger political will have to be included in the sanitation infrastructure in general for effective management.
- The network has to have remote management control this helps in the good management.

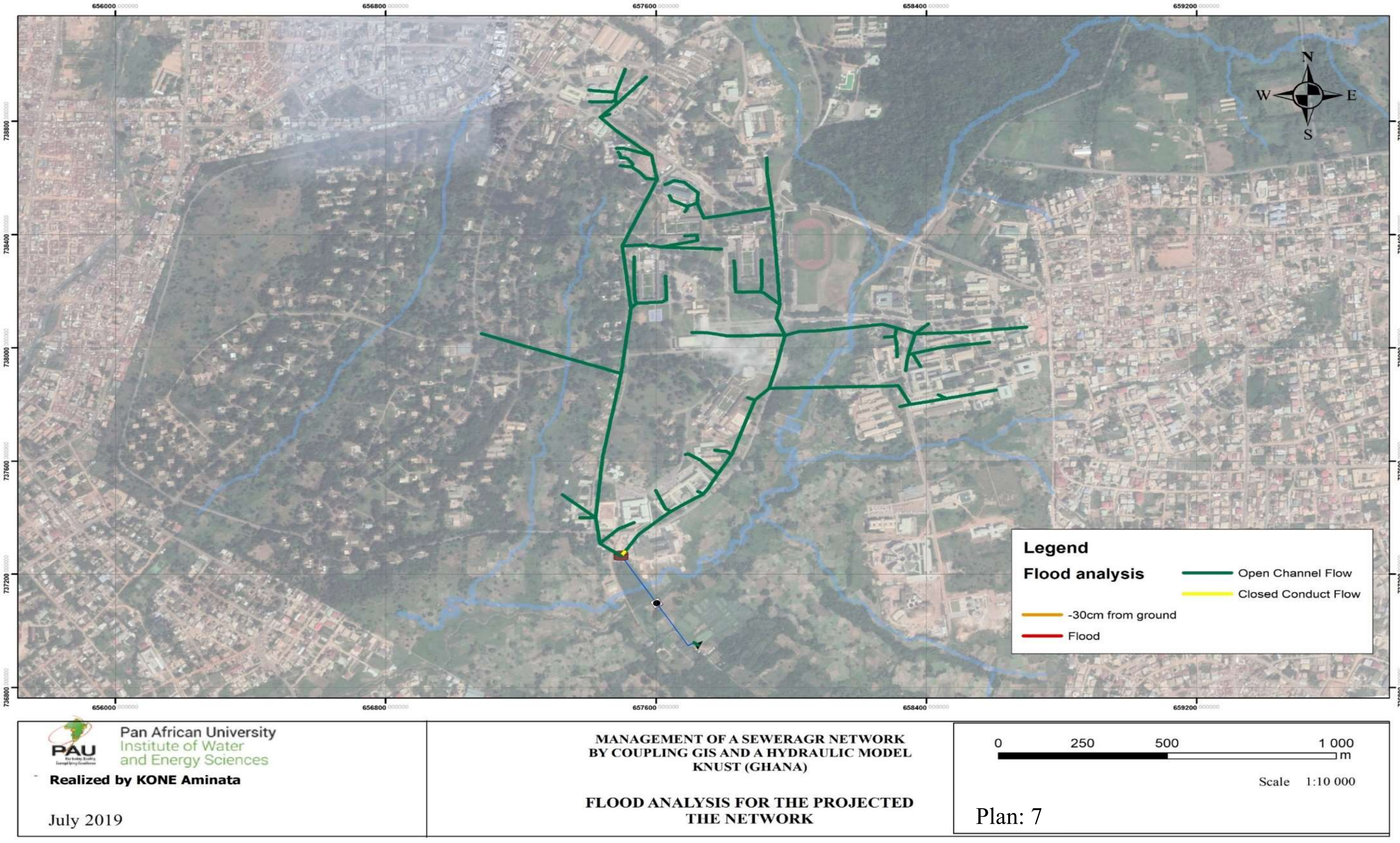

Figure 5-2: Flood analysis of the projected sewerage network

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ANNEX

Annex 1: Master plan of the sewerage network

Source: Development office, KNUST, 2019

Annex 2: Simulation result dry period

MOUSE HD Computation Engine v2009 Release Version (0.0.0.3301)

