Latha's Socio-Hydrology

Understanding and modelling the interactions between hydrological processes and human activities that cause urban flooding in the Latha Township, Yangon, Myanmar

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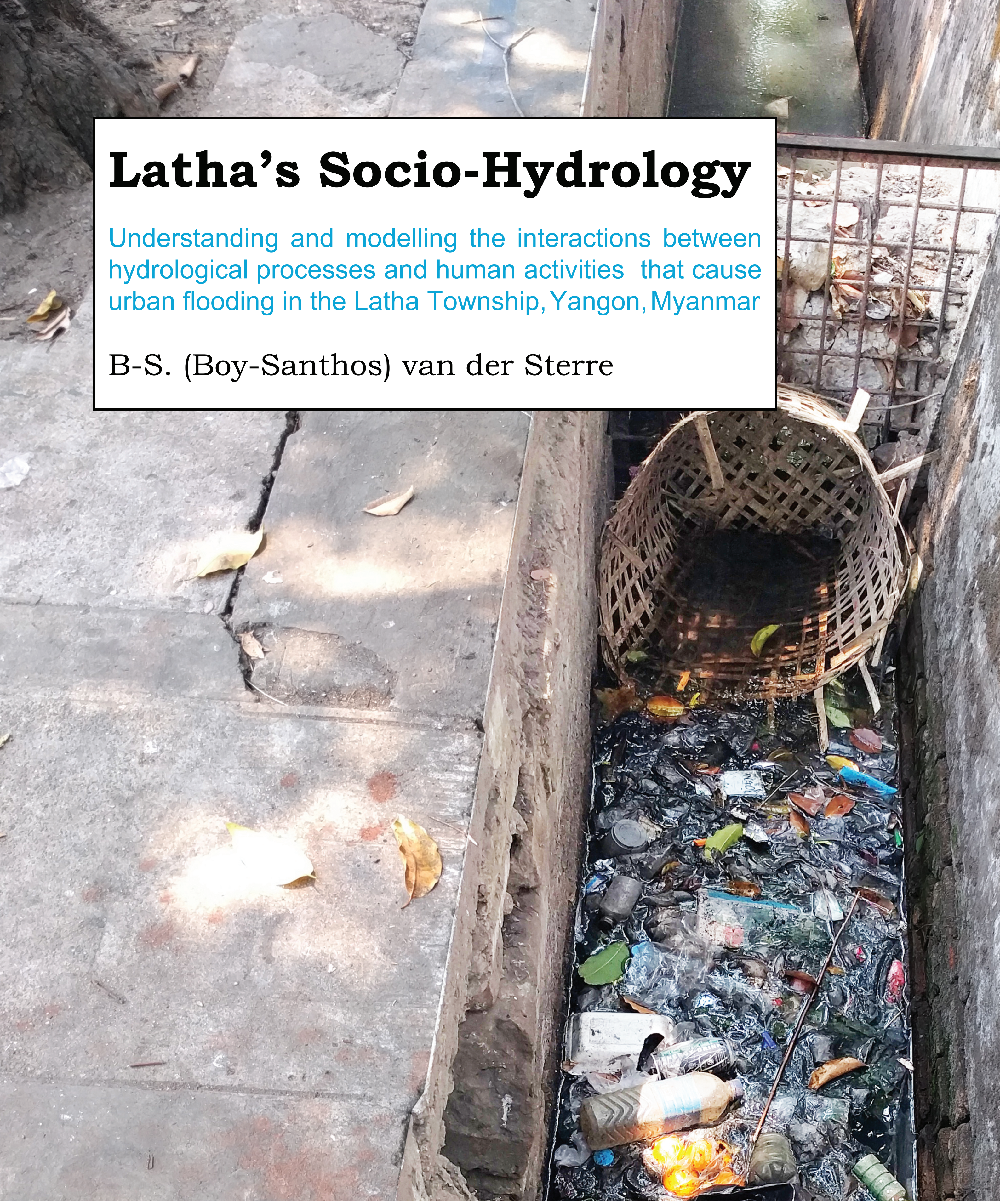

Delft University of Technology

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On the Cover

The cover shows a part of the open drain that runs along Anarwrahta Road in the Latha Township. A lot of waste is disposed directly into the drains and inlets or waste is disposed on the street and eventually ends up in the drains because of insufficient collection and cleaning. This waste might result in blocked drains and urban drainage system structures which could result in floods. Picture taken on April 6, 2017.

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by

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TU Delft

Summary

Urban flood events are causing major nuisance and damage. The frequency and severity of urban flooding (UF) is expected to intensify in the future as a result of ongoing anthropogenic effects like climate change, subsidence, land-use changes and an increasing urbanization of flood prone areas. Despite the nuisance and damage, the urban population is continuously growing and economic wealth is increasing. This results in a higher solid waste production. Previous researchers have studied and modelled the effects of solid waste management (SWM), urban flood management and other human activities on UF and which hydrological and hydraulic processes are involved. However, none of the completed and published studies approached UF from a holistic perspective that explicitly acknowledged and incorporated the existence of threshold behaviour, interactions and feedback between human entities (both citizens and policy-makers) and their modified (originally natural) urban environment. Whereas for human-water systems an additional flood vulnerability is introduced by the dynamic coupling between an inadequate co-evolution of urban flood management and SWM on the one hand, and hydrological processes, hydraulic processes or both on the other hand. To improve the holistic understanding of a human-water system's *human solid waste management - urban flooding interaction* this study provides a developed explorative research methodology that is applied to synthesize a socio-hydrological model (SHM) for a case study of the Latha Township in Yangon, Myanmar. The developed methodology consists of questionnaires, field observations and both semi-structured and unstructured interviews onto which triangulation is applied in order to study the relevant human activities. A scenario based flood modelling methodology is used to research the dominant natural processes. The results of these methodologies are combined into a SHM that describes the coupling between SWM and UF. For the case study, the results of the questionnaires, field observations and interviews (*socio-economic results*) suggested that there was a strong coupling between SWM and UF. However, the flood model methodology suggested that the floods predominantly resulted from the combination of the gravity based urban drainage system (UDS)'s insufficient capacity to temporarily store rainfall that coincided with high water level at the downstream boundary conditions. A SHM was made for the weak coupling that was found between UF and solid waste blockages of the flood gate structures. However, this model consisted of very crude assumptions and processes, especially for waste propagation and waste blockage formation. Therefore, the SHM was considered a toy-model. The socio-economic results were subject to biases and lacked sufficient statistical significance. Moreover, the flood model results were unable to accurately simulate the historical flood records and reported flood frequencies, flood durations and water depths. Triangulation onto the results converges into truthful propositions about the validity of the research results. This leads to the conclusion that the application of the designed research methodology is effective for a research that simultaneously: has an explorative character, has limited financial and human resources, has a high uncertainty in the available data and where multiple scientific disciplines meet. The second conclusion is the existence of a coupling between SWM and UF. The SWM practices of citizens can be affected by the SWM activities of the responsible authorities. An insufficient waste: collection (container) capacity, disposal location distribution and collection frequency can result in waste disposal practices at undesignated sites by citizens. A too ad hoc operational schedule for the collection of waste and cleaning of the streets can result in waste entering the drains before it is successfully collected. Insufficiently organized cleaning and maintenance of the UDS results in the fouling and (partial) blockage of drains and structures and eventually floods. However, the significance of this relation is subject to location specific characteristics. In general, large UDSs with long drains and a highly branched network are expected to have a stronger coupling. In these systems, friction losses and blocked cross-sections caused by waste have a larger effect. Under such conditions, citizen's waste disposal patterns and flood awareness, the municipalities SWM practices and UDS maintenance becomes much more relevant. The SHM of this study does not directly provide a generalisable additional holistic understanding of the coupling between SWM and UF. However, attempts to make an accurate SWM do provide insight in the scientific knowledge gaps that can help to advance this research area. Future research should focus on the required degree of added complexity of natural processes (such as flood dynamics) in SHMs, *"Does more also means better?"*. The limited process understanding of consumables solid waste (e.g. plastic bottles, plastic bags) propagation through UDSs provides a largely unexplored research area that should be studied considering our increased waste production.

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This research would not have been possible without the help of a lot of people of whom I would like to address a few explicitly.

