Methodology
Urban Flood Risk Assessment

September 22nd, 2016

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Methodology
Urban Flood Risk Assessment

Project Flood Risk Accra
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Preface

This methodology is developed in a study carried out by master students from Delft University of Technology (the Netherlands) in collaboration with students from Kwame Nkrumah University of Science and Technology (Ghana). During a project period of ten weeks, the students were supervised by a team of consultants from HKV Consultants and Witteveen+Bos. The project team would like to thank Joost van der Zwet, Job Udo, Gideon Lomoko, Joriën Mendez Groot, Richard Sedafor, Durk Klopstra, Nicole Jungermann and Rudolf Versteeg for their guidance and time spent on the project. This report is the final deliverable of the student project team.

Different tools and activities to collect information for flood risk assessment were tested in the complex, data-scarce and urban environment of Accra. The report is written with an emphasis on lessons learned and recommendations for improving results. Although validation of this methodology is still required, it can serve as a starting point for continued research into the urban flood risk in Accra as well as in other cities.

Executive summary

Poor or lacking urban drainage systems increase the risk of urban floods, especially in cities where the population is growing fast. Ghana's capital Accra, as many other African cities, is periodically subject to strong flooding that claim victims, cause health risks through contaminated overflows, and undermine economic activities. Dense and paved urban landscape reduces the infiltration capacity of the soil, inadequate drainage infrastructure limits the retention of flood water, and the lack of institutional coordination leads to weak management of the services. In addition, the accumulation of solid waste in the drains poses a risk for people's health and reduces the capacity of the drainage system.

All these factors, within a scenario of increasing climate variability and more intense rainfall, are considered in the present study to (a) analyze the flood risk and assess the causes of urban flooding in a pilot area in Accra, using an innovate and integrated approach; and to (b) develop a methodology for urban flood risk assessment that can be applied in other African cities facing similar issues. This research is carried out by students from Delft University and Kwame Nkruma University of Science and Technology (KNUST) and is supported by a cooperation of consultants and funding organisations. The research consists of collecting and organizing relevant technical and social information, in a typical data-scarce context, to answer two research questions: (1) what are the causes of floods in Accra; and (2) what are useful elements in developing a methodology for flood assessment in African cities.

The flood assessment is executed through different activities, from institutional, technical and social angles. Those activities include: *stakeholder consultation; technical and social fieldwork* in a neighborhood scale pilot area - the districts of Alajo and New Town in Accra - to collect technical data and other information; *flood assessment modelling,* by developing a hydrodynamic model based on collected field data; *awareness creation* to bring topics of flood and waste management under attention by engaging with the community and participating in local initiatives; and s*ocial media experiments,* to test the feasibility of gathering georeferenced data from citizens through social media as WhatsApp and Facebook.

To carry out the activities, preparatory steps, background analysis and preliminary studies are completed in advance of organizing the fieldwork. Data on the functioning of the drainage system is collected through smart surveys by the use of the smartphone app AkvoFLOW. The open source geographic information system QGIS is used to process the fieldwork results and draw the drainage network. The software SOBEK is used for building a hydrodynamic model, in which network characteristics and available land height data are combined with hydrological data to carry out 1D and 2D flood simulations. Five different scenarios, based on percentage of the drains clogging with waste and the level of the downstream seawater, are evaluated to simulate flood events and to indicate possible bottlenecks and vulnerable areas. Modelling results are then compared with information of historical floods level, collected through social surveys during fieldwork, to validate the model.

The answers to the research questions (1) and (2) are supported by the findings from fieldwork activities and the modelling results. Floods in the pilot area of Alajo and New Town are caused by a combination of factors: a) the drainage network is not properly designed and maintained; b) high heterogeneity in drain types creates hindrances and makes it difficult to predict the water behavior; c) at specific bottlenecks such as culverts and erosion paths, the capacity of the system is insufficient; d) waste disposal and accumulation in the drains causes blockages in the drainage network as it decreases the capacity especially in low-lying areas, therefore raising awareness on

the negative effects of waste disposal should be addressed in upstream areas since the waste is flushed downstream; e) siltation occurs along the entire drainage network, especially in the major drains and flat areas; and f) lack of spatial planning and weak cooperation between the responsible institutions for urban drainage management results in a lack of drain maintenance which leads to higher flood risks. Based on the hydrodynamic model, no clear conclusions could be drawn on the effects of waste and silt accumulation, given the misrepresentations of the storage capacity of the water system. However, the model suggests that the main influence on flooding comes from imposed downstream water levels and not from the rainfall in the pilot area itself.

The tools applied to analyze the flood risk in the pilot area in Accra are evaluated for the purpose of a flood assessment methodology in African cities. *Social surveys and stakeholder consultation* are useful methods to quickly understand and map relevant problems in the area. They also provide useful data to calibrate or validate model results. With an organized fieldwork strategy using smartphone based collection and a handheld GPS device, a large amount of technical information on the drainage system can be orderly mapped in QGIS in few days. Choosing boundaries for the sub-catchment and deciding to what level of detail the network should be mapped depends on the size of the flood levels that have relevant impact in a neighborhood.

The flood assessment model developed in this research is based on field measurements in the pilot area and elevation data derived from satellites, which introduces uncertainty due to its coarse resolution. The hydrodynamic model gives an impression of the flood prone areas in the neighborhood and helps to assess the effects of varying downstream water levels. Model scenarios of waste and silt clogging are constructed to get insight into the sensitivity of the system. Due to the current stage of development of the model, the accuracy is limited for now. For future research the model could be used to get insight into the effectiveness of measures to reduce the flood risk.

Crowd sourced flood risk mapping is a promising tool to collect data for flood risk assessment given the amount of received reactions after the launched social media experiment. The number of valuable responses could be increased by more clear and simple communication of the message. It is in any way an effective means to raise awareness about the analyzed problematic and to engage citizens in the discussion.

Another good tool to *raise awareness* about waste accumulation causing blockages in the drains is taking part in local initiatives such as a 'garbage removal mission'. Such an initiative creates engagement and mobilizes more community members to join the cleaning activities. Furthermore, developing communication strategies to engage stakeholders, partners and inhabitants in the project is important to create trust, enthusiasm and participation.

In this case study lots of information was collected about the current status of drainage system, the underlying causes of flood risk and the related issues on drainage and waste management. The structural measures proposed could be evaluated using the urban drainage model. The accuracy of the model could be improved by using more detailed height data and by extending the model with more information on the primary drainage system outside the pilot area. Other areas of continued research are: investigating the dynamics of waste flow in the drainage network and assessing the causes of malfunctioning of the waste management services.

The report is written with an emphasis on lessons learned and recommendations for improving results. Although validation of this methodology is still required, it can serve as a starting point for continued research into the urban flood risk in Accra as well as in other African cities.

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1 Introduction

1.1 Context urban drainage in African cities

In many African cities, urban floods are an increasing problem since urban drainage systems are not in line with the strong increase of the population. In the last few years, severe floods hit Ghana's capital Accra. On June 3rd 2015, heavy rains created floods that impacted many parts of the Greater Accra Region. Many people were displaced and lost their property and livelihoods. The flood also caused a filling station to explode, which caused the death of more than 200 people. Adding to these are the costs of disrupted traffic and economic activities. Besides the impact of the generated flood wave, the immense rainfall resulted into pockets of heavily contaminated standing water, affecting the health of the communities that reside in low-lying, vulnerable areas.

Accra is one example of the many African cities with similar development patterns: A strong increase in population, dense and paved urban landscapes, inadequate drainage infrastructure, lack of institutional coordination and poor solid waste management services. Because of the compacted and paved soils in the city, there is hardly any infiltration of rainwater and retention of flood water is limited. During an extreme rainfall event, the drainage system cannot discharge the generated flows of water properly and overtops. This could be due to the layout and dimensioning of the network. Also, the accumulation of solid waste in the drains has a negative impact on water safety and quality. With increasing climate variability and more intense rainfall predicted, cities like Accra are turning into ticking time bombs, where immediate action is needed.

Measures and priorities to reduce disaster risk and losses in lives, livelihoods and health have been set up globally under the Sendai Framework for Disaster Risk Reduction 2015-2030 [1]. The first priority for action is "understanding disaster risk" and is explained as how "disaster risk management needs to be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment". In an environment with little available field data of the urban drainage system, such as Accra and other African cities, it remains a challenge to evaluate the flood risk.

1.2 Objectives

The research objectives of the conducted study are twofold:

1. To analyse the flood risk and assess the causes of urban flooding in a pilot area in Accra, using an innovate and integrated approach;

2. To develop a methodology for urban flood risk assessment that can be applied in other African cities facing similar issues.

1.3 Report outline

This methodology aims at collecting and organizing relevant technical and social information in a data-scarce environment. It bundles all findings, results and lessons learned from a case study in the city of Accra for illustrative purposes and can be a starting point for continued research into urban flood risk in Accra as well as in other African cities facing similar issues.

After the problem introduction and research objectives described in this first chapter, the project approach is described in the Chapter 2. Chapter 3 elaborates on the required preparatory steps in advance of the fieldwork, followed by the organization and planning of fieldwork activities to gather data both on technical and social aspects in Chapter 4. How the collected data can be presented and used to develop a hydrodynamic model is described in Chapter 5. Advice on how to create support for the project and raise awareness about flood risk is included in Chapter 6. In the concluding

Chapter 7, the research questions are evaluated. Continued research needed to further develop the methodology is presented in Chapter 8 and finally, a critical reflection on the delivered methodology is given in Chapter 9. More elaborated results from the Accra case study are included in the appendices of this methodology report.

2 Approach

2.1 Project background

A cooperation is set up between universities and consultants to assess the causes of urban flooding and to analyse the flood risk, to ultimately propose sustainable measures in order to reduce this flood risk in the capital city of Ghana. Within this cooperation, a team of students from Delft University of Technology (TU Delft) spent five weeks in Accra to carry out research on flood risk assessment methods together with students from Kwame Nkrumah University of Science and Technology (KNUST). The two universities and consultancies HKV Consultants, Witteveen+Bos, Berenschot Consultant and Colan Consult bring together different fields of expertise in this project.

The supporting companies have profound experience in Ghana on topics of flood risk, urban drainage and waste management. HKV Consultants has recently worked on the set-up of an Early Warning System (CREW Project) in Ghana and the latter three have worked on Ghana-Netherlands WASH Program (GNWP) projects and have offices in Accra. A long-standing relationship between the universities KNUST and TU Delft has been established through prof. Nick van de Giesen from Water Resources, TU Delft. An overview of the project team members and supervisors is included in Appendix A. The project is supported by ViaWater, a program driving innovative solutions to solve water problems in African Cities.

2.2 Research questions

To achieve the objectives stated in Paragraph 1.2, two research questions are formulated:

1. What are the causes of floods in Accra?
2. What are useful elements in developing a methodology for flood assessment in African cities?

2.3 Activities

To answer the research questions and to approach the flood assessment from institutional, technical and social angles, the activities listed below have been executed:

Stakeholder consultation
Visiting stakeholders in urban drainage to get to know their viewpoint on the causes of flooding in the city of Accra and to learn about institutional issues.

Technical fieldwork
Collecting technical data on the urban drainage system in a neighbourhood scale pilot area, testing different data collection methods.

Social fieldwork
Interviewing local people to gather information on urban flooding and solid waste management from the viewpoint of citizens to compare this to the viewpoint of stakeholders.

Awareness creation
Bringing topics of flood and waste management under the attention amongst stakeholders and citizens, promoting the importance of the project and involving local people.

Flood assessment modelling
Developing a hydrodynamic model based on collected field data to discover what is needed to make such a model useful for analysing causes of urban flooding and finding bottlenecks in a system.

Social media experiment

Testing whether it is possible to gather georeferenced data from citizens through WhatsApp and Facebook.

3 Case study preparation

In this chapter, the required preparatory steps in advance of fieldwork are elaborated. These include creation of a cultural context, background analysis and data synopsis, networking, stakeholder analysis and external communication. Experiences, findings and results of the Accra case are presented in boxes.

3.1 Cultural context

When a research project is set in a foreign environment, it is important to familiarise with cultural norms and values to establish cordial relations. Cultural guides and speaking to natives or people that have lived in the country concerned is advisable in order to discover what kind of behaviour is desired. To start fieldwork well-prepared, it can help to imagine a range of situations that might be encountered. Communication strategies set up beforehand facilitate dialogue during fieldwork. In some situations translators or team members that master local languages are essential. Ways of communication in informal and formal settings might differ and awareness on nuances can help to create positive discussion dynamics.

In Ghana, informal conversations are direct and opinions can be shared freely. In formal settings, addressing authority in the correct manner is crucial to establish a good relation and care should be taken of how to behave. Crossing legs in front of a chief is, for example, an act of disrespect. In some situations, certain religious procedures are to be completed prior to content discussions.

3.2 Background analysis and data synopsis

Investigating what research has already been carried out and what data is available on the topic helps in defining the research scope. When preparations take place from a distance, this can be done through a literature review. Information could for instance be found on urban development patterns, hydrology, climate, historical rain and flood events and past and future drainage related projects. In addition, flood prone areas could be identified and mapped. Looking at the causes of urban flooding from an integrated viewpoint is necessary to understand the complex systems that might be behind it. An example is the influence of solid waste management on urban flooding in the Accra case, which should be included in the research. Creating a synopsis on available and desirable data helps to identify data gaps, which can be addressed in stakeholder meetings.

Rainfall June 3rd 2015

On June 3rd 2015, heavy rainfall that lasted for six hours created floods, impacting many parts of the Greater Accra Region. The recorded rainfall of this extreme event observed at selected stations in Accra is presented in Table 1 Rainfall ranges recorded by the Ghana Meteorological Office are indicated in rainfall frequency curves of Accra (Rainfall range 90-170 mm on June 3rd 2015 in comparison with rainfall frequency curves [2]). These curves are constructed from historical precipitation data and show how often a storm with a certain rainfall depth and duration would occur. The return period of the June 3rd event is 6 - 200 years, confirming its severity

Table 1 Recorded rainfall at selected stations in Accra on June 3rd 2015 [2]

Station	Observed rainfall [mm]
Osu	90.3
Archives	169.4
St. Mary's	154.2
Accra Academy	169.4
Wesley Grammar	96.6
Weija	119.4
Maamobi	89.8
GMET (Legon)	148.3

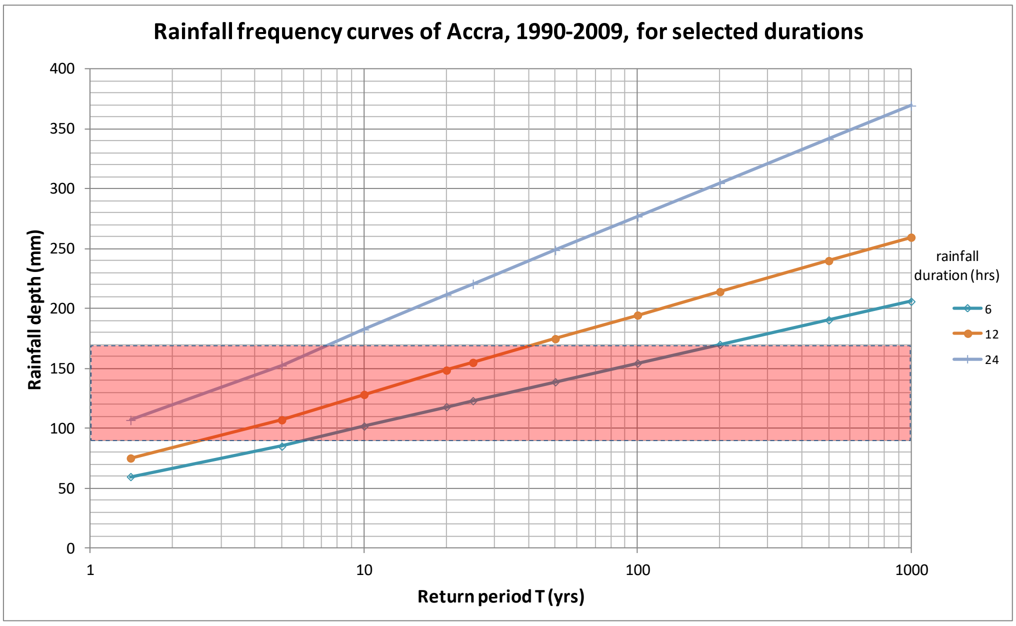

Figure 1 *Rainfall range 90-170 mm on June 3rd 2015 in comparison with rainfall frequency curves [2]*

Causes of flooding

Even small rains events already lead to flooding in the city of Accra. What are the reasons that Accra is not drained well during heavy rainfall mentioned in literature?

- The urban population of Accra grows with more than 4% per year. Many people move to cities because of droughts in the northern parts of the country, looking for other means of living. The rapid urban expansion of Accra transformed the surface of the basin into a nearly impervious area. There is hardly any infiltration of rainwater and retention capacity for flood water is limited. Residential structures are placed in low-lying and unsafe areas close to or on top of drainage channels. Roads have been built across watercourses, leaving no space for the water to flow [4].

- The attempt at flood management and mitigation in Ghana has concentrated on conveyance improvement and channel widening. Creating impervious surfaces through cementing outdoor living areas is locally understood as a strategy to reduce flooding. However, this passes the problem on to those who live further downstream [5].

- The government has not been able to keep up constructing city infrastructure in a pace according to the population increase. Therefore, many neighbourhoods have inadequate infrastructure for energy supply, sanitation services, roads and drainage systems. The drainage network is with its current layout and dimensions not capable of discharging rain water appropriately. Due to a lack of maintenance, capacities are decreased even further.

- Accra's official waste disposal sites are small and overloaded, encouraging illegal disposal in drains or the ocean. Accumulation of solid waste and silt in the drains has a negative impact on water safety and quality. Clogged drains and lagoons cause backwater effects in upstream stretches. Water quality in the water bodies is very low, causing health risk for communities that reside nearby [5].

- The extreme division of responsibilities in urban drainage management in Accra complicates coordination of planning and maintaining. The stakeholders analysis in Paragraph 3.4 gives an overview of the institutions involved.

A more extensive background analysis of the Accra case can be found in Appendix B.

Data synopsis
Meteorological data
As a source for rainfall data, ground measurements and satellite data can be used. Depending on the meteorological institute, rainfall data of measuring stations is collected for different time intervals. Rainfall measurements from Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM) satellites [8, 9] should be corrected by ground weather stations when possible, as raw satellite data is likely to underestimate actual rainfall amounts. For the Accra case, rainfall depths measured at weather stations (**Errore. L'origine riferimento non è stata trovata.**) are 1.3 - 2.5 times higher than GPM rainfall depths for the June 3rd 2015 event (Appendix C).

Hydrological data
Hydrological data on discharges and water levels of large drains and rivers flowing through the city of Accra was not found during the literature study. Ideally, working gauging stations are in place and developed stage-discharge relations are available, linking the flow of the water in a channel to an occurring water level. Water level and discharge measurements can be carried out during rainfall events in the fieldwork period.

Topographical data
Height data of the study area can be taken from a Digital Elevation Model (DEM), orthophotos, toposheets and shapefiles with information on the city's infrastructure. Open height data of the area with 30x30 m grid cells can be generated through NASA's Shuttle Radar Topography Mission (SRTM) [10]. For the Accra case, a DEM with 20x20 m grid cells from Satellite Pour l'Observation de la Terre (SPOT[12]) was made available by HKV Consultants. Although both resolutions are too coarse for urban application, it can give a first indication of the tendency of the landscape and the flow direction of water. For orientation, background street, road and waterway maps in shapefile format were taken from OpenStreetMap Ghana [11], a community

Governmental departments or institutions might hold detailed information on topography and spatial planning, but it might take time and negotiation to obtain this. Reluctance towards giving out information could be based on the time and money spent on data collection. Querying a cut-out of the data files for the study area and for research purposes only, with the promise of sharing findings afterwards, has been one of the approaches of the project team to obtain information from stakeholders.

Figure 2 OpenStreetMap layer [4]

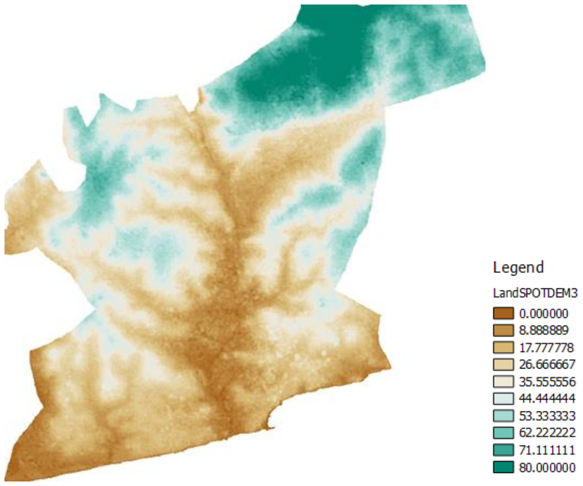

Figure 3 SPOT DEM (AMA boundaries) [12]

3.3 Networking

Networking is an importation preparation activity to acquire knowledge, get support and raise enthusiasm and funding for a project. Stakeholders and researchers might be identified online and in literature and collaborations could be set up already, for example in data sharing. Given the complexity of the issues in urban drainage management, identification of expertise areas within the project is needed to find out what knowledge should be obtained and to realize a targeted search for specialists. Contacting consultancies and companies working on similar projects or in related business can extend basic knowledge on systems and processes.

The project team was supervised by experts from HKV Consultants and Witteveen+Bos. Information on local stakeholders and preparatory advices were shared in advance, whereas expert involvement was received during and support on flood assessment modelling after the activities carried out in Ghana. Witteveen+Bos offered office space and materials in Accra to the project team, as well as usage of the car and driver when available. The local assistance and support from Witteveen+Bos has allowed the project team to achieve much more than expected during the short project period.

Before traveling to Ghana, Dutch waste management companies were contacted in search of knowledge on waste management systems and processes that are in place in the Netherlands. Van Gansewinkel, a large waste service provider, recycler and supplier of secondary raw materials, shared expertise in waste management and equipped the project team with new information and perspectives. Organizing waste management in the Netherlands takes optimized systems, logistics and processes. Lessons learned in the development of a model of the waste market in India were shared. It came forward that waste collection as an idealistic, environmental endeavour does not work and that financial incentive is the most important factor for a successful set up of any kind of waste management system.

3.4 Stakeholder analysis

Analysing stakeholders, their responsibilities and relations towards each other gives an impression of how the concerned urban drainage system is managed, which parties are having influence and which parties are affected.

In preparation of the fieldwork period, four stakeholders with direct responsibilities in construction and maintenance of the urban drainage system of the Accra case study were identified:

- Accra Metropolitan Assembly (AMA)
- Ministry of Local Government and Rural Development (MLGRD)
- Ministry of Roads and Highways (MRH) - Department of Urban Roads (DUR)
- Ministry of Water Resources, Works and Housing (MWRWH) - Hydrological Services Department (HSD)

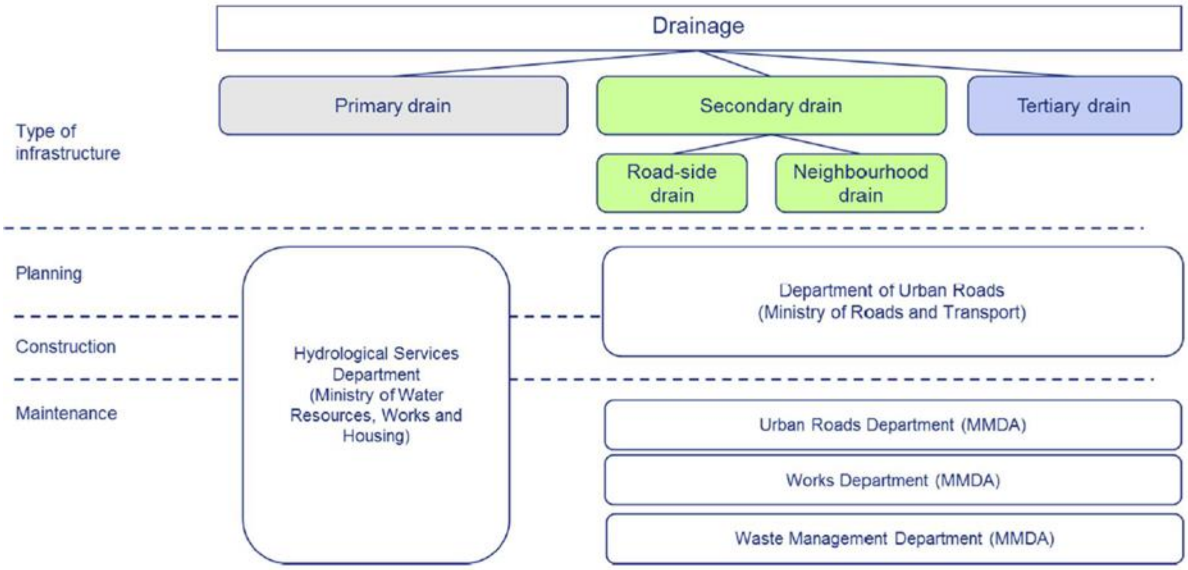

Figure 4 Stakeholder responsibilities in Ghanaian urban drainage management [7]

There is a large division of responsibilities in urban drainage management in Accra, caused by administrative boundaries and political organization [7]. There are sixteen different municipalities (MMDAs) within the Greater Accra metropolitan Area (GAMA), AMA being one of them.

Figure 4 gives an overview of the division of responsibilities in construction and maintenance of urban drainage systems in Ghana. HSD is responsible for programming and coordination of major drainage works in primary drainage systems. Monitoring and evaluating rivers and water bodies throughout the country with respect to flooding is one of its tasks. Responsibility for the construction of secondary and tertiary drains associated with transport infrastructure is assigned to DUR, whereas MMDAs are responsible for operation and maintenance. Within MMDAs, three departments that coordinate activities are identified:

- Urban Roads Department, responsible for maintenance of roadside drains;
- Works Department, responsible for design and management of all assembly building projects;
- Waste Management Department, responsible for a clean environment.

As MMDAs face significant budgetary restraints, adequate maintenance is lacking [7]. Moreover, while MMDAs are responsible for drain maintenance, they are dependent on the private company

Zoomlion for execution of services. MMDAs pay for these services based on a contract at national level by MLGRD, and payments are not necessarily related to performance.

Other identified main stakeholders are:

- National Disaster Management Organization (NADMO), responsible for communication and coordination in case of disasters in Ghana, including floods. NADMO activities are aimed at ensuring support in relief efforts from governmental side;
- Ghana Meteorological Agency (GMET), collecting, processing and archiving meteorological data for various end-users. GMET provides a public weather forecast on a daily basis;
- Ghana Environmental Protection Agency (EPA), dedicated to improving ,conserving and promoting the country's environment under the Ministry of Environment, Science, Technology and Innovation (MESTI);
- Zoomlion Ghana Limited, the largest waste management service provider and recycling company in Ghana. The Accra Composting and Recycling Plant (ACARP) is owned by Zoomlion;
- World Bank, who has given grant support to MLGRD for the Greater Accra Metropolitan Area Sanitation and Water Project (GAMA SWP). MLGRD addresses environmental, sanitary, drainage and perennial flood problems in the GAMA;
- Water Resources Commission (WRC), the overall responsible body for water resources management in Ghana. The commission issues licenses for water use abstraction, educates and creates awareness of water conservation and efficient use of water resources;
- International Water Management Institute (IWMI), a non-profit, scientific research organization focusing on sustainable use of water and land resources in developing countries;
- Universities as KNUST, University of Cape Coast (UCC) and University of Development Studies (UDS), teaching and researching water related topics;
- Citizens, affected by urban floods but also illegally encroaching on flood plains and privately constructing drains.

3.5 External communication

In order to receive attention and set up collaborations, it is important to think about external communication and the perceived credibility and potential. Online presence is a way to give a solid position to a project. A good starting point is asking yourself the question "Why?" (Figure 5), to define a clear purpose, cause and belief that support project activities and that can be communicated to the outside. Writing in everyday life language that resonates well with people of all backgrounds is advisable.

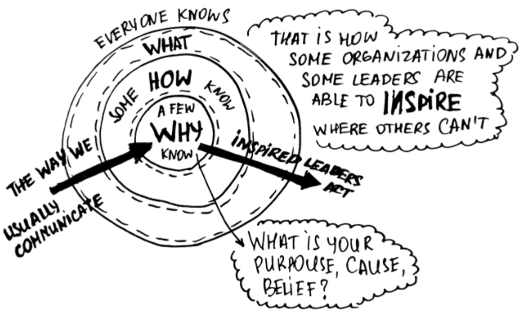

Figure 5 Start with "Why?" [6]

To engage stakeholders and citizens in the project, several communication strategies were developed. On a website (www.floodriskaccra.com), Facebook and Twitter, updates on the project activities and experiences were posted regularly and flyers and business cards were spread out to bring these platforms under the attention. Flyers also functioned as a support in explanations when community inhabitants asked about the project and mission. Giving out business cards with contact information was increased local engagement.

A blog writing strategy can help to keep hold of readers. Instead of summarizing weekly or daily activities, it might be more exciting to post focused stories that in the end cover all project dimensions and activities, including pictures and videos. In this way, online platforms are valuable deliverables and a great reference source. A balance should be found between personal and professional writing styles, given the varied audience that might visit a project website. It might be interesting to read about open-minded perspectives, but care should be taken in stating perceptions and in reflecting on local issues in a correct manner.

Visibility helps to attract attention and to raise awareness. To be easily recognizable and professional, bright blue "Project Flood Risk Accra" T-shirts were worn by the project team during fieldwork.

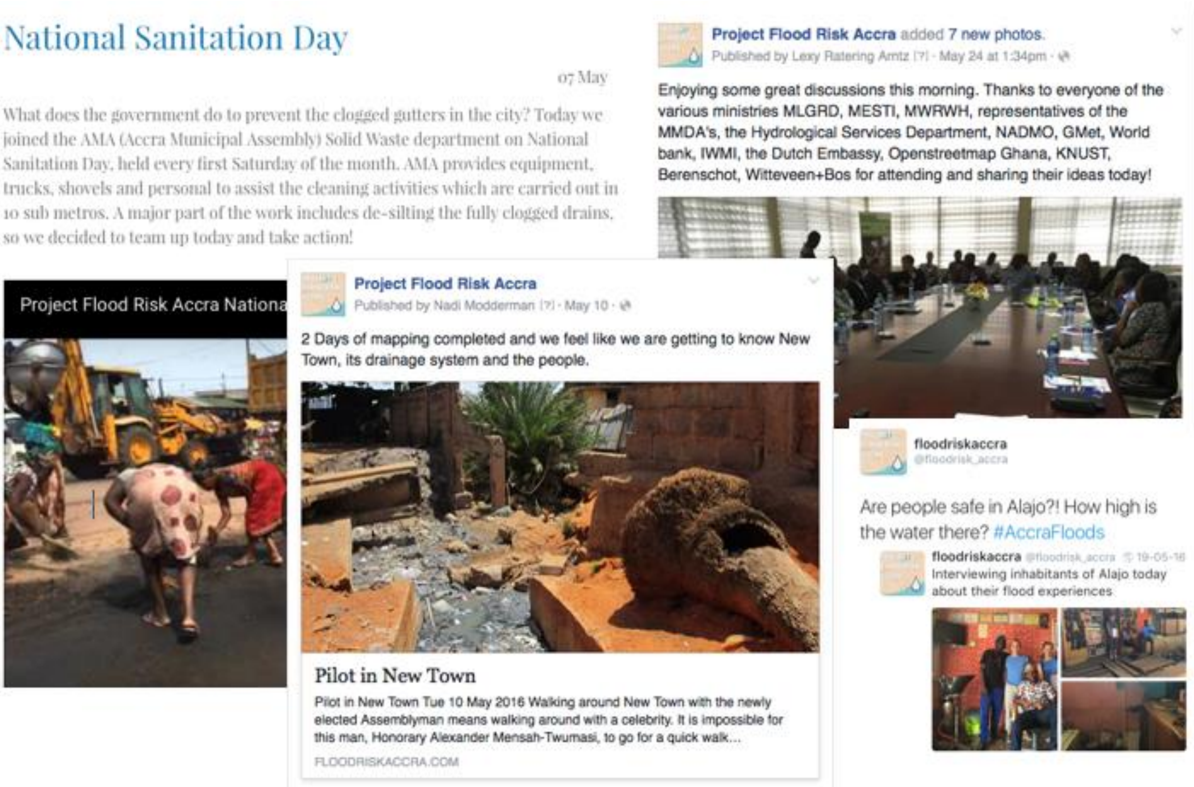

Figure 6 Examples of updates on the project website, Facebook and twitter

4 Local activities

In this chapter, activities that can be carried out locally in and around the study area are elaborated. These include pilot area selection, stakeholder consultation, technical fieldwork and social fieldwork. Moreover, organization, planning and practical issues regarding fieldwork activities and lessons learned are discussed. Experiences, findings and results of the Accra case are again presented in boxes.

4.1 Pilot area selection

Fieldwork is carried out in a selected area, which is referred to as the pilot area in the rest of this report. This paragraph elaborates on the steps to take in selecting a pilot area.

Desk study

The first step to take in selecting a pilot area is to study available literature, background information and news items on flood prone areas. This can already be done in the preparation phase (Chapter 3). First research on the social situation in different neighbourhoods and safety related aspects might also be carried out in the desk study.

The city of Accra is drained by five drainage basins, namely the Lafa, Chemu, South Link, Odaw and Osu Klottey basins(Sarbah, 2016). The Odaw basin is the largest within the AMA district and locates a majority of the city residents, ministries, the national airport, primary commercial zones and other important governmental and non-governmental institutions.

Initiated by the United Nations Development Programme (UNDP), an early warning system was conducted in the CREW-project (UNDP in Ghana, 2016) for multiple regions, including the AMA region. This early warning system indicates flood prone areas and risks of flooding based on weather forecasts. Flood prone areas in the Odaw catchment are displayed in Figure 7.

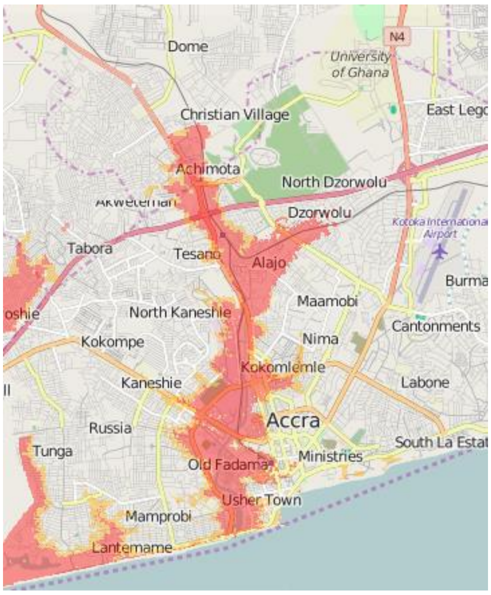

Figure 7 Flood prone areas (Odaw catchment) [17]

Stakeholder consultations

Meetings with stakeholders at the start of the research period can give input for the pilot area selection, as they have local knowledge and experience.

Four of the main stakeholders (AMA, HSD, GMET and NADMO) were visited during the pilot area selection phase. Agbogbloshie, Kaneshie (Graphic Road) and Alajo were mentioned as flooding hotspots. A short description of these areas can be found in Appendix D1.

Set up and ranking of criteria

After the desk study and stakeholder consultations, there might still be a large area containing potential pilot areas. To limit this area, criteria can be set up and ranked in order of importance. Criteria could for example relate to the susceptibility of an area to flooding, urban texture and feasibility of data collection.

The criteria used for pilot area selection in the case of Accra, ranked in order of importance, are:

1. *Susceptibility to flooding*
   Historical flooding within neighbourhoods determines the urgency of the flood risk assessment. For this criteria the frequency of flooding and its consequent damages are assessed;
2. *Urban texture*
   Besides flood problems, low-income areas are likely to experience also waste accumulation in drains and streets, which might cause clogging of the drainage system. The pilot area of choice is therefore a low-income neighbourhood.
3. *Feasibility of data collection*
   Fieldwork can be carried out more easily when the area is located close to the headquarters of the researchers to minimize transportation time and costs. Safety during the fieldwork and acceptance of the project activity by inhabitants are also important parameters to take into account.

A multi criteria analysis for the three potential pilot areas Agbogbloshie, Kaneshie (Graphic Road) and Alajo mentioned by stakeholders is presented in Appendix D2. The order of preference after the multi criteria analysis is firstly Alajo, followed by Agbogbloshie and finally Kaneshie.

On-site visits
It is advisable to visit potential pilot areas that come out positively from the multi criteria analysis to verify findings from the desk study, stakeholder consultations and criteria evaluations. Besides verification, these on-site visits give insight in the drainage system and flood experiences of inhabitants.

To verify the findings of the multi criteria analysis, the areas of Agbogbloshie, Kaneshie and Alajo were visited. The visit to Agbogbloshie confirmed the outcome of the third criterion: the overall atmosphere was perceived as unsafe. In Kaneshie and Alajo the atmosphere was good and people seemed willing to share their experiences.

Watershed delineation and final selection
After the desk study, stakeholder consultations, multi criteria analysis and on-site visits, the global pilot area location is chosen based on neighbourhood boundaries. However, these boundaries do not necessarily coincide with the hydrological boundaries of a catchment. Final pilot area boundaries can be defined through watershed delineation in the open source geographic information system QGIS using a DEM. The chosen threshold value used for the delineation determines the size of a catchment. The smaller the threshold value, the smaller catchments become. The threshold value can be chosen based on the time available to take measurements or, if time is not binding, on the desired size of the area to be mapped.

For the Accra case, a threshold value of 200 is used for watershed delineation. This results in the final boundaries of the pilot area as depicted in yellow in Figure 8. The main drains Odaw and Onyasia run through the pilot area. It includes the southern part of Alajo, west of the Onyasia drain, and a part of its adjacent neighbourhoods called New Town, east of the Onyasia drain.