MOUSE Pipe Flow Simulation –- Status Report –-Dynamic Wave

Index of summary

File Overview

Working dir :	C:\Users\sgatchouli\Desktop\aminata\simulation\	-
Sewer network data (UND) :	Simulation_2Base.mex	25/07/2019 15:37:44
Hydrological data (HGF) :	Simulation_2Base.mex	25/07/2019 15:37:44
Additional parameters file (ADP) :	-	-
Dry weather flow data (DWF) :	Simulation_2Base.mex	25/07/2019 15:37:44
Repetitive profile data (RPF) :	-	-
Runoff Hydrographs (CRF) :	-	-
Hotstart file (PRF) :	-	-
Result File (PRF) :	Simulation_2Base.PRF	25/07/2019 15:37:48
Reduced result file (PRF) :	-	-

Time Overview

Simulation start date :	2009-01-01 00:00:00	Calculation started :	2019-07-25 15:37:57
Simulation end date :	2009-01-02 00:00:00	Calculation ended :	2019-07-25 15:38:10
Save time step [hh:mm:ss] :	0:15:00	Calculation time [hh:mm:ss] :	0:00:13
Maximum time step [sec] :	5	Hotstart start date :	-
Minimum time step [sec] :	1		

Input Summary

Number of Manholes:	307
Number of Basins:	1
Number of Outlets:	1
Number of Storage Nodes:	0
Number of Circular Pipes:	307
Number of Rectangular pipes:	0
Number of CRS defined pipes:	0
Number of Pumps:	1
Number of Controlled Pumps:	0
Number of Weirs/Orifices:	0
Number of Controlled Weirs/Gates:	0
Number of Valves:	0
Number of Controlled Valves:	0

Nodes

Min Invert Level	bache	239,00 m
Max Invert Level	111	274,50 m

Min Ground Level	bache	243,00 m
Max Ground Level	111	276,00 m
Min X Coordinate	60	6,5708E05 m
Max X Coordinate	143	6,587E05 m
Min Y Coordinate	STEP	7,3696E05 m
Max Y Coordinate	103	7,3898E05 m
Total Manhole Volume		474,3 m3
Total Basin Volume		76,0 m3

Links

Total Circular Volume	2133,8 m3
Total CRS Volume	0,0 m3
Total Length	9287,30 m

Time Step parameters loaded from the DHIAPP.INI file

INI file :	C:\PROGRA~1\DHI\2009\bin\DHIAPP.INI
Relative change criteria for inflow time series :	0,100
Low flow limit for inflow time series :	0,010
Maximum relative water level change :	0,100
Maximum variation in Cross Section parameters :	0,100
Cross check low depth limit (relative) :	0,040
Cross check level :	1,000
Maximum Courant Number :	20,000

Simulation Result Summary

Continuity Balance

1 :	**Start volume in Pipes, Manholes and Structures**			**2,5 m3**
2 :	**End volume in Pipes, Manholes and Structures**			**141,4 m3**
3 :	**Total inflow volume**			
	Specified inflows			
	DWF :	5287,4 m3		
		5287,4 m3	**-->**	**5287,4 m3**
4 :	**Total diverted volume**			
	Operational, non-specified outflows			
	Outlets :	5168,7 m3		
		5168,7 m3	**-->**	**5168,7 m3**
5 :	**Water generated in empty parts of the system :**			**8,9 m3**
6 :	**Continuity Balance = (2-1) - (3-4+5) :**			**11,3 m3**
	Continuity Balance max value :		11,3 m3	
	Continuity Balance min value :		0,0 m3	

Boundary Connections

Network loads (discharges)

III

Boundary Condition ID	Type	Connection Type	Location	Temporal variation	Value/pattern/TS name	Validity	Validity Start	Validity End	Minimum Value	Maximum Value	Accumulated Value
									m3/s	m3/s	m3
BC_4	Discharge	All		Cyclic	Profile_1	Unlimited	-	-	0,044	0,076	5287,6

Annex 3: Simulation result Wet period

MOUSE HD Computation Engine v2009 Release Version (0.0.0.3301)