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Preface

More than one decade ago I graduated from high school and started my bachelor Civil Engineering at Delft University of Technology. Even though I was also very interested in genetics and physics, I decided to study civil engineering. Within civil engineering I was especially interested in the large scale projects where technology and engineering collide with process management, politics and society. This more direct coupling of beta and alpha elements was what convinced me to choose for civil engineering.
After I followed the course on fluid mechanics and an introductory course on hydrology (by prof.dr.ir. H.H.G. Savenije) I got interested in water. The fact that we are able to do calculations on something that operates on processes as small as water molecules transpiring through leaf stomata and at the same time study the fluxes of the worlds water cycle amazed me. Even more so, I was fascinated about the holistic relation of all these micro and macro processes. The importance of water for humanity, one of the elements of life, also means that there is a strong societal relation. Not willing to let go of the social aspects of civil engineering, the master Water Management was the right choice.
For my internship I went to the Palestinian Territories to work on a project that tried to help farmers mitigate the effects of (future) climate change, an adventurous experience with again a social element. The increased popularity of socio-hydrology that explicitly recognizes and incorporates a relation between hydrological processes and human activities was a field which I very much enjoyed studying. This, combined with the only recently opening and rapid transformation of Myanmar was for me the ultimate combination of a master thesis topic.

This thesis is the product of little over a year of socio-hydrological research on the relation between solid waste management and urban flooding. Although there have been studies on solid waste management and urban flooding, none of the published studies researched the interactions and dynamics of this topic from a holistic approach.
A methodology was developed to research this coupling, which was evaluated by conducting a case study on the Latha Township in Myanmar's largest city Yangon. Myanmar is a country that experiences rapid economic growth and an accompanying increase in solid waste production. The Latha Township is at the heart of the booming city Yangon. However, Latha's citizens and businesses often experience floods causing major nuisance and damage. If an interaction between solid waste management and the urban drainage system exists Latha seems to be a suitable research area because of the combination of urbanization, economic growth and the occurrence of floods.
This research is of interest to scientists with an interest for mixed-method research in general. More specifically it could be of interest to professionals working on solid waste management or urban drainage. Finally, it might be of interest to policy-makers of Latha and Yangon as the research provided quite some information on the Latha Township.

The used methodology consisted of social sciences methodologies: field observations, semi-structured and unstructured interviews and questionnaires on the one hand and hydrological and hydraulic flood modelling on the other hand. With the combined results of these four methods the initial hypothesis was evaluated and improved. Eventually the improved hypothesis was synthesized into a socio-hydrological model.
The results of this study provide some insights in the perceptions, customaries and activities of Latha's citizens and policy-makers with respect to solid waste management an flood perception. Moreover, the study provides knowledge on properties of urban drainage systems that might be relevant for the coupling between solid waste management and urban flooding.
Unfortunately the found coupling was only limited and the dominant processes provided challenges to be modelled in a socio-hydrological model. Moreover, the robustness of some conclusions could have been stronger if more scientifically sound methodologies were used. However, this research is still relevant as it provides a toy-model based on and inspired by reality that might serve as a basis for future research.

While doing this research, I also got to know the amazing country Myanmar first hand and from up close. I was positively surprised by the friendliness of the people, beautiful nature and fast rate of development. I am interested to see how this country will develop over time, expecting that the Myanmar of today will be quite

different from the Myanmar ten years from now. However, the recent political developments in some parts of Myanmar demand attention and are in need of an appropriate solution. In spite of Myanmar's remaining challenges, but I'm hopeful that Myanmar will continue to move forward.
This research also thought me a great deal about doing social scientific research and its challenges. Although I did it with great joy, I found that doing a scientifically sound study is not that simple. I am thankful for the lessons that I have learned and believe that I am now better equipped to possibly do future research.
I feel that studying the hydrological and hydraulic processes in this research has provided me with an opportunity to combine and implement a lot of the skills that I learned and acquired during my master study.
I have done my best to make this report comprehensible and easy to read, as well as complete and sufficiently detailed. I have found that concise writing is a skill on its own and I admire those who master this skill completely. Nevertheless, I hope that this report will be of interest to you and might provide you with a better understanding of the properties and dynamics of Latha's solid waste management and urban flooding. Enjoy!

B-S. van der Sterre
Delft, October 24, 2017

Contents

Nomenclature

List of Acronyms

ABM	agent based model
ABMing	agent based modelling
CBD	central business district
CCH	conventional household
DEM	digital elevation model
DWF	dry weather flow
FGS	flood gate structure
GL	ground level
GLE	ground level elevation
GLR	ground level reference
HH	household
HHWL	highest high water level (+6.74m MSL)
HWS	human-water system
JICA	Japan International Cooperation Agency
LT	Latha Township
MMU	Myanmar Maritime University
MSL	mean sea level
MWL	mean water level (+3.121m MSL)
NEPS	National Engineering and Planning Service
OFGS	outflow flood gate structure
RHDHV	Royal HaskoningDHV
SHM	socio-hydrological model
SWF	storm weather flow
SWM	solid waste management
TU Delft	Delft University of Technology
TWF	total weather flow
UDS	urban drainage system
UF	urban flooding
WL	water level
YCDC	Yangon City Development Committee
YCDC EDRB	Yangon City Development Committee Engineering Department of Roads and Bridges
YCDC PCCD	Yangon City Development Committee Pollution Control and Cleansing Department
YCDC EDWS	Yangon City Development Committee Engineering Department of Water and Sanitation
YR	Yangon River
YRWL	Yangon River water level
YTU	Yangon Technological University

1

Introduction

This chapter serves as an introduction to the MSc thesis research. First this societal relevance and scientific relevance of this research will be explained. Followed by the research objective and the research questions. This chapter ends with a thesis outline and some guidance for reading the rest of this report.

1.1. Societal Relevance

Urban flooding is a common occurrence (The Telegraph, 2010; Qiu, 2012; TheGuardian, 2017) causing major problems for large cities. For example, the recent Huston floods resulted in nuisance, huge damages and numerous deprived citizens (BBC, 2017).
A large majority of the world's population lives near a sea or ocean in: delta regions, densely rural areas or cities (Small and Nicholls, 2003; Brooks et al., 2006). Futhermore, "coastal populations are widely reported to be growing more rapidly than the global mean, due to net coastward migration, and urbanising" (Nicholls and Lowe, 2004, p.229). And even more (mega) cities can be expected in coastal areas (Nicholls, 1995). These areas are subjected to more and more flood problems (Bijlsma et al., 1995).
The broad consensus is that the combined effects of rapid urbanization with consequential land-use changes and climate change result in increased rainfall-runoff (Yin, Yu, Yin, Liu and He, 2016; IPCC et al., 2013). Moreover, climate models predict an increase of precipitation for the monsoons (IPCC et al., 2013). This results in an increased flood vulnerability for many parts of the world, not only limited to rural areas (Jha et al., 2012).

In an urban setting, drainage is more than just simply (urban) hydrology and hydraulics. Population growth, technological innovations, urbanization, globalization and engineering capacities now have a considerably larger effect than ever before (Werner and McNamara, 2007). People deploy their daily activities, thereby affecting their environment while they react to changes in their surroundings. This in its turn could evoke new reactions with new responses, creating a continuous dynamic of interactions and feedback.
The increasing urbanization and climate change impact (future) urban flooding (UF) (Huong and Pathirana, 2013; Wilby, 2007; Gupta, 2007; Yin, Yu and Wilby, 2016). Processes like land cover change are major contributors to urban flood problems (Wu et al., 2012). "Urban growth, creeping informal increases in paved surfaces and development on flood plains all contribute to the problem." (Ashley et al., 2005, p. 265).
With the increasing urbanization and economic growth comes an increasing solid waste generation (Karak et al., 2012; Dhokhikah and Trihadiningrum, 2012; Katiyar et al., 2013). This increased solid waste production and poor solid waste management (SWM) "can contribute to the impact of UF by blocking drainage, increasing debris and harbouring disease vectors." (Lamond et al., 2012, p.193). "Particularly in many cities worldwide where rapid urban has growth outpaced the capacity of storm sewer drainage" (Yin, Yu and Wilby, 2016, p.744). People's attitude towards solid waste management might also affect UF and investments in an improved handling of solid waste might be an investment worthwhile (Gupta and Nair, 2011).