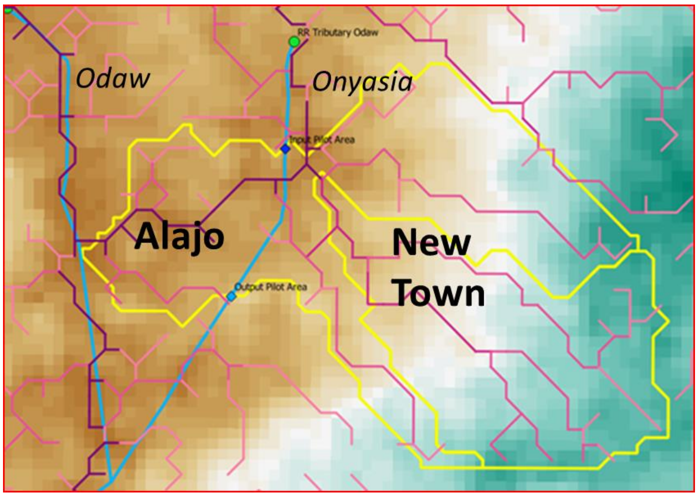

Figure 8 Final pilot area boundaries

4.2 Stakeholder meetings and contact

Stakeholders have local knowledge and experience and when data collection is also relevant for them, collaborations can be set up. Besides, they are often responsible for implementation of policies or measures and can therefore provide in essential information on urban drainage and waste management. Connections within an institution can help getting in contact with the right persons.

In addition, it is important to establish contacts in the selected pilot area. To conduct fieldwork it might be necessary to get consent of influential people such as chiefs, religious leaders, traditionalists and representatives, and connect through them with the community. When going around the neighbourhood, the consent of the representatives can be referred to.

Stakeholder meetings and contact

Setting up meetings with stakeholders takes time and preparation. In Ghana, it is expected to deliver an official letter to respectable offices introducing the project before a meeting can be arranged. Supervisor Frank Annor (TU Delft and KNUST) joined the project team on stakeholder visits to ensure appropriate communication. During the visits, stakeholders were kindly asked for information, data and input and reflection on the project plan and objectives. Valuable information on management systems was obtained during the consultations.

Five of the main stakeholders (AMA, HSD, GMET, NADMO and IWMI) were visited in the first project weeks in Ghana and many other stakeholders were contacted through phone or e-mail. The discussions with stakeholders revealed a need for coordination between the various parties that are responsible for the urban drainage system and for an integrated drainage master plan. It also became clear that more detailed information on the drainage system is needed in order to gain insight in the dynamics of the system. Dr. Kingsford from NADMO specifically mentioned the need "to map the current drainage system and to come up with some sort of classification".

Moreover, the project team had the chance to be an observer at the CityStrength Diagnostic Workshop organized by MESTI and MLGRD and supported by the World Bank. During two days, stresses (longer-term trends that undermine the performance of a system) and shocks (sudden events that impact the performance of a system) that occur in the city of Accra were mapped and the resilience of the city was assessed by representatives from various MMDAs, ministries, departments and institutions (Figure 9).

Stresses that are contributing to the shock event of a flood mentioned at the Drainage Management sector discussion table are the following:

- Limited access to housing in the city, which leads to illegal encroachment and placement of building structures along water courses and in flood prone areas;
- Lack of implementation and enforcement of drainage and spatial plans;
- Badly functioning solid waste management, in which the quality of services differs among neighbourhoods depending on income levels;
- Behavioural issues from citizens towards waste disposal;
- Lack of coordination between parties responsible for parts of the urban drainage system;
- Inadequate funding for operation and maintenance of the drainage system.

Figure 9 Stakeholders in discussion during the CityStrength Diagnostic Workshop

Establishing neighbourhood contact

Before starting data collection, the assemblymen of New Town and Alajo were contacted. Assemblymen voluntarily form the link between the official city council and the community of their neighbourhoods, and as they are chosen by the community itself, it is very important to get their consent for measurements. Especially because the chosen pilot area with parts of Alajo and New Town is considered a rough part of the city, it is good to have the back of the assemblymen. Both the assemblyman of New Town and Alajo took the project team on a tour through their neighbourhoods, during which they did not only provide the project team members with inside information on and bottlenecks regarding floods. They also introduced them to local people that would be able to help during the Accra case research or to grant the permission to conduct field.

Waste management system Accra

The waste management system in place aggravates the flood risk in a low-income neighborhood. The city council (AM) solid waste department provides a waste collection service, for 25 cedis per months for a large waste container and 15 cedis for small container (operated by Zoomlion) to be emptied every week. AMA has different levels of fees for different income areas. Not all households use this service as they don't want to allocate the amount of money. They either cannot afford it or don't make it their priority. Instead they dispose of their waste through individual waste pickers. For 1-2 cedis tricycles collect your waste and dump it in an pile of waste in neighbourhood from which it is transferred to a governmental dumpsite where a fee has to be paid. More often, the individual waste pickers dump the garbage that they collect in the drains during the night. Most inhabitants should be aware of the illegit disposal of waste by the individuals they pay to get rid of their waste.

It is hard to pinpoint whether the improper disposal of waste is an attitude problem, financial constraint, or a lack of available services provided. It is clear that these factors influence the amount of waste that can be found in the drains. Many stakeholders and inhabitants of the pilot area state that the awareness about improper waste disposal exists, and that people still keep dumping illegally as there is no enforcement. There are a lot of rules, but yet no fine or sentence will ever be given out. Some locals say that you can go to the police but they won't do anything with your complaint. For some inhabitants, the fee for waste disposal is a substantial amount of their income. The financial constraint triggers attitudinal problems towards waste. For some, the problem is simply the existence of a fee for waste disposal, and they refuse to pay for this service. Throwing waste into the drains cannot only be justified from people's bad attitude, lack of awareness, or financial considerations. There also exist a lack of targeted facilities and services (as trash bins, waste collectors, education) in some neighborhoods that should be provided by public or private institutions. Some initiatives are there to address the provisions of different waste services. It should be mentioned, however, that it is a huge challenge to carry out waste management when people encroach illegally and do not register.

4.3 Smart surveys

Data required to answer research questions can be obtained through the use of smart surveys during technical and social fieldwork. Smart surveys concern the implementation of innovative tools or ways to conduct a research. In this methodology, these are represented by the use of smartphone apps to collect data.

To easily collect, evaluate and display geographically referenced data, the Akvo Flow app and online dashboard provided by the Akvo Foundation are used for the Accra case study. Akvo Flow is a multi-language tool, available for Android smartphones[14]. Instead of collecting data using paper notes that need to be entered on a computer afterwards, data is gathered, shared and organized through smartphones or tablets. Surveys can be created online and downloaded on any Android device, after which surveys can be filled in offline as well. Completed survey forms are uploaded automatically to the dashboard as soon as the device connects to internet. As Android devices have camera and GPS options, less measurements tools have to be carried into the field.

Figure 10 and 11 respectively show the Akvo flow dashboard, where surveys can be prepared and stored in the form of questionnaires, and a map with all locations where surveys were taken during the fieldwork in Accra.

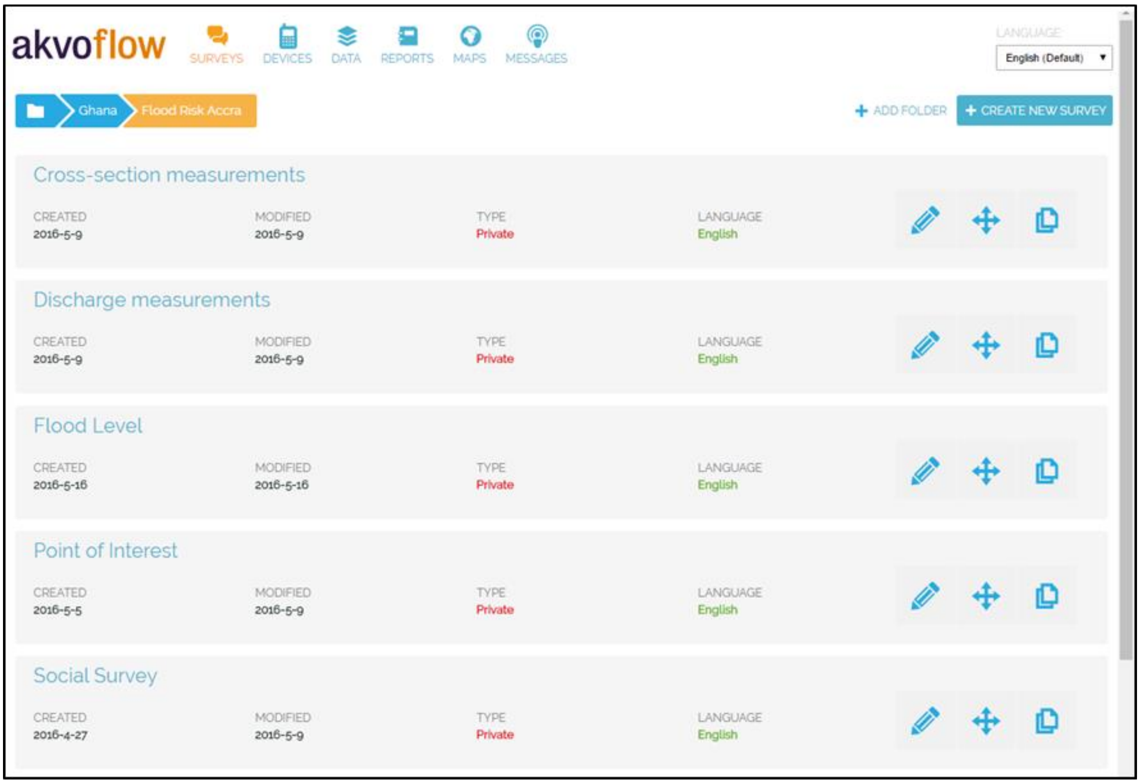

Figure 10 Akvo Flow online dashboard

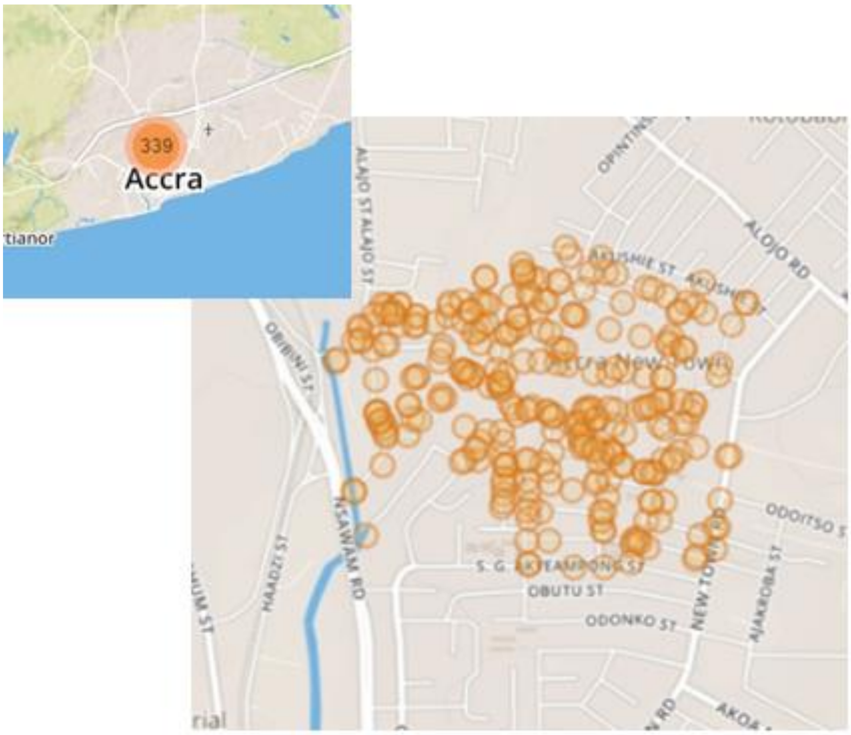

Figure 11 Akvo Flow georeferenced survey location

The use of the Akvo Flow app entails the concession of a license. This methodology makes use of the Akvo Flow app through the acquisition of a TU Delft license. Open source apps with similar application and specifications can be used, such as KoBoToolbox [15]. It is developed by the Harvard Humanitarian Initiative, aiming to provide an open source suite of tools for data collection and analysis in humanitarian emergencies and other challenging environments

4.4 Technical and social surveys

A preliminary analysis on what data should be collected is to be carried out to formulate relevant questionnaires to use during the fieldwork and to avoid missing important information afterwards. For this reason, it is smart to think about responses and the way the data should be finally displayed. Formulating questionnaires is a process of continuous improvement in order to only keep relevant questions in. After each trial of testing the surveys, questions can be edited to better fit the field research. To get an insight into urban drainage systems and drainage and waste management, both technical and social contexts can be studied in the pilot area.

The survey categories used for the study case in Accra is shown in Table 2.Technical surveys include information on the type, materials and state of the drainage network, network surroundings and waste presence and effects. This information is needed to understand and model the existing situation. Social surveys deal with the perception of local people on flooding problems and waste issues. Citizens can provide useful information about past flood events and waste disposal practices. Social surveys are also important in view to propose mitigating measures to waste management issues, as services have should be provided according to the needs and behaviours of inhabitants. In addition, interviewing people presents a moment to raise awareness about the flood risk and correct waste management.

Appendix D3 contains the survey forms used for the case study of Accra. They represent the final version of a series of questionnaires that have been implemented during the fieldwork. For the drainage network features, the options available as answers comply with a classification of the reaches that was finalized only after attaining a detailed understanding of the actual network layout. This classification is reported in the same Appendix D3. Table 3 reports the collected information, its purpose and its implementation in the project.

Table 2 Survey categories

Technical surveys	***Social surveys***
Drainage network features	Flood experience
Waste and clogging	Waste management
Discharge measurements	
Flood level marks on structures	
Points of interest	

Table 3 - Data collected during the fieldwork in Accra, purpose and use

Collected data	***Purpose***	***Use***
	Technical data (physical features of the system)	
	Drainage network features:	
Type of reach (manmade/ erosion/ erosion+manmade/ floodplain/ culvert)	Outline drainage network	Classification; Model drainage network QGIS and SOBEK
Covering (open /covered/partially covered drain)	Outline drainage network	Classification; Model drainage network QGIS
Location of the reach (along a road/alley/etc.)	Outline drainage network and surroundings	Model drainage network QGIS and SOBEK
Cross section of the reach (shape, width, height)	Quantify the capacity of the drainage network	Classification; Model drainage network QGIS and SOBEK
Material of the bottom and side of the drain/eroded channel (concrete/pavement/sand/clay/bricks/stones/rocks)	Qualify the flow throw the reach (quantify the friction)	Classification; Model drainage network QGIS and SOBEK
	Waste and clogging	
Type of waste	Characterize the type of waste	Analysis/description of the waste issue
Possible source	Characterize the type of waste; identify responsibility	Analysis/description of the waste issue
Waste influence on the drainage	Quantify the drainage capacity reduction	Analyse waste effect; Model scenarios in SOBEK
	Discharge measurements	
Velocity/flow rate	Measure the flow discharge along reaches, during rainfall	Set boundary conditions and calibrate the model in SOBEK*
	Flood level marks on structures	
Height till the mark	See the extent of past flood events; identify flood-prone spots	Validate the hydrodynamic model in SOBEK
	Other points of interest	

Vulnerable structures (schools/hospitals/gas station/etc.)	Identify vulnerable objects/potential damages	Create QGIS shapefile to improve Open Street Map; Vulnerability map*
Special features or structures along the network	Identify demolished reaches or structures (culverts/bridges) that can cause blockage and capacity reduction	Classification; Model drainage network QGIS and SOBEK; Analyse scenarios of capacity reduction in SOBEK
Social data (Information gathered from residents)*		
Data of interviewee		
Gender/Age/Occupation	Classify interviewees	Qualification and evaluation of the answers
Flood experience		
Last flood at that location	Retrace and see the extent of past flood events; identify flood-prone spots	Analysis of flooded areas; Calibrate the hydrodynamic model in SOBEK
Pictures of water level	Identify and record flood marks	Create a pictures archive
Causes of flooding	Understand people perception about drainage and waste management and flood risk	Compare community and institutional perspectives; Analyse scenarios of capacity reduction in SOBEK; Identify possible measures to reduce the flood risk
3rd of June event – water level	See the extent of past flood events; identify flood-prone spots	Validate the hydrodynamic model in SOBEK
3rd of June event – damages	See the extent of past flood events	Identify possible measures to reduce damages; Vulnerability map*
3rd of June event – warning system	Understand the functioning of the flood management	Recommendation: need for warning system
3rd of June event – taken actions/help given/help received	Comprehend behaviour of people during disasters	Recommendation: need for emergency plans
3rd of June event – return period	Assess the frequency of flooding	Calibrate the model in SOBEK
Individual implementation of structural solutions to prevent flooding	Outline layout, state and maintenance drainage network	Recommendation: capacity needs and identify possible measure
Waste management		
Place of waste disposal	Identify locations waste disposal sites	Analysis/description of the waste issue
Responsible for waste collection	Distinguish waste management actors (private/public collection)	Analysis/description of the waste issue
Frequency of collection	Assess waste collection frequency	Analysis/description of the waste issue
Waste collection fee	Quantify waste disposal fee	Analysis/description of the waste issue; Compare

		community and institutional perspectives
Reason of waste in the drains	Understand people perception about waste management and flood risk	Compare community and institutional perspectives

**Actions not performed in the case study of Accra, but recommended to accomplish an extended Flood Risk Assessment*
***Social survey results are presented in Appendix D3.*

4.5 Planning and logistics

It is important to make a solid planning and keep track of project developments day by day during the fieldwork period. Through a planning, one can avoid being unprepared and disorganized upon arrival in the field, while keeping records allows to draw everyday conclusions to improve the project. Planning activities include the set-up of a project diary, preparation of field maps and tools necessary to the data collection, and the formulation of a valid strategy to conduct the surveys.

Set up a project diary

A project diary is essential to keep track of the project steps and daily observations. It might for example contain weather conditions, project notes, carried out activities and short reports. Daily feedback can be used to adapt the general method to the case study at hand.

Prepare field maps

Once a pilot area is chosen, field maps can be prepared to conduct the surveys. A preliminary visit is advisable in order to get an overall understanding of and familiarity with the pilot area, for example to be able to recognize reference points. To create printed maps, the online Field Papers tool from OpenStreetMap can be used [16], which generates multi-page atlases. Data on the drainage network layout, flow direction, measurement points and vulnerable structures can be annotated directly on the maps in addition to the information that is collected through smart surveys.

Maps created with the Field Papers tool were used during the fieldwork in the Alajo and New Town pilot area to map the drainage network, note the direction of the flow when and map vulnerable structures and extra information. An example of a generated atlas is shown in Figure 12 Atlas generated in Field Papers online tool. After defining a common and logic legend (Table 4), information is noted directly on the map.

Figure 12 Atlas generated in Field Papers online tool

Table 4 Legend for notations in Field Paper maps

Object	***Symbol***	
Drainage network		
Manmade Drain – open		Blue straight line
Manmade Drain – partially covered		Blue dotted line
Manmade Drain – covered		Blue zigzagged line
Erosion path		Black line
Erosion + Manmade (eroded path with bricks or demolished drain)	E+M	Black line with notation (E+M)
Direction of the flow		Arrow
Vulnerable structures		Rectangle/Geometry of the area
Extra information	*	Numbered asterisk linking to a comments list

Gathering tools and assessing their accuracy

Tools needed for the data collection could for example include GPS devices, measurement tape and stopwatches, either loose or on a smartphone or tablet. To understand the operation, sample measurements could be taken in advance. In the same trial, surveys can be improved and a first strategy for data collection can be set up.

Tools used for the Accra pilot study are the following:

- Field Paper maps, to mark characteristics of drain and surroundings;
- GPS device, to obtain accurate geolocations and routes;
- Measuring tapes and stick, to take measurements on drain dimensions;
- Laser Distance Meter, to measure the dimensions of the larger drains;

- Rope, to take cross-section measurements in case the measuring tape is not long enough. Dimensions are marked and measured afterwards;
- Stopwatch, for discharge measurements;
- Smartphones and tablets that support the Akvo Flow app, to conduct smart surveys;
- Battery packs, in case the electronic devices have empty batteries.

Assessing the validity of the measurements is important, since the used tools may have different levels of accuracy or not be the most appropriate ones for the type of analysis. Detailed analysis of the tool applications, accuracies and possible mitigation measures can be found in Appendix D4.

Data collection strategy

Defining a data collection strategy is the key to fieldwork success. There are several steps and actions that have to be considered and planned tidily. Once the study area is defined and it is clear which data has to be collected and why, planning the locations and frequencies of measurement points is the next step. This includes a division of the area in sub-zones to be surveyed. Once in the field, data collection is most efficient when each group member has an assigned task.

Tasks division performed during the Accra pilot study consisted of:

- One person leading the group along the chosen path and drawing the network on Field Paper maps;
- One person keeping track of the walked route with the GPS device;
- One or two persons taking measurements with measurement tools;
- One person inserting the data on the survey forms, with the smartphone app;
- One person capable to translate local language (Twi and Ga) and mediate on the way to ask questions or to pray if necessary.

Two weeks were needed to collect data in New Town and Alajo. All the area was covered to track down each component, natural or manmade, of the drainage system. Eventually, 339 measurements were carried out, as displayed in **Errore. L'origine riferimento non è stata trovata.** below.

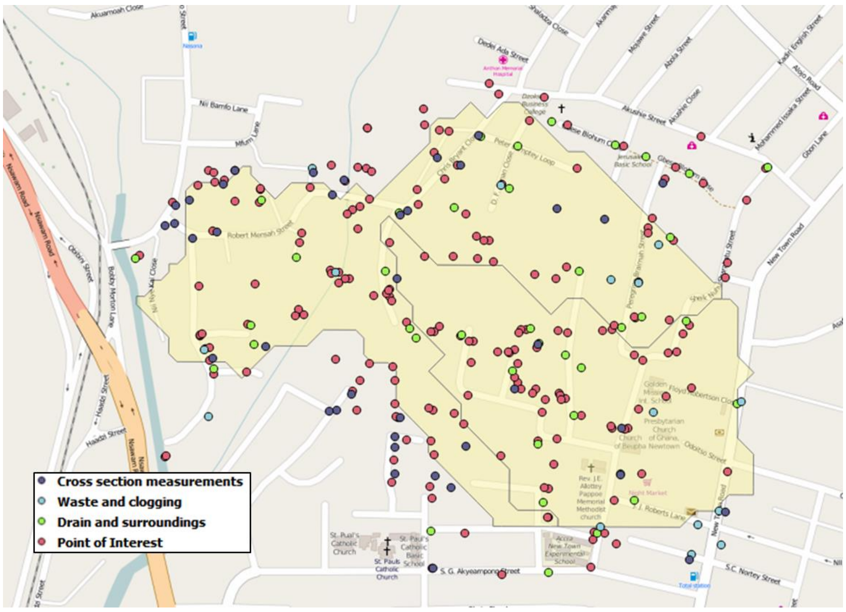

Figure 13 Measurement point locations

4.6 Lessons Learned

Strategical planning and preparation beforehand is not sufficient to guarantee that everything in the fieldwork will go as planned. On the contrary; there are plenty of unexpected things that change daily activities and outcomes. The purpose of this paragraph is to share some important lessons learned during the fieldwork of the Accra case study.

Organization and logistics
The hours during which to carry out fieldwork have to be chosen carefully in areas with hot climate. Proper protection against sun and heat and continuous hydration are required. Also, hygiene should be taken into account. Contact with contaminants can be prevented by wearing gloves and carrying dirty tools in separate buckets, as drains do not only contain rain water but also faecal matter and other dirt.

Sometimes the project team split up in smaller groups and, given the unfamiliarity with the area, the groups easily lost each other. Each member should be equipped with a working phone to allow for constant contact.

Interactions with locals
Interactions with locals are the most unpredictable component of the fieldwork. It happened often that inhabitants started asking a series of questions that slow down the data collection process, which is not always desirable. It is important, however, to address their curiosity in a quick manner and to remain polite as receiving consent for a project from locals is essential for the development and success of the research. Handing out project flyers turned out to be helpful in this matter.

Sometimes it was needed to enter private areas. One should always have respect and gratitude for the owners' availability. In conclusion, an open, positive and smart attitude is required when carrying out fieldwork in dense urban areas.

Technical data check and processing
During data processing, it might turn out that the collected information does not match with the information available from literature studies. For instance, ground elevation values from the used DEM did not always correspond to the altitude displayed on the GPS device. Therefore, validating available data during fieldwork can be helpful to avoid confusion if the processing is done later.

Data were not always processed immediately after each collection, and important daily conclusions or observations were forgotten. Noting down the latest findings is important to improve surveys and to remember experiences.

5 Flood Assessment model

The data collected during fieldwork is used to build a hydrodynamic model, in which network characteristics and available land height data are combined with hydrological data to carry out 1D and 2D flood simulations. The purpose is to discover whether it is possible to use such a model for analysis of causes of urban flooding and to find bottlenecks in a system. For the Accra case, influences of clogged gutters and downstream sea levels are tested through scenarios. In future research, a similar model could also be used to get insight in the effectiveness of flood risk reducing measures.

To process fieldwork results in an orderly and accessible way, the open source geographic information system QGIS is used. The calculation tool SOBEK is used for building the hydrodynamic model. More information on these programs can be found in Appendix E1.

In this chapter, the steps to take to convert collected field data to a hydrodynamic model and how this was applied in the Accra case are described, both for QGIS and SOBEK. Moreover, results of 1D and 2D flood simulations for the Accra case are presented.

5.1 QGIS data processing

QGIS is used to visualise the data obtained from Akvo Flow surveys and to create the drainage network by combining this data with GPS tracks and notes on Field Paper maps. Visualising the data points, the coverage of the data points over the pilot area is shown. The steps to take for the data processing in QGIS are schematized Figure 14.

Data processing is a task that should be carried out continuously during the fieldwork period. In that way missing or additionally needed data can be discovered in an early stage and surveys can be adjusted.

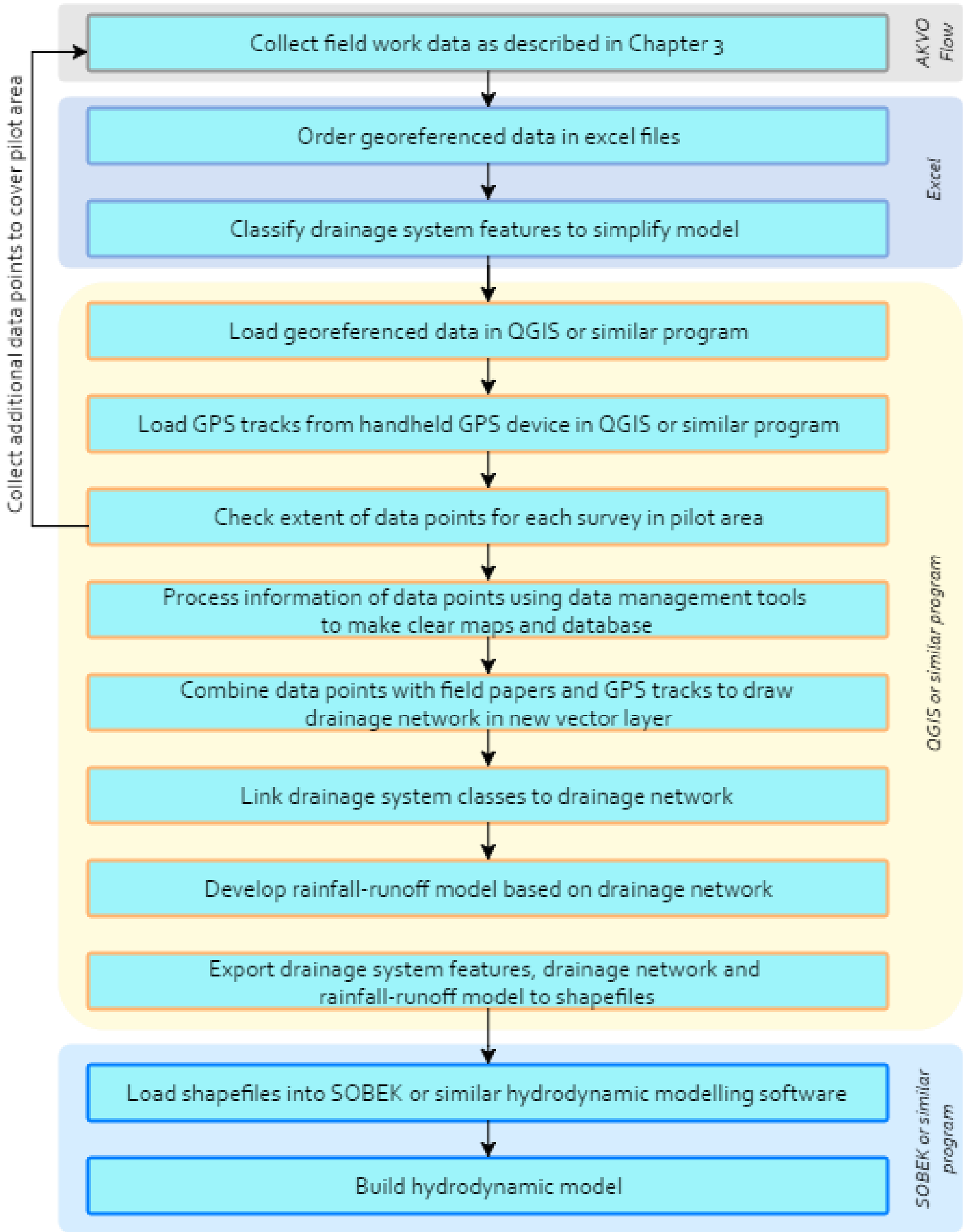

Figure 14 Flowchart data processing QGIS

As an example, the results of the steps are elaborated and visualised for the case of Accra.

Collect field work data

As described in Chapter 3, the field work data is collected using the Akvo Flow application on smartphones and tablets. The responses to the survey questions are organized automatically in an Excel file format (Figure 16). In 10 days of fieldwork, 34 Excel files with a total amount of 339 data points were obtained in the pilot area (Figure 15).

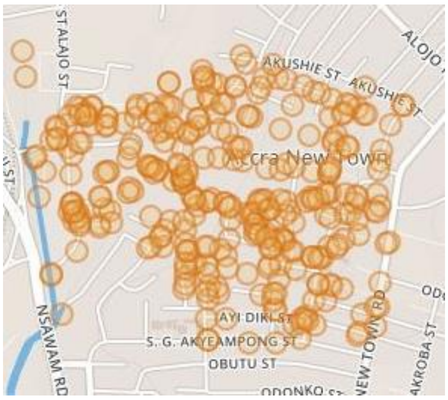

Figure 15 Data points in AKVO Flow App

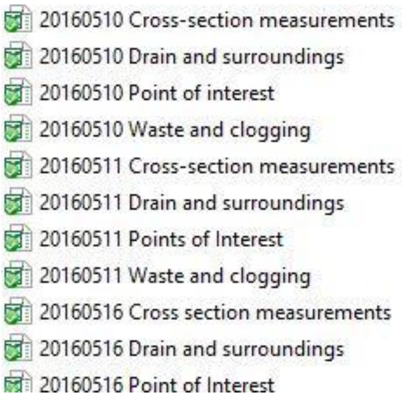

Figure 16 Excel files containing data points

Order georeferenced data in excel files

Data for each day of fieldwork are stored in a separate Excel file. Data can be edited manually after downloading to create a neat database (Figure 17 and Figure 18). For example, the ID for the first data point identified as a4pe-b9fc-8x85 is given the logical ID number 1. In order to prepare the data for QGIS, the files need to be saved in Excel as a'97 workbook.

Identifier	Repeat no	splay Nar	Device identifier	Instance	ubmission Dat	Submitter	Duration	01017|Lati	LON--|Lon	ELE--|Elev	CODE--|Ge	Width of the	the drain u	of the drai	ter level in	13540916|Take picture	mments on the pr	
a4pe-b9fc-8x85	1		Nadi Huawei	15770927	27-05-2016 14	Lexy Ratering Ar	00:00:52	5.5685252	-0.2179709	24.9	2k3cr7n	37000	3300	0		https://akvoflow-93.s3.amazonaws.com/ima		238461
en2d-hef0-e0kc	1		Nadi Huawei	14740922	27-05-2016 11	Lexy Ratering Ar	00:06:50	5.5993222	-0.2210530	47	2klowo2	20900	4650			https://akvoflow-93.s3.amazonav	trapezoidal	3d1f0f
a985-k92g-redu	1		Nadi Huawei	17790930	27-05-2016 13	Lexy Ratering Ar	00:01:20	5.5735720	-0.2044703	31	2k6czpo	6270	2560			https://akvoflow-93.s3.amazonaws.com/ima		c6943c
9rfn-2nkk-r0u8	1		Cate Samsung Table	14700956	25-05-2016 15	Caterina Marine	00:03:44	5.5892922	-0.2173989	34.8	2kfpxfx	18000			4000	https://akvoflow-93.s3.amazonav	waterlevel	9318a3
731c-8wtm-aa5a	1		Nadi Huawei	14561036	17-05-2016 11	Lexy Ratering Ar	00:00:48	5.5912580	-0.2168913	23.1	2kgvxs8	620	890	875	20			a8a9da
emsq-h1ub-j6as	1		Nadi Huawei	18570957	17-05-2016 11	Lexy Ratering Ar	00:00:31	5.5913524	-0.2166557	41	2kgy2xy	310	200		20			915cc3
gmb1-sdkt-r90t	1		Cate Samsung Table	11861011	17-05-2016 16	Caterina Marine	00:00:19	5.5867956	-0.2132373	48.1	2ke8cec	300	300		10			3a49d5

Figure 17 Data in Excel file before ordering

ID	Latitude	Longitude	Width of the drain [mm]	Height of the drain until street level	Height of the drain until	Water level in the drain [mm]	Comments	Picture
1	5.56852522	-0.21797095	37000	3300	0			https://akvoflow-93.s3.amazonaws.com/
2	5.59932221	-0.22105364	20900	4650			trapezoidal shape	https://akvoflow-93.s3.amazonaws.com/
3	5.57357201	-0.20447039	6270	2560				https://akvoflow-93.s3.amazonaws.com/
4	5.58929226	-0.217398941	18000			4000	waterlevel is height drain - 4000 mm	https://akvoflow-93.s3.amazonaws.com/
5	5.59125806	-0.21689133	620	890	875	20		
6	5.59135241	-0.21665578	310	200		20		
7	5.58679561	-0.213237342	300	300		10		

Figure 18 Data in Excel file after ordering

Classify drainage system

The field work revealed a range in dimension of the drains. To simplify the model a classification of the cross-sections is set up. The method used for this classification is elaborated in appendix E2.

Table 5 Classes assigned to cross-section with different shapes

SHAPE	CLASS (HEIGHT X WIDTH IN MM)
U-shape	500 x 550
	600 x 600
	650 x 600
	900 x 600
	750 x 900
	850 x 900
	1100 x 1350
Rectangular	200 x 300
	400 x 400
	400 x 600
	500 x 650
	700 x 950
	800 x 900
	500 x 1600
	850 x 1150
Culvert	Ø500
	Ø700
	Ø900
Erosion path	250 x 500
	250 x 1500

Load georeferenced data in QGIS

The ordered excel files containing the georeferenced data points are imported into QGIS, using the XY tool, to visualize the measurements and locations in the pilot area. Loading the data of all the surveys gives an overview of the extent of carried out the field work.

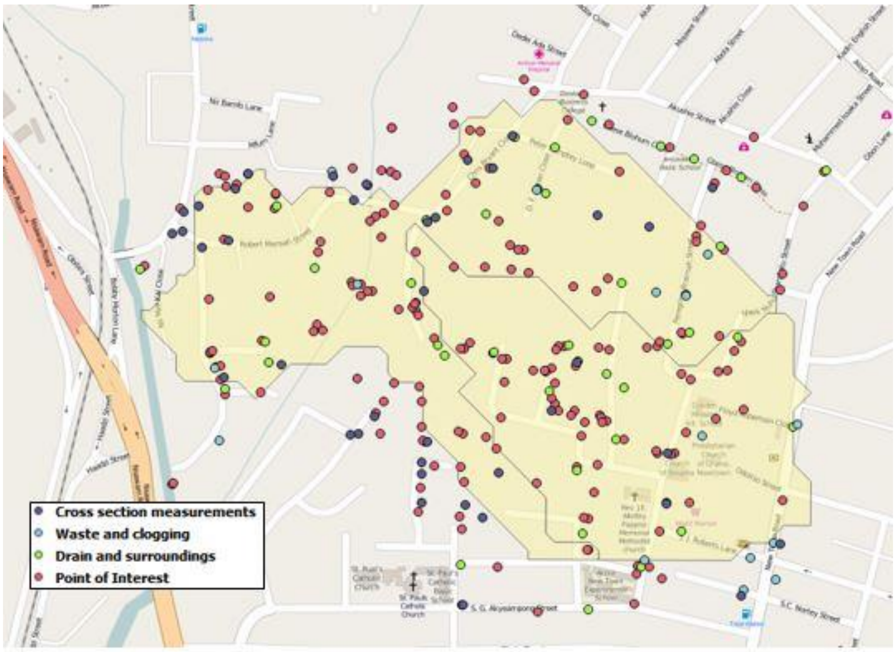

Figure 19 Projection of georeferenced data points from surveys in QGIS

Load GPS tracks in QGIS

Also GPS tracks can be uploaded to visualise the routes taken during fieldwork (Figure 20). The complete fieldwork route and all the drains were tracked with the GPS device.