MOUSE Pipe Flow Simulation –- Status Report –-Dynamic Wave

Index of summary

File Overview

Working dir :	C:\Users\sgatchouli\Desktop\aminata\simulation\	-
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Hydrological data (HGF) :	rain10yearsBase.mex	22/07/2019 15:09:04
Additional parameters file (ADP) :	-	-
Dry weather flow data (DWF) :	rain10yearsBase.mex	22/07/2019 15:09:04
Repetitive profile data (RPF) :	-	-
Runoff Hydrographs (CRF) :	Simulation_1Base.CRF	18/07/2019 15:25:34
Hotstart file (PRF) :	-	-
Result File (PRF) :	rain10yearsBase.PRF	22/07/2019 15:09:08
Reduced result file (PRF) :	-	-

Time Overview

Simulation start date :	2006-01-01 00:00:00	Calculation started :	2019-07-22 15:09:07
Simulation end date :	2006-01-02 00:00:00	Calculation ended :	2019-07-22 15:09:39
Save time step [hh:mm:ss] :	0:01:00	Calculation time [hh:mm:ss] :	0:00:32
Maximum time step [sec] :	2	Hotstart start date :	-
Minimum time step [sec] :	1		

Input Summary

Number of Manholes:	307
Number of Basins:	1
Number of Outlets:	1
Number of Storage Nodes:	0
Number of Circular Pipes:	307
Number of Rectangular pipes:	0
Number of CRS defined pipes:	0
Number of Pumps:	1
Number of Controlled Pumps:	0
Number of Weirs/Orifices:	0
Number of Controlled Weirs/Gates:	0
Number of Valves:	0
Number of Controlled Valves:	0

Nodes

Min Invert Level	bache	239,00 m
Max Invert Level	111	274,50 m

Min Ground Level	bache	243,00 m
Max Ground Level	111	276,00 m
Min X Coordinate	60	6,5708E05 m
Max X Coordinate	143	6,587E05 m
Min Y Coordinate	STEP	7,3696E05 m
Max Y Coordinate	103	7,3898E05 m
Total Manhole Volume		474,3 m3
Total Basin Volume		80,0 m3

Links

Total Circular Volume	2133,8 m3
Total CRS Volume	0,0 m3
Total Length	9287,30 m

Time Step parameters loaded from the DHIAPP.INI file

INI file :	C:\PROGRA~1\DHI\2009\bin\DHIAPP.INI
Relative change criteria for inflow time series :	0,100
Low flow limit for inflow time series :	0,010
Maximum relative water level change :	0,100
Maximum variation in Cross Section parameters :	0,100
Cross check low depth limit (relative) :	0,040
Cross check level :	1,000
Maximum Courant Number :	20,000

Simulation Result Summary

Continuity Balance

1 :	**Start volume in Pipes, Manholes and Structures**				**2,4 m3**
2 :	**End volume in Pipes, Manholes and Structures**				**101,4 m3**
3 :	**Total inflow volume**				
	Specified inflows				
	Runoff :	12377,0 m3			
	DWF :	4708,9 m3			
		17085,9 m3		**-->**	**17085,9 m3**
4 :	**Total diverted volume**				
	Operational, non-specified outflows				
	Outlets :	16999,2 m3			
		16999,2 m3		**-->**	**16999,2 m3**
5 :	**Water generated in empty parts of the system :**				**8,8 m3**
6 :	**Continuity Balance = (2-1) - (3-4+5) :**				**3,4 m3**
	Continuity Balance max value :		3,4 m3		
	Continuity Balance min value :		-50,1 m3		