Thus waste disposal patterns, waste collection practices and other solid waste management related activities could play a role in the interaction that humans and societies have with the urban drainage system (UDS). For example, the disposal of waste on the streets might result in a partial blocked sewer drain, resulting in an increased flood probability during a heavy rainfall event (Leita et al., 2016). As a possible reaction citizens could implement flood protection measures on a household level (Harries, 2012), demand for an improved UDS (Moatshe, 2017) or change their waste disposal behaviour. These reactions have a feedback to the UDS's behaviour and properties, changing future dynamics.

The Latha Township in Yangon, Myanmar is also experiencing fast economic growth (Khaing, 2015) and suffers from UF that might have a relation with SWM (Khin Wyne Phyu Phyu, 2015). Therefore the Latha Township is selected as a suitable case study for this research (see Chapter 2). The case provides an good opportunity to research which key human actions, SWM activities, hydrological processes and hydraulic processes are dominant factors in the occurrence of UF and how these dynamics are intertwined.

1.2. Scientific Relevance

This study is one of the first study which incorporated human SWM activities as an integral part of the UF problem by means of an actual existing case in an south-east Asian setting.

Until now, the majority of the past research on UF has been primarily focussed on isolated processes or closely related clustered processes that play a role in the manifestation and effects of UF. Such studied processes or effects are for example on physics/environmental sciences e.g.: hydraulics and hydrology (Schmitt et al., 2004; Maksimović et al., 2009; Zhang, Wen and Li, 2014) or social-economic sciences, e.g.: social sciences (Hansson et al., 1982; Harries, 2012), economic sciences (Nicholls, 2004; Gregory, 2009) and actuarial Science (Browne and Hoyt, 2000; Botzen and Van Den Bergh, 2008).
However, "The significant modification of the water cycle by human activity has primarily been treated as an external perturbation to such natural systems."(Troy et al., 2015, p. 3667). Therefore, "(...) externalizing the dependencies between human action and the availability, quality and dynamics of water clearly poses limitations to making predictions about water within the Anthropocene (Thompson et al., 2013)." (Troy et al., 2015, p. 3667). Thus, the emerging non-linear behaviour from feedback mechanisms and from the existence of thresholds, tipping points and dissipation processes that are active in and across human-water system (HWS)s for different spatial and temporal scales (Werner and McNamara, 2007) no longer allows for an external perturbation approach and demands for a two-way coupling approach.

Socio-hydrology is proposed as a use-inspired scientific discipline that focuses on understanding, interpreting and allows for scenario development of the flows and stocks in the human-modified water cycle across time and space (Sivapalan et al., 2014). Blair and Buytaert (2016) and Troy et al. (2015) give a good introduction to socio-hydrology, providing an overview of recent developments and current challenges.
On integrating this two-way approach for the HWS interaction, there have been a few published socio-hydrological studies (see Table 1.1). The number of publications is growing since this research area starts to get more attention since IAHS introduced its new scientific decade *"Panta Rhei – Everything Flows"* (IAHS, 2013).
The overview of Table 1 from Troy et al. (2015) reflects that the majority of the current published research is primarily focused around the development of societies (e.g. Van Emmerik et al. (2014)) or water availability (e.g. for drinking water supply (Srinivasan, 2015) or agriculture (Zhang, Hu, Tian, Yao and Sivapalan, 2014)).
An example of socio-hydrological studies that are specifically focussed on the human-flood interaction is the series of three studies by Di Baldassarre and Viglione. However, this series of studies is based on a synthetic situation using artificial relations and imaginary data. In contrary to the research of Di Baldassarre et al. and Viglione et al., this thesis study is based on an actual case.

Since this research is partially about people and how they are affected by floods, people's flood awareness might be of importance. To get a better understanding of individual's flood awareness the paper by Burningham et al. (2008), provides quantitative and qualitative sociological insights. Flood awareness could be an essential characteristic of a society when modelling flood interaction and coupling with the floodplain. It was concluded that "class is the most influential factor in predicting flood risk awareness, followed by flood experience and length of time in residence" (Burningham et al., 2008, p. 216), where class was meant social class. This paper can serve as a reference for Latha's citizens. A note has to be made that these results are probably socio-cultural bounded, and thus could be conflicting with the applicability to Yangon's citizens. There are no substantive publications that specifically focus on waste disposal patterns and its relation with UF.

There have been studies focussed on solid waste in drainage systems (Arthur, S, Crow and Pedezert, 2008) the

Table 1.1: Examples of explicit SHMs that modelled a HWS. Used abbreviations: Agent Based Model (ABM), System Dynamics (SD), Stochastic Model (SM).

Reference	**Approach**	**Case Study**	**Modelling Objective**
Dawson et al. (2011)	ABM	Towny, United Kingdom	Flood Incident Management
O'Connell and O'Donnell (2014)	SM	Human–flood interactions, synthetic model	To develop an ABM framework
Werner and McNamara (2007)	ABM	Katrina, New Orleans	To develop an ABM framework
Srinivasan (2015)	SD	Water supply and demand, India	System Understanding Historic Events
Van Emmerik et al. (2014)	SD	Agriculture-Environment water competition, Australia	System Understanding
Zhang, Hu, Tian, Yao and Sivapalan (2014)	SD	Groundwater dynamics, China	Validation of SD framework
Di Baldassarre, Kooy, Kemerink and Brandimarte (2013)	SD	Human–flood interactions, synthetic model	System Understanding
Di Baldassarre, Viglione, Carr, Kuil, Salinas and Blöschl (2013)	SD	Human–flood interactions, synthetic model	System Understanding
Viglione et al. (2014)	SD	Human–flood interactions, synthetic model	System Understanding

majority of these studies is about solid waste deposits (Ashley and Bertrand-Krajewski, J-L Hvitved-Jacobsen, T. Verbanck, 2004) or other soil types primarily focussed on maintenance of drains (Bijnen et al., 2017). One study specifically researched gross solids in intermittent flow through small pipes (Littlewood and Butler, 2003). However, differences in the characteristics of the drains in the Latha Township compared to the small pipes is considerably large for this study to be sufficiently representative. On the topic of sewer inlet blockages a recent study was completed (Leita et al., 2016), that showed a stochastic methodology to asses the impact of blocked sewer inlets. How large gross (solid) waste is propagating through large combined sewer systems that are poorly maintained in a non-western setting has not been researched yet.

It could be concluded that the first few steps into socio-hydrology have been taken. However, when it comes to urban (pluvial) flooding and the relation with solid waste management, no studies have been published. These other completed studies do not provide any insights to what extents urban pluvial flooding affects human responses that in turn affect the urban pluvial flooding. What also remains unknown is how the different temporal and spatial scales interact with this HWS, especially since the daily live actions such as producing waste (water) have entirely different scales as the policy development of the creation of an urban drainage network. Similar differences occur within the natural system, where a local convective storm may produces high rainfall intensities for a short duration very locally, while climate change might have slowly changing global effects.

1.3. Research Objective

The *solid waste management - urban flooding* interactions have hardly been studied in a holistic approach. This resulted in a twofold explorative study objective: On the one hand obtaining an improved holistic understanding of the human solid waste management - urban flooding interaction for a human-water system using the case of the Latha Township and on the other hand contributing to the development of a methodology to asses such interactions.

Such research could provide useful insights on how the HWS is affecting society and how society is affecting the HWS in return. The insights might serve as starting point for policy development. For the scientific community it will be the first study that focusses on urban pluvial flooding (in a south-east Asian setting) while specifically acknowledging the interaction between human solid waste management activities and hydrological/hydraulic processes that might cause urban flooding.

The central research question that will be answered with this MSc thesis is:
To what extent is a human-water system a coupled system for solid waste management and urban flooding and how could a social-hydrological model help to understand this human-water system interaction for the case of urban flooding?

In order to answer this central research question the following sub-questions should be answered:

1. What are the most relevant human solid waste management activities that contribute to urban flooding and how does urban flooding affect human activities?

   All citizens have a daily pattern in which they consciously and unconsciously interact with their UDS. Each time they flush their toilet or throw away their (solid) waste in a drain, they also affect their drainage system. Moreover, the occurrence of a flood or the long absence of flood might also change people's activities and actions for better or worse. Maybe a recent flood results in the demand for improvements to the drainage system, which reduces the probability of future flood events. Alternatively, the long absence of floods might result in more citizens disposing waste at undesignated locations such as on the streets or directly into the drains. The increased waste in the drains might result in blocked drains, causing floods that would not have occurred otherwise. In this research the Latha's citizens were observed and studied to answer this sub-question. The results were used to extract generalized and location specific conclusions.