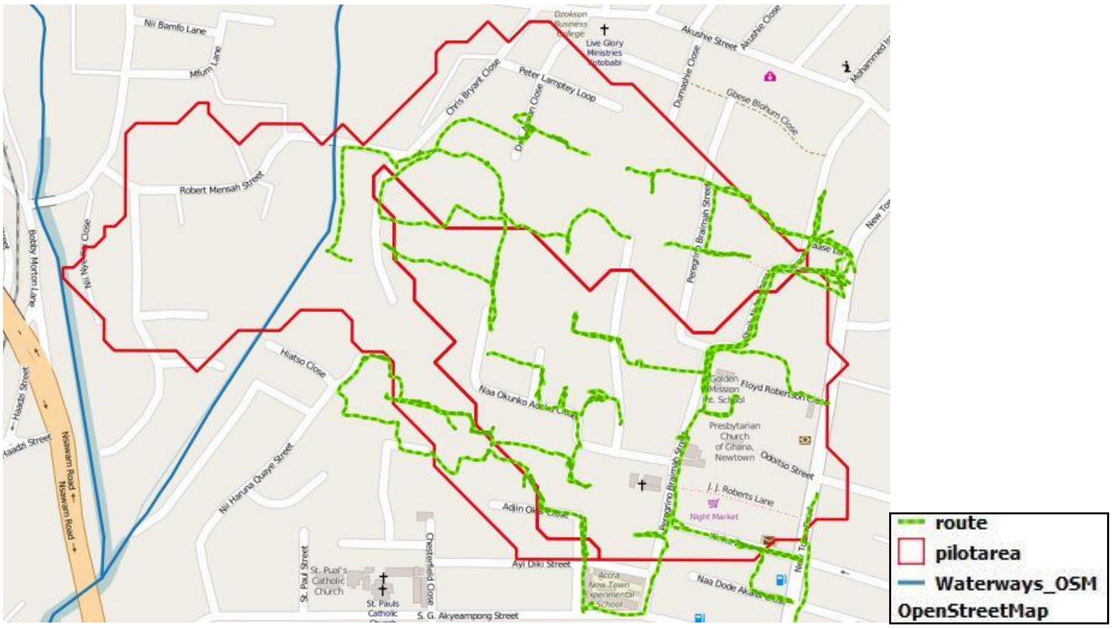

Figure 20 Projection of GPS track obtained from fieldwork 11 May 2016 in QGIS

Check extent of data points for each survey in pilot area

Loading the GPS tracks and the data points into QGIS shows the area covered during the field work within the catchment boundaries. By processing the data during the fieldwork period the progress in the field work can be monitored and total coverage of the pilot area can be ensured. If data points are missing, additional fieldwork can be carried out to complete the database.

Process information of data points using data management tools

Results of different surveys can be presented as different layers and combined in one concise document (Figure 22).

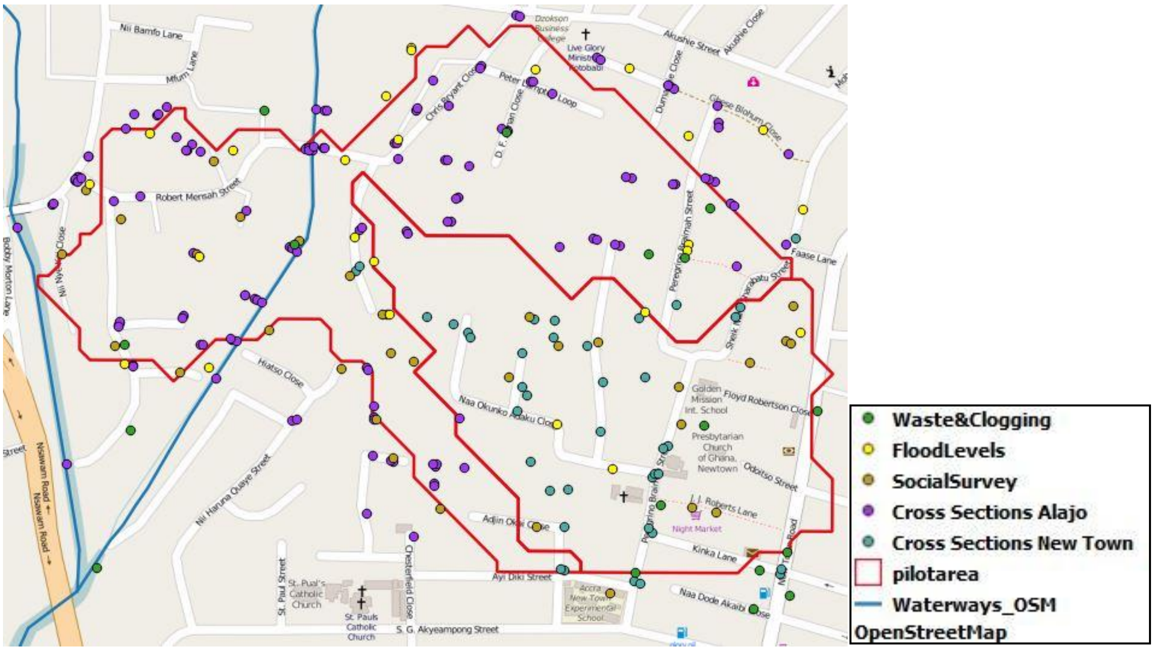

Figure 22 Result of data processing in data points

Combine data points with field papers and GPS tracks to draw drainage network

Combining GPS track information, survey responses and annotated field paper maps, a drainage network can be constructed as a vector line layer in QGIS, using the open street map layer as reference background(Figure 23). Open street map is used, because of the inaccuracy of the mobile phones and GPS handheld device, as discussed in appendix D4.

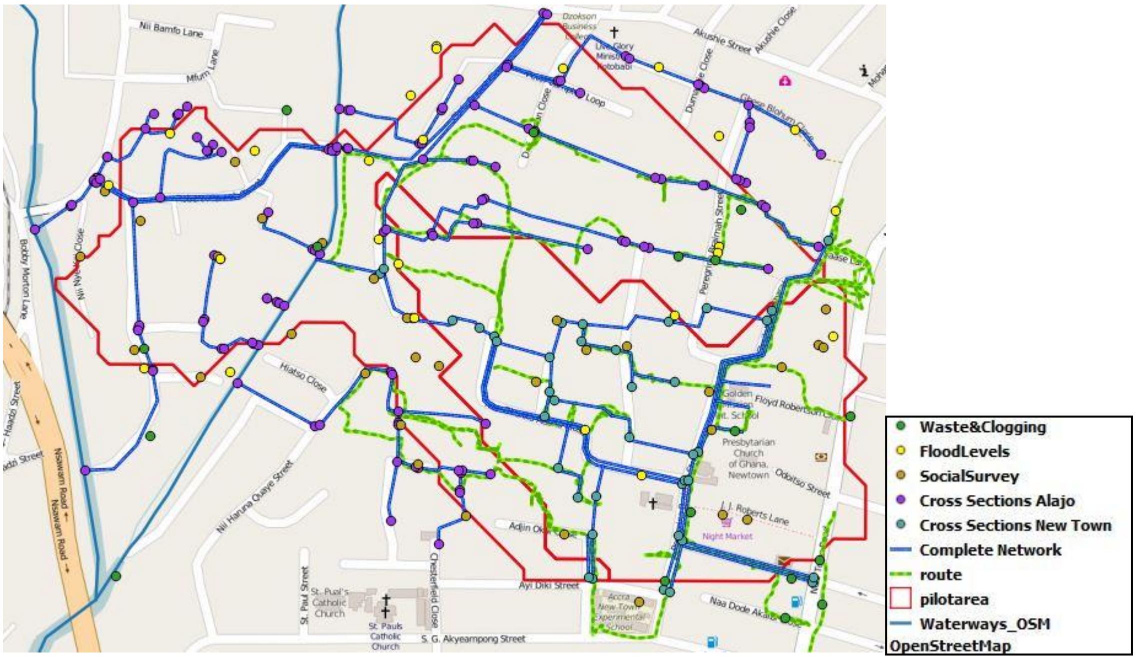

Figure 23 Drainage network constructed in QGIS based on Field Papers, data points and GPS tracks

Link drainage system classes to drainage network

Information measured in cross-sections during technical surveys is manually linked to stretches drawn in QGIS (Figure 24).

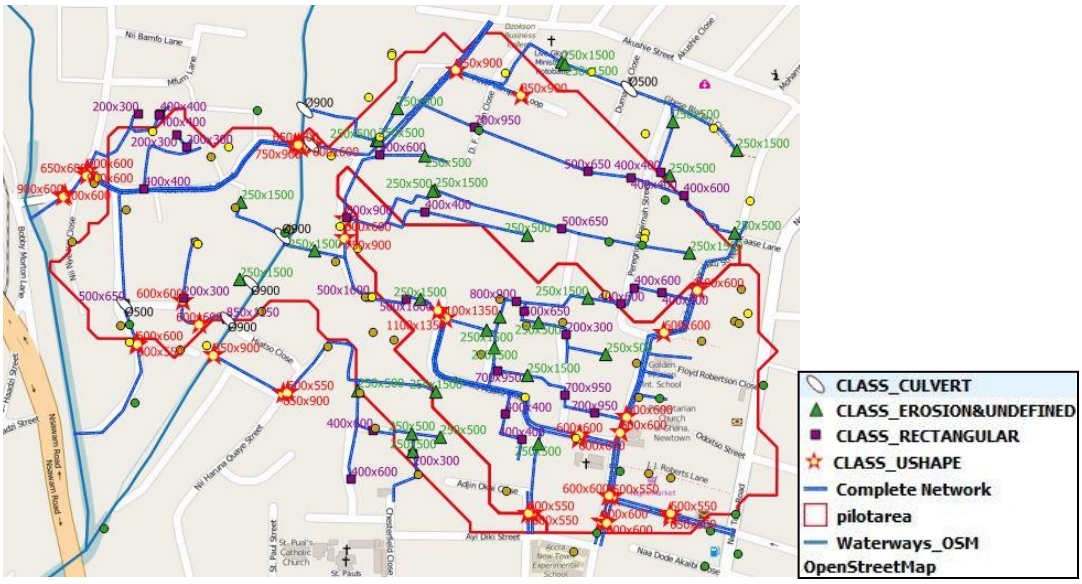

Figure 24 Drain classification linked to constructed drainage network in QGIS

Develop rainfall-runoff model based on drainage network

A watershed delineation resulted in the pilot area for the case study of Accra. For the drainage network derived from the steps above, a rainfall-runoff model can be developed. For each individual drain or stream in the network a catchment is determined based on the boundaries of the watershed. The area of each sub-catchment is calculated and this area is assigned to a pour point that flows into the drain or stream in that catchment (Figure 25). These points can be loaded into SOBEK and are used to determine the discharge per area for a particular rainfall event.

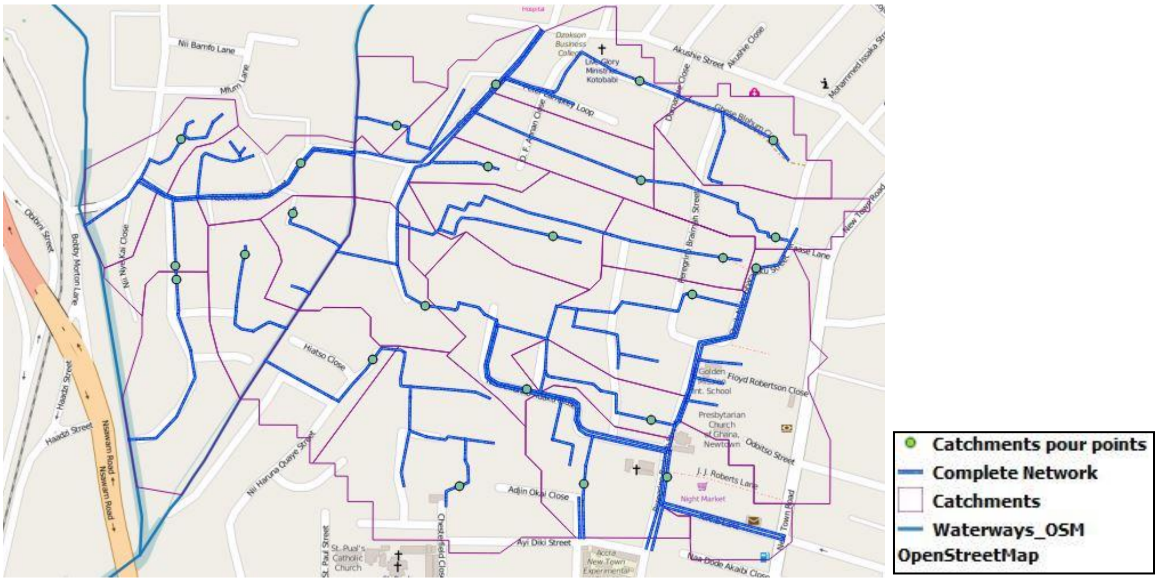

Figure 25 Rainfall-Runoff model in QGIS based on constructed drainage network and delineated catchment

Export drainage network and features as shapefiles

The layers of the drainage network and the cross-sectional areas are exported as shapefiles.

Load shapefiles into SOBEK

The shapefiles made in QGIS are loaded into SOBEK, which is the starting point for the construction of a hydrodynamic model. Further steps are explained in Paragraph 5.3.

5.2 Results of QGIS data processing

The result of the data processing in QGIS are shapefiles that visualize the data points on the map and list characteristic information in the attribute tables. The most important outcome of the data processing is the complete drainage network for the pilot area including a classification of the drains. Besides the complete drainage network the documents listed in Appendix E are products of the data processing.

Table 6 Documents as a result of QGIS data processing

Document	***Format***	***Content***	***Purpose***
Drainage network	Excel, shapefile	Location, length, cross-section, class, shape, material of drain	Input for SOBEK model
Social Survey	Excel, shapefile	Location, flood experiences, community waste collection	Input for waste and flood management
Flood Levels	Excel, shapefile	Georeferenced flood levels of historical flood events	Calibration of SOBEK model and input for flood management
Waste and Clogging	Excel, shapefile	Waste characteristics and locations	Input for waste management and SOBEK scenarios

5.3 Data Processing SOBEK

Network data from shapefiles made in QGIS are combined with satellite elevation and rainfall data to build a hydrodynamic model in SOBEK. The steps to take for building a hydrodynamic model in SOBEK or similar software are schematized in Figure 26.

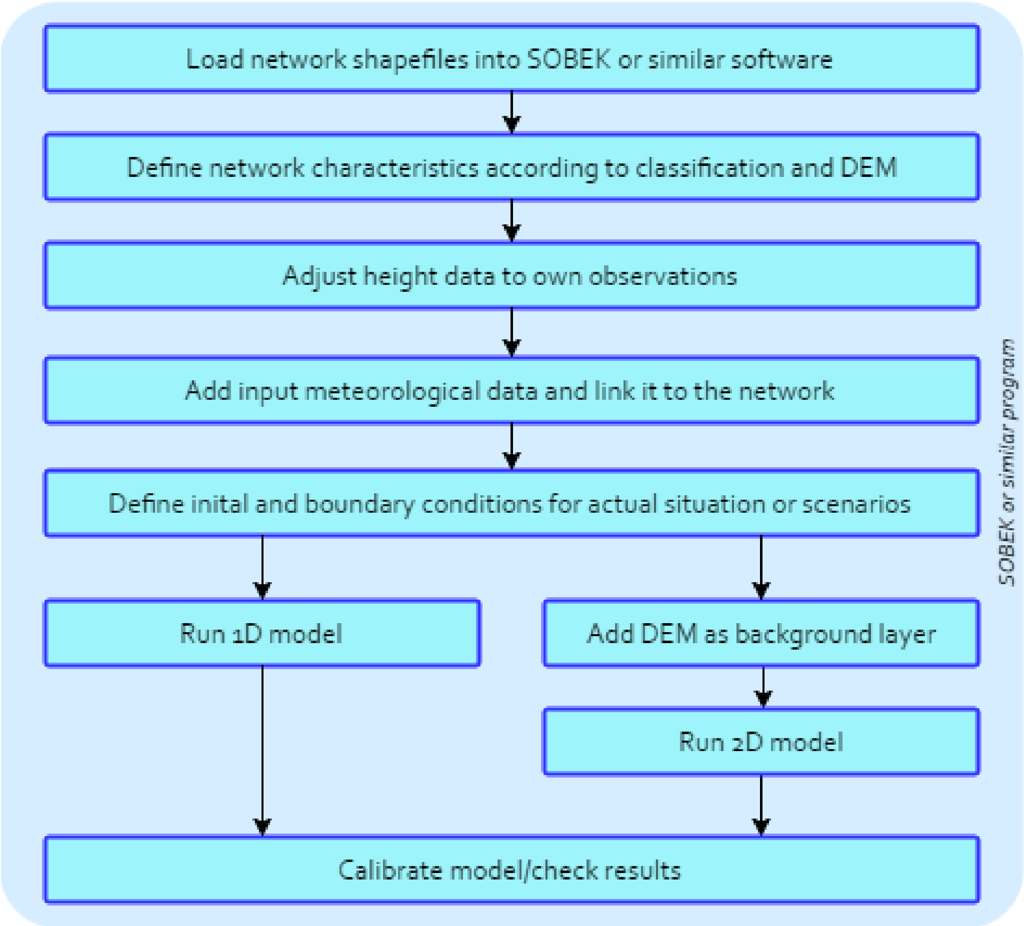

Figure 26 Flow chart data processing in SOBEK

As an example, the results of the steps are elaborated and visualised for the case of Accra.

Load network shapefiles into SOBEK or similar software

The shapefiles with georeferenced information on the drainage network made in QGIS are imported into SOBEK.

Define network characteristics according to classification.

Characteristics on type and dimensions are assigned to each of the reaches in the drainage network according to the classification system defined in Appendix E2.To model the main streams that run through the pilot area, Odaw and Onyasia reaches are added to the network with cross-sections as measured during fieldwork Figure 27. Applied friction coefficients are derived from [13] and displayed in Table 7. Surface levels are inserted at the beginning and end of reaches based on SPOT Digital Elevation Model[12] heights.

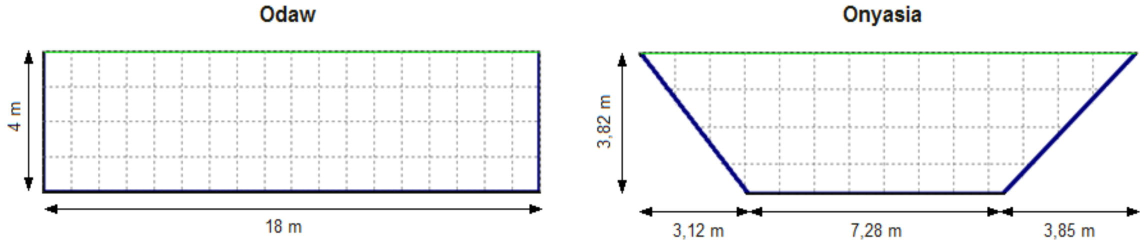

Figure 27 Odaw and Onyasia cross-sections

Table 7 Classification cross-sections in SOBEK

Type	***Manning Friction Coefficient***	***Explanation and reference to classification in [13]***
U-shape	0.014	Concrete; Finished; Maximum (A-d-3)
Rectangular	0.014	Concrete; Finished; Maximum (A-d-3)
Culvert	0.011	Concrete; Culvert, straight and free of debris; Normal (A-d-1)
Erosion path	0.035	Earth, winding and sluggish; Earth bottom and rubble sides; Maximum (C-b-4)
Odaw and Onyasia drains	0.012	Concrete; Finished; Normal (A-d-3)

Adjust height data to own observations

The used DEM has a 20x20 m grid, which is quite rough for research on neighbourhood scale. Flow directions in SOBEK are determined based on height data and may be incorrect due to this low DEM accuracy. Surface levels are adjusted manually where needed based on observations from fieldwork to correct flow directions.

Add input meteorological data and link it to the network

As the heavy rains of June 3rd 2015 are a direct cause of the Accra case research and information on these rains is available from memos and social surveys [3, Appendix D3], this event is selected for first modelling tests. Global Precipitation Measurement satellite data on rainfall in June 2015 is used as input meteorological data for the SOBEK hydrodynamic model. Simulations are carried out from 03-06-2015 00:00:00 until 05-06-2015 000:00:00 only to limit calculation time. The rainfall during this period can be found in Appendix C.

The sub-catchment areas developed in the QGIS rainfall-runoff model (Paragraph 5.1 - Develop rainfall-runoff model based on drainage network) are assigned in rainfall-runoff nodes and connected to the SOBEK drainage network through on-channel connections. With these areas, the discharge in each reach is determined by SOBEK for the rainfall event that is used as input meteorological data.

Define initial and boundary conditions for actual situation or scenarios

Four boundary conditions are defined in the Accra case hydrodynamic model (Figure 28 and Table 8) namely BC1 Odaw Upstream, BC2 Odaw Downstream, BC3 Onyasia Upstream and BC4 Onyasia Downstream. As there is not enough information available on discharges and water levels to set boundary conditions and to calibrate the model, five scenarios on downstream sea water levels and drains clogged up with waste are considered instead of the actual situation:

S1 Medium
S2 High
S3 Waste_20
S4 Waste_50
S5 Waste_90

Boundary conditions and scenarios are specified below.

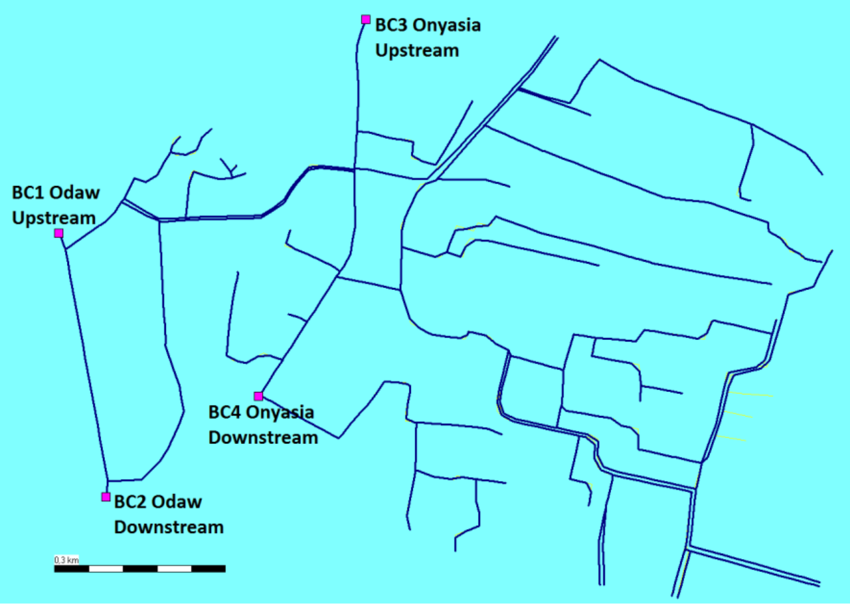

Figure 28 Model boundary conditions

Table 8 Model boundary conditions

Boundary Condition	Type
BC1 Odaw Upstream	Discharge
BC2 Odaw Downstream	Q,h-relation
BC3 Onyasia Upstream	Discharge
BC4 Onyasia Downstream	Q,h-relation

Q,h-relation boundary conditions

Downstream Q,h-relations are calculated based on the Odaw and Onyasia cross-sections and estimated flow velocities. A flow velocity of 1.5 m/s is assumed when the Odaw and Onyasia drains are filled up half and a flow velocity of 3 m/s is assumed when the drains are full. The Q,h-relation boundary conditions BC2 and BC4, presented in Table 9, are the same for all scenarios.

Table 9 BC2 and BC4

Boundary Condition	Water level [m above datum]	Discharge [m³/s]
BC2 Odaw Downstream	3 (empty)	0
	5 (filled up half)	-54
	7 (full)	-216
	20	-216
BC 4 Onyasia Downstream	6.18 (empty)	0
	8.09 (filled up half)	-26
	10 (full)	-123
	20	-123

Discharge boundary conditions

Discharge boundary conditions BC1 Odaw Upstream and BC3 Onyasia Upstream are based on base flow and rainfall discharge. Base flow is set as the downstream discharge from the Q,h-relation in the respective drain and rainfall discharges are calculated based on total Odaw and Onyasia catchment sizes defined through QGIS pour point delineation (Figure 29). The total amount of rainfall in the GPM data between 03-06-2015 000:00:00 and 05-06-2015 00:00:00 is 69,7 mm, of which the main part falls between 03-06-2015 19:00:00 and 03-06-2015 23:00:00 (4 hours). For the SOBEK model, a total amount of 70 mm spread over 4 hours in the whole Odaw and Onyasia catchments is assumed. In Table 10, the rainfall discharge that is added to the base flow during rain hours is displayed.

Table 10 Rainfall discharge calculation

	Odaw catchment	Onyasia catchment
Surface area from QGIS pour point delineation [m²]	188.850.000	23.480.000
Total rainfall [mm]	70	70
Total rainfall [m3]	13.219.500	1.643.600
Rainfall duration [hours]	4	4
Rainfall discharge [m³/s]	918	114

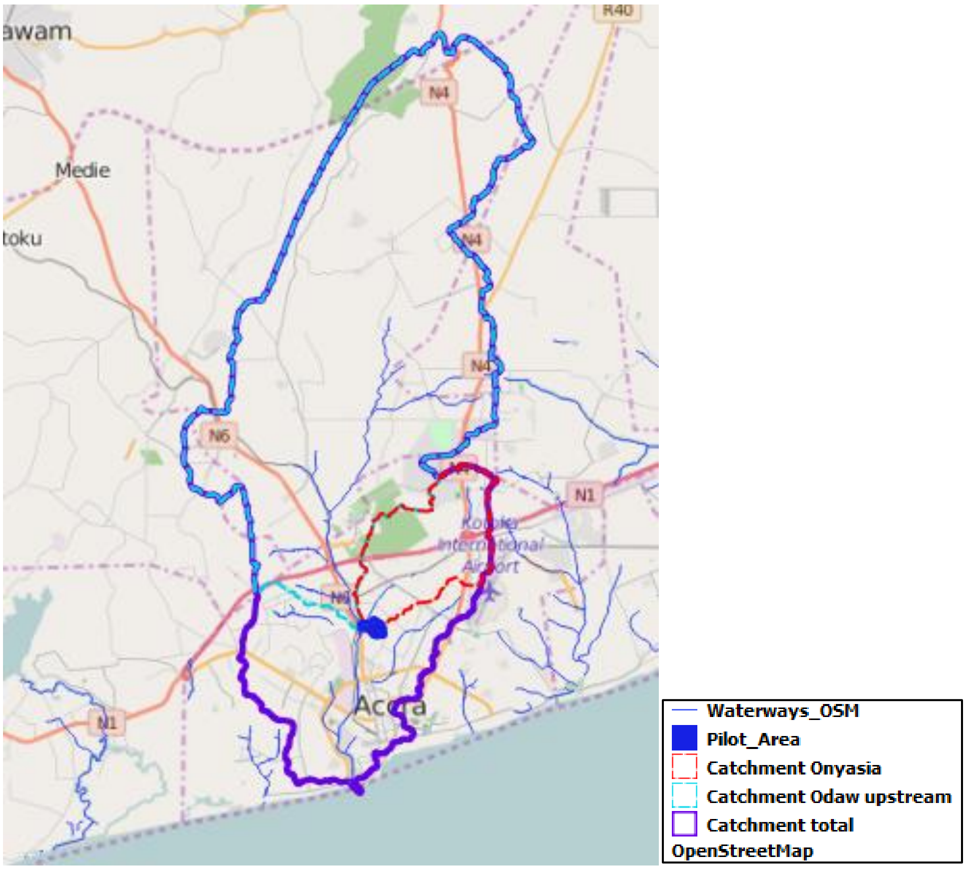

Figure 29 Sub-catchment area contributing to discharge in Odaw and Onyasia drain

Scenario S1 Medium

In the S1 Medium scenario, medium downstream sea water levels are considered. In the model, this is Onyasia and Odaw drains are initially filled up half. Q,h-relations for BC2 and BC4 are as defined in Table 9. For the discharge boundary conditions, base flow is chosen as the Q,h-relationship value for a half full drain and rainfall discharge from Table 10 is added to this base flow during rain hours. This results in the following boundary conditions:

Table 11 BC1 Odaw Upstream in S1 Medium

Date [dd-mm-yyyy]	Time [hh:mm:ss]	Discharge [m³/s]
03-06-2016	00:00:00	54
03-06-2016	19:00:00	972
03-06-2016	23:00:00	54
20-06-2016	00:00:00	54

Table 12 BC3 Onyasia Upstream in S1 Medium

Date [dd-mm-yyyy]	Time [hh:mm:ss]	Discharge [m³/s]
03-06-2016	00:00:00	26
03-06-2016	19:00:00	140
03-06-2016	23:00:00	26
20-06-2016	00:00:00	26

Scenario S2 High

In the S2 High scenario, high downstream sea water levels are considered. In the model, the Onyasia and Odaw drains are initially full. Q,h-relations for BC2 and BC4 are as defined in Table 9. For the discharge boundary conditions, base flow is chosen as the Q,h-relationship value for a full drain and rainfall discharge from Table 10 is added to this base flow during rain hours. This results in the BC1 and BC3 boundary conditions as presented in Table 13 and Table 14.

Table 13 BC1 Odaw Upstream in S2 High

Date [dd-mm-yyyy]	Time [hh:mm:ss]	Discharge [m^3/s]
03-06-2016	00:00:00	216
03-06-2016	19:00:00	1134
03-06-2016	23:00:00	216
20-06-2016	00:00:00	216

Table 14 BC3 Onyasia Upstream in S2 High

Date [dd-mm-yyyy]	Time [hh:mm:ss]	Discharge [m^3/s]
03-06-2016	00:00:00	123
03-06-2016	19:00:00	237
03-06-2016	23:00:00	123
20-06-2016	00:00:00	123

Scenarios S3 Waste_20, S4 Waste_50 and S5 Waste_90

In the scenarios S3, S4 and S5, clogging up of drains with waste is considered. All waste scenarios are run under the boundary conditions of the S1 Medium scenario. Adjustments are found in culvert cross-sections and friction coefficients (Table 15). In the S3 Waste_20, S4 Waste_50 and S5 Waste_90 scenarios culvert cross-sections are reduced by 20, 50 and 90% respectively. Culvert friction coefficients are derived from [13]. The maximum Manning coefficient of 0.014 for culverts with bends, connections and some debris (A-d-2) is applied in the culverts in all waste scenarios.

Table 15 Adjusted culvert cross-sections

Initial culvert diameter	Culvert diameter S3 Waste_20	Culvert diameter S4 Waste_50	Culvert diameter S5 Waste_90
Ø500	Ø400	Ø250	Ø50
Ø700	Ø560	Ø350	Ø70
Ø900	Ø720	Ø450	Ø90

Add DEM as background layer

For 2D simulation, the SPOT Digital Elevation Model[12] is imported as a grid in SOBEK. The bottom friction value for this grid is set as a Manning coefficient of 0.025.

Run model (1D and/or 2D)

An impression of the final network is given in Figure 30. The five scenarios are simulated in 1D and 2D.

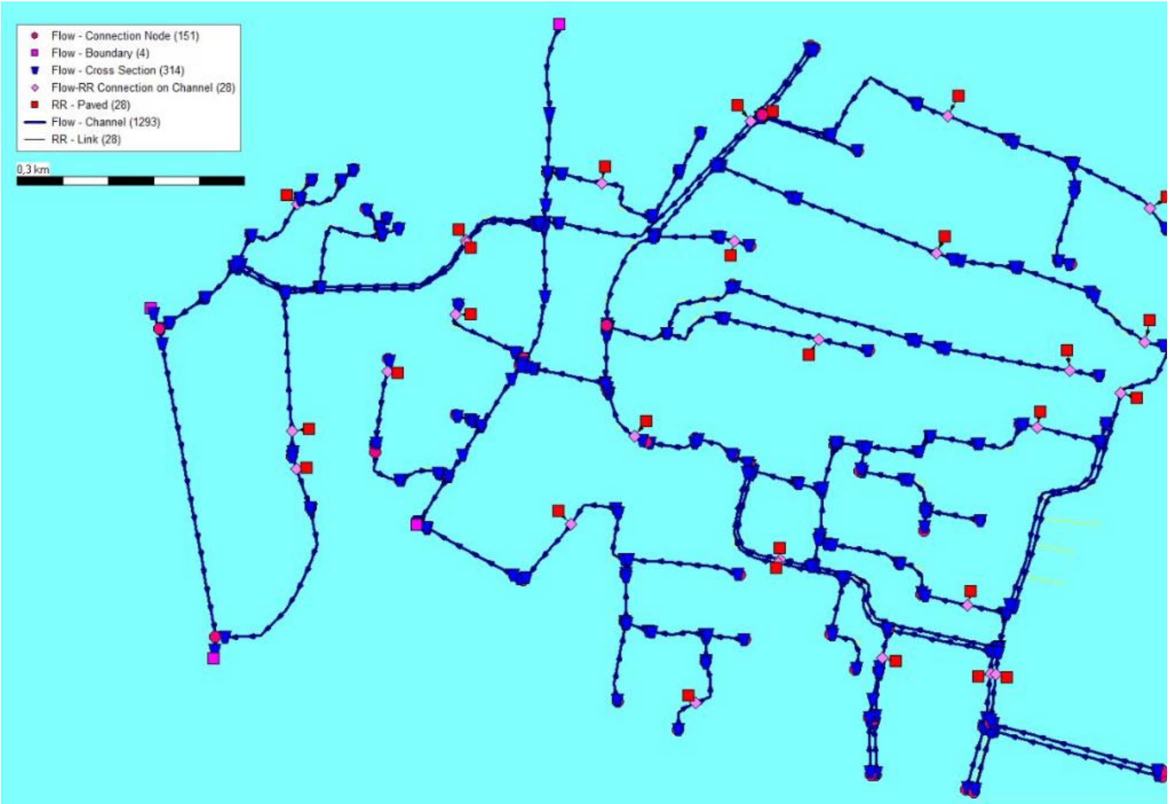

Figure 30 Final network impression

Calibrate model/check results

To present model results in a clear and orderly manner, network maps and calculation results are exported from SOBEK as shapefiles and CSV files respectively and imported into QGIS. Modelling results in maps for all scenarios are presented in Appendix G and discussed in this paragraph.

From [3] it is known that the June 3rd 2015 rainfall events coincided with high downstream sea water levels. 1D and 2D model results for the S2 High scenarios are presented in Figure 31 and Figure 32 respectively. In these figures, field data on flood level marks from June 3rd 2015 rainfall events obtained during social surveys is included to check model results. The presented flood levels are the maximum levels that occur during the simulation period. In all scenarios, flood water flows into the main drains after the end of the rainfall hours.

As water cannot flow out of the drains in the 1D model, resulting water levels are higher than they would be in reality. Nevertheless, it can give an impression of bottlenecks and vulnerable areas. As can be seen in Figure 31, water levels tremendously overtop the Odaw and Onyasia drains and drains in the Alajo area in the 1D simulation. In the New Town area, only minor overtopping occurs at culverts, erosion channels and just after rainfall-runoff connection nodes. Indeed it is known from social survey results that floods occurred mainly in the Alajo area, with flood levels up to 2 m, and that the main part of the New Town area was spared.

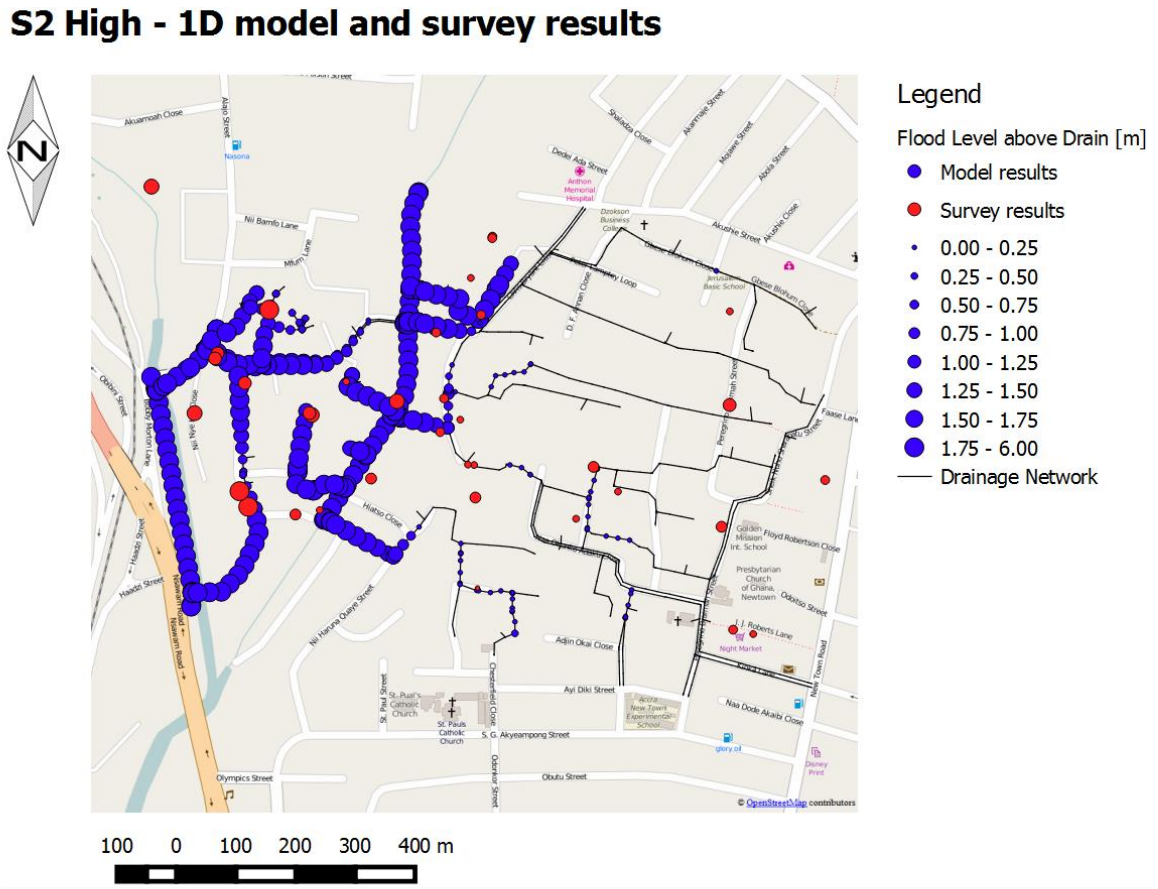

Figure 31 S2 High - 1D model and survey results

Because of the rough DEM accuracy, complete 20x20 m cells connected to a network segment are marked as flooded when water levels overtop that segment in the 2D simulation. Therefore, flooded areas in 2D model results might show larger flooded areas than would occur in reality. Because of manual adjustment of DEM surface levels for flow direction correction (explained above - Adjust height data to own observations), ground levels of reaches do not always match with the background DEM. As the ground levels of reaches have been lowered, the higher surrounding DEM levels prevent water from overflowing complete grid cells in the case that water levels overtop drain segments.