Boundary Connections

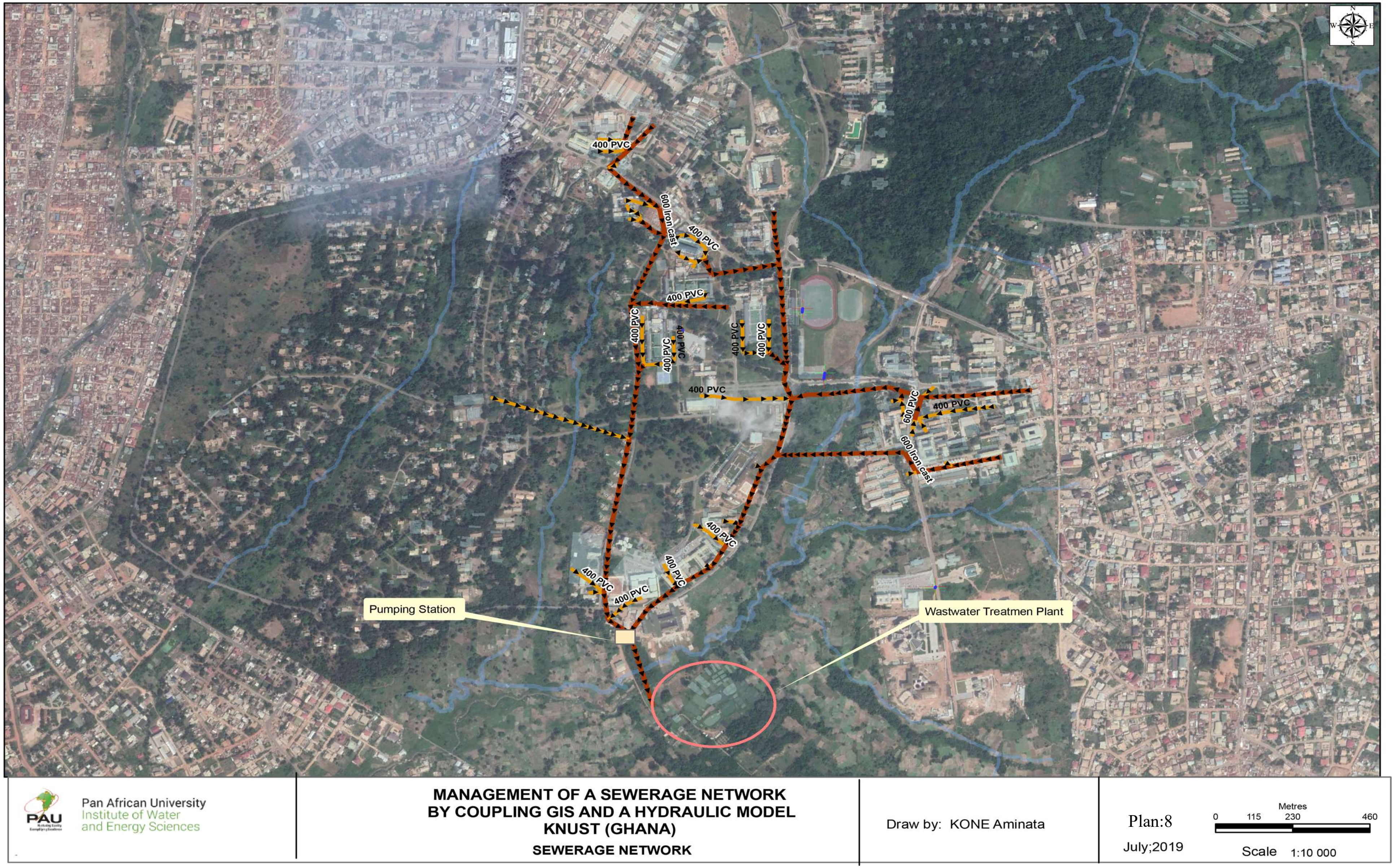
Network loads (discharges)