2. What are the most dominant urban drainage system properties and processes that cause urban flooding from a hydrological and hydraulic perspective?

   Urban flooding could have a multitude of causes ranging from (partially) blocked drains, to too high rainfall runoff and from ineffective operational practices to too little storage. To answer this question Latha's UDS flood dynamics were studied. The results and conclusions for Latha's UDS will be compared to other types of UDSs to extract general conclusions.

3. What could be a possible social-hydrological model for the coupling between solid waste management and urban flooding and how could this be used to better understand a human-water system?

   If there is evidence that Latha's HWS is coupled, relevant human interactions and physical processes should be included in a SHM. The challenge will be to acknowledge that reality is far more complex, but simplifications and assumptions still result in an realistic modelling concept. The synthesized SHM's capability to provide additional insights will be evaluated while considering its limitations and simplifications. Moreover, the relevance for other cases will be discussed.

4. To what extend is the methodology used in this research effective to study the interactions between human solid waste management activities and urban flooding?

   Since this topic has not been studied from a socio-hydrological model perspective, a research methodology had to be developed for this research. The selected methodology consisted of elements from both social sciences and hydrology that were combined and applied to a case study. The suitability of the designed methodology will be evaluated on its strengths and weaknesses.

For this research has a few research constrains based on the selected case study. For more details, please read Section 2.3.

1.4. Thesis Outline and Guidance for Reading

In the next chapter (Chapter 2) the case study: The Latha Township is introduced. The location, (physical) characteristics, institutional set-up and socio-economic situation will be explained as well as the case's wider geographical context. Appendix A might provide additional information on the Latha Township for those who are interested. This chapter also provides research constrains and an initial hypothesis that was used in this case study.

Chapter 3 is dedicated to the developed methodology for this research. Appendix C provides more background information on the used and collected data. The presented data both originates from efforts and earlier published work by others and from collections and observations that were the results of this research.

The results (Chapter 4) were divided into three parts. The first part presents the most important results of the questionnaires, field observations and interviews. The second part is focussed on the results of the flood model simulations. The third part is centred around the combined results of the previous two parts that were used for the synthesis of the socio-hydrological model.

The most important discussion points are presented in Chapter 5 and the conclusion (Chapter 6) will provide brief answers to all the research questions.

This mixed method research has resulted in a large amount of materials, methods, results and discussion points that were not always essential for the main objective of this research but do provide additional information. Therefore this report comes with numerous extensive appendices. For more information and results of the questionnaire methodology see Appendix B. More details and results on the interviews are provided in Appendix D. If you are interested in the used materials and methods of the flood model together with additional results and discussion points then take a look at Appendix E. Finally Appendix F provides additional information on the initial SHM hypothesis, its evaluation, the improved model concept and the physical model.

2

Case Study: Latha Township

This research used the case of the Latha Township as a basis (also see Section 3.2.1). The Latha township is situated in Myanmar's largest city Yangon. This chapter describes why the Latha Township served as a case for this research. Second, this chapter elaborates on background information about the case's location. For a more elaborate introduction to the Latha Township, you are referred to Appendix A. In the third section some research constrains will be discussed briefly and finally the initial hypothesis of Latha's socio-hydrological model (SHM) is presented.

2.1. Case Introduction

While the climatological changes for Yangon may vary over the time scale of years, decades, centuries or even longer, Latha's citizens and Yangon City Development Committee (YCDC) policy makers interact with the Latha *floodplains* on a daily basis.
For many years, Yangon is facing urban floods during the rainy season (NASA, 2008; Coconuts Yangon, 2015, 2017). This has resulted in a lot of damage and nuisance in the past. For example, a 2015 major flood event in 14 of Yangon's townships caused damage for about US$8.5 million (Phyu, 2015). However, the recent flood events have not been able to slow down Myanmar's economic growth: "Despite severe flooding, the economy [of Myanmar] continued to perform well in the closing fiscal year. Growth is forecast to accelerate during 2016 on recovery in agriculture and increases in foreign direct investment." (Asian Development Bank, 2016, p. 216). Moreover, the damage and nuisance of these severe flood events (see e.g. Figure 2.1) did not stop Yangon's expansion and urbanization (Khaing, 2015; Morley, 2013) and more new developments are already planned (JICA and YCDC, 2013, 2014).
The increased population and urbanization has resulted in an increase in Yangon's waste production (Shwe Yee Saw Myint, 2016), more than Yangons solid waste management (SWM) system can adequately handle (Kyaw Phone Kyaw, 2015). A fraction of the produced waste ends up in Yangon's drains and canals (Khin Wyne Phyu Phyu, 2015; Myat Nyein Aye, 2017), potentially contributing to urban flooding.

Latha was used as a case study to research the interaction between solid waste management and urban flooding and to test the research methodology. This specific township was used since it is one of Yangon's most flood prone downtown areas (Kyaw Mein Oo, personal communication, April 6, 2017), see Figure 2.2. Moreover, its location in Yangon's business district (see Section 2.2.3) made it an economic important area on which floods had a large impact. Furthermore, due to the high degree of commercial activities and high population density (see Section 2.2.4) there was a high waste production probability with the potential for interactions between SWM and urban flooding (UF).

Figure 2.1: Flooded street in Yangon during a 2015 urban flooding event. Obtained from (Kathmandu Post, 2015)

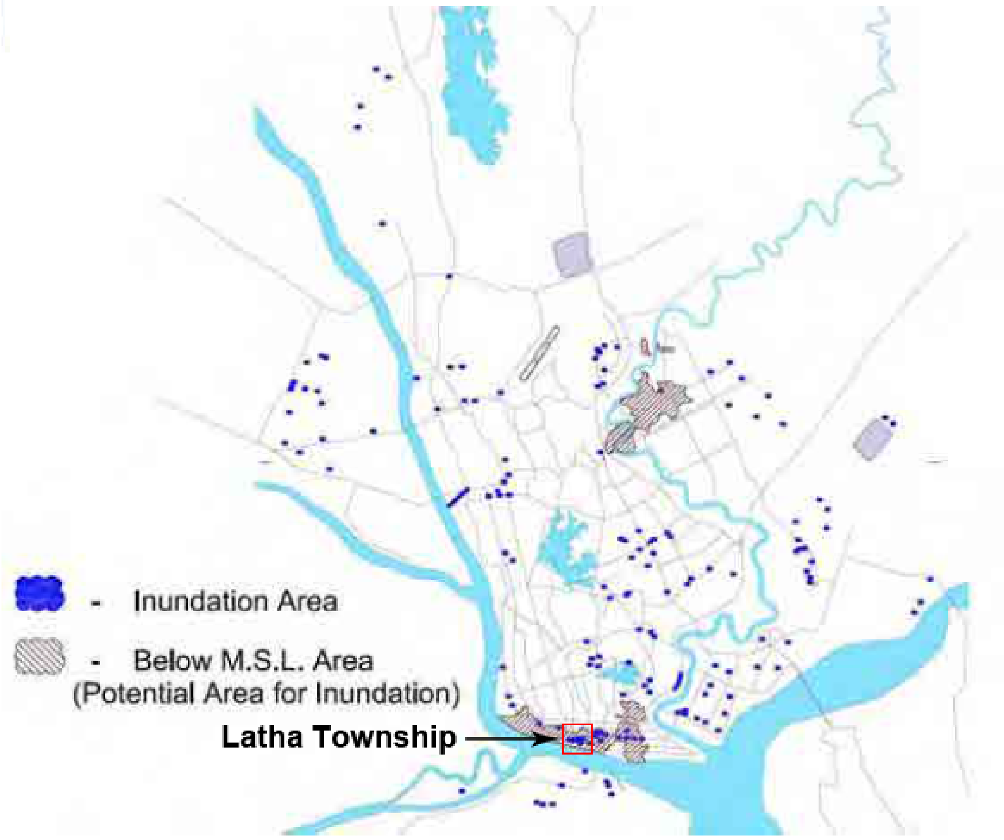


Figure 2.2: Inundation potential within Yangon. The Latha Township is often inundated as could been seen from the figure. Modified from (JICA, 2014*a*, p.4).