In Figure 32 it can be seen that in 2D model results major floods occur in the middle part of Alajo and, around the most northern parts of the Onyasia drain, along the Odaw and Onyasia drains and at some bottlenecks as culverts, erosion paths and after rainfall-runoff nodes in the New Town area. This again matches the information on the June 3rd 2015 floods obtained during social surveys. In the 2D modelling a large part of the New Town area experiences flood water levels between 0.00 and 0.10 m, as water cannot be discharged directly on the already overtopping Odaw and Onyasia drains.

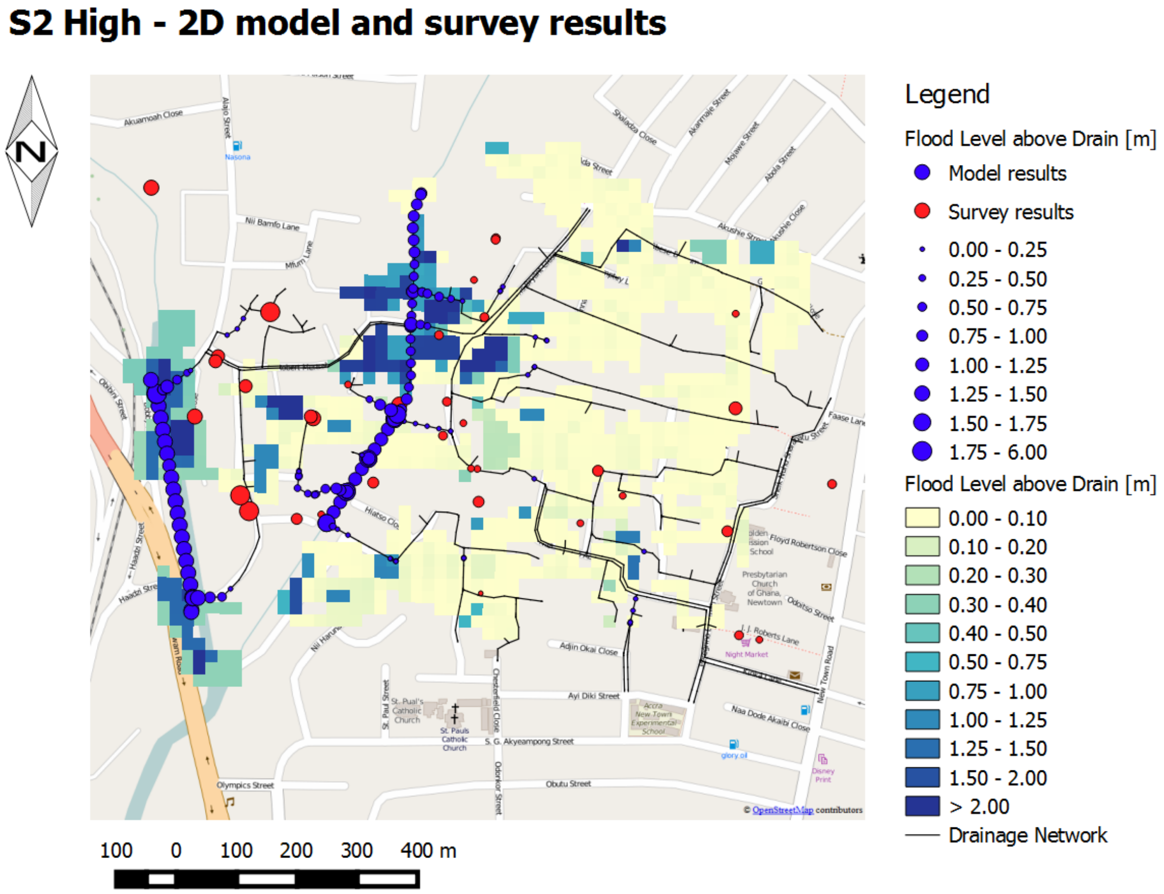

Figure 32 S2 High - 2D model and survey results

Model results are also checked on flow velocities in the drains. Flow velocities result to stay mainly between 0.5 and 4.5 m/s and are considered realistic. Incidentally higher velocities up to 10 m/s are found at critical locations in scenario S2 High with initially full Odaw and Onyasia drains and in S5 Waste_90 with 90% reduced culvert cross-sections, especially in 1D simulation. This is explained by the impossibility of water to flow outside of the drains, because of which larger volumes of water stay in the small system in the model than in reality.

In both 1D and 2D model results minor or major flooding occurs after all rainfall-runoff connections. This can logically explained, as the amount of rain water from an entire sub-catchment enters in one cross-section in the middle or downstream of the sub-catchment. In reality, it would enter divided over all upstream segments and floods would not necessarily have to occur at these locations.

5.4 Results of SOBEK Flood Assessment Modelling

In 1D simulation results presented in Appendix G, some minor overtopping occurs throughout the pilot area before culverts, before erosion paths or after rainfall-runoff connection nodes in the S1 Medium scenario. In the S2 High scenario, major overtopping (1.75 - 6 m) occurs along the Odaw and Onyasia drains and in drains in the Alajo area. Additionally, some minor overtopping occurs in the New Town area before culverts or after rainfall-runoff connection nodes. Comparing the overtopping results of these scenarios in 1D shows a high impact of the discharges and water levels applied to the Odaw and Onyasia drain, or more general, of downstream sea water levels.

Rainfall discharge from the upstream Onyasia catchment and the pilot area cannot enter the overloaded main drains.

Waste scenarios are compared to the S1 Medium scenario, as these are run under the same boundary conditions. From the maps in Appendix G it can be concluded that there is no significant difference between the results of the 1D S1 Medium scenario and the 1D S3 Waste_20 scenario. Apparently, a diameter decrease of 20% does not lead to significantly increased flooding during a rainfall event with June 3rd 2015 intensities. Considering the 1D S4 Waste_50 simulation results, overtopping occurs before some culverts or erosion paths, with a backwards effect: floods also occur further upstream in the network segments. This is due to the 1D error that water cannot flow out of drains, discussed in the Paragraph 5.3 – Calibrate model/check results. The S5 Waste_90 shows major overtopping of up to 21 m throughout the whole neighbourhood, because of culverts. The same backwards effects occur in this scenario as in scenario S4 Waste_50. As small drains connect to the main drains through culverts and water cannot pass through, no overtopping occurs along the main drains.

2D simulation results show the same results as 1D simulation results when scenarios S1 Medium and S2 High are compared. No major overtopping of drains occurs in S1 Medium, only some minor overtopping at culverts, erosion paths or just after rainfall-runoff nodes. In S2 High, major floods occur in the middle part of Alajo, around the northern parts of the Onyasia drain, along the Odaw and Onyasia drains and at some bottlenecks as culverts, erosion paths and after rainfall-runoff nodes in the New Town area. In the 2D modelling results, a large part of the New Town area experiences flood water levels between 0.00 and 0.10 m, as water cannot be discharged directly on the already overtopping Odaw and Onyasia drains.

Considering waste scenarios in 2D simulation results, there is more overtopping before some culverts but no significant differences in flooded areas between the S1 Medium, S3 Waste_20, S4 Waste_50 and S5 Waste_90 scenarios. As water can flow overland in 2D simulation, results show to be less extreme than in the 1D model where water cannot flow out of drains.

5.5 Combining fieldwork experiences with remote sensing

Remote sensing data used for the case of Accra are the DEM, with a coarse grid of 20x20 m and the GPM rainfall data. Combining the fieldwork experiences with the remote sensing data leads to two interesting findings.

1. *Critical locations in the drainage system seem to be identifiable using remote sensing data.*

By analysing satellite height data of the DEM and deriving a flow accumulation map, problematic (natural) drainage channels can be identified. During fieldwork, a natural drainage channel through which a lot of the water in the neighbourhood needed to be drained was encountered. This was affirmed by both the locals and observed by the team during a small rain event, in which the discharge was considerably higher in that reach compared to the discharge in other drains flowing downstream. Parts of this natural drain were completely demolished by the force of the water it needs to convey during rain events (Figure 33). The location was clearly a critical location that needs construction work to prevent further erosion and flooding of property alongside. This leads to the conclusion that such critical locations can be identified using the DEM, or in other words that hotspots can be identified by looking at the flow accumulation patterns in the neighbourhood. In Figure 33 such a flow accumulation map is shown. Dark coloured grid cells indicate accumulation of water given the natural slope of the landscape. The critical location found in the neighbourhood is marked with a red star.

The demolition is located along a drainage channel which was not properly designed, which is in contrast with the constructed road-side drain (depicted as a purple star in Figure 33) located south of the critical point. The damage encountered in the field could have been prevented by designing the drainage system according to the natural flow pattern. Measures to improve the drainage system in the neighbourhood should therefore focus on places where there is higher flow accumulation. This technique could be of use in an area with steeper slopes to identify critical erosions. In flat areas, such as the Alajo area, this technique might not work sufficiently.

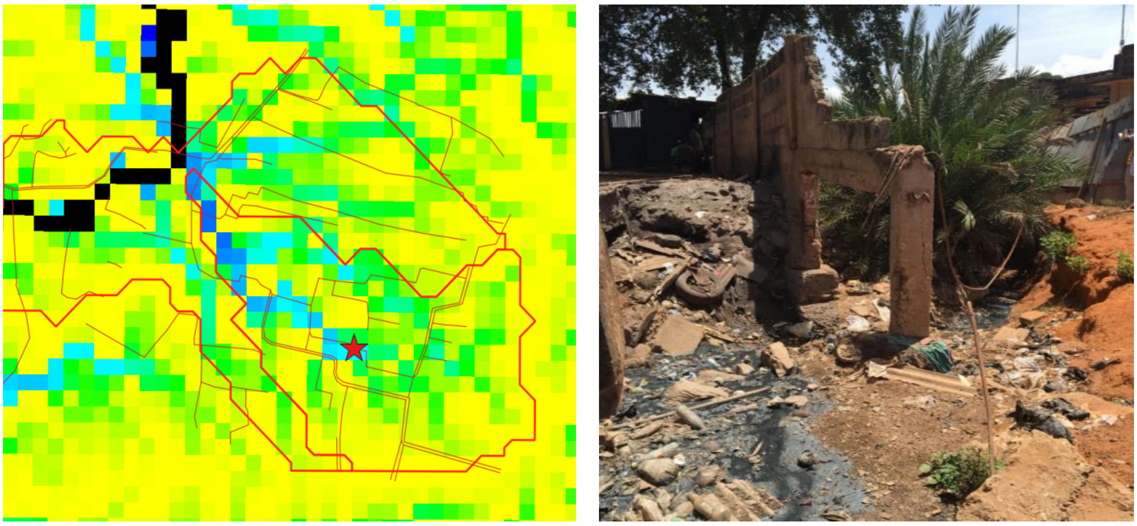

Figure 33 Comparing satellite and field data: critical locations in the system

2. *Catchment boundaries can be defined based on remote sensing data.*

The catchment boundaries of the pilot area were defined using watershed delineation techniques in the QGIS/GRASS environment, which uses the DEM for this derivation. The actual flow boundaries, where drains start and end, and directions of the drains in the neighbourhood generally match the delineated boundaries. Even though the DEM has a coarse grid, it can be used in urban application to define different sub-catchments that are found in reality. This is validated for a threshold of 100 in the delineation technique. For lower threshold values to delineate catchments, the results have to be validated.

6 Awareness creation

Raising awareness is a central activity when dealing with problematics such as floods or bad waste management. With it, the carrying out of the project already represents an improvement to the situation. Awareness can be created when collecting surveys, especially social surveys where engagement with community people is high. Other strategies for enhancing awareness and gathering important information are introduced in the next paragraphs, such as a 'Social Media Experiment' and taking part in local initiatives as a 'Garbage Removal Mission'.

6.1 Social Media Experiment

Because of the lack of available field data on the drainage system at community level, the project team tried to call out to citizens to upload valuable information via social media and help create an urban drainage map of the city. Since almost every Ghanaian owns a smartphone, pictures can be used to collect data for building a drainage model, which can be used to simulate the flood risk in the city. Social media channels WhatsApp and Facebook are used to gather georeferenced pictures of drains which will be analysed on dimensions used to map out the drainage system in space.

Respondents are likely to have an interest in the project and by establishing a relationship one can gather valuable information. Therefore, creating a drainage map by using individual uploads could be the first question posed in a sequence. A follow-up question could be used to gather georeferenced pictures of the experienced flood levels during a flood event which will be used to map out the flood extent in space.

Next to collecting information about the drainage system and dynamics, launching a social media campaign increases awareness for the cause. By taking a picture of their gutter, people are asked to reflect on the functioning of drainage system in their neighbourhood. Are there drains and are they clean? And if no, why so? Creating a participatory social media action with an engaging tagline, as "want to help make the city flood-proof?" creates involvement in the project and start good dialogues.

The message launched by the Project Flood Risk Accra is reported below. The message aims to collect pictures of the drain to map the drainage network at a larger scale. Figure 34 is attached to the message, to give demonstration of the correct picture to take and share.

Concept Message Social Media Experiment:

Want to help make the city of Accra flood-proof? Create a detailed drainage map of Accra by sending your picture via WhatsApp to +233 24 392 2807 and afterwards share your location. Place your foot or any other recognizable object to reflect the true dimensions of the drain. Every week we pick the best posed picture to win phone credit. Medaasi Paa! @Project Flood Risk Accra"

Figure 34 Example of picture to share

In case the contacting person shows interest in the project and is willing to help, more information is asked with a follow up message. An example is shown below:

> *"Thank you for sending your picture! Could you help us with some additional information? Does your neighborhood flood when it rains? Is the drain located on one or both sides of the street? Where does the drain start and end? Are there any structures or waste clogging the drains? Thanks!*

To launch the social media campaign, the project team contacted the staff of iSocial TV [18], a private initiative that aims to bring social networking from the web - Facebook, Twitter and Whatsapp – into the television set. I social TV has almost 30,000 likes on Facebook and can reach over 7000 members through Whatsapp. Our message is promoted among members accompanied by a broadcasted video with instructions.

Next to their online activities, the crew of iSocial runs a 30min program on TV twice a week. To support the launch, a video was shot in which the project team was dared for a cleaning session. The team went to the district of Kaneshie (flood sensitive area) asking residents for permission to clean their households and gutters. Through this activity, the project team was able to raise awareness about the effect of improper waste disposal on the capacity of the drainage network.

After launching the message, in only one week more than 150 pictures were received. However, not everybody shared a picture reporting the drainage network, or the correct location. Among the only 3 contacts that sent a good picture with location attached, a winner was chosen and announced on the Facebook page of the project. Followers were dared to do even better and motivated to keep helping the project. The experiment is still ongoing and new updates can be read in the Facebook page of the project 'Project Flood Risk Accra'.

In the Figure 35 below, the winning picture with the shared location is shown.

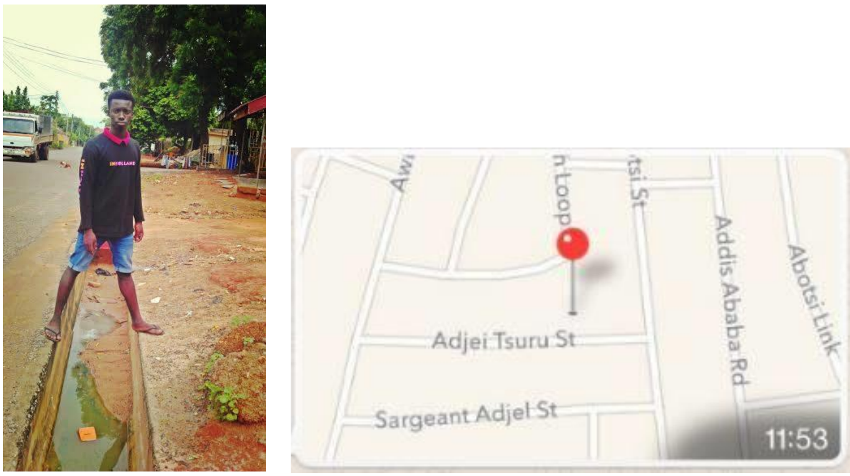

Figure 35 First winning picture with location of Social Media Experiment

The number of received reactions shows that collecting data through social media is a promising tool. The video has over 56,600 views and more than 115 shares. Hundreds of people sent us a reaction through WhatsApp. Although not all information is relevant, the experiment teaches us valuable lessons about social media as a tool in crowd-sourced flood risk mapping.

With an improvement of the launched message, the number of valuable responses could be increased. We evaluated that the message as of now was probably not clear enough. The multiple steps to be taken as described in the video instruction could be too complicated to convey or the audience encountered difficulties in understanding the purpose of the experiment or the technical concept of drainage processes. A data collection request through social media should be extremely simple to get the most out of it. We can conclude that in a relatively short time, many people can be reached given that the message is catchy. Our video was uploaded during a weekend with extreme floods in the city and this certainly helped to get attention.

Alternative requests about past flood events such as flood marks pictures, explanations of damages, personal stories might be more simple requests or resonate better with people. However, the same kind of irrelevant responses such as personal pictures or just general messages can be expected of course and filtering responses will always be necessary. In all cases, social media remains a very effective means to raise awareness about the cause of project or research.

6.2 Garbage removal mission

Organizing a garbage removal mission is an effective method to raise awareness about the harmful effects of waste disposal on the flood risk level of the city. It is possible to scale up the cleaning activities by collaborating with existing initiatives that promote a clean environment. The more the people involved, the bigger the impact of the initiative. Proper tools have to be gathered for every volunteer involved to minimize their exposure to the waste. Taking videos of the action and spreading them over social media can further spread awareness.

The project team joined the city council on National Sanitation Day, initiated to raise awareness and educate people about proper waste disposal. The National Sanitation Day is organized every first Saturday of the month by the AMA (Accra Metropolitan Assembly) Solid Waste department. AMA provides equipment, trucks, shovels and personal to assist the cleaning activities which are carried out in 10 sub metros. A major part of the work includes de-silting the fully clogged drains.

Pictures of the Garbage Removal Mission are attached below.

Figure 36 National Sanitation Day, Garbage Removal Mission

Figure 37 Project Team in action during the National Sanitation Day

Figure 38 Project Team in action during the National Sanitation Day

Watching the project team clean the drains in front of their houses and shops, made some traders think twice. Why should outsiders come in and clean our waste? At moments, the presence of the team caused quite a stir and mobilized more community members to join the cleaning activities. We conclude that the garbage removal mission was an effective means to raise awareness about waste accumulation causing blockages in the drains. Wearing project t-shirts and handing out flyers about the project helped to make this connection.

7 Conclusions

The conclusions described in this report answer the research questions described in chapter 2:

- What are the causes of floods in Accra?
- What are useful elements in developing a methodology for flood assessment in African cities?

Below we first assess the flood causes in the pilot area looking at social, institutional and technical issues. The method to carry out this assessment includes several practical and innovative elements, which are described next.

7.1. What are the causes of floods in the pilot area in Accra?

Drainage network

Based on observations and interviews with locals it can be concluded that the drainage network is not properly designed and poorly maintained. Standard roadside drains but also erosion paths and privately constructed channels are part of the drainage system. As the government does not provide sufficient help and structural solutions, individuals and communities (churches, schools) in the neighborhood start building their own drains to protect their property. This is causing the system to be highly heterogeneous, with poorly connected reaches between different shaped drains and erosion paths. Problems are also shifted downstream to where constructed drains end in eroded channels.

Looking at the model results, we conclude that the capacity of the system in the pilot area is sufficient to drain a rainfall event similar to the disastrous June 3rd 2015 event. The model shows that the main cause of flooding is the downstream water level of the Alajo drain and not the rainfall in the pilot area itself. The event only triggers local overtopping at culverts and erosion paths. At such bottlenecks, the capacity of the system in the pilot area is insufficient.

Waste and silt accumulation

Waste disposal causes blockages in the drainage system as it decreases the cross-sectional area of the drain. Structures such as culverts, curves in drainage channels, broken drain covers and buildings or shacks on top of drains cause waste to accumulate and obstruct the flow. People defecate in the open drains and dump their organic waste into eroded channels next to their house, polluting downstream neighbours during floods.

Based on field observations it appeared that the presence of waste is more hazardous in low-lying areas. In areas with steeper slopes, the waste in the drains was more easily washed away during a rain event. Hence, waste accumulation could be attributing more to flood risk in low-lying areas and improvement of waste services should be prioritized there. However, raising awareness on the negative effects of waste disposal should be addressed in upstream areas. Much of the waste is flowing downstream into Odaw drain (the main drainage canal in Accra). It is recommended to investigating the waste flow in the Odaw drain, to identify accumulation points and to assess the effects on the flood risk in the neighbourhoods.

Based on the hydrodynamic model no clear conclusions could be drawn on the effects of waste and silt accumulation within the pilot area with the 1D model, nor with the 2D model. The 1D model overestimates the water levels: the water flow is blocked at culverts, leading to extremely high water levels in the upstream reaches. These extreme water levels are caused by a misrepresented storage capacity of the water system, as only the drains are included in the 1D cross-section, and not the storage capacity of the streets along the drains.

The 2D model, where overland flow occurs, underestimates the effects: it appeared that a 90% decreased culvert diameter does not lead to significantly higher flood levels than the initial culvert diameter. The relatively small effect on flood water levels is due to overestimation of the storage capacity in the 2D model. A more accurate elevation model with higher grid resolution is necessary to improve the results.

Siltation can be found along the entire network and silt accumulates in risky quantities in the primary drains. Continuous dredging works are needed to get rid of the seemingly endless supply of sand. The natural channels that connect to the primary drainage system, to which many eroded channels and unpaved roads are connected cause a significant sediment load on primary drains. The siltation is highest in in flat (non-sloped) channels and areas like Alajo.

The amount of waste in the drains can be attributed to a malfunctioning waste management system. This is due to different factors: attitude problem, financial constraints, lack of available services provided. However the exact contribution of these factors cannot yet be determined. Due to the badly working waste management system, there are large amounts of waste accumulating in the drains which has a negative impact on flood risk.

Institutional issues
From the workshop with stakeholders and during the social survey it appeared that the present institutional system concerning urban drainage is malfunctioning. The main problem is that many organizations have a shared responsibility in urban drainage (maintenance, construction, flood disasters, etc).The resulting lack of spatial planning and drain maintenance lead to higher flood risks in Accra. There is no enforcement of a spatial plan or drainage plans and therefore illegal shops are built on drains and the space along the watercourses of the Onyasia and Odaw Drain have been encroached upon. In case a flood disaster strikes, there exist no feedback loop between the different institutions involved. Every time after a flood event, NADMO writes a report to the AMA to describe the damages. However, nothing happens with this valuable information which points to the moist critical spots in the neighbourhood for improvement.

Interviews collected during the social surveys show that people are highly displeased with what they feel as lack of commitment of the institutions to improve the situation. Communities have to provide themselves with individually initiated solutions to ensure their safety against floods.

Downstream water levels
Some inhabitants of Alajo refer to their area as a 'bathtub', as they are located between two primary streams. Many speak of the high water levels in the Odaw and Onyasia drains that cause flooding in their area, in addition to pluvial nuisance that arrives from higher parts (north) of Alajo. The hydrodynamic model results confirm their observations, as the model shows that the main influence on flooding comes from imposed downstream water levels and not from the rainfall in the pilot area itself.

The causes of high downstream water levels have not been assessed in this study, but could be:

- limited capacity of primary drains
- waste accumulation
- back water effect from Korle Lagoon caused by sea water levels or other blockage of water flow

7.2. What are suited elements for a flood assessment methodology in African cities?

Different tools and activities are used in this project to assess the flood risk in an urban developing context. In a short time span, lots of technical and social information about the drainage management is obtained. In this section the question is addressed how the tools described in this report are suited to analyse flood risk in African cities.

Social survey and stakeholder consultation

Social surveys and stakeholder consultation are useful methods to quickly understand and map relevant problems in the area. It also provides useful data to calibrate or validate model results.

Factors that influence proper functioning and management of the drainage system were mapped out through stakeholder consultation and interviews with inhabitants. Perspectives on topics such as coordination amongst responsible institutions, implementation of structural works or maintenance, waste services provision, attitudinal problem towards waste disposal and awareness about flood risk were collected. This creates a broad view on the complex flooding issues that Accra is facing and allowed for comparing the ideas of stakeholders working at the institutional level with the experiences of inhabitants in the neighbourhood. Furthermore, through 'social surveys' technical information can be obtained on flood levels that can be used in hydrodynamic model to validate and calibrate the model results.

Fieldwork – Technical Survey

The objective of the technical survey was to map the drainage system and to collect data as input into a hydrodynamical model. The study proves that - using an organized fieldwork strategy - a lot of field data can be collected in a short period. The entire drainage system of the neighbourhood was mapped, including erosion paths and tertiary and household drains. It is certainly usefull to have a map of the entire drainage system, in order to derive the subcatchments. However, it was not necessary to include all tertiary and household drains into the hydrodynamic model and therefore these cross-sectional measurements were unnecessary after all.

Different useful tools have been applied when gathering the necessary information: Smartphones were used to collect data in the field which facilitated data organization and processing. Improving the smart surveys to local conditions took some time. Additionally, holding a GPS device and notating information on field papers is necessary to orientate in the field and draw the drainage network in QGIS afterwards.

For flood assessment, the size of flood levels that have relevant impact in a neighbourhood should be at the basis of the decision on what scale fieldwork should be carried out.

Flood Assessment model

A flood assessment model can provide the following important information:

- It gives an overall picture of the flood problem in terms of causes and consequences.
- It highlights the most flood prone areas.
- It enables assessment of scenarios by including and varying rainfall events, potential mitigation measures and drainage problems like accumulation of waste and sand.

The model produced in this research is based on field measurements in the pilot area and elevation data derived from satellites. The challenge in constructing such a model is to collect accurate and useful data. This study showed that different sources and collection tools are available and useful to explore (see previous paragraph). The main uncertainty in the model is introduced by the elevation data, which has a rather coarse resolution in horizontal (30m) as well as vertical direction (1m).

Comparing model results to social survey results, it can be concluded that a simple hydrodynamic model can give an impression of which areas are more and which areas are less flood prone on a neighbourhood scale. Also the effects of varying downstream water levels can be assessed, even though the digital elevation model has a relatively low resolution. It should be stressed, however, that boundary conditions are estimations and that the model has not been calibrated. No conclusions could be drawn on the waste effects with the 1D model nor the 2D model. For the 2D model a higher detailed model (higher resolution 2D grid), would be necessary. For the 1D model the results can be improved by taking into account the storage capacity of the streets in the 1D model cross-sections. For future research the model could possibly be used to get insight into the effectiveness of measures to reduce the flood risk.

In this study scenarios of waste and water levels have been applied. This is a good technique to get insight into the sensitivity of the water system for these factors. In reality, the dynamics of waste in the system complicate the assessment of floods, as the load on the system differs in time and specifically during a rain event. Model scenarios of waste and silt clogging are a promising method to get insight into the sensitivity.

Social media experiment

The objective of the social media experiment was to investigate whether this technique can be a promising substitute for field measurements. The number of received reactions show that collecting data through social media is a promising tool for crowd-sourced flood risk mapping. This high potential is supported by the fact that about 60,000 people were reached [ref: Facebook stats] with this experiment within 4 weeks. However the experiment did not give much valuable technical data. With an improvement of the launched message, the number of valuable responses could be increased. A data collection request through social media should be extremely simple to get the most out of it. In all cases, social media remains a very effective means to raise awareness about the topic of project or research.

Raising awareness

Organizing a garbage removal mission is an effective means to raise awareness about waste accumulation causing blockages in the drains. The activity can create engagement and mobilize more community members to join the cleaning activities. Furthermore, developing communication strategies to engage stakeholders, partners and inhabitants in the project is important to create trust, enthusiasm and participation. Wearing project t-shirts and handing out flyers about the project during field work, and keeping an online, updated presence on website and social media were effective means to create awareness and involve locals in the discussions.

Incorporating lessons learned from the various steps undertaken during this project, a step-wise methodology is recommended which is included in Appendix F. These steps are useful in mapping the drainage system and analysing the causes of flood risk in a pilot study in a smart, easy and fast way.

Through answering the research questions, recommendations to reduce the disaster risk were investigated. These structural and non-structural measures have come up in discussions with stakeholders and inhabitants and are summarized in Appendix H. In further research, these measures can be evaluated using the urban drainage model.

8 Discussion

During a short time span of this project, the team was able to collect a lot of information about the current status of drainage system, the (underlying) causes of flood risk and the related issues on (waste) management. In a typical African city with data problems, different tools and activities have been implemented to obtain the required information. These tools we have assessed individually and from our recommendation we have identified useful elements for development of a methodology, as presented in the previous section. In this section, the effectiveness, accuracy and efficiency of some tools are discussed. Furthermore areas of continued research are identified.

8.1 Discussion Methodology

Flood Assessment

Primary Drainage system

More data is needed on the primary drainage system. The available information on the cross sections of the Odaw drain and its tributaries is outdated. Canalization of parts of the drainage system has led to a different situation, influencing the discharges and velocities. The accuracy of the available discharge data should be checked with the current and future situation. The number of gauging stations should be increased to provide accurate and continuous data.

Detailed height Data

Data of the DEM can be used to implement the drainage network in a hydrodynamic model as handheld GPS delivers unreliable data. The actual slopes of the drains can be approximated in this way. Manual adjustments are needed when the slopes of the drainage channels do not match reality. However, this implicates the simulation in the hydrodynamic model as the 2D grid does no longer match the 1-D drainage network and floods are not simulated correctly. A high resolution DEM with smaller grid size is needed

Dynamics of Waste

The dynamics of waste in the drainage system is not taken into account in the flood assessment model. More analysis is needed to check what happens with the movement of the waste with the flow of water through the drainage network. This would further approach reality instead of analysing static 'waste clogging' scenarios. In the same respect, to model the entire Odaw catchment, a morphology component describing the sediment flow essential to reflect the flood risk as it decreased the cross section of the primary drains substantially. This is also a dynamic load on the drainage system.

Rainfall data

For the hydrodynamic model, (raw) satellite data can be used to simulate a rain event, which has been done in this research. However the amounts are likely to underestimate the actual rainfall, as the satellite data is aggregated over a large extent, and local rainfall peaks are not accounted for. To design and plan an urban drainage system and test measures to improve the system, updated IDF curves are needed to construct rain events with certain design return periods. Preferably, climate scenarios are included to create a robust system for the future. This rainfall information was not available or obtained during this project.

Flood Risk Analysis

In this research the analyses of the flood extent and flood water levels are based on one rain event. This was sufficient to get insight into the impact of different factors on the water levels. However, to get to a flood risk analysis, more information is needed on the probability of flooding and the consequences of flooding. Therefore continued research on how to derive the probabilities and how to value the damage of flooding is recommended.

Social Surveys

Social Surveys are a good way to gather important information about the state of the drainage system, past flood events, people's disaster responses and waste management. However, answers to the interviews are highly subjective as they depend on individuals. The majority of the answers are considered reliable. Yet, people may tend to exaggerate a certain fact, as a flood event, because it touched them emotionally. In certain cases, the answers are confirmed by still visible damages on structures. Regarding the waste issue, people can feel ashamed to admit they throw things into the drains and they easily blame the government for the scarce operation. Therefore, the gathered data has to be critically analysed to provide reliable and useful information. Expert judgment and comparison to information and perspectives shared through stakeholder consultation can help to assess the reliability of the gathered information.

Technical Field Surveys

Errors in the field measurements can be caused by inaccurate reading of results, lack of experience with the tools or malfunctioning of tools. Regular checking of the tools is needed and tasks and responsibilities have to be divided among the team members to maintain consistency in data collection. Measurements in the field must be performed multiple times to decrease inaccuracy. It is important to use the most up to date field paper maps to avoid disorientation during the surveys. When implementing the drawn network to QGIS, the comparison with the GPS track is needed to limit the inaccuracy, given the better precision of the GPS device.

It is interesting to figure out what level of detail is necessary to conclude on the flood risk levels in the city of Accra. In this project, every drain encountered in the neighbourhood is mapped. If you research flood risk on a bigger city-wide scale, what is a good level at which you can start omitting neighbourhood level drains? Perhaps through GIS analysis, a synthetic neighbourhood drainage map can be derived by combining flow accumulation patterns from the DEM and OpenStreetMap data.

8.2 Recommendations for further research

During our fieldwork we created a map of the drainage network of a pilot area, in an effort to assess the current status of the system. This fieldwork and the surveys used to map the drainage system can be easily extended to mapping other infrastructure in the neighbourhood. Recent graduates who perform their national service at a government institutions could be trained and given the task to map out the city. Detailed information of the neighbourhoods is desperately needed for proper city planning. A more elaborated methodology is needed, in addition to this guideline to map the drainage system.

To explore waste management and its implications for urban drainage, more research is needed to understand all the logistical issues. By asking questions in the neighbourhood and during stakeholder consultation about waste services, we received a lot of information and insight. However, we did not have time to fully map the waste services provision in Accra. Waste management is a service that is organized city-wide and many players, both private and public are involved. In order to propose sustainable measures on how to decrease the quantities of waste in the drainage system, more research need to be conducted on waste management in the city.

Be aware that talking with community people could get complicated for cultural barriers, such as differences in language and formalities. In this case, it is always recommended to be accompanied by locals, who can help with translation and mediation. Moreover, curiosity about your work can lead people to ask plenty of questions that can reduce the efficiency of your fieldwork activities considerably. This can be solved having flyers available with you, aimed to redirect people to a website with official information about the project.

References methodology

References Chapter 1
[1] *Sendai Framework for Disaster Risk Reduction - UNISDR*. (2016). *Unisdr.org*. Retrieved 17 May 2016, from http://www.unisdr.org/we/coordinate/sendai-framework

References Chapter 3
[2] Ogink, H. June 3 2015 Floods in Accra, Assessment Summary.

[3] Udo, J. (2016). *Memorandum on October 2011 floods in Accra.* Delft.

[4] *Stormwater Solutions in Ghana*. (2016). *Waterworld.com*. Retrieved 3 May 2016, from http://www.waterworld.com/articles/2011/09/stormwater-solutions.html

[5] *Rain, D., Engstrom, R., Ludlow, C., & Antos, S. (2011). Accra Ghana: A City Vulnerable to Flooding and Drought-Induced Migration. UN-Habitat (Ed.).*

[6] *Why start with why*. (2015). *@tisquirrel*. Retrieved 18 June 2016, from https://tisquirrel.me/2015/02/05/why-start-with-why/

[7] GNWP. (2014). *Cape Coast Metropolitan Assembly WASH Masterplan*. Cape Coast: GNWP.

[8] *Precipitation Measurement Missions - TRMM*. (2016). https://pmm.nasa.gov/TRMM.

[9] *Precipitation Measurement Missions - GPM*. (2016). https://pmm.nasa.gov/data-access/downloads/gpm.

[10] *Shuttle Radar Topography Mission - UGSG*. (2016). http://glcf.umd.edu/data/.

[11] *OpenStreetMap*. (2016). *OpenStreetMap*. Retrieved 3 May 2016, from https://www.openstreetmap.org/

[12] *CNES*. (2016). https://spot.cnes.fr/en/SPOT/index.htm.

[13] Ackom, E. (2009). *Flood Modelling and Simulation Using Hydrodynamic Model and GIS*. Stuttgart.

[14] Foundation, A. (2016). *Akvo Flow | Akvo.org*. *Akvo.org*. Retrieved 18 April 2016, from http://akvo.org/products/akvoflow/

References Chapter 4
[15] *KoBoToolbox | Data Collection Tools for Challenging Environments*. (2016). *Kobotoolbox.org*. Retrieved 14 June 2016, from http://www.kobotoolbox.org/

[16] *Field Papers*. (2016). *Fieldpapers.org*. Retrieved 19 April 2016, from http://fieldpapers.org/

[17] *Early Warning System*. (2016). Lelystad.

References Chapter 5
[12] *CNES*. (2016). https://spot.cnes.fr/en/SPOT/index.htm.

[13] Ackom, E. (2009). *Flood Modelling and Simulation Using Hydrodynamic Model and GIS*. Stuttgart.

References Chapter 5
[18] (2016). *Isocialonline.com*. Retrieved 13 May 2016, from http://www.isocialonline.com/

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Appendix A – Project team and supervisors

Project team, from left to right: Evelien Martens (TU Delft), Lexy Ratering Arntz (TU Delft), Caterina Marinetti (TU Delft), Nadi Modderman (TU Delft), Kofi (KNUST) and Daniel Atta Yao Avafia (KNUST).

Supervisors, from left to right: Nick van de Giesen (TU Delft) , Frank Annor (TU Delft, KNUST), Joost van der Zwet (HKV Consultants), Job Udo (HKV Consultants), Gideon Lomoko (Witteveen+Bos) and Jochem Schut (Witteveen+Bos).