VI

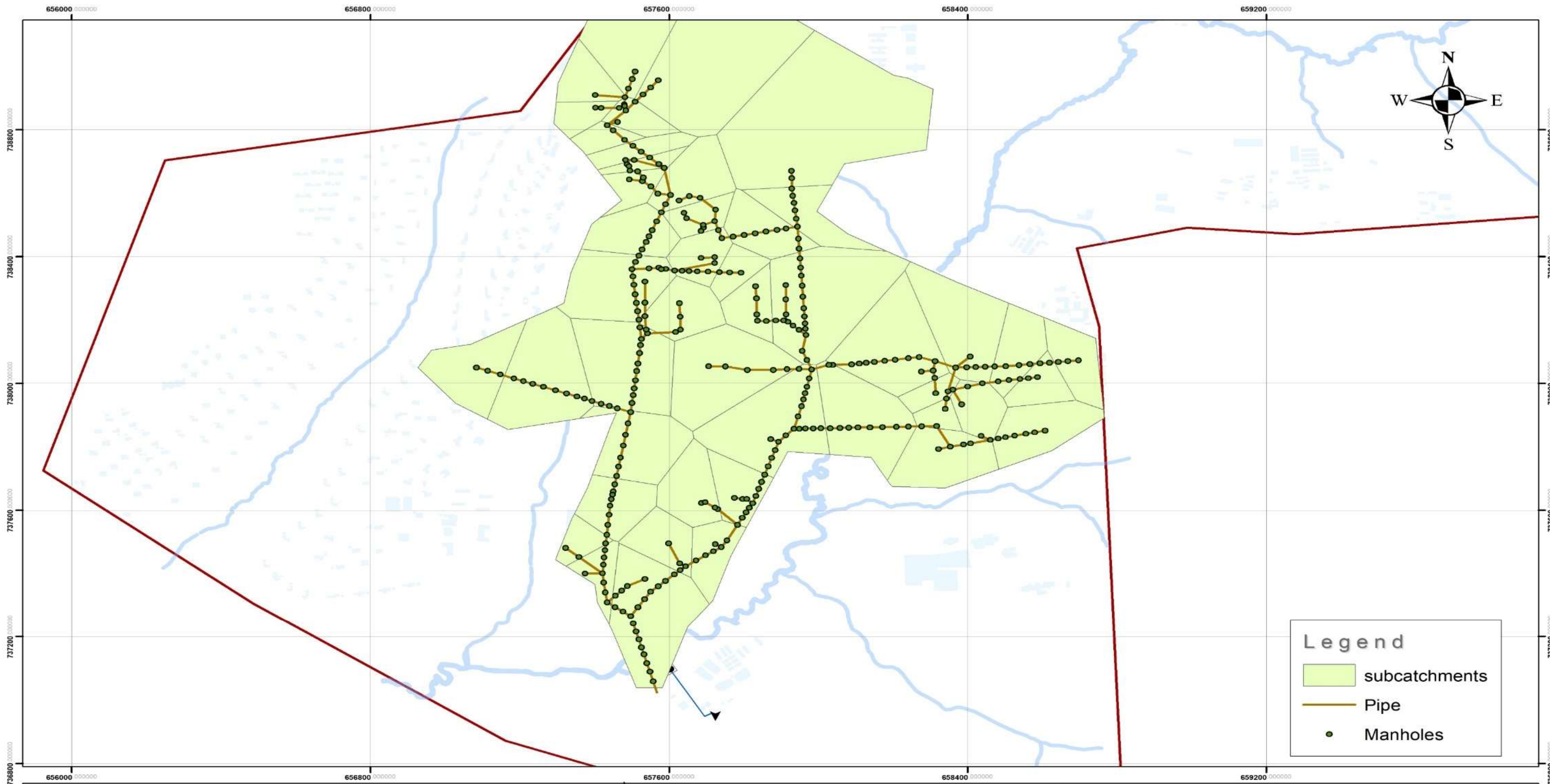
Boundary Condition ID	Type	Connection Type	Location	Temporal variation	Value/pattern/TS name	Validity	Validity Start	Validity End	Minimum Value	Maximum Value	Accumulated Value
									m3/s	m3/s	m3
BC_4	Discharge	All		Cyclic	Profile_1	Unlimited	-	-	0,044	0,076	5287,6

VII

Annex 4: Spatial view of the sewerage network



Annex 5: The division of the catchment in sub-catchment function to the manholes



Pan African University
Institute of Water
and Energy Sciences

Realized by KONE Aminata

July 2019

MANAGEMENT OF A SEWERAGR NETWORK BY COUPLING GIS AND A HYDRAULIC MODEL KNUST (GHANA)

SUB-CATCHMENT

0 245 490 980 m

Scale 1:10 000

Plan:9

Annex 6: Horton Result

OID	OBJID	CatchmentID	Length	Slope	ParBID	AISteep	AIFlat	APSmall	APMedium	APLarge	LocalNo	MISteep	MIFlat	MPSmall	MPMedium	MPLarge
0	1	Catchment_630	81	0.97	D	0	65.3	0	0	34.7	0	80	70	30	30	12
1	2	Catchment_657	236	0.78	D	0	87	0	0	13	0	80	70	30	30	12
2	3	Catchment_655	470	1.22	D	0	83	0	0	17	0	80	70	30	30	12
3	4	Catchment_658	540	1.43	D	0	50	0	0	50	0	80	70	30	30	12
4	5	Catchment_656	101	0.26	D	0	87	0	0	13	0	80	70	30	30	12
5	6	Catchment_654	40	0.23	D	0	80	0	0	20	0	80	70	30	30	12
6	7	Catchment_652	33	0.37	D	0	67	0	0	33	0	80	70	30	30	12
7	8	Catchment_653	86	1.12	D	0	70	0	0	30	0	80	70	30	30	12
8	9	Catchment_649	56	0.92	D	0	50	0	0	50	0	80	70	30	30	12
9	10	Catchment_650	55	0.92	D	0	60	0	0	40	0	80	70	30	30	12