2.2. Background Information on Myanmar, Yangon & Latha

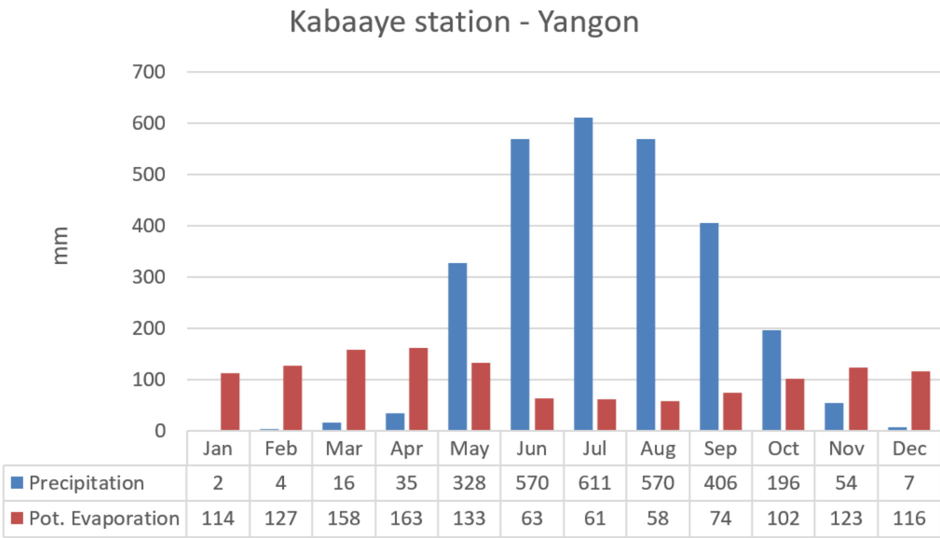
2.2.1. Myanmar

Latha is a township in Myanmar's largest city Yangon. Myanmar, or by its old name Burma, is officially known as the Republic of the Union of Myanmar and is situated in south east Asia (see detail Figure 2.3). The country's area totals to about 765,000 km^2 (CIA, 2016) and is bordering the Andaman Sea, the Bay of Bengal, Bangladesh, India, China, Laos and Thailand. In Myanmar live about 56.3 million people, with 34 % of the population living in urban areas (CIA, 2016). The country has a GDP of US$ 283.5 billion estimated for 2015 (CIA, 2016) and it is expected that this will grow in the near future. As a result of 2011's democratic reforms and easing of most Western sanctions Myanmar transformed tremendously over the past few years, from a dissolved military junta to a fast growing economy (7.2 % for Myanmar in FY2015 Asian Development Bank (2016)). The official capital is Naypyidaw, but the largest city in Myanmar is Yangon (also known as Rangoon, see Figure 2.3).

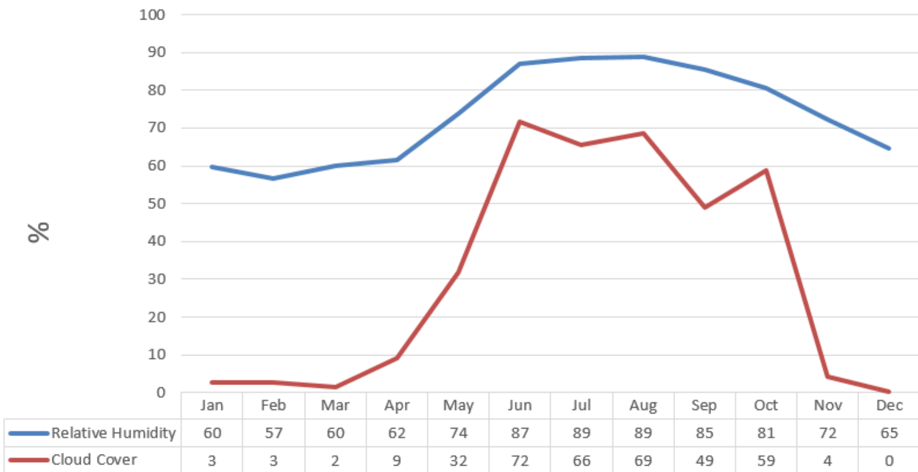
2.2.2. Yangon Region

Yangon could refer to the independent Yangon Region or to the city Yangon (see appendix, Figure A.3). In this research, Yangon was used to describe the city Yangon unless specifically stated otherwise. The Yangon Region has an area of about 10,000 km^2, a population of about 7.4 million people and it is the most developed region of Myanmar (MIP - DP, 2015, p.1).
The region has a climate with 3 seasons: cold season (roughly from November to February), hot season (roughly from March to May) and a rainy season (roughly from June to October), as could be seen from Figure 2.4. During the rainy season large monsoon weather fronts (Sen Roy and Kaur, 2000) reach the coast of the Yangon region. Figure 2.4a shows the monthly average rainfall for the Yangon Region. On average July is the wettest month of the year for Yangon, with a long term monthly averaged precipitation of 602 mm/month (as much as in a very dry year for the Netherlands). Climate change in the past few years has resulted in upwards trends for the annual total precipitation of Myanmar's coastal areas (Win Zin and Rutten, 2017) and thus an increase in future annual rainfall can be expected.

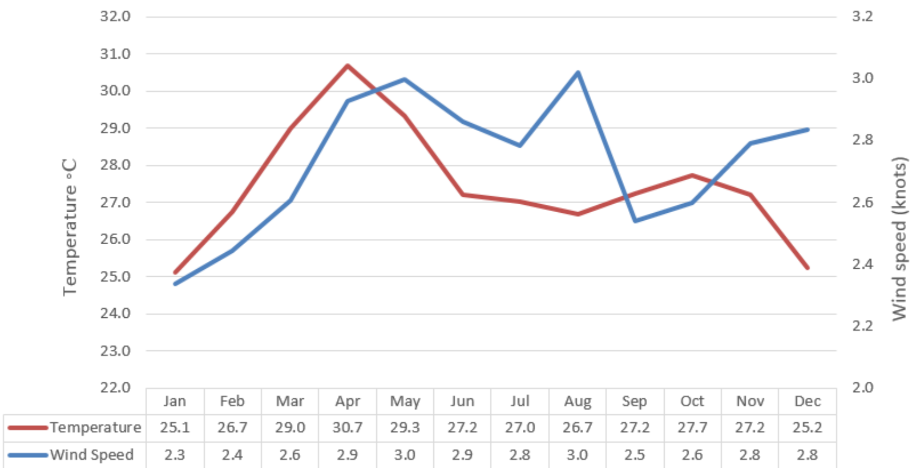
Figure 2.3: Map of the Republic of the Union of Myanmar (modified from : UN Cartographic Section (2012)). Water levels in Myanmar are with respect to mean sea level (MSL) at Kyaikkami (JICA and Ministry of Forestry - Myanmar Survey Department, 2004). Kyaikkami was formerly known as Amherst.



(a) Long term monthly averaged precipitation and evaporation, values in mm/month



(b) Long term monthly averaged relative humidity and cloud cover data



(c) Long term monthly averaged temperature in °C and wind speed in kn

Figure 2.4: Climatologic parameters of Kaba Aye Weather Station, Yangon City (See Figure 2.5). Obtained from (Van der Horst, 2017, p.10).

2.2.3. Yangon

The city Yangon (Figure 2.5) is the former capital of Myanmar. It is situated at the (south) coast of Myanmar in the Yangon Region, 34 km upstream from the mouth of the tidal Yangon River (JICA and YCDC, 2013). Apart from the Yangon River, multiple other rivers and creeks flow past and through the city (see Figure 2.2 for an impression, and for more details read Appendix A and see Figure A.6).
The city has an area of almost 600 km^2 and is divided into 33 different townships (see appendix, Figure A.7) which all are administered by the YCDC (YCDC, 2017). About 5.16 million people live in Yangon city's urban areas (MIP - DP, 2015, p.16), with the highest population densities (Figure 2.6) in the central business district (CBD) and downtown townships (for more information see Appendix A, Figure A.8).
Figure 2.5 shows the location of the Latha Township within Yangon City, which will be introduced in the next section. The figure also shows 3 points of interest that are sometimes referred to within this report and appendices. The first point is the Kaba Aye Rain Station, situated roughly 13 km away from the Latha Township. This is Yangon's only rainfall station and data from this station was used for this research (see appendix, Section C.3.13). The second point is the Yangon Port, and the third point is Monkey Point. Both points are relevant when considering the Yangon River water levels (see appendix, Section C.3.11).