Appendix B – Background analysis

B1 Urban Development

Ghana is one of the fastest growing economies of West Africa. Its population of approximately 27 million people generate a per capita GDP of around $ 1400 (2014) [9]. Accra is the administrative, political and commercial capital of Ghana with a population of around 4 million in 2010, accounting for 15.4 per cent of Ghana's total population [10]. The greater Accra region is made up of 16 different municipalities with different sizes, the MMDA's. Depending on the size, they are named Metropolitan, Municipal, or District Assemblies.

Accra it is the capital of Ghana since 1877, when Accra started hosting the British colonial headquarters. Urban growth has been influenced by the cocoa trade in the 19th century. Colonial administration brought commerce and residential segregation policies defined the neighbourhoods of today. Officials settled in the higher elevated areas of the Ridge and Cantonments in the city. The native population, particularly the Ga people, lived in crowded, disorganized areas near the market and sea coast. Neighbourhoods in Accra display the extremes in living conditions, there exist chaotic and unsanitary slums, emergent middle class areas and exclusive expatriate European and elite African enclaves.

Since the late 1980s, the city has experienced an average annual growth rate of 4.3 %. The national growth rate is 2.3%. The immigrant flux, forced to find other ways of living in the city after serious droughts, has put tremendous pressure on the housing solutions and infrastructure for the new residents. Globalization and Economic growth have helped contribute to the city's expansion in all directions. The lack of sustainable urban planning strategies have resulted in urban sprawl and traffic congested streets. Continued urban expansion overruns rural and agricultural land surrounding the city and without regard to infrastructure or planning. At first, the densities of these developments are low at the fringes. Problems are created as the city grows by filling in areas between older neighbourhoods that lack roads, sewers and other infrastructure. Solutions to resolve these problems are costly in response [7].

B2 Hydrological Analysis

Surface

The geology of Accra consists of lateritic soil groups that are easily erodible. Laterites are soil and rock types that are rich in iron and aluminium (causing the red-rusty colour), mostly formed in hot and wet tropical areas [2]. These type of soils provide a significant source of sediment for the drains [1] There is limited vegetation in the metropolitan area. Most of the surface is urbanized. Savannah scrubland can be found in the spare open spaces within the city.

Rainfall

The monthly rainfall distribution is shaped by the movement of the Inter tropical convergence zone (ITCZ), causing wet and dry seasons. The migration of the ITCZ causes two wet periods in Ghana. From May-June the strongest wet period occurs when the ITCZ moves up north, followed by a weak wet period in Sep-Oct when he ITCZ migrates southwards. The yearly average rainfall amounts to 810 mm. West Africa has experienced rainfall variations over the years. Mean annual rainfall dropped 30% during the Sahelian Droughts in the 70s and 80s [7].

Rainfall intensity duration frequency (IDF) relationships are an important tool in water resources engineering for assessing risk and vulnerability. For engineering applications in a certain region, constructing IDF curves helps to predict when the region will be flooded. Frequency analysis is carried out on annual maximum daily and shorter interval rainfall extremes to assess the return period of the rainfall events. Given the short hydrological response time of the urban catchments in the city, short duration IDF curves were developed by Logah, Kankam-Yeboah and Bekoe with data from 4 meteorological stations within the Greater Accra region (GAMA) [1] and improved by Worldbank consultants. Rainfall distributions for 0.5 to 24 hour intervals are presented in Figure 1.

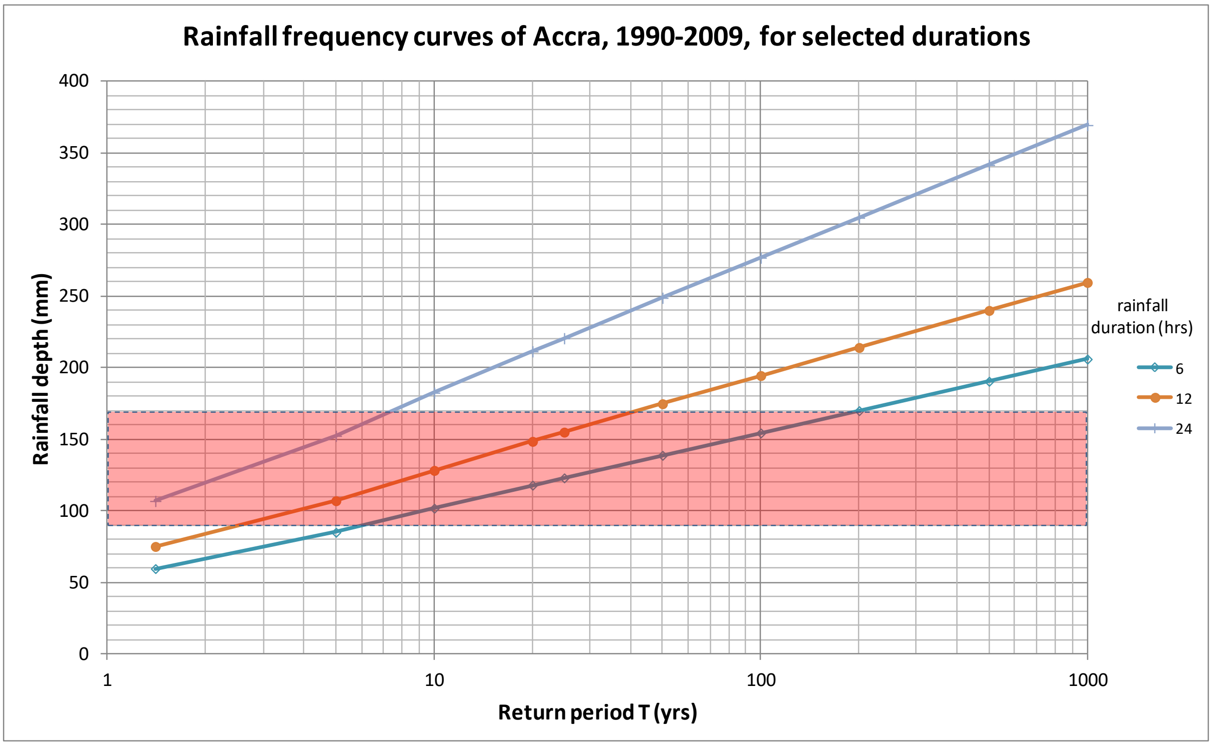


Figure 39 Rainfall range 90–170 mm on June 3, 2015 compared with the rainfall frequency curves for 6, 12, and 24 hour durations for Accra [3]

Historical Rain events

On June 3rd 2015, heavy rains created flooding that impacted many parts of the Greater Accra Region. Over 200 people lost their lives and many more were displaced and lost their property and livelihoods. See the figure below. The recorded rainfall of the extreme rainfall event are presented in table 1 [3]. The rainfall lasted for six hours during the night. The rainfall range that was recorded by the Ghana Meteorological Office is indicated in the graph of the IDF curves. The return period of the event thus varied between 6 and 200 years, confirming the severity of the events. Included in the table are also the recorded rainfall values from a previous serious rainfall event of October 26, 2011 (between 9 and 11 people were killed by heavy rainfall) for comparison [4].

Table 16 Observed rainfall at selected stations in Accra on 3/6/15 and 26/10/11

Station	June 3, 2015	October 26, 2011
Osu	90.3	70.7
Archives	169.4	110.9
St Mary's	154.2	
Accra Academy	169.4	107.8
Wesley Grammar	96.6	
Weija	119.4	
Maamobi	89.8	124.9
GMET (Legon)	148.3	120

Drainage Basins

Drainage of storm water in the city mostly takes place though natural drains and concrete lined channels. There exist eight drainage basins in the city through which rainfall is discharged to the sea: Densu, Korle, Lafa, Chemu, Osu, Kpeshie, Sakumo and Songo Mokwe Basins. The primary drainage system in the Korle Basin is the Odaw Drain and its tributaries Nima, Onyasia, Dakobi and Ado. These streams drain the major urbanised areas and central bussines disctricts of Accra. The Odaw drains to the sea via Korle Lagoon [3]. The catchment area is about 35x10km (308 km^2) [4].

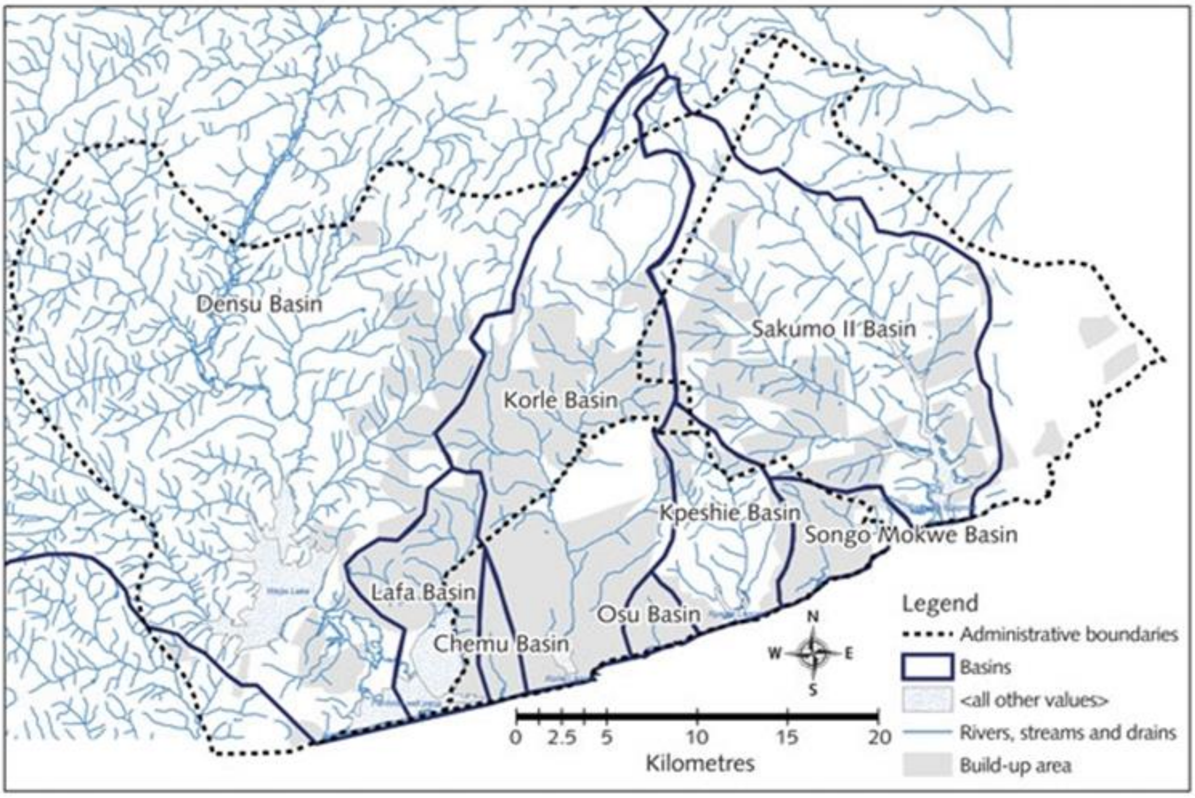


Figure 40 Basins in the Greater Accra Region [4]

Many of the drainage channels are poorly developed and maintained and erosion and siltation is problematic. Consequently, the low-lying areas in the Odaw Catchment flood frequently. During the extreme rainfall event of june 3rd, The flooding occurred around Nkruma Circle, Alajo, Adabraka, Graphic Road and Dansoman.

B3 Climate Change Impacts

Droughts are a significant impact of climate change for Africa. Agriculture is heavily dependent on the seasonal characteristics of rainfall. Agriculture and livestock form the backbone of Ghana's economy, accounting for 32% of GDP in 2009. 55% of the economically active population works in this sector [8]. Climate researchers predict shifts and growing intra-seasonal variability in the ITCZ over West Africa.

If periods of droughts to worsen and prolong, migration of agricultural workers from the north to urban environment on the coast is likely to sustain. This influx of people puts additional stress on limited resources such as food, water, farmland and electricity. Due to less fresh water discharge from the rivers, the intrusion of salt water from the ocean becomes a big treat to farmlands and water bodies. In the coastal areas high salinity levels deteriorate the groundwater and make it useless for any water use [7].

B4 Causes of flooding

Even small rains events already lead to flooding in the city of Accra. What are the reasons that Accra is not drained well during heavy rainfall?

- The urban population of Accra grows by over 4% a year. Many people are drawn to the cities because of droughts in the northern parts of the country and they are looking for other means of living. The rapid urban expansion of Accra transformed the surface of the basin into a nearly impervious area. There is hardly any infiltration of rainwater and retention capacity for floodwater is limited. Residential structures are put in low-lying and unsafe areas close and in drainage channels. Roads have been built across watercourses, leaving no space for the water to flow [5].
- The attempt at flood management and mitigation in Ghana has concentrated on conveyance improvement and channel widening [6]. Creating impervious surface through cementing outdoor living areas in a locally understood strategy to reduce flooding. However it does so by passing the problem on to those downstream [7].
- The government has not been able to keep up with the population increase in building of the city's infrastructure. Therefore many neighborhoods have inadequate infrastructure such as energy supply, sanitation services, roads and drainage system. The current layout and dimensioning of the existing drainage network is not able to discharge the rainwater appropriately. Due to a lack of maintenance, the capacities of the drainage system
- The study of the current solid waste handling is essential to come up with solutions for the flooding problems. Accra's official waste disposal sites are small and overloaded, encouraging illegal disposal in drains or the ocean. The accumulation of solid waste in the drains has a negative impact on water safety and quality. Due to a lack of maintenance, siltation further reduces the capacity of the system. Clogged drains and lagoons cause backwater effects in the canals upstream, causing flooding. The water quality in these water bodies is very low, causing health risk for communities that reside nearby. [7]
- The extreme division of responsibilities in urban drainage management in Accra complicate coordination of planning and maintaining. The stakeholders analysis in Chapter 3 gives an overview of the institutions involved.

B5 Solid & liquid waste management

In the Greater Accra Metropolitan Area (GAMA) there exist a challenging environmental sanitation situation. Solid and liquid waste is not properly managed. Official waste disposal sites in the city are small and overloaded. Within the MMDA's, communal solid waste containers are excavated irregularly and as a consequence overflow. Waste ends up in open drains and watercourses.

Open defecation and discharge of raw faecal sludge into open drains, river bodies and open spaces is serious threat to public health. Sanitation solutions in are especially poor in low-income neighbourhoods. Many do not have individual toilets and depend on the presence of communal toilet blocks. There are no functional faecal and septic sludge treatment facilities in GAMA. The only functional solid waste treatment facilities are the Kpone (Tema) landfill and Accra compost plant. They are located far from the majority of waste collection zones in city [13].

B6 Overview of Drainage-Related Projects

- The Ghana Netherlands WASH Program (GNWP)

Water and Sanitation Hygeine Masterplans for 5 district in Greater Accra. Prepared by Berenschot, Witteveen + Bos and Simavi on behalf of the Dutch Embassy and the Ghanaian Ministry of Local Government and Rural Development

- The Conti project.

Accra Sanitary Sewer and Stormwater Drainage Alleviation Project, aimed at improving the drainage and sewer system in AMA, with focus on the Odaw Basin. The project includes the construction of an engineered landfill for Accra. The Project is current on hold [14].

- The GAMA Sanitation and Water Project

Ministry of Local Government and Rural Development, funded by the Worldbank. This project is aimed at providing environmental sanitation and water supply services to priority low-income areas of the Greater Accra Metropolitan Area. Tender is open for application [13].

- The CREW (Community Resilience Through Early Warning) project

A UNDP funded project, carried out by NADMO, National Disaster Management Organization. This project aims to build capacities within the country to reduce disaster risk through the development of an integrated early warning system. National Level Flood and Drought Risk Assessments and Mapping are completed. Accra is selected as a pilot district and hotspots are analysed.

- SWITCH

Comprehensive study on problems and solutions for urban water management in Greater Accra, developed by, among others, IRC and IWMI. The current status of the system was assessed and strategic directions for the future set out. The findings from this project are being utilized within official planning processes.

References

[1] Kankam-Yeboah, K., Logah, F., & Bekoe, E. (2013). Developing Short Duration Rainfall Intensity Frequency Curves for Accra in Ghana. *International journal of latest research in engineering and computing* , 67-73.

[2] *Laterite*. (2016). *Wikipedia*. Retrieved 17 March 2016, from https://en.wikipedia.org/wiki/Laterite

[3] Ogink, H. June 3 2015 Floods in Accra, Assessment Summary.

[4] Udo, J. (2016). *Memorandum on October 2011 floods in Accra*. Delft.

[5] *Stormwater Solutions in Ghana*. (2016). *Waterworld.com*. Retrieved 3 May 2016, from http://www.waterworld.com/articles/2011/09/stormwater-solutions.html

[7] *Rain, D., Engstrom, R., Ludlow, C., & Antos, S. (2011). Accra Ghana: A City Vulnerable to Flooding and Drought-Induced Migration. UN-Habitat (Ed.).*

[8] *Climate Change Knowledge Portal*. (2016). *Sdwebx.worldbank.org*. Retrieved 7 April 2016, from http://sdwebx.worldbank.org/climateportal/countryprofile/home.cfm?page=country_profile&CCode=GHA

[9] *Ghana | Data*. (2016). *Data.worldbank.org*. Retrieved 7 April 2016, from http://data.worldbank.org/country/ghana

[10] Koney, R. (2016). *Greater Accra - Government of Ghana*. *Ghana.gov.gh*. Retrieved 7 April 2016, from http://www.ghana.gov.gh/index.php/about-ghana/regions/greater-accra

[11] GNWP. (2014). *Cape Coast Metropolitan Assembly WASH Masterplan*. Cape Coast: GNWP.

[12] City Strength Diagnostic in the Greater Metropolitan Area (GAMA), Pre-diagnostics Report, Worldbank Group, City Strength

[13] Notice-WB637, GAMA Water and Sanitation Project

[14] *Ghana: U.S.$660 Million Conti Project Hits a Snag*. (2015). *allAfrica.com*. Retrieved 16 June 2016, from http://allafrica.com/stories/201506082568.html

Appendix C – GPM rainfall data

Date and time	Rainfall [mm/30 min]	Date and time	Rainfall [mm/30 min]
3-6-2015 00:00	0	4-6-2015 00:30	0,09
3-6-2015 00:30	0	4-6-2015 01:00	0
3-6-2015 01:00	0	4-6-2015 01:30	0
3-6-2015 01:30	0	4-6-2015 02:00	0
3-6-2015 02:00	0	4-6-2015 02:30	0
3-6-2015 02:30	0	4-6-2015 03:00	0
3-6-2015 03:00	0	4-6-2015 03:30	0
3-6-2015 03:30	0	4-6-2015 04:00	0
3-6-2015 04:00	0	4-6-2015 04:30	0
3-6-2015 04:30	0	4-6-2015 05:00	0
3-6-2015 05:00	0	4-6-2015 05:30	0
3-6-2015 05:30	0	4-6-2015 06:00	0
3-6-2015 06:00	0	4-6-2015 06:30	0
3-6-2015 06:30	0	4-6-2015 07:00	0,09
3-6-2015 07:00	0	4-6-2015 07:30	0
3-6-2015 07:30	0	4-6-2015 08:00	0
3-6-2015 08:00	0	4-6-2015 08:30	0,77
3-6-2015 08:30	0	4-6-2015 09:00	0,17
3-6-2015 09:00	0	4-6-2015 09:30	0
3-6-2015 09:30	0	4-6-2015 10:00	0,17
3-6-2015 10:00	0	4-6-2015 10:30	0,17
3-6-2015 10:30	0	4-6-2015 11:00	0,09
3-6-2015 11:00	0	4-6-2015 11:30	0,09
3-6-2015 11:30	0	4-6-2015 12:00	0,17
3-6-2015 12:00	0	4-6-2015 12:30	0,09
3-6-2015 12:30	0	4-6-2015 13:00	0
3-6-2015 13:00	0	4-6-2015 13:30	0
3-6-2015 13:30	0	4-6-2015 14:00	0
3-6-2015 14:00	0	4-6-2015 14:30	0
3-6-2015 14:30	0	4-6-2015 15:00	0
3-6-2015 15:00	0	4-6-2015 15:30	0
3-6-2015 15:30	0	4-6-2015 16:00	0
3-6-2015 16:00	0	4-6-2015 16:30	0
3-6-2015 16:30	0	4-6-2015 17:00	0
3-6-2015 17:00	0,85	4-6-2015 17:30	0
3-6-2015 17:30	0	4-6-2015 18:00	0
3-6-2015 18:00	0	4-6-2015 18:30	0
3-6-2015 18:30	0,34	4-6-2015 19:00	0
3-6-2015 19:00	2,73	4-6-2015 19:30	0
3-6-2015 19:30	3,16	4-6-2015 20:00	0
3-6-2015 20:00	7,43	4-6-2015 20:30	0
3-6-2015 20:30	9,05	4-6-2015 21:00	0
3-6-2015 21:00	10,16	4-6-2015 21:30	0
3-6-2015 21:30	10,16	4-6-2015 22:00	0
3-6-2015 22:00	8,2	4-6-2015 22:30	0
3-6-2015 22:30	8,11	4-6-2015 23:00	0
3-6-2015 23:00	6,75	4-6-2015 23:30	0
3-6-2015 23:30	0,77	5-6-2015 00:00	0
4-6-2015 00:00	0,09		

Appendix D – Fieldwork

D1 Description of potential pilot areas

Agbogbloshie

Agbogbloshie is an unplanned neighbourhood, former wetland, within the city of Accra[1]. Points of interests in this area are the onion market and the world's largest E-waste (see Figures 3 and 4). Houses are mostly wooden shacks that lack water and sanitation. The nickname of Agbogbloshie is Sodom and Gomorrah, after two condemned biblical figures, due to the harsh living conditions.

Figure 41 Onion market Agbogbloshie (Author's source, 2016)

Figure 42 Odaw river Agbogbloshie (Author's source, 2016)

Kaneshie

Graphic Road (Winneba Road towards the North) is the main road that runs through Kaneshie, a planned neighbourhood[2]. Kaneshie is a residential area, also known for its commercial activities as Kaneshie Market, a major trading centre.

Figure 43 Drain Graphic Road (Author's source, 2016)

Figure 44 Kaneshie Market [4]

Alajo

Alajo is similar to Agbogbloshie: an unplanned neighbourhood[2]. This neighbourhood is characterized as a dense populated area with few commercial activities in the form of roadside stalls. Although the most practiced religion in Ghana is Christianity, Alajo gives home to a large Muslim community.

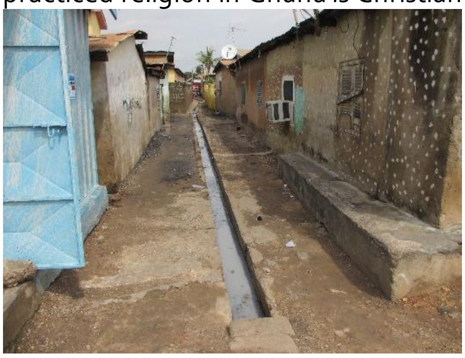


Figure 45 Housing in Alajo (Author's source, 2016)

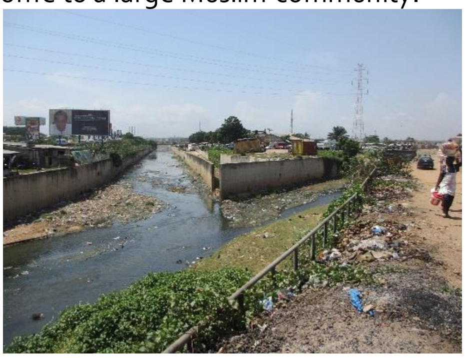


Figure 46 Carprice (Author's source, 2016)

D2 Multi criteria analysis for pilot area selection

Priority values are given to the defined criteria. Potential pilot areas are rated from 0 - 10 for each criterion, depending on the extent to which the criterion is applicable to the concerned area. The higher the score, the more applicable the criterion is. After rating each individual criterion, priority values and criterion scores are multiplied and summed up per area. Areas with high scores are preferred for final selection over areas with low scores.

1. *Susceptibility to flooding*

The three neighbourhoods are all subjected to flooding if rain events occur. All areas are rated with a 10.

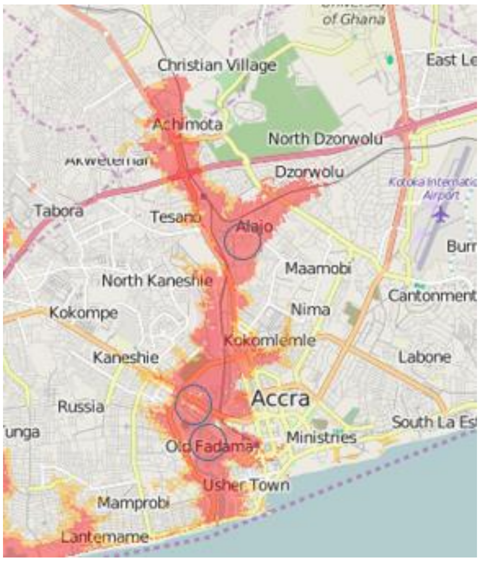


Figure 47 Flood prone areas (Odaw catchment) [5]

2. *Urban texture*

The slum index (Jankowska, 2013) is used to categorize the income level of the neighbourhoods. As depicted in figure 10 below, Agbogbloshie and Alajo are classified as slums or low income neighbourhoods and are both rated with a 10. A score of 5 is given to Kaneshie, given the presence of economic activities.

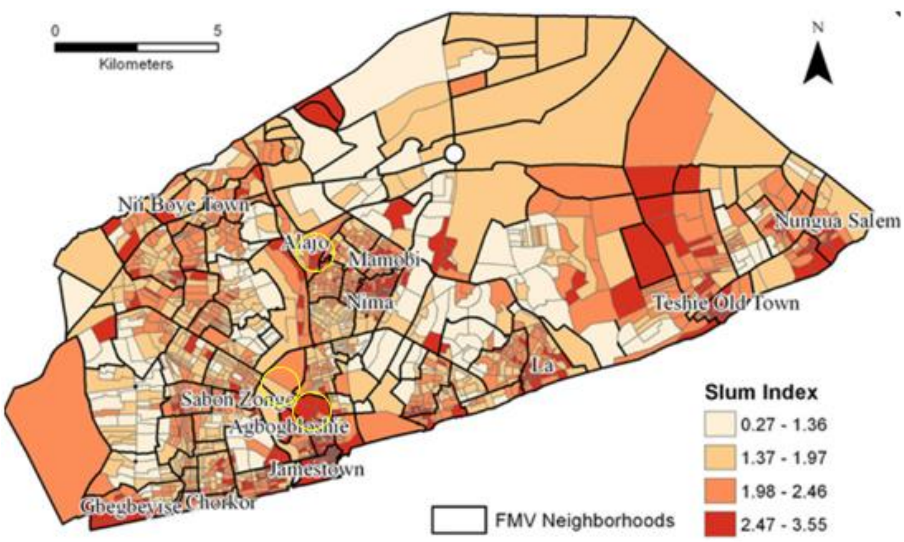


Figure 48 Slum Index Accra Metropolitan Assembly [3]

3. *Feasibility of data collection*

The Witteveen+Bos office provided to the project team is located in Dzorwulu. To limit transportation time and costs from the office to the pilot area, nearby areas are preferred over areas further away. In this light, Alajo is preferred over Agbogbloshie and Kaneshie. Safety during field work also influences the feasibility of data collection. Based on consultation of local people and colleagues, Agbogbloshie is appointed to be a relatively unsafe area, while Kaneshie and Alajo are considered safer for carrying out fieldwork. Combining the transportation and safety aspects, Alajo is rated 10, Kaneshie 5 and Agbogbloshie 0.

The table below shows the result of the multi criteria analysis. From table 2 it follows that the order of preference after the multi criteria analysis is firstly Alajo, followed by Agbogbloshie and finally Kaneshie.

Table 17 MCA Pilot Area selection

Criteria	*Priority value*	*Score Agbogbloshie*	*Score Kaneshie*	*Score Alajo*
1. Representativeness of the flood prone areas	3	10	10	10
2. Urban texture	2	10	5	10
3. Feasibility of data collection	1	0	5	10
Total score		**50**	**45**	**60**

D3 Akvo Surveys Forms (Technical Surveys and Social Survey)

Following, the Akvo questionnaires used to collect data in the field are reported. For the drainage network features (Table 3), the options available as answers comply with a classification of the reaches that was finalized only after attaining a detailed understanding of the actual network layout. The classification is shown in Table 4.

Examples of special structures are also given in Table 9, following the survey form "Other points of interests". These structures can either be vulnerable structures or constructions that decrease the capacity of the drainage network or influence its functioning.

Technical Surveys

Table 18 Drainage network features – survey form

Drainage network features

Question	Response
1. Enter geolocation	
2. Take picture	
3. Width of the drain [mm]	
4. Height of the drain until street level [mm]	
5. Height of the drain until cover [mm]	
6. Type of drain	Manmade Erosion Erosion+Manmade Floodplain Culvert
7. Cover of drain	Open Partially (covered) Covered
8. Description of location of drain	One sided road Two sided road Alley Not applicable (n/a)
9. Shape of drain	U-shape Rectangular Erosion big Erosion small Pipe
10. Material bottom drain	Concrete/pavement Sand/clay/stones Stones/rocks
11. Material walls drain	Concrete/pavement Sand/clay/stones Stones/rocks
12. Space for comments on the previous questions	

Table 19 Classification of the reaches

Type

Manmade drain	
Erosion path	
Erosion + Manmade	Combination of erosion and bricks/manmade structures/supports 
Floodplain	

Culvert	
Cover	
Open	
Covered	Drain covered with different type of structures: concrete cover; moving metal; moving wood piles; shops 
Partially covered	
Road	

2 sided road	Drains present at both side of the road 
1 sided road	Only one drain/erosion path at the side or the center of the street 
Alley	Reach placed in an alley 
Not applicable (n.a.)	Just a drain or an erosion path not placed in any road or alley; it could be placed between houses or in places not reachable from the road
Shape	
U-shape	

Rectangular	
Pipe	
Erosion small	
Erosion big	
Material bottom/side	
Concrete/pavement	

Sand/clay	
Bricks	
Stones/rocks	

Table 20 Waste and clogging – survey form

Waste and clogging	
Question	**Response**
1. Enter geolocation	
2. Is there any waste in the drain along the stretch?	Yes/No
3. Take a picture of the waste in the drain	
Only answer if you responded YES to Q2	
4. On what location in the drain do you identify waste?	Curve/angle
	Joint (multiple drains changing to single drain)
	Split (single drain changing to multiple sub-drains)
	Straight course of drain
	Eroded water path
Only answer if you responded YES to Q2	
5. Do you identify any special structures that cause clogging?	No special structure
	Culvert
	Buildings
	Vegetation
	Collapsed drain
	Pipes (electricity, water)
	Bricks

	Woods
	Crossing for people
6. Does the waste block the cross-section of the drain?	Yes, partly
	Yes, completely
	No
Only answer if you responded Yes, partly to Q6	
7. What percentage of the drain cross-section is blocked?	0-20
	20-40
	40-60
	60-80
	80-100
Only answer if you responded YES to Q2	
8. What are the types of waste in the drain?	Municipal Waste
	Industrial Waste
	Construction & Demolition Waste
	Hazardous Waste
	Waste from Electrical and Electronic Equipment (WEEE)
	Packaging Waste
	End-of-Life Vehicles (ELVs) and Tyres
	Agricultural Waste
Only answer if you responded Municipal Waste to Q8	
9. What are the types of municipal waste in the drain?	Paper, cardboard
	Glass
	Metals
	Textiles
	Organics
	Wood
	Plastics
	Fecal matter
10. Is there any waste nearby the drain?	Yes/No
Only answer if you responded YES to Q10	
11. Take a picture of the waste nearby the drain	
Only answer if you responded YES to Q10	
12. What are the types of waste nearby the drain?	Municipal Waste
	Industrial Waste
	Hazardous Waste
	Construction and Demolition Waste
	Mining Waste
	Waste from Electrical and Electronic Equipment (WEEE)
	Biodegradable Municipal Waste
	Packaging Waste
	End-of-Life Vehicles (ELVs) and Tires
	Agricultural Waste
Only answer if you responded Municipal Waste to Q12	
13. What are the types of municipal waste nearby the drain?	Paper, cardboard
	Glass
	Metals
	Textiles
	Organics
	Wood
	Plastics
	Fecal matter
14. Do you see signs of solid waste management around the drain?	No, only loose items
	Yes, bins (small)

	Yes, containers (big)
	Yes, collection in bags
	Yes, waste pickers/company in action
15. Space for comments on previous questions	

Table 21 Discharge measurements – survey form

Discharge measurement *

Question	Response
1. Enter geolocation	
2. Take picture of drain	
3. Flow Velocity in the Drain (Measurement 1). Insert the Time in [sec]	
4. Flow Velocity in the Drain (Measurement 1). Insert the Distance in [m]	
5. Flow Velocity in the Drain (Measurement 2). Insert the Distance in [m]	
6. Flow Velocity in the Drain (Measurement 2). Insert the Time in [sec]	

**Flow velocity measurement is carried out throwing a floating object inside the drain, defining a travel distance and dividing this distance by the time needed by the object to travel it (m/s). The experiment is repeated two times. The final result is the average between the two experiments.*

Table 22 Flood level marks on structures – survey form

Flood level marks on structures

Question	Response
1. Enter geolocation	
2. Take picture of flood level	
*3. Height of the water level above drain (mm)**	

**Each flood mark is calculated starting from the upper level of the drain, to measure more accurately as possible how much the received water exceeds the capacity of the drainage system.*

Table 23 Other points of interest – survey form

Other points of interest

Question	Response
1. Enter geolocation	
2. Take picture of point of interest	
3. Classify the point of interest	Vulnerable object (school, church etc.) Structure in/along drain (that can cause reduction in the network capacity) Other
Only answer if you responded Structure in/along drain to Q3	
4. Does the Structure Cause Clogging of Waste in the drain at the moment of measurement?	Yes/No
5. Please provide a short comment on the picture	

Table 24 Examples of points of interest

Culvert	
Shops over drain	
Demolished drain	
Pipes crossing inside the drain	

Social Surveys

The methodology implemented in this case study has the purpose to provide a new smart, easy and fast way to collect relevant information about the state of the drainage system and related issues: drainage and waste management, flood hazards and disaster handling. It is important to analyze these topics not only from an institutional point of view, but also at a community level, bearing in mind that inhabitants are responsible parties and first victims of flood disasters. Residents can provide information regarding historical floods, frequency of flooding, size of the event and its consequences, early warning system and actions during and after a disaster. Special attention is payed to the 3rd June 2015 flood event. In addition, information about the routine waste management is easy to collect.

Therefore, technical surveys are supported by social surveys, to have a comprehensive contextualization. Data from social surveys are also used to empirically validate the results from the model built with technical data. Flood marks on households or flood levels indicated by residents offer a reliable measure. Those levels can be confronted with the flood levels resulting from the SOBEK model to validate the truthfulness of the latter.

Table 25 below summarizes the type of relevant information gathered from interviewees. The survey is divided in three main parts: data on the interviewee, flood experience and waste management. The Akvo survey form implemented in the fieldwork is found in Table 12. It is important to specify that, to facilitate the communications, translators took part in the activity.

Table 25 Type of relevant information collected from interviews

Data of interviewee	Gender
	Age
	Occupation
Flood Experience	Last flood at the location
	Water level above drain (mm) on 03/06/2015
	Picture of water level on 03/06/2015
	Water level above drain (mm) on 12/05/16 and/or 21-22/05/16*
	Picture of water level on A)12/05/16 B)21-22/05/16
	Permanence water on street after 03/06/2015 flooding
	Damages for floodings on 03/06/15
	Flood Warning System on 03/06/2015
	Personal conduct during the 03/06/15 flooding
	Help received during the 03/06/15 flooding
	Help received after the 03/06/15 flooding
	Return period event as the 03/06/2015 flood (personal perception)
	Causes of flooding (personal perception)
	Individual implementation of structural solutions to prevent floodings
Waste Management	Place of waste disposal
	People/institution responsible for waste collection
	Frequency of collection/individual disposal
	Waste collection fee
	Causes of waste in drains, even when waste collection works (personal judgement)
	Willingness to pay a fee for waste collection

*On May 12th, 21st and 22nd 2016 small rainfall event occurred.

Table 26 Social Survey form

Social Survey	
Question	**Response**
Location&Interviewee	
1. Please enter your geo-location	
2. Gender of the interviewee	Male
	Female
3. Age category	Youth (<24)
	Adult (24-59)
	Senior (60+)
4. Occupation	
Flood experience	
5. When was the last flood at this location? Specify date, flood level above drain (mm) and comments.	
6. Did you experience flooding at this location during the June 3rd 2015 event?	Yes/No
Only answer if you responded Yes to Q6:	
7. What was the water level above the drain (mm) on June 3rd 2015?	
Only answer if you responded Yes to Q6:	
8. Picture of water level on June 3rd 2015	
Only answer if you responded Yes to Q6:	
9. How long did the water stay in the street after the June 3rd 2015 flooding?	
Only answer if you responded Yes to Q6:	
10. What damages did you encounter as a result of the June 3rd 2015 flooding?	No damages
	Business related damages
	Structural damages to house and surroundings
	Personal items loss
	Vehicle damages
11. Were you warned in any way that a flood was coming on June 3rd 2015? Please specify	
12. What did you do during the June 3rd 2015 flooding?	
Only answer if you responded Yes to Q6:	
13. Did you receive any help during the flooding?	Yes, government/NADMO
	Yes, community people
	Yes, family
	No
Only answer if you responded Yes to Q6:	
14. Did you receive any help after the flooding?	Yes, government/NADMO
	Yes, community people
	Yes, family
	Yes, from NGOs
	No
15. How often does a flooding as the one on June 3rd 2015 occur?	
16. What do you think is the cause of floodings in your area?	
17. Have you implemented any structural solutions to prevent floodings?	Yes/No
Only answer if you responded Yes to Q19:	
18. Specify structural solutions and the occasion of implementation	
19. What was the water level above the drain (mm) on on A)12/05/16 B)21-22/05/16?	
20. Picture of water level on on A)12/05/16 B)21-22/05/16	
21. Space for comments	
Waste management	
22. Where do you normally leave your waste?	