X

10	11	Catchment_648	36	1.36	D	0	47	0	0	53	0	80	70	30	30	12
11	12	Catchment_651	70	0.96	D	0	65	0	0	35	0	80	70	30	30	12
12	13	Catchment_671	66	0.6	D	0	80	0	0	20	0	80	70	30	30	12
13	14	Catchment_666	238	1.59	D	0	43	0	0	57	0	80	70	30	30	12
14	15	Catchment_663	290	1.1	D	0	44	0	0	56	0	80	70	30	30	12
15	16	Catchment_647	107	1.01	D	0	41	0	0	59	0	80	70	30	30	12
16	17	Catchment_646	341	1.86	D	0	42	0	0	58	0	80	70	30	30	12
17	18	Catchment_664	281	1.44	D	0	45	0	0	55	0	80	70	30	30	12
18	19	Catchment_674	193	1.13	D	0	61	0	0	39	0	80	70	30	30	12
19	20	Catchment_668	114	1.67	D	0	64	0	0	36	0	80	70	30	30	12
20	21	Catchment_669	329	1.27	D	0	44	0	0	56	0	80	70	30	30	12

21	22	Catchment_659	140	1.45	D	0	56	0	0	44	0	80	70	30	30	12
22	23	Catchment_672	274	1.23	D	0	60	0	0	40	0	80	70	30	30	12
23	24	Catchment_660	311	1.07	D	0	60	0	0	40	0	80	70	30	30	12
24	25	Catchment_661	150	1.65	D	0	73	0	0	27	0	80	70	30	30	12
25	26	Catchment_662	71	0.53	D	0	89	0	0	11	0	80	70	30	30	12
26	27	Catchment_673	84	0.57	D	0	72	0	0	28	0	80	70	30	30	12
27	28	Catchment_639	114	1.84	D	0	86	0	0	14	0	80	70	30	30	12
28	29	Catchment_637	255	1.48	D	0	80	0	0	20	0	80	70	30	30	12
29	30	Catchment_641	117	0.61	D	0	70	0	0	30	0	80	70	30	30	12
30	31	Catchment_640	68	1.17	D	0	60	0	0	40	0	80	70	30	30	12
31	32	Catchment_643	103	1.06	D	0	85	0	0	15	0	80	70	30	30	12

32	33	Catchment_642	284	1.34	D	0	50	0	0	50	0	80	70	30	30	12
33	34	Catchment_638	300	1.2	D	0	46	0	0	54	0	80	70	30	30	12
34	35	Catchment_636	200	1.71	D	0	88	0	0	12	0	80	70	30	30	12
35	36	Catchment_633	115	1.4	D	0	65	0	0	35	0	80	70	30	30	12
36	37	Catchment_631	172	0.82	D	0	60	0	0	40	0	80	70	30	30	12
37	38	Catchment_645	90	0.67	D	0	50	0	0	50	0	80	70	30	30	12
38	39	Catchment_634	108	1.16	D	0	45	0	0	55	0	80	70	30	30	12
39	40	Catchment_644	118	1.53	D	0	43	0	0	57	0	80	70	30	30	12
40	41	Catchment_635	84	1.22	D	0	43	0	0	57	0	80	70	30	30	12
41	42	Catchment_632	112	1.11	D	0	69.5	0	0	30.5	0	80	70	30	30	12
42	43	Catchment_675	92	0.92	D	0	70	0	0	30	0	80	70	30	30	12

43	44	Catchment_665	87	0.76	D	0	60	0	0	40	0	80	70	30	30	12
44	45	Catchment_667	104	1.55	D	0	60	0	0	40	0	80	70	30	30	12
45	46	Catchment_670	152	2	D	0	51	0	0	49	0	80	70	30	30	12