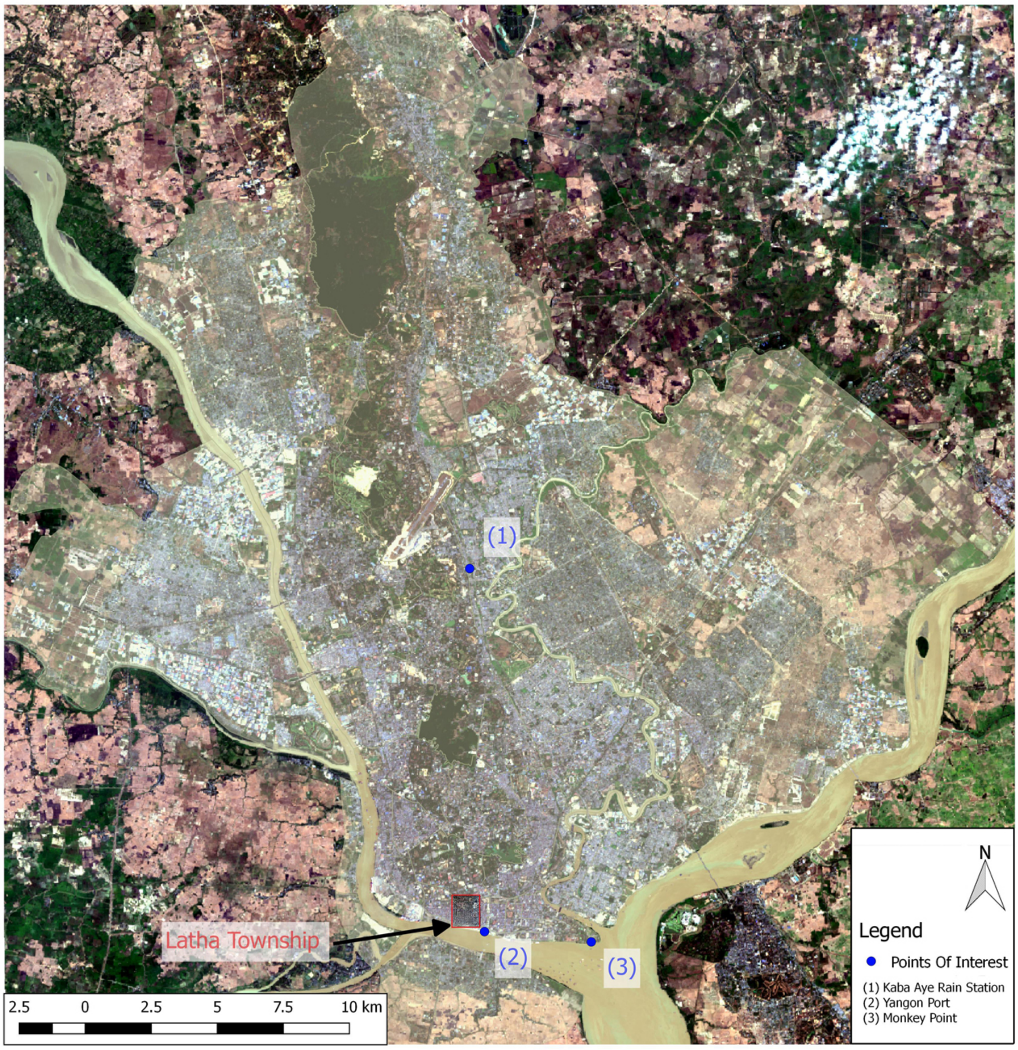


Figure 2.5: Map of the city Yangon. The Yellow overlay gives the boundaries of the city. The red rectangle indicates the location of the Latha Township. Furthermore, there are 3 points of interest indicated on the map that may be referred to at later stages. The first is the location of the meteorological station that records the rainfall for Yangon. It is about 13 km as the crow flies from the meteorological station to the centre of the Latha Township. The second location is the Yangon Port Area, that starts at the south east corner of the Latha Township. The third location is Monkey Point, at this location the water levels of the Yangon River are modelled/measured (see Section C.3.11). Monkey point is about 5 km downstream of the outlets for the Latha Township

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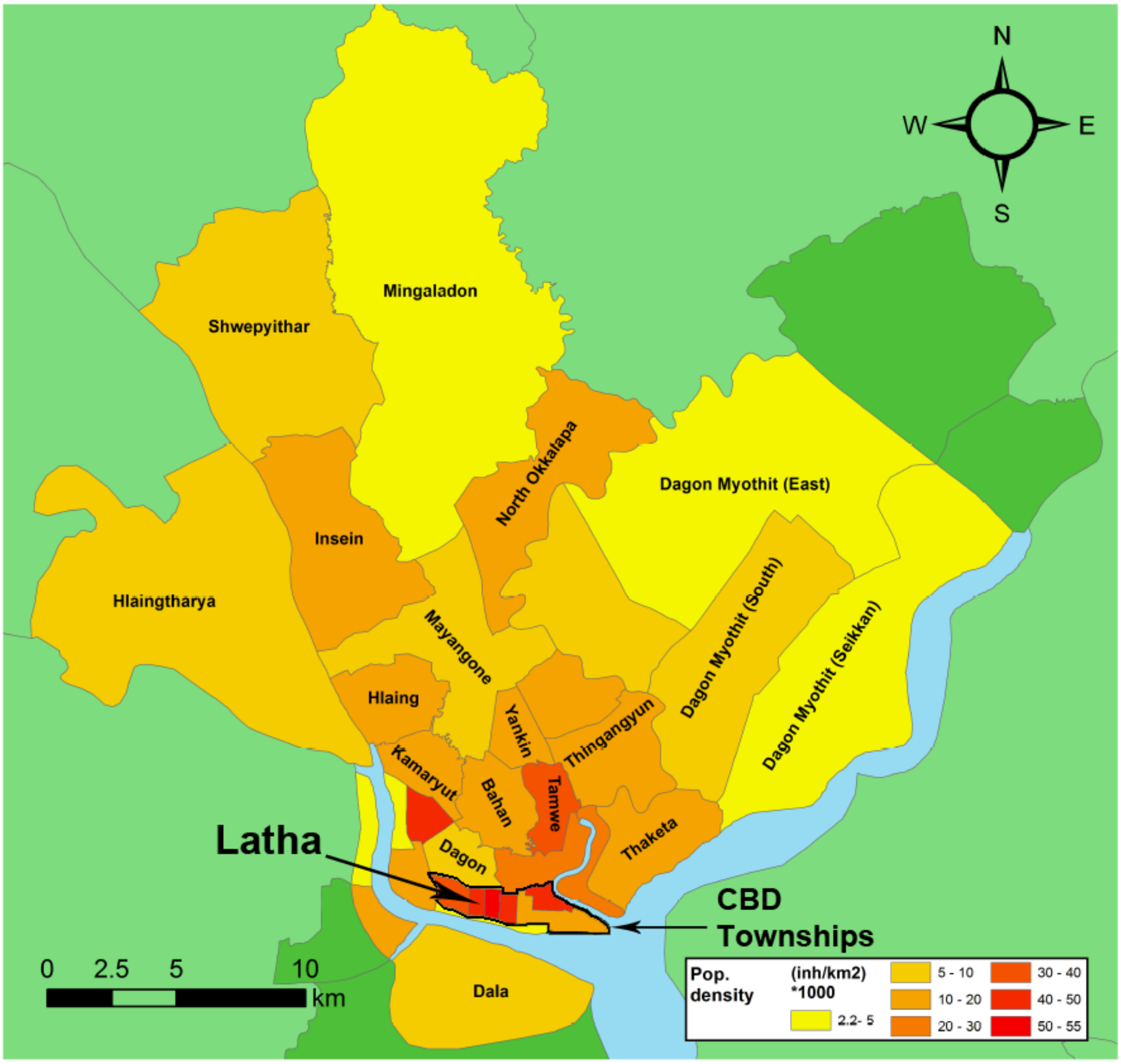


Figure 2.6: Map of te population density in Yangon's different townships. Only the names that fit are shown together with Latha (for all names see Figure A.7). The central business district (CBD) consists of 6 downtown townships (see Appendix A, Figure A.8) that have the highest economic, commercial and financial activity (JICA and YCDC, 2013). The image shows that Latha is one of the most densely populated areas in the city. Modified from (Van der Horst, 2017, fig.2.3).