23. Does anybody come to collect the waste?	
24. How often is waste collected or how often do you bring your waste to the dumpsite?	
25. How much do you have to pay for waste collection/dumping?	
26. If there is waste collection, why do you think that there is still waste in the drains?	

Major findings

Interviews were collected in the pilot area of Alajo and New Town. Figure 2 shows the location of the interview. The online database contains the shapefile "Social Surveys". In its attributes table, the answers to the surveys are reported.

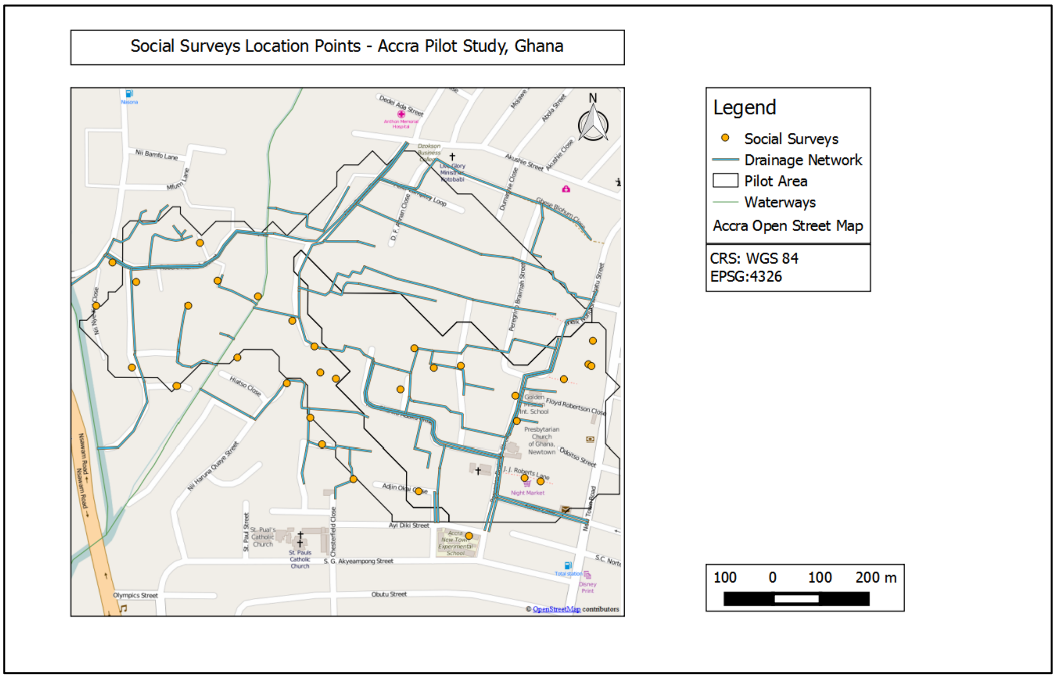


Figure 49 Location of interviews

- Data of interviewees

Data of the interviewees are presented in Table 12 below.

Table 27 Data of the interviewees

Number of interviewees	*33*			
Male %	49	Of whom:	Senior (60+)	12.5%
			Adult (24-59 y.o.)	75%
			Youth (15.24)	12.5%
Female %	51	Of whom:	Senior (60+)	0%
			Adult (24-59 y.o.)	88%
			Youth (15.24)	12%

- Flood experience

Out of the 33 interviewees, 22 experienced floods on June 3rd 2015; 8 experienced floods also during smaller events, as on May 12th, 21st and 22nd 2016; 8 did not experience any flood. For the flood levels refer to Figure 12, 13 and 14, below. In addition, flood levels gathered from the technical survey "Flood Level Marks" are also reported in Figure 16. Overall, the elevated area of New Town does not present significant flood marks, while they are considerable in the downstream area, next to the Onyasia drain, and in Alajo South in the cone between the Odaw and the Onyasia drains.

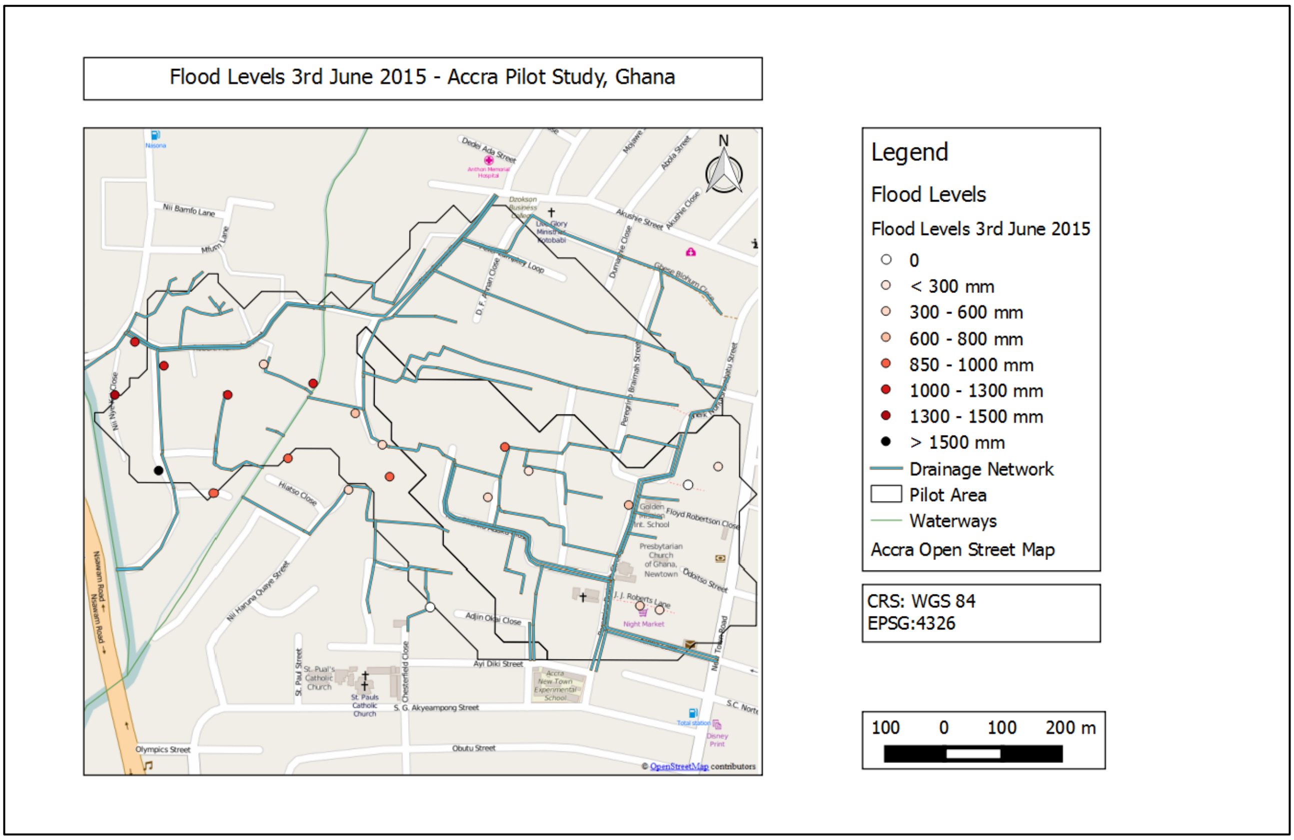


Figure 50 Flood levels June 3, 2015

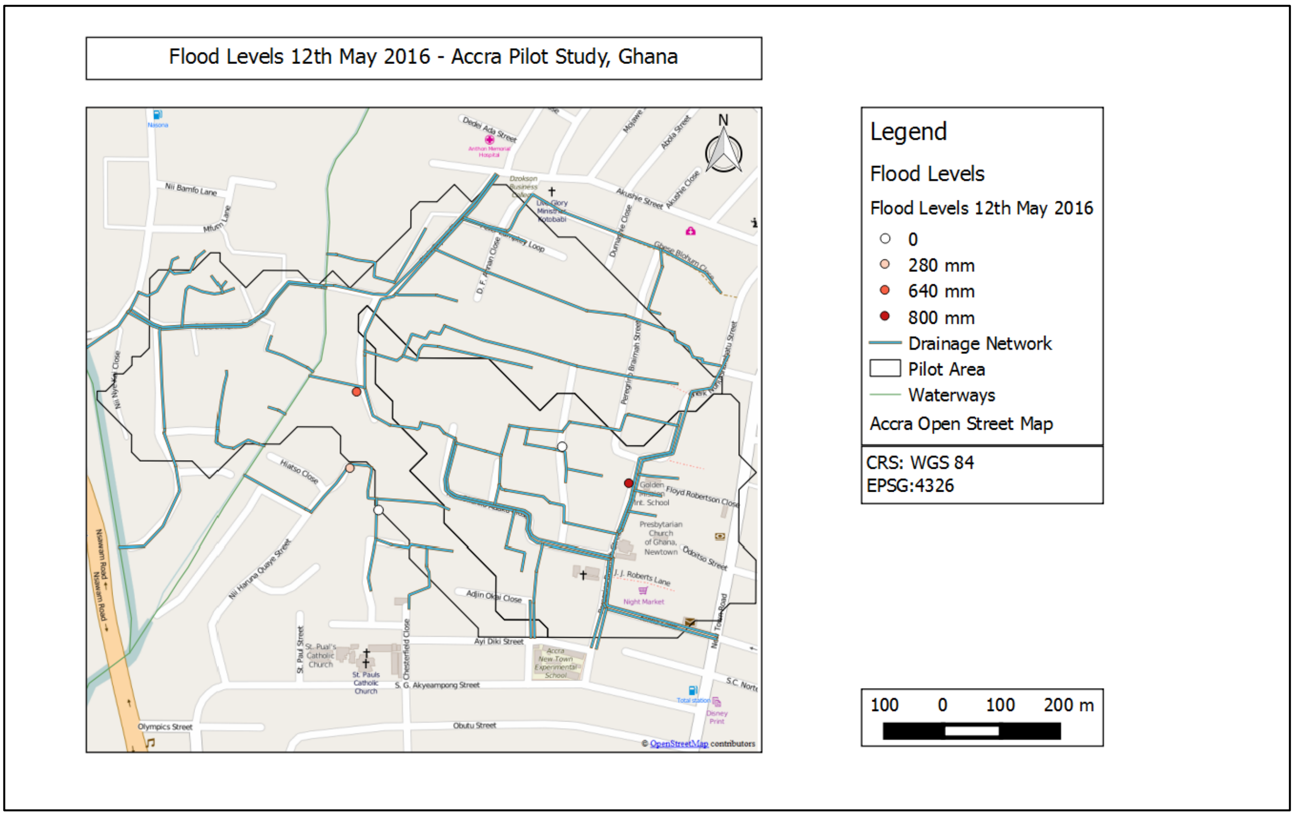


Figure 51 Flood levels May 12, 2016

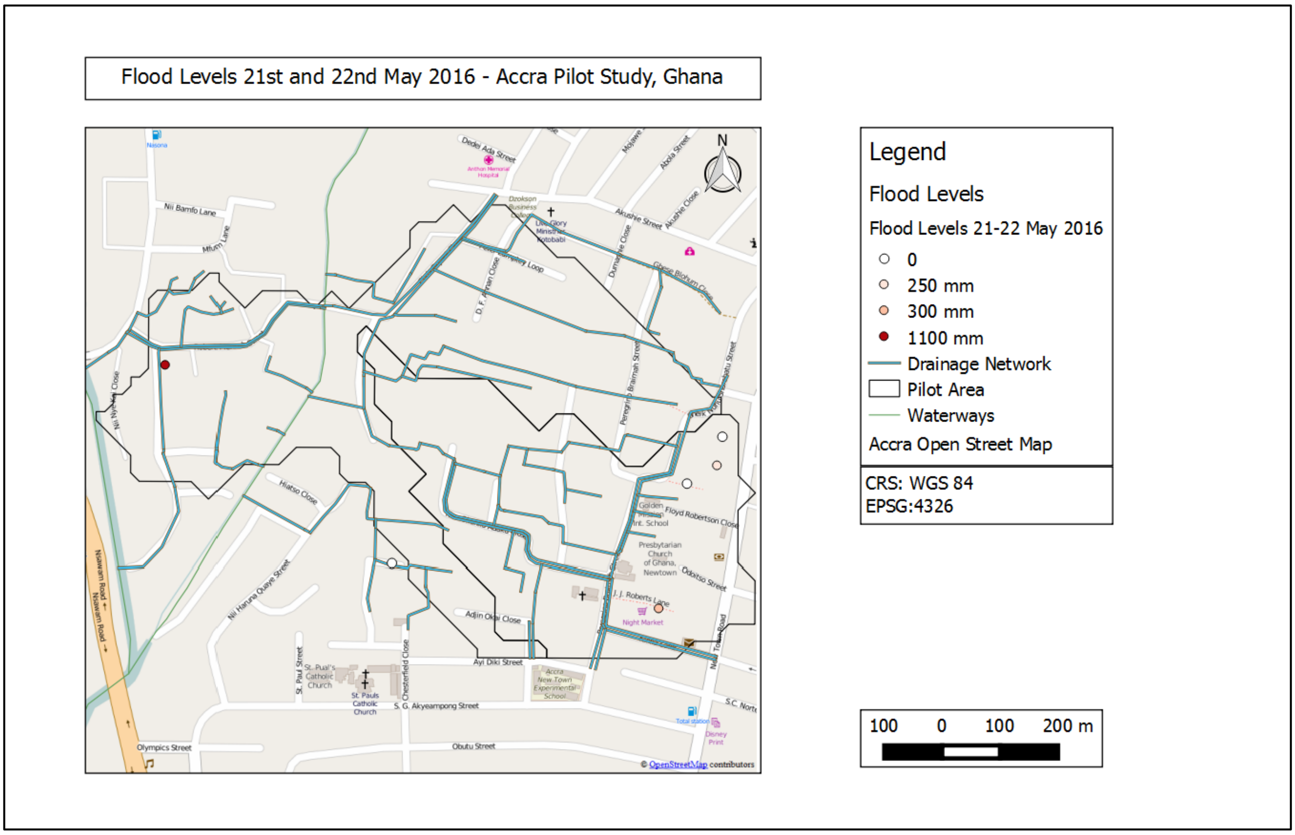


Figure 52 Flood levels May 21-22, 2016

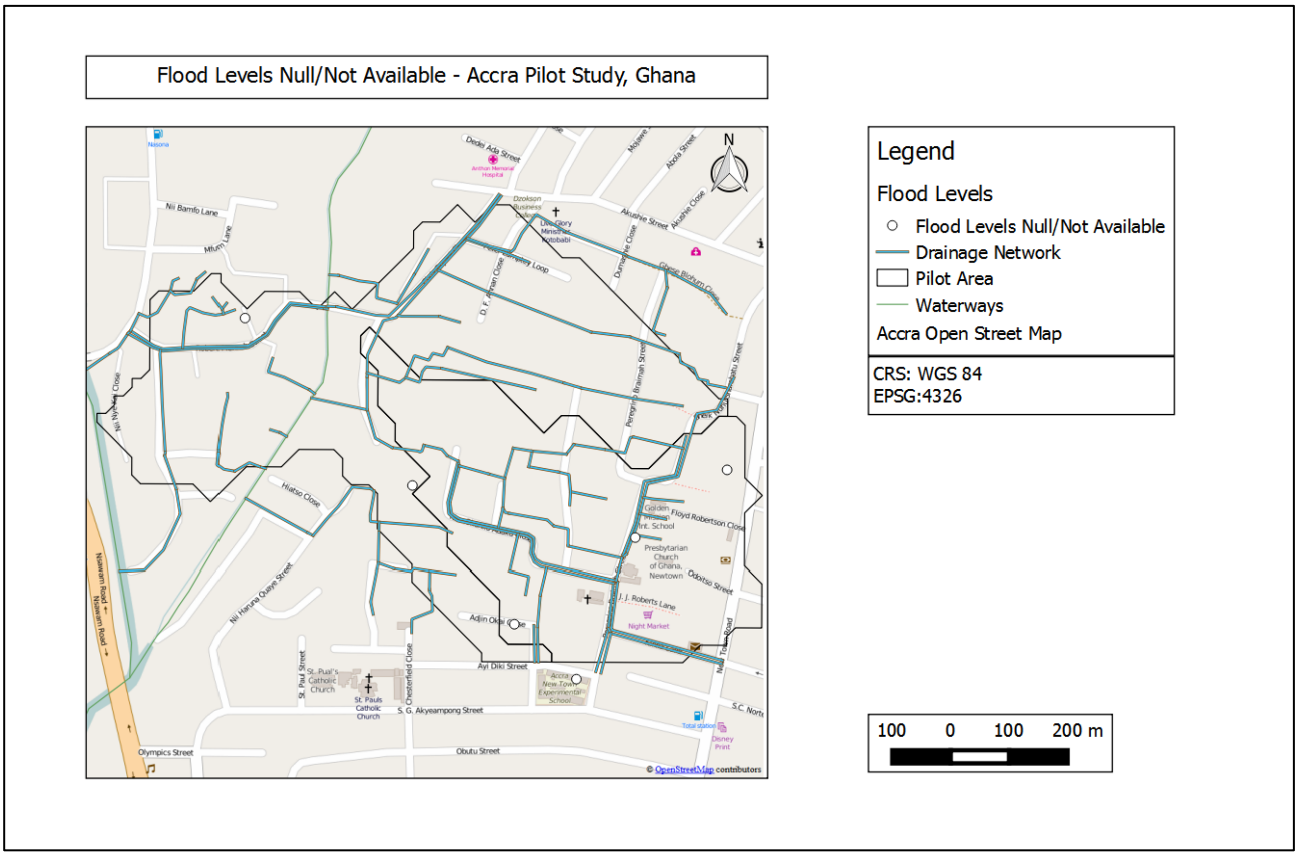


Figure 53 Flood levels not available

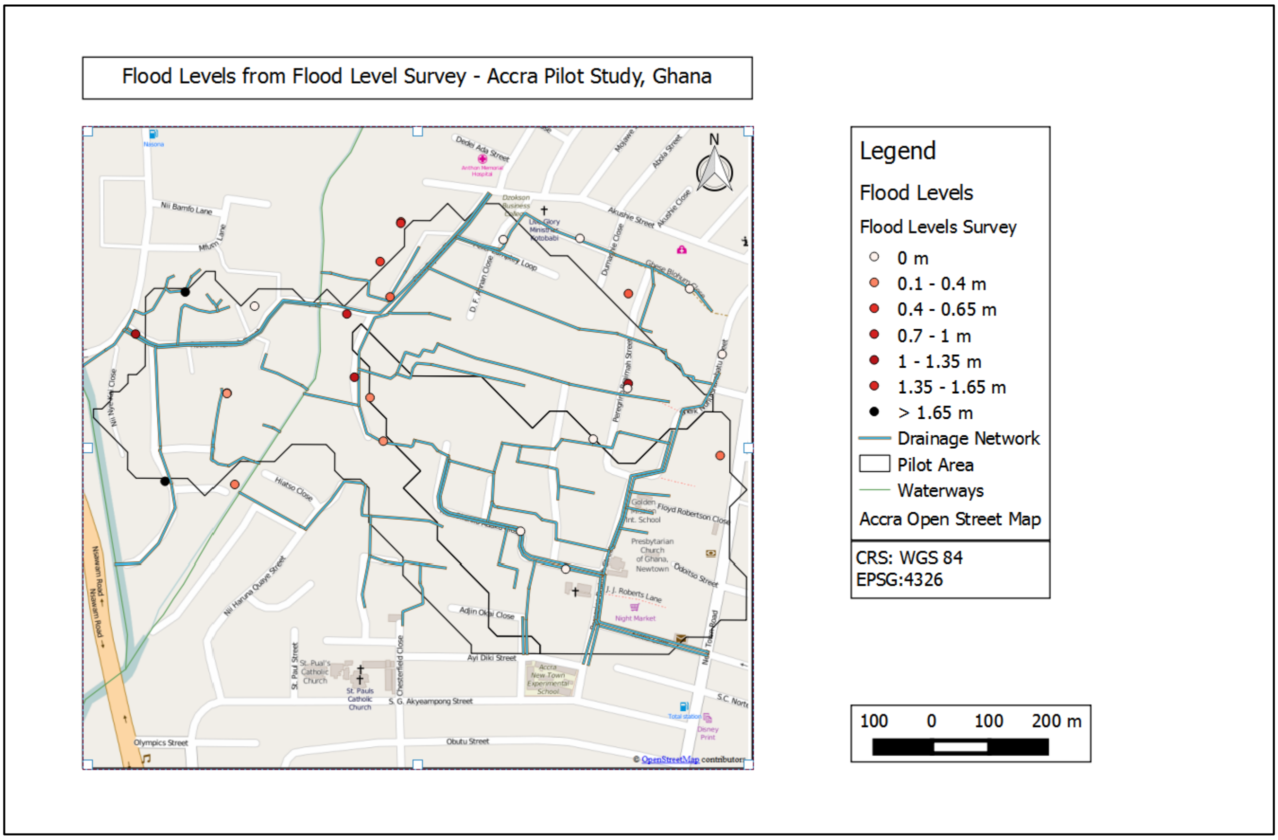


Figure 54 Flood levels combined

Regarding the 3rd June event, lots of information were available. Main findings are listed below:

- The permanence of water on the street after the flood consistently varied from site to site, ranging from 30 minutes to 4 hours.
- Damages were registered, especially business related (loss of merchandise; damages to shops) and at household level (loss of personal items, damages of structures and furniture). Shops lie along the roads, even upon the drains, which makes them more exposed to damages when a flood occurs.
- None of the interviewees was warned about the extent of the imminent flood. Hence, everyone reported the need of a reliable warning system to protect people's life and activities.
- 45% of the interviewees stayed in their household, given the difficulty to run away or the concern to leave their goods. They took shelter on roofs or in elevated structures. The other 55% managed to escape, some of them giving help to people in trouble.
- No aid was given during the flood event by any institution. Only afterwards, NADMO agents assisted few affected families with providing mattresses and blankets.
- Answers about the frequency of flooding are highly variable. Small floods seem to occur on a yearly scale, while big events as the June 3rd on a larger scale. Some on the interviewees reported a return period of once per year during the rainy season. But the most common answer got from residents on the pilot area was 5 years return period.

A relevant insight is obtained when asking personal opinions about the causes of flooding. Residents have a good understanding of the problematic and they listed a series of important reasons: elevation profile of the area; small capacity of gutters; missing gutters; waste clogging; overflow of the Odaw and/or Onyasia drains; and others, including sand sedimentation, intense urbanization that reduces the infiltration increasing the runoff, long duration of heavy rainfall.
Given the scarce assistance and action from the government, some inhabitants implemented localized structural solutions, as walls, elevated pavements, small drains. It is clear that these private constructions increase the heterogeneity of the drainage network and influence the runoff path and the surrounding area. The unplanned and constant modification of the drainage system at private level makes even more difficult to forecast the water behaviour of a next rain event.
Yet, not everybody can afford the building of a gutter. Privately constructed drains are mainly found next to schools and churches that have more financial availability.

- Waste management

The majority (45%) of the interviewees dispose the waste into the near trash bin or in containers provided by the Zoomlion waste collection company. The 27% collects the waste at home and they wait for private collectors to dispose it. Only two people (6%) admitted they throw the waste into the drains, while the 15% said they personally provide to the dispose without specifying how.

Private collectors are autonomous workers who provide a door to door collection service. The reason they give for their independent job is that the governmental service is inefficient and trash bins are few and always full. Frequency of collection can be daily or weekly, and the price of the service ranges between 1-5 GHS per collection, for a maximum of 20 GHS per month. The price of the waste collection depends on its volume or weight. A common price per sac is about 1-2 GHS.

Where the Zoomlion service works, the collection is made weekly or monthly. Communal trash bins are emptied and prices for the community are around 20 GHS per month. Also in this case prices vary depending on the volume, ranging from 2 to 4 GHS per single emptying of container.

Residents are willing to pay, but the price is clearly too high compared to the low wage, bearing in mind the neighbourhoods are classified as low-income level area. The willingness to pay comes from the need to live in a better and cleaner environment that people express. They complain about the waste presence on the streets and into the drains, but responsibility should not only be given to the government. Inhabitants are also responsible for the environment they live in.

Even if the waste collection works, the presence of waste in the drains is still considerable. People link this fact to different reasons. Mainly is because of a bad attitude, originated by financial constraints, poor provision of facilities and services or ignorance. Others say the problem depends on financial constraints only.

- Reflection on social surveys validity

Social Surveys are a good way to gather important information about drainage system behavior, flood events, flood hazards, people practices and waste management. However, answers to the interviews are highly subjective as they depend on individuals. The majority of the answers are considered reliable. Yet, people may tend to exaggerate a certain fact, as a flood event, because it touched them emotionally. In certain cases, the answers are confirmed by still visible damages on structures and the stated entity of the event is confirmed.
Regarding the waste issue, people can feel ashamed to admit they throw things into the drains and they easily blame the government for the scarce operation.

Therefore, the gathered data has to be critically analyzed to provide reliable and useful information. Expert judgments are considered enough to assess the reliability of the gathered information.

- Comparing findings from Social Surveys and Workshop

During the workshop held on April 23rd 2016, the discussions provided viewpoints of the institutions about causes of bad waste disposal and influence of the waste accumulation on flood risk. Comparing what the institutions said with the people actual perception gives a better insight to identify weak points and needs, in order to eventually propose possible measures to improve the waste management or reduce the flood risk.

Looking at both community and institutions sides is indeed very important: enforcement of laws or actions from institutions are not efficient if people do not change their attitude; in the same way, community initiatives and efforts cannot change any situation if they are not supported by the institutions. That means, not only cooperation and collaboration among institutions is needed, but also between institutions and the community.

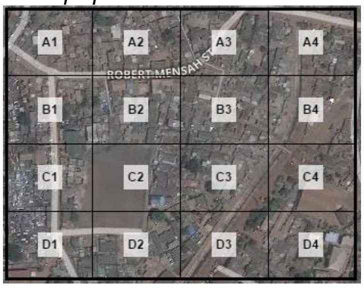
Reflection on people's attitude:
From the workshop, it emerged that waste disposal in the drains is more an attitude problem than a financial constraint. The attitude is considered the main issue determining waste presence in the system and it mostly originates by financial constraint. In addition, it is also triggered by a lack of education, enforcement, planning within the community and access to waste collection services.
People perceive the same. They recognize the bad attitude of throwing waste in the drains is blameworthy, but they also accuse the government and the institutions for imposing such high prices for waste disposal, for the poor provision of facilities, services and education.
This shows how, without the commitment from both sides, any improvement can be reached: people do not feel encouraged to change their attitude if they are not educated or if facilities are not present.

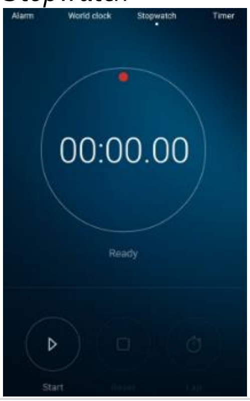
Reflection on the causes of floods:
As recognized by the institutions, not only waste accumulation is the cause of flooding. The unplanned settlements and uncontrolled developments, as the encroachment of waterways banks and buffer zones, also play a decisive role on flood risk. This is a fact that the majority of the interviewees ignores. Residents link the floods mainly to the improper drainage system, to the elevation profile of the area, and the intensity of the rain events. They usually do not feel the responsible for their personal risk.
On the other side, there are poor monitoring services. People are not warned from any institution. Awareness is not raised and they cannot be completely blamed for their reckless actions.
This is the example of how the bad interaction and poor collaboration between community and institutions worsens the situation once again.

D4 Accuracy in data collection

Data during the field work is collected using both analogue and digital measurement tools. Analog measurements contain a certain error caused by inaccurate reading of results, lack of measurement experience or malfunctioning of measurement tools. In case of human errors, often a higher level of accuracy can be reached by increasing the number of measurements, which increases the measurement experience. Malfunctioning of tools will give a constant error in the data. For digital measurement tools, the accuracy is often specified in the manual. For each measurement tool the application, accuracy and mitigation of measurement errors is displayed in Table 13.

Table 28 Tools, their application, accuracy and error mitigation measures

Tool	Application	Accuracy	Mitigation
Field papers 	Field papers are used to identify the catchment boundaries[8], drainage network and vulnerable structures in the field.	The map can be outdated which makes orientation in the field harder. Implementation of the hardcopy drainage network into QGIS results in a inaccuracy of approximately 5 to 15m.	Use most up to date maps. Check identified drainage system with GPS tracker to translate hardcopy system into QGIS.
Handheld GPS device 	Handheld GPS device is used to track the path of the field work. Also the device is used to check the accuracy of the smartphones on the first day of field work. The GPX-files can be uploaded into QGIS, excel and google earth.	The accuracy of the GPS device is <15m, depending on the satellite reception[6].	Accuracy of the measurements can be increased by taking way points and comparing these with the measurements of the phone GPS.
Measuring tape 	Tape is used to measure the dimension of the cross-sections.	Accuracy depends on the experience and the reading of the person taking the measurement. The accuracy is approximately 1 cm.	Division of task and responsibilities within the project team increases the accuracy of the measurements.
Stick 	The measurement stick is used to obtain the height of the drains.	Accuracy depends on the experience, the reading of the person taking the measurement and the proper attachment of the tape onto the stick. The accuracy is approximately 1-2 cm.	Regular checking the attachment of the tape to the stick decreases the chance of malfunctioning.

Laser distance meter 	The laser distance meter is used to measure dimensions of the drain if the width exceeded the measuring range of the tape.	The accuracy of the device is approximately 1 mm[7]. The laser has to be carefully used in order to get the right measurement.	The compass function of the meter can be used to hold it horizontally and decrease the inaccuracy. The measurement is performed twice.
Rope 	A rope is used to measure the depth in case of water flowing in the drain. The rope is kept vertically by placing a heavy object at the end. The heavy object has to be placed close to the water surface. If the object touches the water, it will be washed away.	Placing the object close to the water surface introduces an accuracy of approximately 2 – 10 cm. Also marking the level on the rope and measuring it afterwards introduces a inaccuracy of a few cm.	Ideally two people take this measurement. One holds the rope and lowers the object, while the other keeps track of the object approaching the water surface. Measurement of the rope should be carried out immediately after the measurement. The measurement is performed twice.
Stopwatch 	The stopwatch is used to record the time it takes for a floating object to cover 5m of distance.	The reaction time of the person measuring gives an inaccuracy of a few seconds. The higher the flow velocity the higher the inaccuracy.	Accuracy can be increased by performing the measurement multiple times.
Smartphones 	Smartphones are used to collect the data of the technical and social surveys. The GPS of these devices is used to locate the data points.	The accuracy of the GPS of the smartphone is approximately 5 – 25 m, depending on the satellite reception.	The GPS is more accurate if the location is fetched multiple times at the same data point. So by repeating this action the accuracy is increased.

References

[1] *Agbogbloshie*. (2016). *Wikipedia*. Retrieved 16 June 2016, from https://en.wikipedia.org/wiki/Agbogbloshie

[2] *Neighborhoods of Accra*. (2016). *Wikipedia*. Retrieved 16 June 2016, from https://en.wikipedia.org/wiki/Neighborhoods_of_Accra#Slums

[3] Jankowska, M.M., Weeks, J.R., & Engstrom, R. (2011). Do the most vulnerable people live in the worst slums? A spatial analysis of Accra, Ghana. *Annals Of GIS*, *17*(4), 221-235.

[4] *List Of All The Major Markets In Ghana And Their Respective Histories*. (2016). *Latest Ghanaian Breaking News Headlines.*. Retrieved 2 July 2016, from http://www.ghanaparrot.com/list-of-all-the-major-markets-in-ghana-and-their-respective-histories

[5] *Early Warning System*. (2016). Lelystad.

[6] Garmin Etrex Series. (2005). Garmin. Retrieved 21 June 2016, from http://www8.garmin.com/specs/eTrex_spec_sheet_0105.pdf

[7] GLM 150 Professional Laserafstandsmeters. (2016). Bosch Professional. Retrieved 21 June 2016, from https://www.bosch-professional.com/nl/nl/glm-150-23315-ocs-p/

[8] Make - Field Papers. (2016). Fieldpapers.org. Retrieved 21 June 2016, from http://fieldpapers.org/compose#17/5.59024/-0.21484

Appendix E – Data Processing

E1 Software

QGIS

QGIS is a free and open source Geographic Information System. It is a platform for geospatial data processing maintained by volunteer developers. QGIS is compatible with many different data format types. Users can create maps with many layers, of raster or vector type, using different map projections. The vector data is stored as either point, line, or polygon-feature. Each feature or raster grid cell links to a database or tabular file containing information about the geographic feature, which is called the attribute table. By installing plugins in QGIS, useful features to the software can be added. When starting a new project, spend time selecting the appropriate coordinate system, which is WGS 84 UTM 30N in the case of Accra.

The software can be downloaded from the QGIS project website and is supported by good documentation and tutorials, available through http://www.qgistutorials.com/ and other sources such as http://gis.stackexchange.com/. In this methodology, the functions and plugins in QGIS that are used in the steps are mentioned. For detailed information about the installation, use and processing of such functions, we refer to the online documentation.

SOBEK

A hydrodynamic model is a tool able to describe or represent in some way the motion of water in a certain system, which in this case is the surveyed drainage network. The hydrodynamic model built in this methodology uses the SOBEK suite, developed by Deltares. *SOBEK* is a powerful modelling suite for hydrological purposes such as flood forecasting and optimization of drainage systems. Unfortunately the software is not open source and a license is needed to run the model using full capacity. Universities or supporting consultancy companies might be able to provide with the license file. In other cases, the alternative for hydrodynamic modelling software that are available in the public domain is HEC-RAS (Hydrologic Engineering Center's River Analysis System), developed by US army corps of engineers, designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels.

E2 Classification of the drainage system

In order to distinguish drains based on sizes a classification is set-up. The width measurements are assumed to be more reliable than the height measurements, because silt and waste inside the drains complicated the height measurements. The classification is carried out for the all the different shapes encountered during the fieldwork. U-shaped drains and the rectangular drains and is created based on the cross-sectional area, which is obtained by multiplying the height by the width.

Classification U-shaped drain

The obtained cross-sectional areas are gathered in groups with a range of 0.10 m^2 each. For example the drains with a cross-sectional area between 0.300 and 0.399 m^2 are listed in Table 14.

Table 29 Example classification U-shape drains

Measurement		Cross-sectional area
Height (mm)	Width (mm)	(m^2)
540	600	0.324
550	620	0.341
550	620	0.341
550	620	0.341
570	600	0.342
570	600	0.342
560	620	0.347
560	620	0.347
600	600	0.360
600	600	0.360
600	600	0.360
600	600	0.360
640	620	0.397
640	620	0.397
		Average: 0.354

The average width of these selected drains approximates 600 mm. The height is then calculated based on the known average cross-sectional area and the width. The values are rounded. In total seven classes were distinguished. The measured drains with a cross-sectional area between 0.300 and 0.399 m^2 are lumped in class 600 x 600 mm (height x width). This classification method is carried out for all the measured drains in the pilot area. Seven classes are distinguished for the U-shaped drains. Those classes are listen in Table 15.

Table 30 Classification U-shape drains

Measurement		Cross-sectional area	Class (height x width)
Height (mm)	Width (mm)	(m^2)	(mm x mm)
>500	>450	0.200-0.299	500 x 550
>540	>600	0.300-0.399	600 x 600
>660	>600	0.400-0.499	650 x 600
>890	>620	0.500-0.599	900 x 600
>740	>890	0.600-0.699	750 x 900
>800	>850	0.700-0.799	850 x 900
>1100	>1300	1.400-1.499	1100 x 1350

Classification rectangular drain

The same process as for the U-shaped drain is carried out for the rectangular drain. Compared to the U-shaped drains, there is more variation in the sizes of the width and the height. For the rectangular drains, eight classes are determined.

Table 31 Classification rectangular drains

Cross-sectional area	Class (height x width)
(m^2)	(mm x mm)
0.000-0.099	200 x 300
0.100-0.199	400 x 400
0.200-0.299	400 x 600
0.300-0.399	500 x 650
0.600-0.699	700 x 950
0.700-0.799	800 x 900
0.800-0.899	500 x 1600
0.900-0.999	850 x 1150

Classification culverts

Culverts are mainly located at the outlet point of the micro drainage system into the primary drains. These locations are densely built up and therefore difficult to access. The size of one accessible culvert is assumed to be equal to the other outlet points. The dimension of the culverts that connect the micro drainage system with the primary drains is set to be Ø900 mm.

In the neighbourhoods a few culverts and constructions underneath roads classified as culverts are surveyed. These drains are smaller than the outlet points and assumed to be all Ø500 mm.

Table 32 Classification culverts

Location	Class
	(Ø mm)
Outlet point primary drain	900
Connection drains neighborhood scale	500

Classification erosion paths

Location where no drains were situated, but where clearly drains are needed, erosion paths direct the flow. These erosion paths are defined in terms of small and big. A small erosion path is generally located between houses or in small alleys. Big erosion paths are situated at outlet points at the primary drainage system and at locations where the water force has demolished existing drains or roads.

Table 33 Classification erosion paths

Erosion path	Class
	(mm x mm)
Outlet point primary drain	250 x 1500
Connection drains neighborhood scale	250 x 500

Appendix F – Summary Methodology Steps

This represents a summarizing guideline of the steps used in the methodology.