In the past decades, Yangon City has grown tremendously (Figure 2.7). "Foreign investment in Burma, particularly from China, is on the rise", "hitherto greenfield sites surrounding the city have been built upon", the "demand for office space has grown, and construction taking place in the city centre is of an ever-enlarging vertical scale" (Morley, 2013, p. 601). "Burma's largest city must be recognized as being in the midst of a process of environmental alteration, a reshaping that reflects the nation's push for modernity and development" (Morley, 2013, p. 601), a process that will continue in the near future as there are plans to develop the city even further (JICA and YCDC, 2013, 2014).

Within the city there are ground level elevation variations. Foothills that originate from the Yangon Region's low, long hills in the north-south direction which gradually transition into the delta plains west, south and eastwards (see appendix, Figure A.11). However, all urban areas close to the rivers (including Latha) are low laying areas with ground level elevations just a few meters above mean sea level (also see appendix Section C.3.8).

Figure 2.7: Urban development of Yangon City throughout the years. The current township borders are highlighted in yellow in all images. Obtained from (Van der Horst, 2017, fig.2.7).

2.2.4. Latha Township

The Latha Township (Figure 2.8, also known as Yangon's China Town see Figure 2.10a) is one of six townships in Yangon's CBD. With an area of about 70 hectares and a population of just over 25,000 people (MIP - DP, 2015) it is one of the smallest townships (surface area wise), but a township with one of the highest population densities (Figure 2.6).
The township has a grid like structure with four main roads running from west to east (Bo Gyoke Road, Anarwrahta Road, Maha Bandula Road and Strand Road). Two main north-south oriented roads (Lanmadaw Street and Shwedagon Pagoda Road) together with the train tracks in the north and the Yangon River in the south confined the township (see Figure 2.9).

Based on its land use characteristics found during field work (see Figure 2.10) the township was split up into three areas: the hospital area, the residential area and Strand Road (night) Market (see Figure 2.9. In the northern hospital area the building density was relatively lower and the area was more unpaved and *green) (Figure 2.10b)*. Along the south side of Strand Road a recently (early 2017) opened new (night) market area (Figure 2.10c) hosted a lot of food market stands. The residential area (Figure 2.10a), with its smaller north-south oriented streets, was where the majority of Latha's citizens live (MIP - DP, 2015) and where a large number of shops, restaurants and street shops sold their products. The residential area can be split up in a upper block between Anarwrahta Road and Maha Bandula Road and a lower block between Maha Bandula Road and Strand Road.

Figure 2.8: Satellite image from the Latha Township. The image shows train tracks at the north boundary, a large street (Strand Road) on the south boundary. Even further south, outside of Latha's boundaries are Yangon Port terminals on the Yangon River's quay. The west boundary is Lanmadaw Street and the east boundary is Shwedagon Pagoda Road. The top part area has a lower building density and shows more signs of vegetation compared to the central and lower part of Latha. These areas have a grid like structure. For more details about the names of different areas see Figure 2.9. Modified from Google Maps.

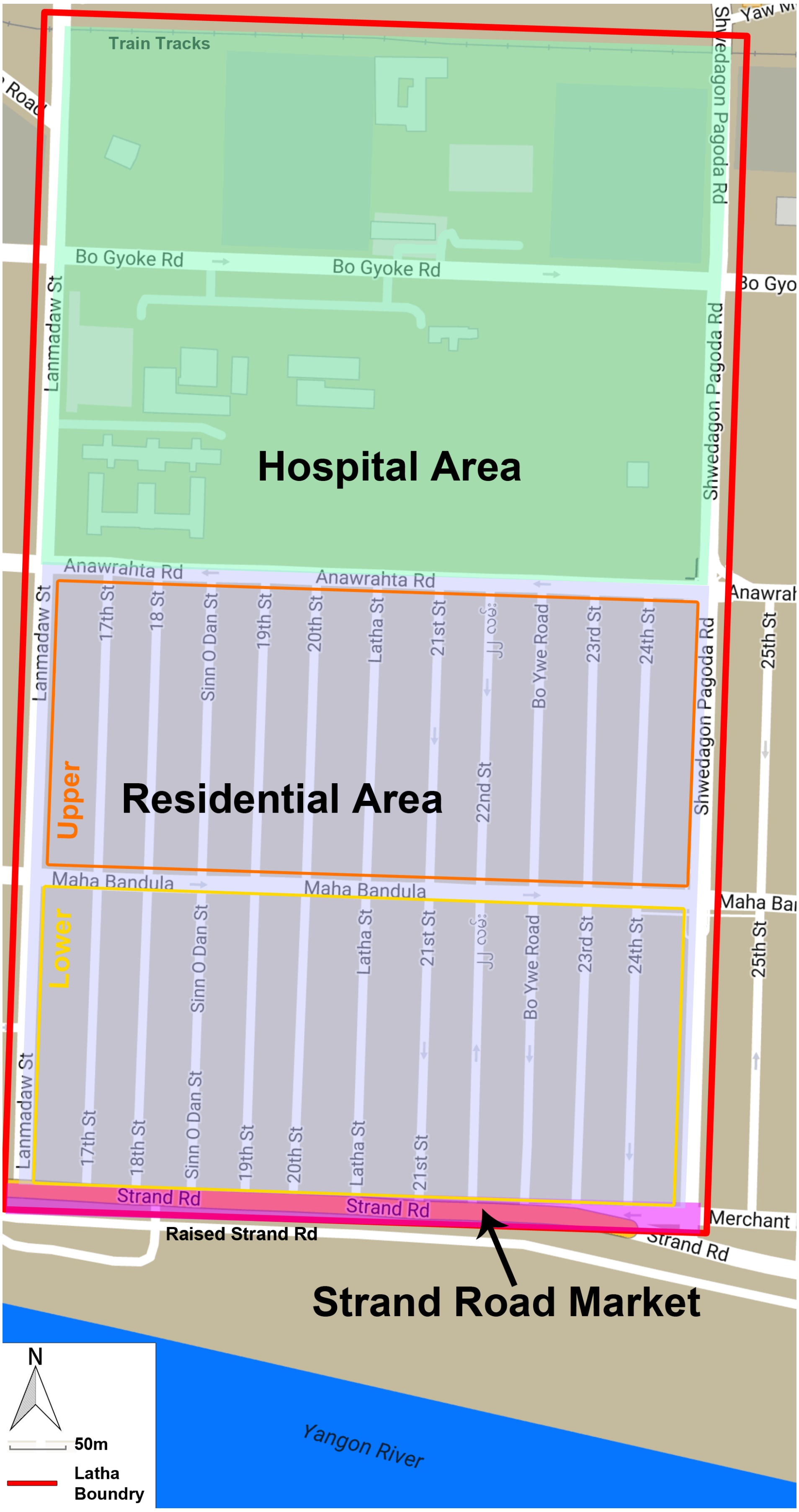


Figure 2.9: This report sometimes refers to streets and/or locations within the Latha Township. This map provides an overview of the streets and locations. The Latha township is confined by the Train tracks at the north of the area, Strand Road at the south of the area, Lanmadaw Street at the west of the area and Shwedagon Pagoda Road at the east of the area. Based on its characteristic Latha was divided into 3 areas: the hospital area, the strand road market and the residential area. The residential area could be split up in a upper block between Anarwrahta Road and Maha Bandula Road (orange) and a lower block between Maha Bandula Road and Strand Road (yellow). Modified from Google Maps.

(a) Maha Bandula Road in the Latha Township during Chinese new year, seen from the junction with Maha Bandula Road and Shwedagon Pagoda Road looking to the west. Picture taken on January 28, 2017.

(b) Hospital area on the left and the residential area on the right. Seen from the junction between Lanmadaw Street and Anarwrahta Road, looking in north-east direction. Picture taken on February 8, 2017.

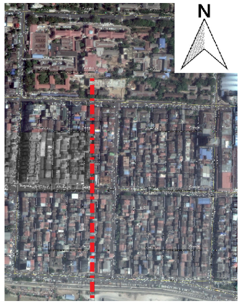
(c) Strand Road (night) market at the south side of Strand Road between 20th Street and Latha Street, looking in east direction. In this area a lot of salesmen sold their products. Picture taken on April 3, 2017.