1. Prepare the Case Study

Cultural Context

- Familiarize yourself with the cultural context and preferred ways of communication

Background Analysis

- Develop a context about the flooding problems by researching the historical developments of the city and drainage projects, the climate and geology, underlying causes of flooding, related fields

Networking & Specialists

- Discussing the scope with specialists and sharing information will increase the quality of results, and develop your perspectives on the problems

Stakeholder Analysis

- Map out all stakeholders involved in urban drainage management of the city and think about interesting collaborations.

Data Inventory

- Collect data about rainfall, stage-discharges, and height of the pilot area

Communication

- Develop communication strategies to engage stakeholders, partners and inhabitants in the project.

2. Fieldwork

Choosing a Pilot Area

- Define the catchment boundaries of the pilot area using watershed delineation technique in QGIS.
- The derived flow accumulation map points to problematic drainage 'hotspots'
- Define criteria and assigned priorities to select pilot area
- Contact local stakeholders and explore the area

Smart field surveys

- Smartphones can be used to collect data in the field to facilitate data organization and processing using online survey application software.
- Hold a GPS device and notate information on field papers to orientate in the field
- Technical Surveys
    - Prepare a classification of drain types beforehand. This classification should be linked to standard drains sizes if encountered.
    - Collect data about the drainage network, flood marks, waste presence and waste effects on the urban drainage.
    - Divide the technical surveys per topic, to organize and process your data afterwards.
- Social Surveys
    - Gather information from residents' flood experiences, such as recorded flood levels and their perspective on the causes of flooding.
    - Ask questions about household waste management,
    - Link the findings from the Social Survey to both technical data and information obtained from institutional analysis.

Planning and Logistics

- Keep track of the project development through a project diary.
- Divide tasks and responsibilities beforehand; organize the data collection following a strategy to set the measurement locations and the tasks for each member.
- Prepare field maps and tools before to go to the field

3. Data Processing

Software
Organize Data
Hydrodynamic Model

- Construct a 1-D drainage network
- Connect RR-nodes
- Simulate a specific rain event.

Scenarios & Calculations

- Develop different scenarios to understand, for example, the influence of waste accumulation on the discharge capacity and the effect of the water level in watercourses downstream.
- (Check developed measures that can mitigate flood risk and design an appropriate system)

Model Results

Flood levels gathered through 'social surveys' can be used in hydrodynamic model to validate and calibrate a certain flood event

4. Raising Awareness

Social Media Experiment

- Create a participatory social media action with an active tagline, such as "want to help make the city flood-proof?" This creates involvement in the project and starts up good dialogues. Useful responses for flood assessment can be gathered during the social media survey, given the message is clear about the data collection.

Garbage Removal Mission

- Organize a mission/ event to raise awareness about the effect of waste disposal in the drains on the experienced flood risk.

5. Conclusion

- Summarize all findings in a flood risk assessment report.
- Evaluate on applied tools and activities to collect relevant data.
- Identify opportunities for further research.

Appendix G – Modelling results

S1 Medium - 1D model results

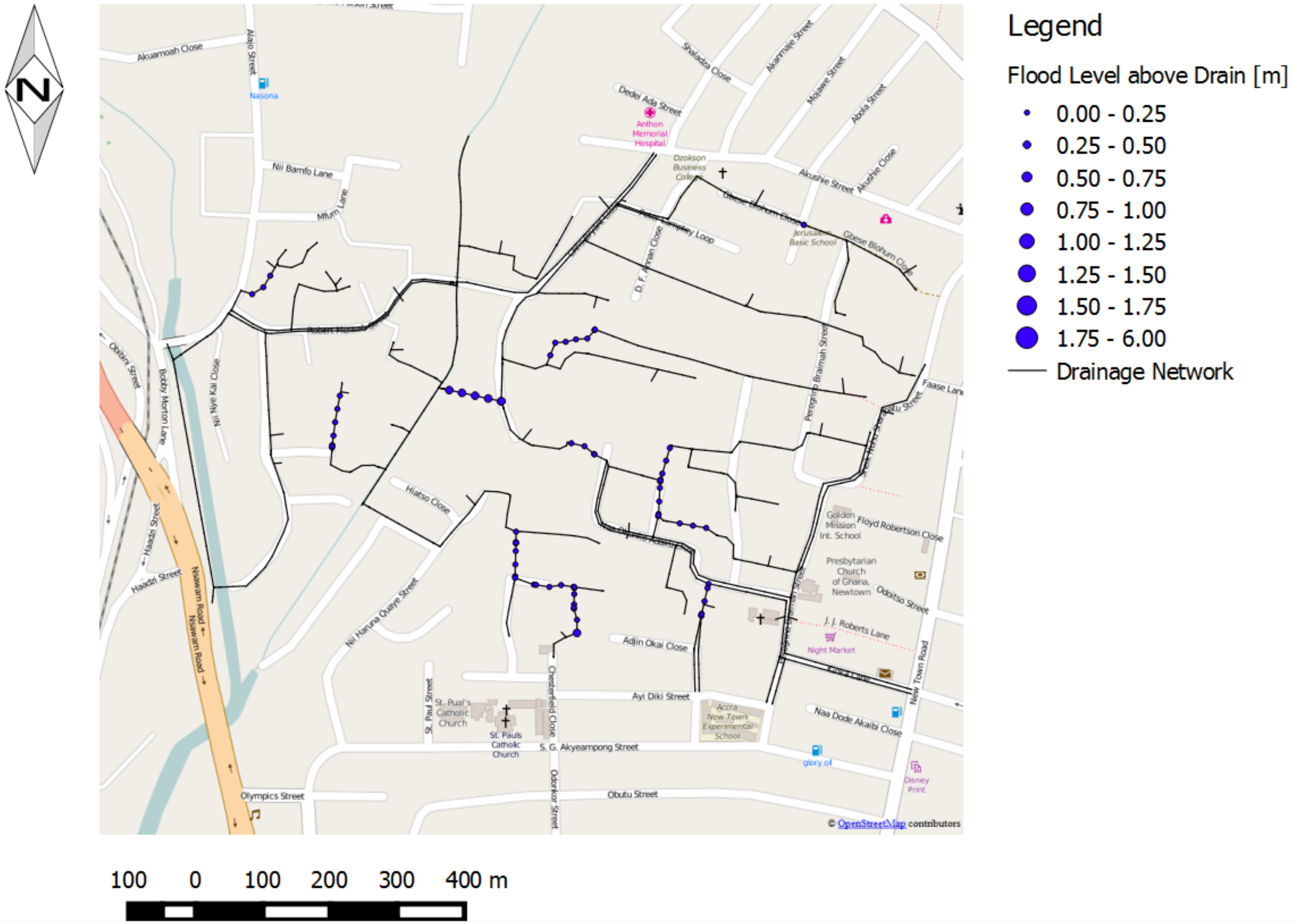


Figure 55 Scenario S1 Medium 1D model results

S2 High - 1D model results

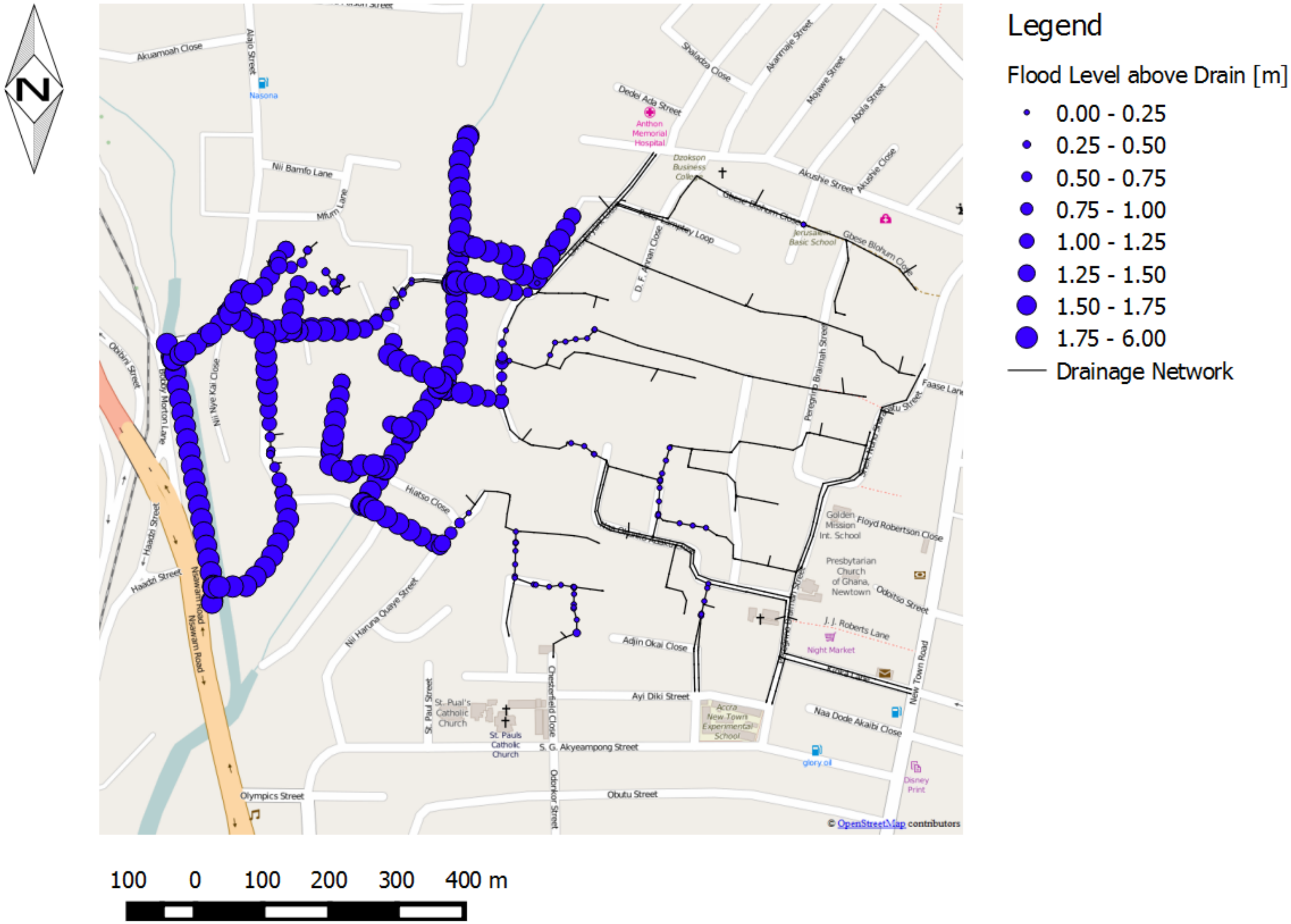


Figure 56 Scenario S2 High 1D model results

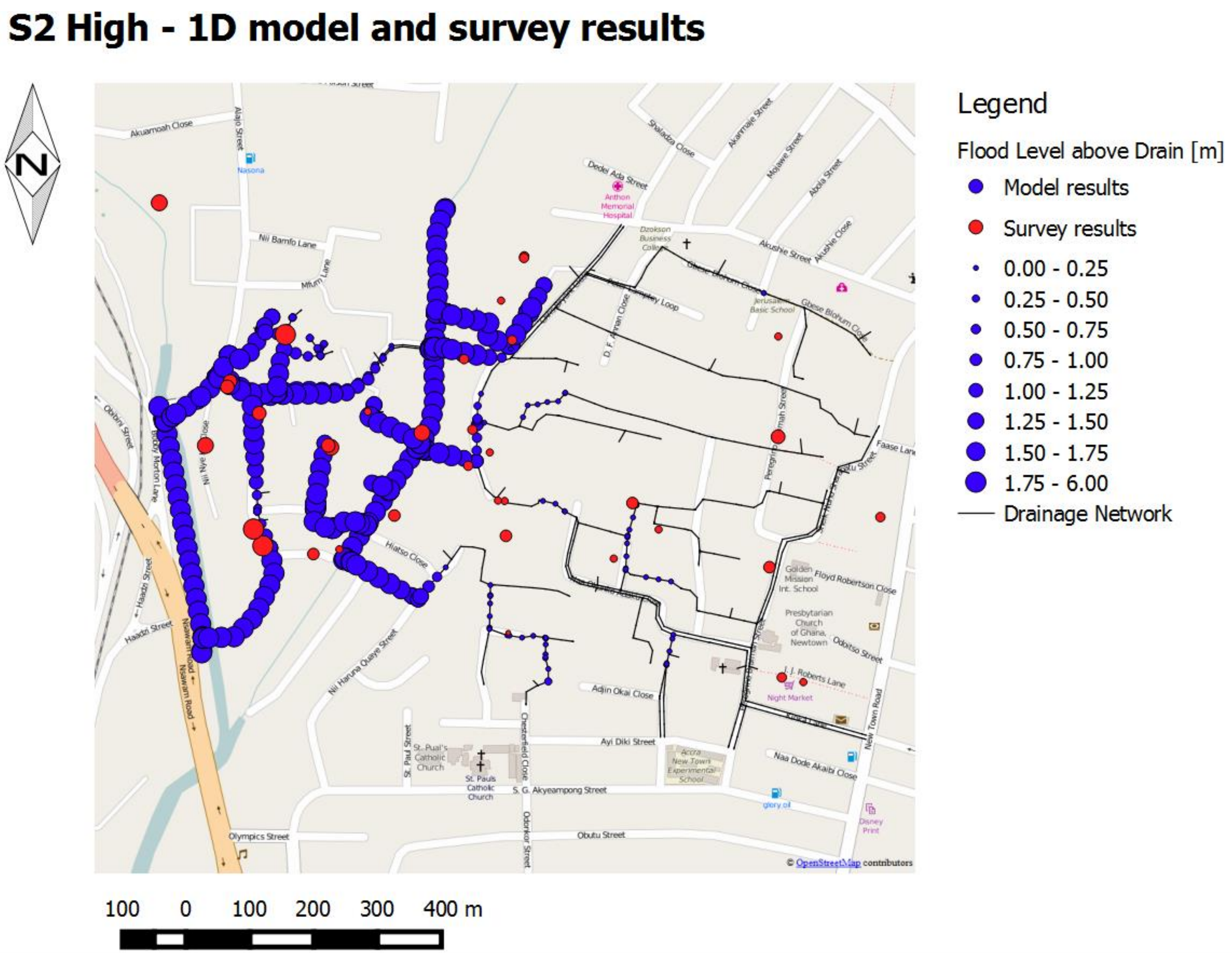


Figure 57 Scenario S1 Medium 1D model and survey results

S3 Waste_20 - 1D model results

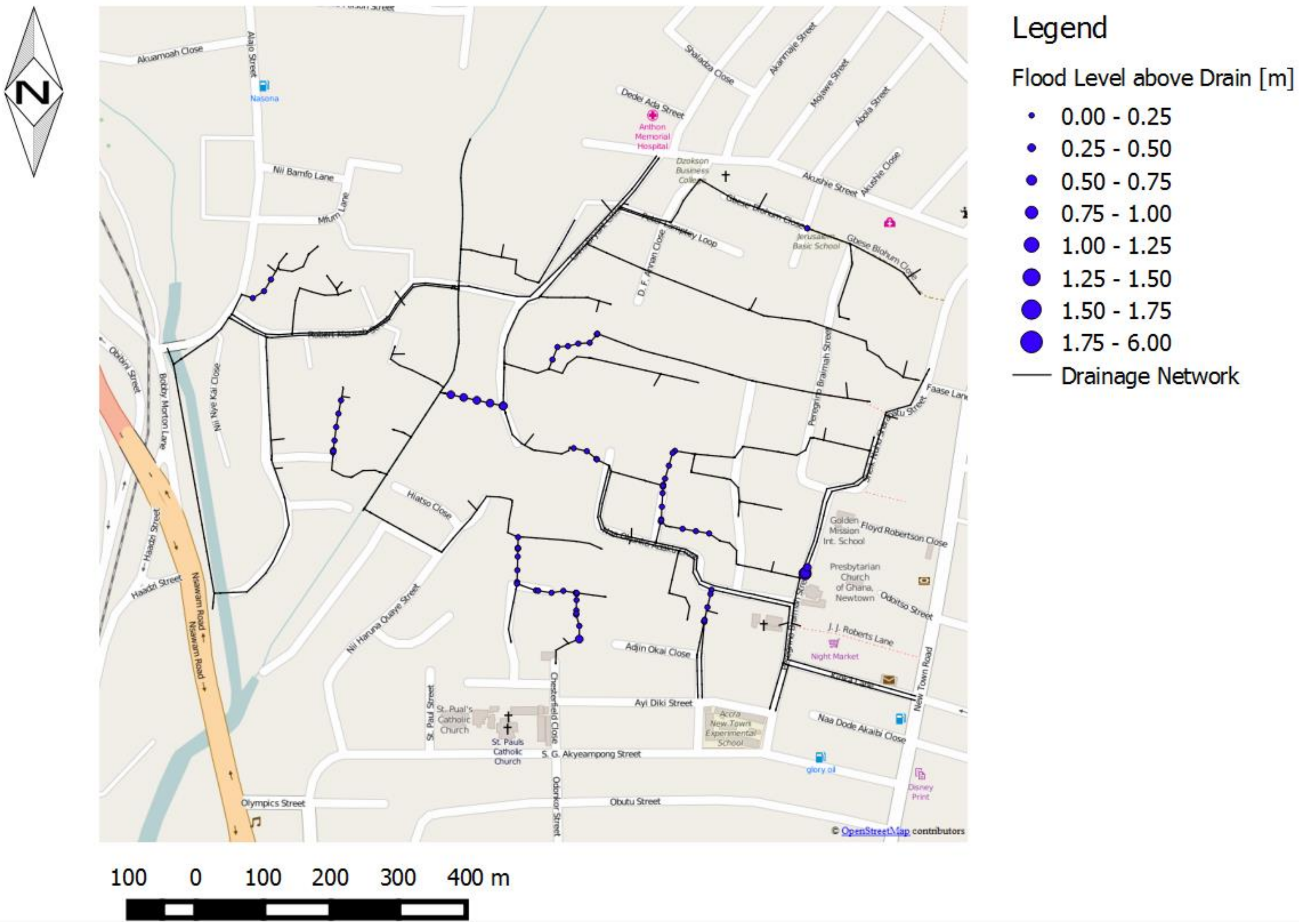


Figure 58 Scenario S3 Waste 20% 1D model results

S4 Waste_50 - 1D model results

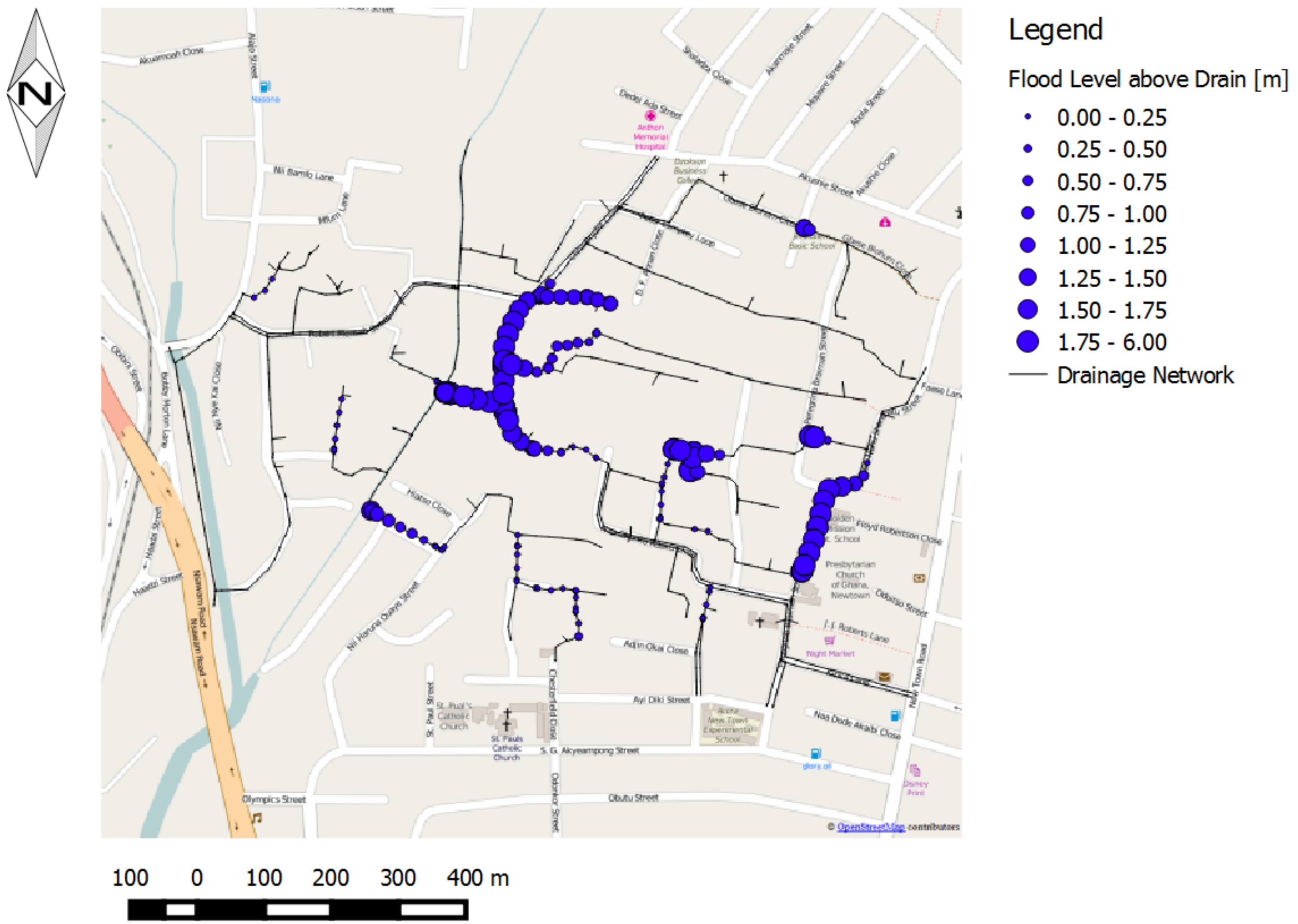


Figure 59 Scenario S4 Waste 50% 1D model results

S5 Waste_90 - 1D model results

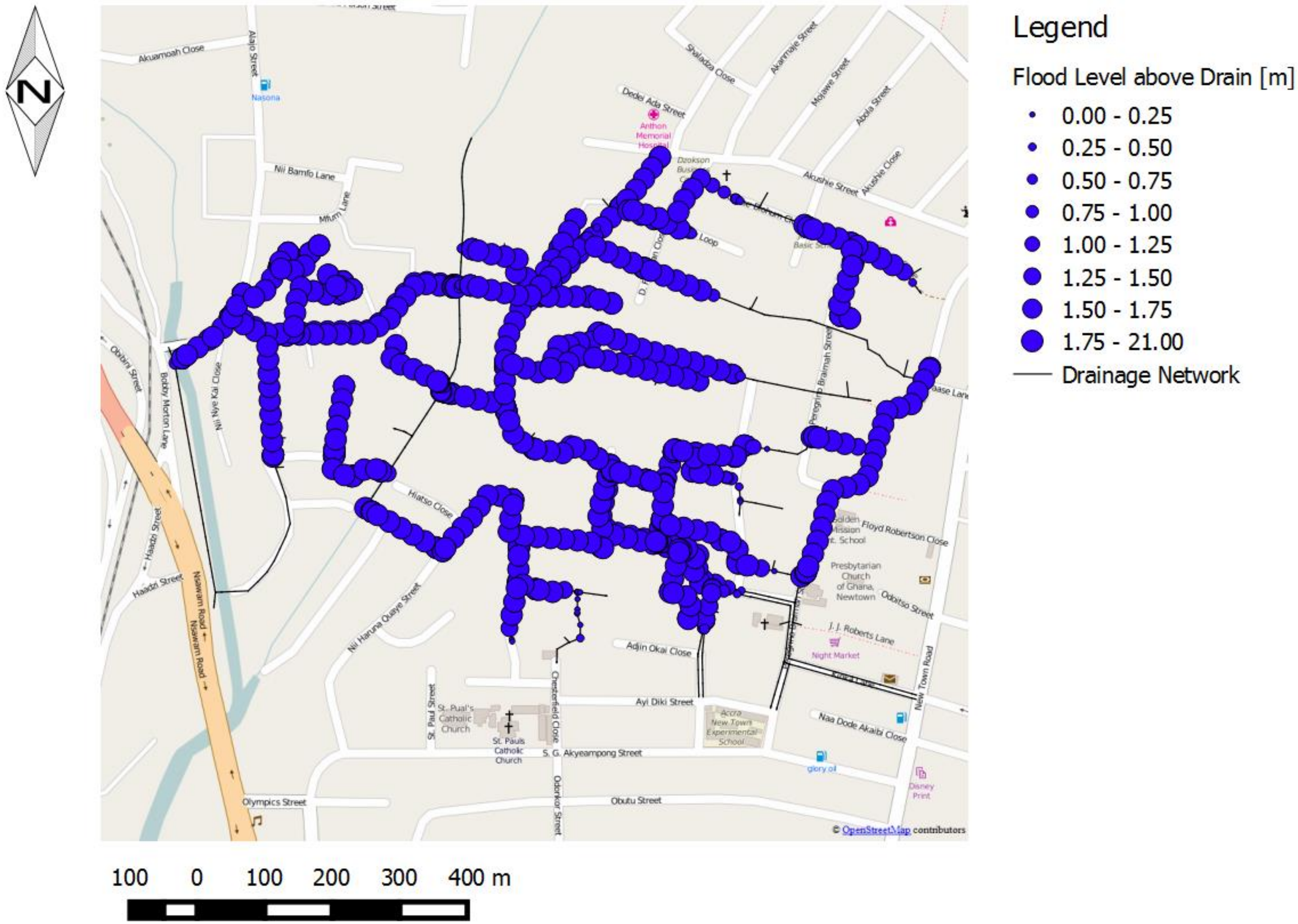


Figure 60 Scenario S5 Waste 90% 1D model results

S1 Medium - 2D model results

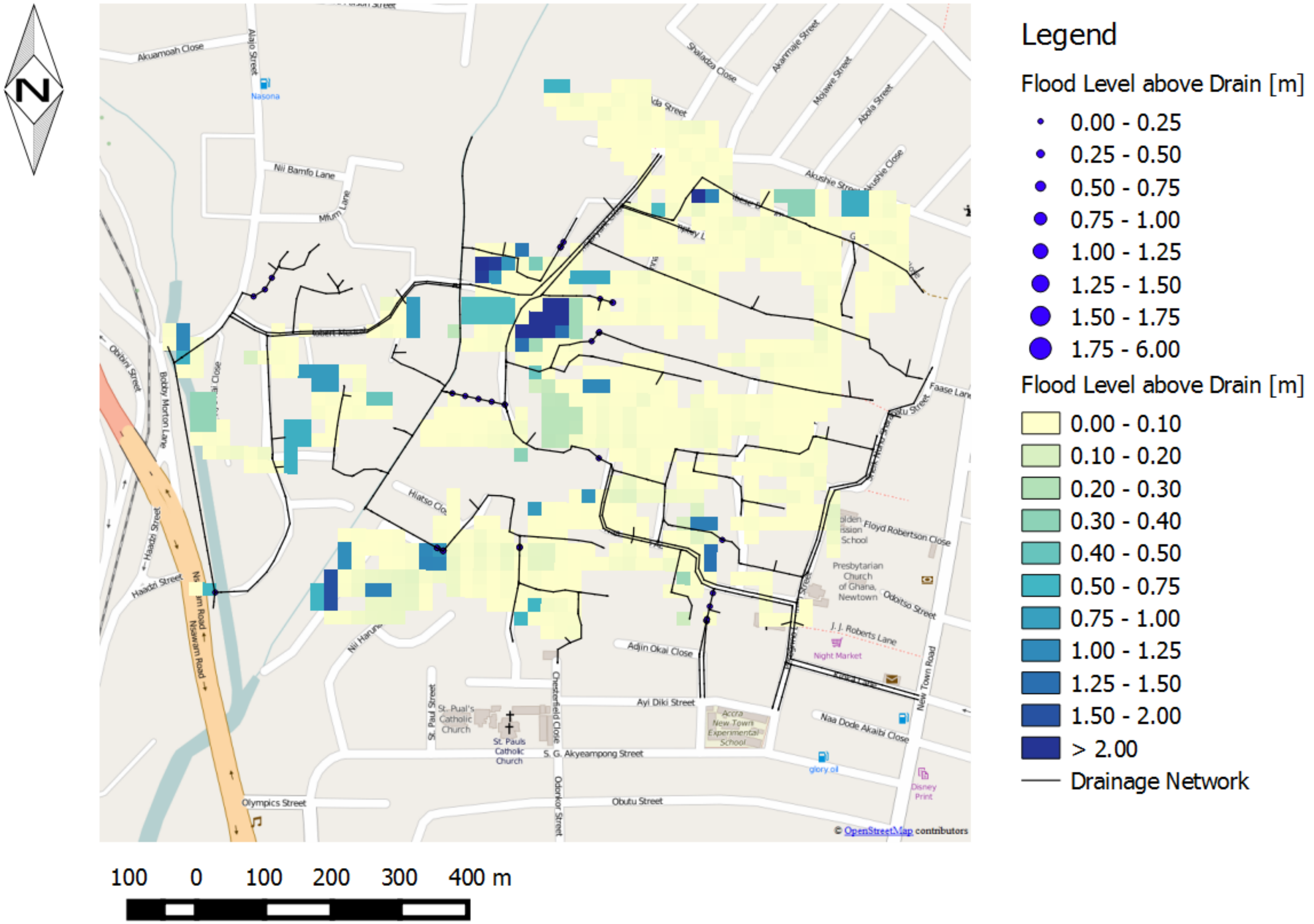


Figure 61 Scenario S1 Medium 2D model results

S2 High - 2D model results

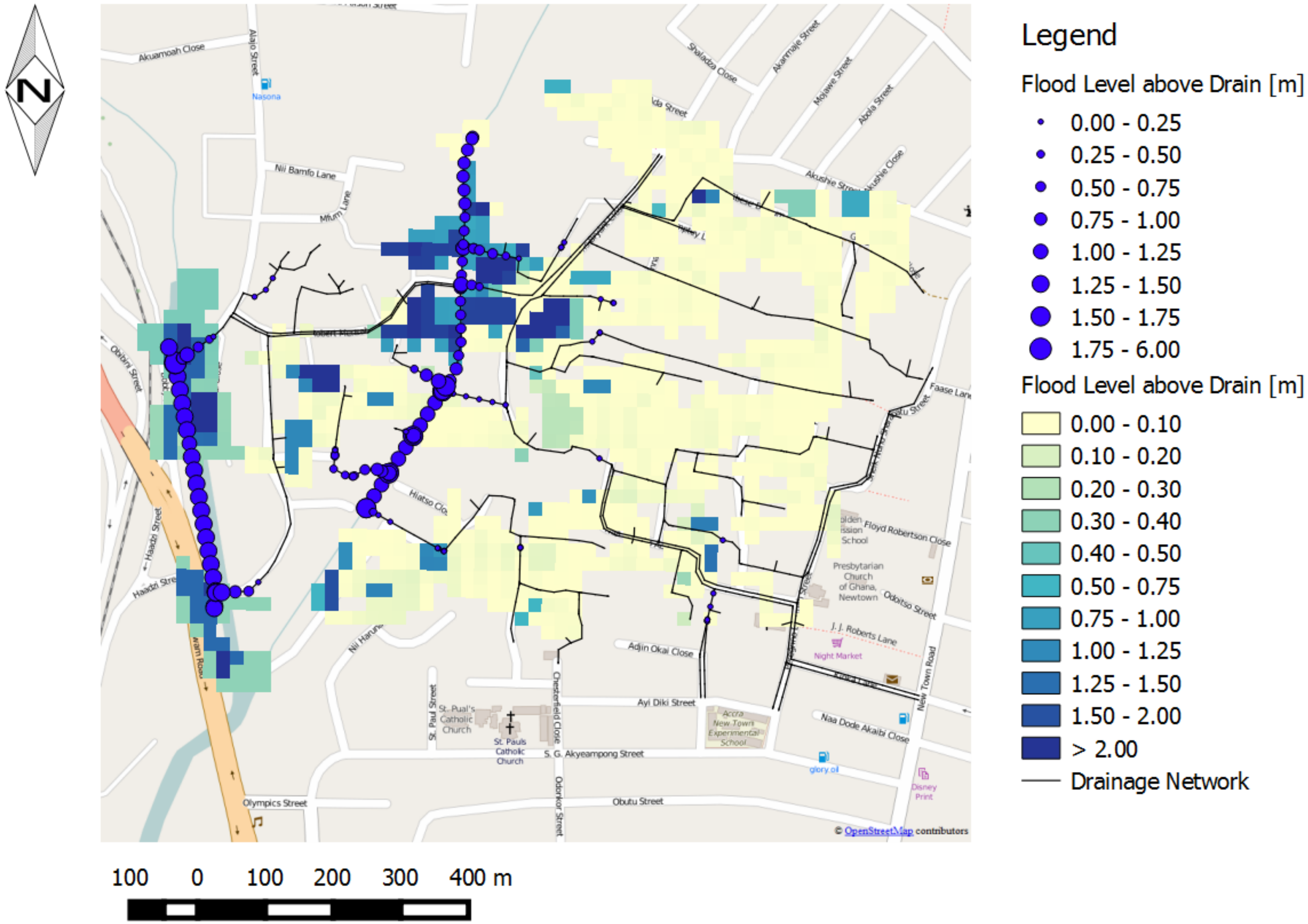


Figure 62 Scenario S2 High 2D model results

S2 High - 2D model and survey results

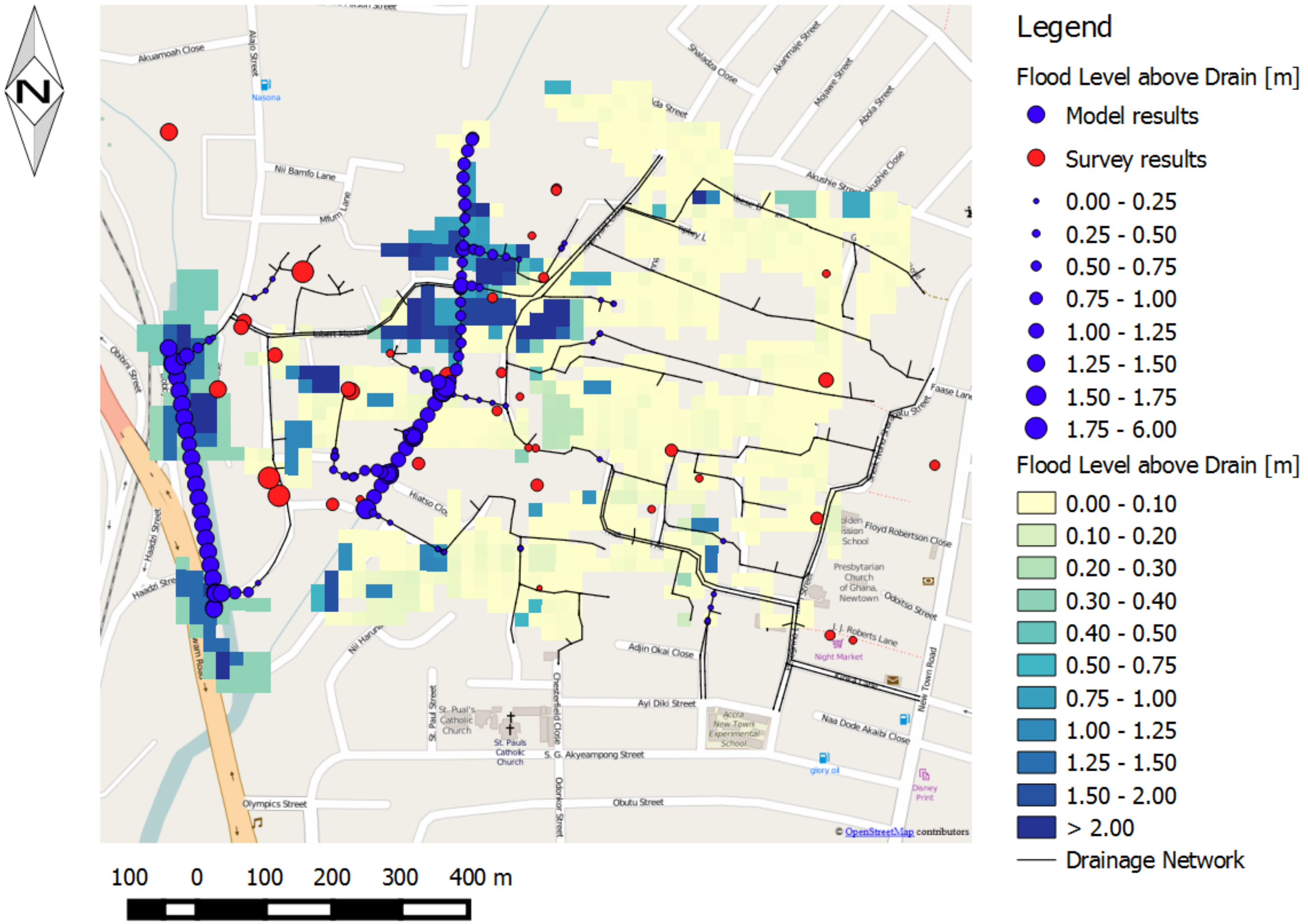


Figure 63 Scenario S2 High 2D model and survey results

S3 Waste_20 - 2D model results

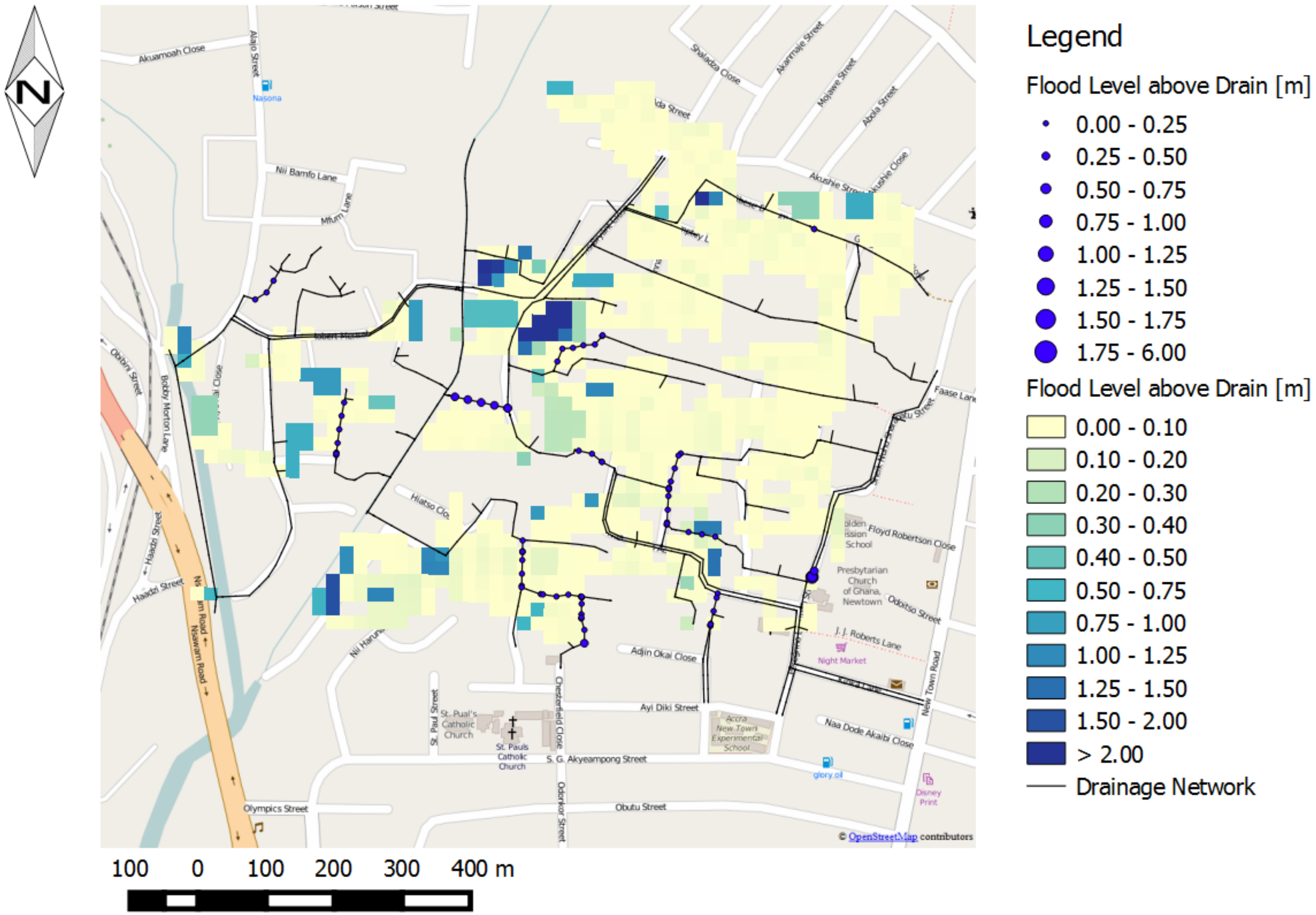


Figure 64 Scenario S3 Waste 20% 2D model results

S4 Waste_50 - 2D model results

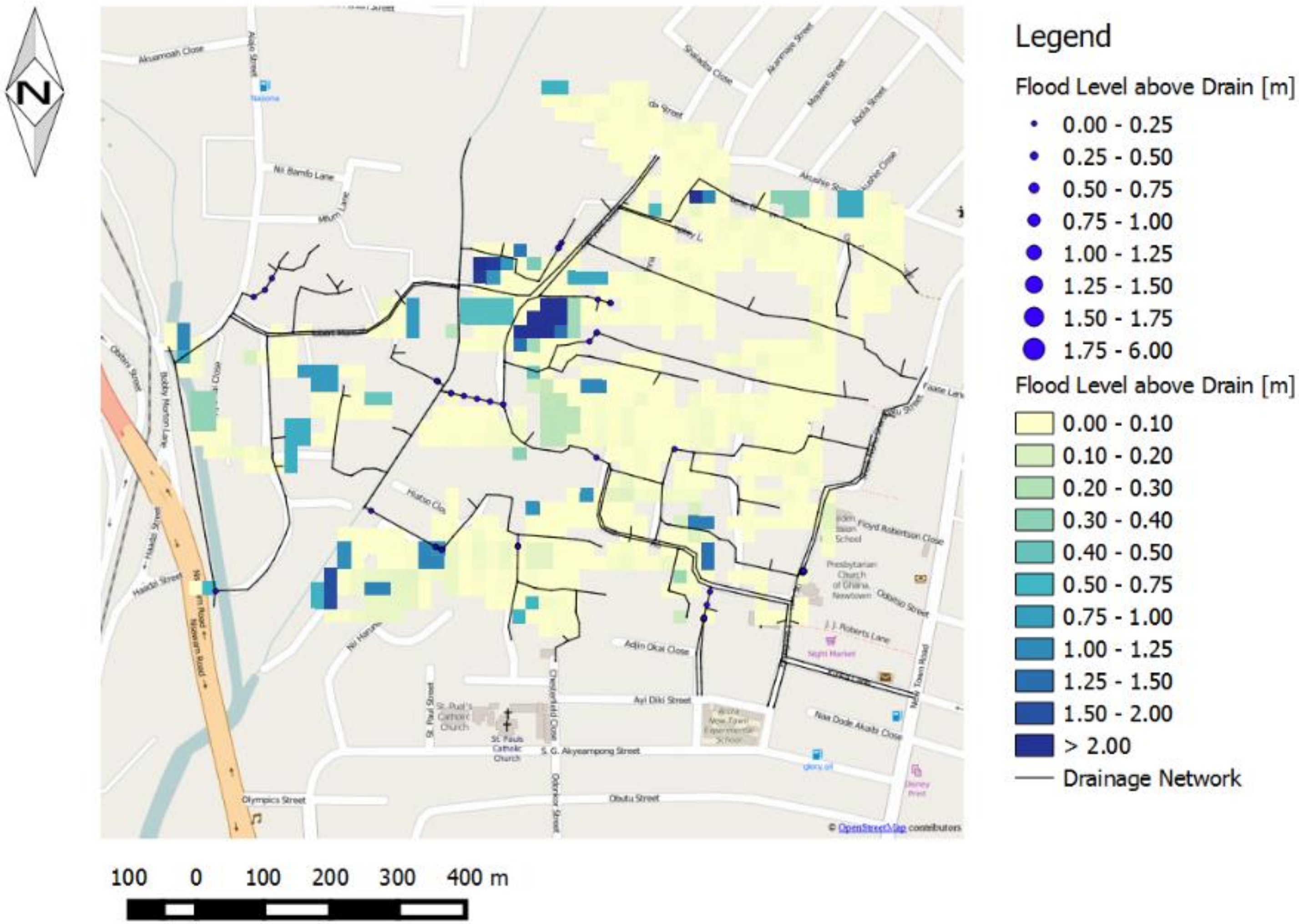


Figure 65 Scenario S4 Waste 50% 2D model results

S5 Waste_90 - 2D model results

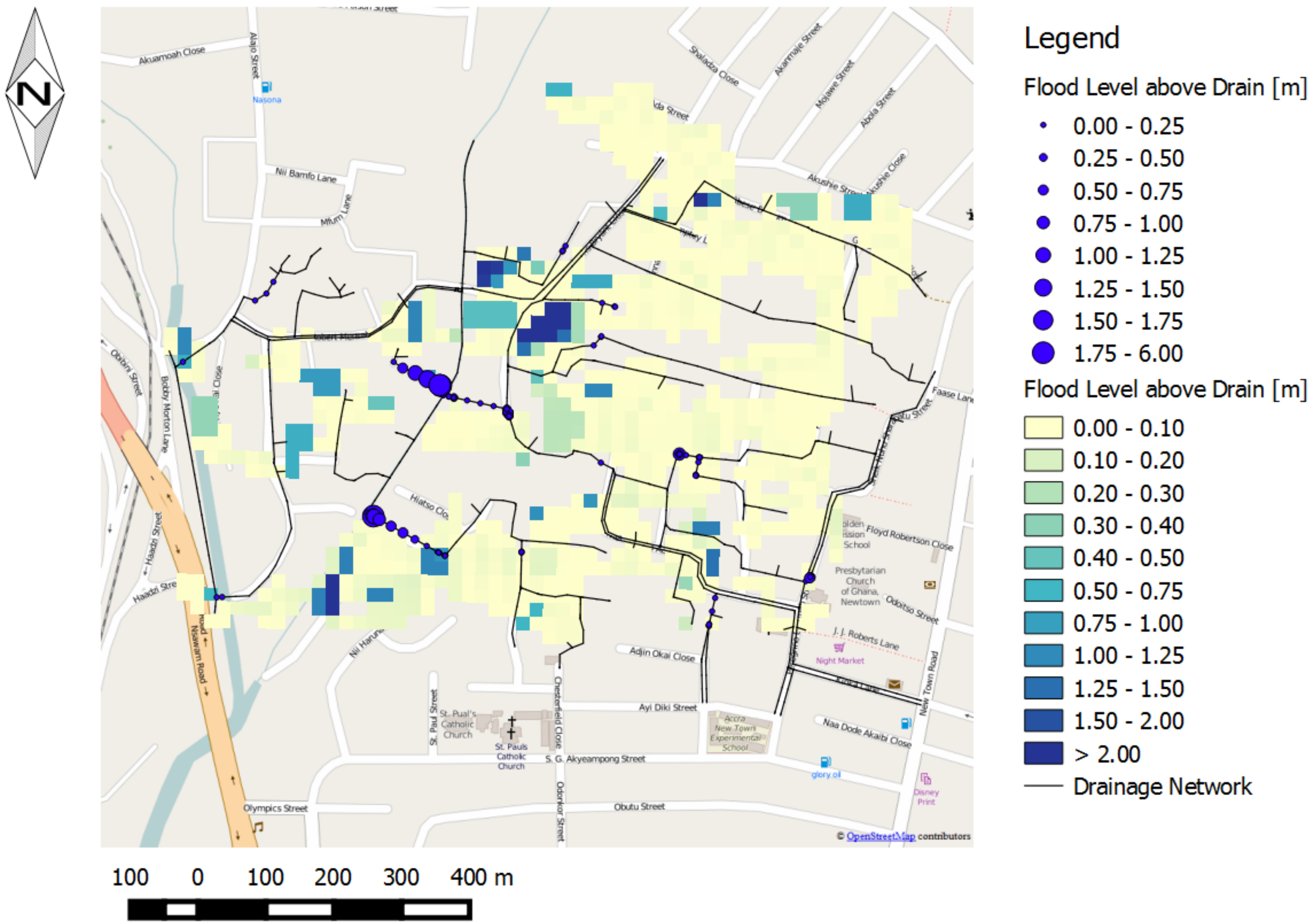


Figure 66 Scenario S5 Waste 90% 2D model results

Appendix H – Disaster Risk Reduction measures

Drainage Map There is no regulated drainage system or a map of the drains at the neighbourhood level. No capacity analysis has been performed. Creating and implementing a drainage plan at neighbourhood level could help solve all the issues with flooding and erosion in the higher parts of the pilot area, New Town. In the lower part of the pilot area, near Alajo, more is needed to solve the flooding problems as the low lying area is highly influenced by the water level in the primary drainage system.

Retention The surveyed neighbourhood of Alajo is an area located between the Odaw and Onyasia drains. In case of large rain events, the drains overtop (Onyasia drain first, then Odaw drain) and floods the low lying area which functions like a bathtub. The flood risk cannot be reduced on neighbourhood scale as the capacity of the primary drainage system is too low. Either retention upstream could reduce the water load onto the system, or bigger primary drains are needed.

Effective urban planning for retention areas can only succeed to prevents encroachment when a clear function is attached to the assigned area. A good example are soccer fields that serve as retention ponds. No one plays outside when it rains and no police force is needed to control the area.

Erosion Measures to improve drains in the neighbourhood should focus in places where there is higher flow accumulation. These Hotspots can be identified by looking at the natural flow accumulation patterns in the neighbourhood, derived from the DEM. Likely, critical erosion channel will be identified, given the landscape is sloped.

SUDS Introducing green areas and applying Sustainable Urban Development Solutions (SUDS) can work for districts in development. In existing neighbourhood, there is no space as the surface is too densely built to apply effective sustainable measures. Creating a green channel in the case of Alajo would be disastrous as the water velocities are too high and will erode away the land. Protection of banks and hinterland and increasing flow capacity of the primary drains should be the focus of measures in our pilot area.

Delaying flow in the neighbourhood itself with household retention measures, such as storage tanks (If it rains inhabitants catch rain with buckets) and infiltration measures can be encouraged. These measures could reduce erosion and pluvial flooding in the neighborhood of New Town. The water is perceived as clean. Measures should be evaluated given the intensity of a tropical rainfall event and whether they make sense.

Warning System To mitigate the current flood risk exposure, warning systems are needed for residents living in flood prone areas. Inhabitants are taken by surprise by rain events and the floods. They want to receive advice on the actions they have to take when a flood is coming, at which locations they can seek refuge, how much time do they have left before the flood is coming.

Urban Planning Spatial planning is challenging in Accra because of institutional arrangements and landownership issues. The hydrological services department is in charge of planning retention areas, governmental officials at the level of the MMDA (Municipal, Metropolitan District Assembly) are in charge of enforcing this land use planning. These agencies do not communicate about their plans. Moreover, government planners encounter difficulties to enforce a function or purpose to the land as it is privately owned. Chiefs that own land in a flood prone area, can still continue to sell this land, not aware of the function attached to the land or simply ignoring it and selling it during the dry season. The problems in spatial planning are created by the lack of coordination and consulting between institutions. Because of the power of the local chiefs, they should be engaged in the discussion from the start.

Appendix I – Workshop Report

PROJECT FLOOD RISK ACCRA

WORKSHOP REPORT

Topic: *Urban Flood Risk Assessment Accra*
Date: *May 24th 2016*
Time: *9:00 am – 1:00 pm*
Venue: *International Water Management Institute (IWMI)*

This report summarizes the presentations and discussions that took place during the workshop on urban flood risk assessment on May 24th 2016. The workshop was organized by a team of students from Delft University of Technology (the Netherlands) and Kwame Nkrumah University of Science and Technology (Ghana). During the workshop, the project team elaborated on the conducted fieldwork and preliminary results of the first five weeks of Project Flood Risk Accra. The workshop brought together stakeholders in the field of urban drainage, offered a possibility to share ideas on storm water management and created a platform for young professionals with a vision on the development of the city of Accra.

Chapter 1 Workshop Outline
Chapter 2 Summary Presentations
Chapter 3 Summary Group Discussions
Chapter 4 Group Discussion Wrap-Up
Appendix List of participants

1. Workshop Outline

[08:30 - 09:00]	**Arrival participants**	
[09:00 – 09:05]	**Opening**	Richard Sedafor
[09:05 – 09:25]	**Introduction**	Lexy Ratering Arntz
[09:25 – 09:45]	**Mapping the Drainage System**	Evelien Martens & Nadi Modderman
[09:45 – 10:15]	**New Technologies**	
	Open Street Map Initiative	Enock Seth Nyamador
	Social Media Experiment	Caterina Marinetti
[10:15 – 10:30]	***Break***	
[10:30- 12:15]	**Statements & Discussion**	
	Break up for group discussions	
	Presentation on Drainage Solutions for Accra	Kofi Asare Aboagye
[12:15 – 12:45]	**Wrap up**	
[12:45 -13:00]	**Closing**	Lexy Ratering Arntz
	Lunch	

2. Summary Presentations

In the opening and introduction speeches, all attendees are welcomed and the project team is introduced. A special thanks is given to the International Water Management Institute for providing the workshop venue. The importance and purpose of the workshop is put forward as an opportunity to bring together stakeholders in urban drainage, to share ideas on the management of storm water in Accra and for the young and ambitious to present their visions.

The objectives of Project Flood Risk Accra are assessing causes of urban flooding in Accra and developing a methodology for urban flood risk assessment for African cities. The challenge was posed by the extreme rainfall events of June 3rd 2015, rapid urban expansion, insufficient capacity of the current urban drainage system, ineffective solid waste management and negative health effects as an effect of floods and dirty drains. During the CityStrength Workshop organized by the World Bank on May 4th and 5th 2016, that was attended by project team members, it was put forward that floods form one of the main societal challenges for the city of Accra. Lack of coordination between the various responsible parties in urban drainage is a complicating factor. The need for an urban drainage master plan, in which activities of planning and maintenance are arranged, is clear. Project Flood Risk Accra is introduced as a smart and easy way to assess the state of a drainage system, to map out bottlenecks and to present information in such a way that it can be accessed by all stakeholders involved.

In the next presentation, attendees are taken through the fieldwork experiences and data processing. Fieldwork preparation included the selection of a pilot area for measurements. Possible pilot areas were selected by carrying out a watershed delineation in the open source geographic information system QGIS, in which flow direction and flow accumulation are determined through a Digital Elevation Model and the size of a watershed is determined by defined thresholds. For the final selection, on-site visits to selected watersheds and discussions with stakeholders were decisive. Evaluation of criteria such as flood susceptibility, urban texture and feasibility of data collection led to the choice of studying parts of New Town and Alajo. New Town and Alajo were appointed by stakeholders as flood prone areas, with a partly improved drainage system, and their location provided quick and easy transportation from the project office.

Contact with the Assemblymen of New Town and Alajo was established for research permission and guidance through the neighbourhood. Routes to follow during fieldwork were determined with maps from the website Fieldpapers.org and tracked continuously with a handheld GPS device. Technical measurements were collected through surveys in Akvo Flow, a tool for easy data collection, evaluation and displaying using a simple Android smartphone app and an online dashboard. Similar open source software alternatives are available online. All data were collected geographically referenced through phone and tablet GPS systems, that were checked on accuracy with the handheld GPS device. Technical surveys included questions on drain cross-sections and surroundings, waste and clogging, flood levels and points of interests. Situations that the project team encountered regularly during the fieldwork were drains clogged with silt and waste, eroded streets as main water flow paths, demolished or badly maintained drains and privately constructed drains by households and churches. During a relatively small rain event of approximately 15 mm on May 12th 2016 in the pilot area waste was found to be flushed away without serious clogging in the small drains, sediment of unpaved roads was found to be flushed into drains, some road-side drains were found compete filled, others completely empty and the Onyasia drain was found filled more than half.

For data processing, two programs are used:

- QGIS, a free and open source desktop geographic information system application that provides data viewing, editing and analysis;
- SOBEK, a calculation tool in which complex flows and water related processes can be simulated. Phenomena and physical processes are sketched in 1D network systems and 2D horizontal grids. Open source alternatives are available online.

Geographically referenced survey results are downloaded as excel files from the Akvo Flow dashboard and uploaded into QGIS, in which the data included in the excel file is presented in an attribute table. The drainage network is drawn in QGIS based on uploaded GPS tracks and field paper notes and technical measurement results are linked to the network. Network shapefiles are imported from QGIS into SOBEK for analysis of flood scenarios. GPM satellite rainfall data is used as meteorological input for the SOBEK model. For data processing a link is made to Open Street Map Ghana, a community mapping initiative with an open database, to integrate data and to scale up fieldwork activities.

Besides technical surveys, social surveys have been carried out in the same pilot area in New Town and Alajo to get an insight in the current situation of drainage, waste and disaster handling. Moreover, social surveys serve to check results of the SOBEK flood model by comparing flood levels appearing in the model to the flood levels indicated by inhabitants of the neighbourhood. Questions in the social surveys are mainly based on the rainfall event of June 3rd 2015 and the flood levels, damages, actions during and after flood and help during and after flood. Questions on warning systems, causes of flooding, private solutions to prevent flooding and waste management were also included. Both during technical and social surveys, the project team encountered a high level of engagement of local people participating in surveys and showing points of interest. A handful of personal stories from local people that were heard during the social surveys were shared during the workshop. Josephine, resident in Alajo, went to bed at 9 p.m. on June 3rd 2015 and woke up soaked in water one hour later. Barber Saviour found his shop flooded 1 meter above the drains when he entered the morning after. And a grandmother responsible of a household of 25 persons received only one mattress to sleep on when they returned to their ruined property after sheltering on higher grounds. A woman selling next to the Onyasia drain and her husband were surprised by the floods, took the children on their shoulders and were rescued from the strong currents by young man from the community that had formed a human chain. An elderly woman who protects the sides of the eroded drain next to her house covering it with coconut shells received mattresses and blankets after the floods.

To show which technologies can help in mapping the drainage system of Accra, Enock Seth Nyamador presents his experiences as a volunteer mapper for Open Street Map Ghana and shows the benefits of an open data society. His presentation sparks a discussion about open data for public and private purposes and financial implications of sharing data.

Besides open platforms, social media such as Facebook, Twitter and WhatsApp can form interesting tools for collecting data on drainage systems with the help of citizens and for raising awareness. The project team is promoting Flood Risk Accra on Facebook, Twitter, Whatsapp and the own website. Moreover, it is carrying out a Social Media Experiment in gathering information on the drainage network of Accra by collecting georeferenced pictures from citizens on Whatsapp. This information could possibly be used to build a drainage model, in which floods can be simulated. The Social Media Experiment is carried out in collaboration with iSocial TV, that aims to bring social networking from the web (Facebook, Twitter and Whatsapp) into a television set. Stressing out the lack of available field data on the drainage system at community level, the project team calls out to the citizens of Accra to upload valuable information and help create an urban drainage map of the city. To raise awareness, a video was shot for the iSocial TV show, a thirty minutes program in which persons are dared to do something they have never done before. The project team was challenged to ask Kaneshie residents the permission to clean their households and drains and, with this permission, to actually do so.

3. Summary Group Discussions

After a break, participants are divided in four groups to discuss on explicit statements meant to trigger reactions. Groups are asked to debate for 15 minutes and to conclude each statement by wrapping up in 5 minutes. A summary of the group discussions is presented in this chapter, whereas conclusions per group are included in the following chapter.

Statements:

1. "Clogging of gutters with waste is more of an attitude problem than a financial constraint"

   Are fees for waste collection too high for people to be able to pay them? Or are people unwilling or lazy when it comes to proper disposal of their waste? Is the amount of service adequate for what is paid through fees or taxes? How should solid waste collection services be arranged in low income (illegally encroached) communities?

2. "If all gutters in Accra would be clean, floods would no longer occur"

   Waste accumulation in gutters affects the capacity of the urban drainage system. Gutters are clogged, in some neighbourhoods more than in others. Is waste accumulation the main cause of floods in Accra? Are people aware that they influence proper functioning of the system by individual actions when they dispose of waste in drains? If everyone would be aware of how their waste influences the flood risk in the city, would all gutters in Accra be clean?

3. "A shared technical database is needed to coordinate urban drainage management issues"

   Stakeholders mention a lack of coordination between institutions as one of the main reasons of malfunction of the urban drainage system. On what scale should urban drainage be managed? How could an urban drainage master plan for the city of Accra be created? Why is data difficult to obtain? Are data files and documents too scattered to be found, or do they simply not exist? Should there be an open database with technical information on the drainage system?

4. "The traditional way of drainage in Accra is the future way of drainage"

   This statement is introduced by a presentation on a green future of Accra by Kofi Asare Aboagye. He discusses how Sustainable Urban Drainage Systems (SUDS) can be implemented in order to reduce the flood risk of the city. His visionary speech resonates well with the attendees. 'Traditional' refers to the concrete drainage systems that are currently implemented.

Group 1:

Statement 1: Both financial constraint and attitude are problems related to the wrong disposal of waste into the drains. A special focus is put on the origin of such attitude. The financial obstacle is represented by high fees for waste disposal, especially in low-income level areas. A part of the participants believes that this constraint, together with scarce accessibility to dumping sites, leads people throwing their refuse on streets and in gutters. Others consider the cultural background to be the cause of it. Such cultural background consists of ignorance and indolent behaviour when it comes to correct waste disposal. Some pointed out the rural area as the source of this bad attitude: people coming from villages are the carriers of a neglectful and careless behaviour, which influences other residents of the city. However, not everybody agrees on this viewpoint, objecting that villages are often cleaner than urban areas and their footprint is limited. Eventually, the whole group agrees that attitude is the main problem and that enforcement of laws and a stricter check on correct waste disposal are urgently needed.

Statement 2: After a discussion on the meaning of the statement itself, the entire group agrees it is not true. Although waste is a major concern and it diminishes the capacity of the drainage system creating bottlenecks (especially downstream), it is not the only factor leading to flooding. Other issues include the lack of a proper drainage system. Drains are too small, badly maintained or even missing; the buffer capacity is limited; the urban development keeps going unplanned and uncontrolled, especially along rivers where people encroach on buffer zones. Legislation should be enforced and upstream retention of storm water should be increased to prevent flooding.

Statement 3: The group agrees that institutions involved in the drainage field should have access to data. However, some organizational issues remain regarding a proper coordination of the data sharing. Drainage masterplans and river basin plans should incorporate data from all the different levels involved in the drainage field, which presents the need to share data and to cooperate to improve the situation. Agreements and laws can enhance the sharing and the cooperation to strengthen a city planning. Participants agree that for public purposes and governmental organizations data should be free, while they can still be sold to the private sector.

Statement 4: The discussion starts with the groups' opinion what the traditional way consists of. 'Traditional' stands for the way the drainage is handled now. That includes missing drains, inadequate dimensions of the existing network, limited storage, bad maintenance, limited infiltration capacity due to the urban sprawl, presence of waste inside gutters. The city is developing without a proper control, flood risks are high and people unsafe. The traditional way is therefore rejected as the one to go into the future. One

unique general approach is not the key to improve the situation, given the heterogeneity of the involved areas. A mix between a conventional approach and new sustainable solutions for drainage management could be the way to undertake. Everybody agrees that technology must suit the environment and that newly chosen systems have to apply to the surrounding existing setting.
A focus is given to illegal dwellings along rivers and in flood prone areas. In order to implement new solutions a displacement of illegal residents may be necessary. This is not necessarily negative for people, as they are actually rescued from an unsafe location. A major issue eventually comes up: even if the best planning is designed, financial constraints and limited resources are obstructing factors. In order to face this problem, national policies and laws should help the development planning in a way that it takes the whole picture of the city of Accra into account. An integrated masterplan is therefore necessary.

Group 2:

Statement 1: From the statement discussion it resulted that both attitude and financial constraints are problems. Attitude regards laziness, indifference and a general lack of education among the people of the community. Financial constraints are represented by high fees for waste disposal and limited facilities: only a small number of dump bins is provided, collector trucks are not always available and waste management is generally very weak. This contributes to the bad attitude of certain people, who do not think about consequences of their wrong disposal. Negative attitudes should be curbed by law enforcement and a policy of price differentiation can help establishing affordable prices for everybody. People should be encouraged to denunciate wrong conducts. In addition, a participant highlighted the possibility of recycling waste to limit its presence on the streets and in drains.

Statement 2: The statement leaves out other factors that influences the flooding problem. The drainage plan has to be analysed taking the whole city plan into account. Besides waste accumulation, the drainage network itself is not efficient; the amount of space available for water is shrinking due to the urbanization and the use of concrete, illegal dwellings lie along the waterway; most of the wetlands in Accra have been encroached on and rain intensity is raising. After listing the factors contributing to the flood risk, participants discussed possible solutions, of which training children could be a starting point. People could be encouraged to do the right things even with rewards, but making people aware is not enough; a proper planning of the urban setting has to come first.

Statement 3: Everybody agrees that availability of data and cooperation between institutions are big issues. Accessibility to information, maps and data should be easy, especially for engineers working on urban drainage. One institution should be responsible for coordinating the cooperation of the assemblies, for instance the Ministry of Local Government and Rural Development. Constraints to data sharing are financial interests, corruption, and lack of funding.

Statement 4: The opinion that the traditional way is not efficient to ensure a correct drainage of the city of Accra It is shared by the participants. Therefore, a discussion about how to improve the situation is initiated. Implementation of new measures can only be reached through the willingness of people to change and make efforts, with enough funding and enforcement of right policies. SUDS should be adopted in the whole city: hard surfaces should be replaced by green spaces, especially along water channels. However, a lot of houses are constructed on waterways. Some participants agree in the need to demolish such dwellings, given the fact that they lie in a flood prone area that should be reserved for extra storage and that represents a high risk for the residents. Eventually, the participants agreed that a combination of different measures would be ideal, since what works in one place, would not necessarily work in another place as well.

Group 3:

Statement 1: Clogging of gutters is more of an attitude than a financial problem. There are, however, many more factors. Waste collection systems are not flexible and not sticking to promised schedules. People fail signing up for collection or choose for (what they think are) cheaper options. Regarding attitude, it can be said that people do not care about where garbage end up, they just want to get it out of their place. Even when fees are very low, people keep dumping it on illegal places. The problem is that there is no enforcement of laws by fining offenders, so there is no reason for them to stop it. Everyone that dumps illegally, knows that what he is doing is wrong. People do not see the essence of paying for waste management. They should look at the management and treatment system behind the waste and they should be made responsible themselves.

Statement 2: The answer to the statement is no. There are many more factors that influence floods , such as urbanization with hard, impermeable surfaces, no development planning, high rain intensities, very small drains linked to very big drains, insufficient capacity for the urbanized situation, bad coordination between parties, land owning by chiefs because of which there is no overview or planning possible, encroachment on flood plains, siltation without dredging or leaving silt next to the drain so that if flows back again, low levels in the Odaw drain in combination with high sea levels and lack of monitoring systems.

Statement 3: Mainly coordination between different MMDAs should be improved, with thinking in stretches instead of MMDA boundaries. Parties have their own money and their own constraints. When an institution gets funding, it wants to work on the subject on its own. When something involves multiple parties, there is always one coordination institution, whereas the rest is only supporting. Coordination is lacking for a long time already. It is unclear who is responsible for (smaller) urban drains or whom to contact in case someone wants to construct a drain. If data collection costs money, the data should not necessarily be given away freely, only if it applies public institutions. People do not know the right channel to ask for information. An additional problem is that institutions sometimes promise data that they do not have because they do not want to acknowledge the fact that they do not have it.

Statement 4: The situation of Accra has not got right with the traditional ways, either because the traditional is not good or because the traditional is not implemented in the right way. Flood plains are encroached. If green areas are to be added next to a drain, firstly the people that are living there have to be moved. The drainage system cannot do without the traditional way, but solutions can be added along it. Solutions as implementing more pervious areas such as grass field in gardens should also be applied on micro level, where everybody can make a difference and where people should not wait and sit back for government action. This message should be spread among citizens. However, private solutions can lead to more problems in other areas. Traditional systems can be improved through proper maintenance, engineering and better coordination between institutions. More money should be invested on national level in drainage and waste systems.

Group 4:

Statement 1: The participants agreed that throwing waste in the drains is more of an attitude problem than a financial constraint, but besides these aspects it is also a capacity problem. Although the AMA has contracted waste collection companies, service provision in the neighbourhoods is lacking. Some households need three containers instead of one in order to collect the waste, because the waste collection does not occur frequently. Dumping sites are sometimes fully filled and people are forced to take their garbage back home, so it is more convenient to dump it somewhere else illegally. The waste collection does not function because the Accra region is too scattered when it comes to administrative institutions. Lack of coordination between these institutions makes it hard to control the waste collection in Accra as a whole.

Waste collection is traditionally a women's or children's job. Children are sent to the dumping site with the needed amount of money to dump, but sometimes use this money to buy something else and dump the waste somewhere illegally.

Another problem is the fee for waste collection. Corruption within the waste management results in fees for waste collection that are too high, which people are not able or not willing to pay.

Statement 2: No, the main cause of flooding is the improper construction of the drains. There are not enough drains and there is uncontrolled construction of drains by inhabitants. These drains are not always maintained properly. The growth of the city has led to an increased amount of paved surfaces, which results in more runoff. The capacity of the drains in not enough to cope with this runoff. All natural water courses are blocked by walls and houses. Flooding has been a problem for centuries. An article written by the Ghanaian Chronicle in 1895 presents the problem of flooding in Accra as a result of a bad drainage network. In North Kaneshie, a drain is constructed and well maintained. No waste ends up in the drain and no flooding occurs, could this be an example that proves the statement?

Statement 3: It is shared by the participants that documents produced with public money should be open and freely available for everyone. The major challenge is to manage the database, keeping it up to data and validating the published documents. One institution should have this responsibility. Apparently a database managed by the National Information Technology Agency (NITA) already exists on data.gov.gh, but documents need to be added to fill the database. Also the Savannah Accelerated Development Authority (SADA) is mentioned as a good example for other administrative institutions to share data online. In general, the process of requesting information is too complicated and lead times are too long. It happens frequently that employees who have been appointed for an information request have already left the firm and did not carry over the request, because of which the person waiting for the information will never get it.

Statement 4: The group agrees on the fact that the traditional concrete drains have not provided a solution for the drainage system so far. However it is not feasible to implement other drainage solutions in existing neighbourhoods due to spatial constraints. The spatial development currently consists of implementing solutions as a reaction to problems that arise, which should change into a proactive approach in planning for future scenarios. A vision for, for example, the next 20 years should be created. All the designs for the city are medium term plans for about 4 years, with the lack of a vision on future spatial urban drainage plans. When a vision is created for the city of Accra, more sustainable measures can be considered and implemented.

4. Group Discussion Wrap-Up

At the end of the discussion rounds, a representative of each group is asked to come forward and present the group's final conclusions for each statement.

Statement 1: **"Clogging of gutters with waste is more of an attitude problem than a financial constraint"**

Group 1: Attitude is underlying the financial constraint. A bad attitude towards waste disposal is triggered by the financial constraint.

Group 2: In addition, the bad attitude towards waste disposal is triggered by a lack of enforcement, education and community engagement.

Group 3: Attitude is worsened by financial constraints. Poor planning pronounces attitude issues.

Group 4: There is a lack of access to waste collection services and there is not enough capacity.

Statement 2: **"If all gutters in Accra would be clean, floods would no longer occur"**

Group 1: No. Cleaning gutters will reduce flooding, but there are other more important factors such as unplanned settlements and uncontrolled developments, capacity of the existing system and limited water retention.

Group 2: No. In addition to the comments of group 1, factors such as poor monitoring services and encroachment of buffer zones should be mentioned.

Group 3: No. Encroaching water ways and retention are the main reasons. There is no enforcement of the laws regarding waste management.

Group 4: No. Cleaning the gutters will help but that is not enough to prevent flooding.

Statement 3: **"A shared technical database is needed to coordinate urban drainage management issues"**

Group 1: Yes, but there should be different data sets among public and private institutions. For public purposes, information should be free.

Group 2: Open data should be encouraged, but creating the database in itself is a problem. There is no group consensus on whether the information in such a database should be free.

Group 3: Open data enhances innovation, but there should be a mechanism of coordination put in place. The Greater Accra Metropolitan Area (GAMA) could serve for this. A sustainability token (GHS 1-5) payment system for researches could be an option.

Group 4: The NITA data collection is not functioning. There has to be one institution that controls the data.

Statement 4": **"The traditional way of drainage in Accra is the future way of drainage"**

Group 1: No. Drainage management should be planned using an integrated approach. A light should be shed on land-use systems and enforcement.

Group 2: SUDS should be adapted to local contexts and evaluate the solutions first. Does it work where you placed it? Building codes for retention guidelines should be reviewed and a policy direction should be created. There is a lack of institutional coordination for maintenance of the traditional drains. Upstream retention basins should be constructed.

Group 3: No. Sustainable is the future. Modification should come before urbanization. To restore the existing urban landscape, we should create parks at schools, plant trees along river channels, expand open channels and reclaim land in vulnerable areas.

Group 4: Not everywhere. But it is difficult to adopt SUDS in existing neighbourhoods. A long term vision for Accra in 20 years is needed.

Appendix – List of Participants

Institution	*Name*
Accra Metropolitan Assembly	Fiifi Baodi
Assemblyman New Town	Alexander Mensah
Berenschot International	Robert Quartey
Colan Consult	Emmanual Agyenim-Boateng
Ghana Meteorological Agency	Captain Stephen Komla
Ghana Meteorological Agency	Andrew Nkansah
Hydrological Services Department	Sylvester Darko
Hydrological Services Department	Seth Kudzordzi
International Water Management Institute	Marloes Mul
International Water Management Institute	Seth Owusu
International Water Management Institute	Benjamin Ghansah
La Nkwantanang Madina Municipal Assembly	Kwasi Adarkwa
Ministry of Environment, Science, Technology and Innovation	Levina Owusu
Ministry of Environment, Science, Technology and Innovation	Elfrida Ashong
Ministry of Local Government and Rural Development	Eric Kofi Afornorpe
Ministry of Local Government and Rural Development	Prosper Apawudza
National Disaster Management Organization / United Nations Development Programme	Phil Mantey
Open Street Map Ghana	Enock Seth Nyamador
Royal Netherlands Embassy, Accra	Fred Smiet
Safi Sana	Jos van der Ent
Witteveen+Bos	Richard Sedafor
Witteveen+Bos	Joriën Mendez Groot
Witteveen+Bos	Gideon Lomoko
World Bank	Frederick Addison
World Bank - CityStrength	Rachael Annan
Project Flood Risk Accra	Kofi Asare Aboagye
Project Flood Risk Accra	Lexy Ratering Arntz
Project Flood Risk Accra	Evelien Martens
Project Flood Risk Accra	Nadi Modderman
Project Flood Risk Accra	Caterina Marinetti