Figure 2.10: A clear difference should be observed between Latha's residential area (Figure 2.10a) and Latha's hospital area (Figure 2.10b). The hospital area had much less purvious areas, a lower building density and a lower population density. At Strand road, only market salesmen sell their products from stands.

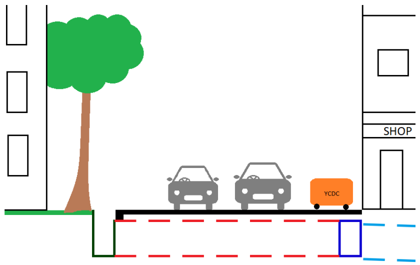
An interview with the Yangon City Development Committee Engineering Department of Roads and Bridges (YCDC EDRB) made clear that the residential area and Strand Road market were Latha's flood prone areas. The hospital area had too high ground level elevations to be flooded and the same applies to the neighbouring and other downtown townships, albeit for the Lanmadaw Township to a lesser extent (see Table D.2). Apart from the low elevation, the high ratio of paved to unpaved areas and the high building density also resulted in less infiltration, faster run-off processes and more nuisance to Latha's citizens. Since the area was one of the most commercially active areas the damage to entrepreneurs and the nuisance for costumers was high and the group of people being affected large. Moreover, in case of a flood of (one of) the three main roads (Anarwrahta Road, Maha Bandula Road and Strand Road) the transport of numerous commuters and passer-bys was affected.
Figure 2.11 provides an illustrative cross-section of the Latha residential area. There was a small gradient in the ground level elevation, from high in the north to low in the south. In the west-east direction the outskirts of the township were in general higher than the centre of the township around Latha Street. For more information about the ground levels see Section C.3.8.
At the north side of Anarwrahta Road an open drain connected the hospital area to the residential area (dark green drains). Underneath the three main roads, culverts connected the different drains (red dashed lines). Covered off, concrete drains made up the large majority of the township's drainage system, running parallel on both sides of the small north-south streets (light blue dashed lines) and parallel to the main roads (dark blue lines). A drain along the south side of Strand Road (mostly open) eventually connected the drainage network to three gate outflow structures that discharged into the tidal Yangon River. For more information about the drainage network see Section C.3.7. For more information about the gate outflow structures see Section C.3.9, Section C.3.12 and the previously referred sections about the urban drainage system (UDS). For more information about the Yangon River water levels, see Section C.3.11.
Just south of Strand Road, the ground level elevation had a sharp increase (see Figure 2.11d and Figure 2.11a). Here was *Raised Strand Road* (see Figure 2.9, officially also called Strand Road), for the transport of trucks with containers to the different terminals of the Yangon Port. Due to the large elevation difference (~2 meter, see Figure A.18) this road acted somewhat like a large dike, separating Latha's southern boarder and the Yangon River (see Figure 2.11d).

As earlier mentioned in this section, the residential area was a mix of households and commercial activities. In general the majority of the shops were situated along the main roads or the beginning of the smaller side streets, however there were some exceptions. There was also a difference to be made between shops and restaurants who operate their business from a building or from a market stand on the street. For more details see Section C.3.4.

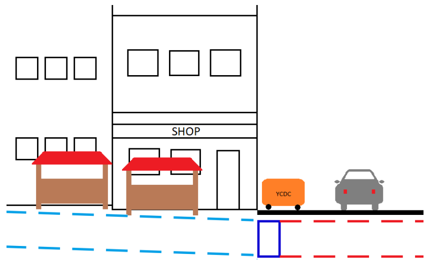
Latha's citizens were relatively high educated, had a high employment rate and in general were older than Yangon's citizens in general (MIP - DP, 2015). Moreover, Latha was part of the downtown central business district. Here the living prices were one of the highest throughout the city and thus on average Latha's citizens were more wealthy (Kyaw Mein Oo, personal communication, April 6, 2017). For more socio-economic data about Latha see Section 3.1.2.



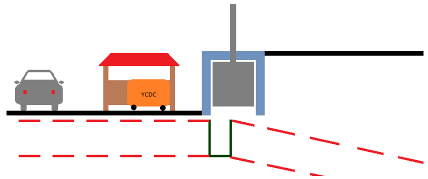
(a) The red line gives the direction of the cross section for Figure 2.11e. Although the exact location is not relevant as Figure 2.11e is only illustrative.for what a typical cross-section looks like through the Latha Township.



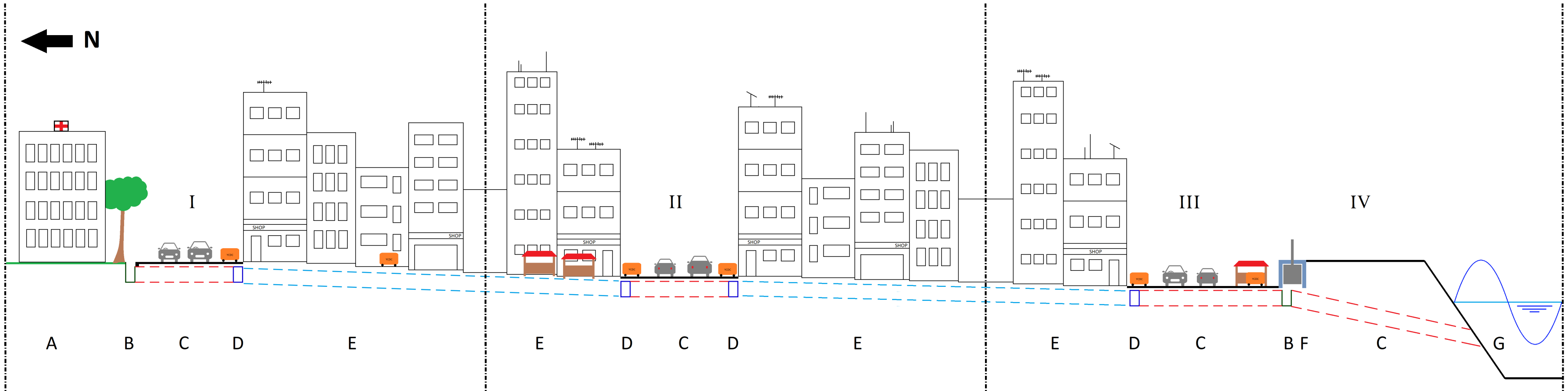
(b) Detail of Figure 2.11e, that shows the *green* hospital area, the open drain along the north side of Anarwrahta Road and a closed one on the south side, with a culvert connecting them underneath Anarwrahta Rd.



(c) Detail of Figure 2.11e, that shows a shop in the street, 2 market/street shops a container and a car driving along a main road. The blue dashed lines are covered drains running north-south on both sides of the street.



(d) Detail of Figure 2.11e, showing a market at Strand Rd., together with the open drain that runs parallel to the majority of Strand Rd. The drains come together at one of the 3 FGSs that drain to the Yangon River.



(e) Indicative cross-section (not to scale) for the Latha Township, illustrating a typical street in the Latha Township. The cross-section has no specific location as the exact distribution of building layers, shop and market locations and container locations does not represent an actual location. The northern part of the township consists of the hospital area (A), which is a relative pervious area. Parallel to Anarwatha Road (I) is running an open drain (B) and a covered drain (D), that is connected through an underground culvert (C). Covered drains run along the houses (E) and drain towards Maha Bandula Road (II). Eventually the drains go underneath of Strand Road (III) and joined by the open drain that runs along the southern side of Strand Road to a FGS (F) and eventually discharges into the tidal Yangon River (G). Raised Strand Road (IV) and a small strip of the Yangon Port have higher GLEs and serve somewhat like a wide dike, separating the southern Latha border and the Yangon River.

Figure 2.11: This figure provides an indication of a typical cross-section of the residential area of the Latha Township.

2.2.5. Institutional Set-Up of Yangon & Latha Township

Yangon had a very hierarchical institutional set-up. For Yangon city there was the YCDC, which had a large number of departments working on different agendas YCDC (2017). The city was divided into multiple districts, consisting of several townships (see appendix, Figure A.7). Each township was divided into wards that made out the smallest institutional unit/administrative areas. Within the Latha Township there were ten wards (Figure 2.12), numbers 1 to 8 are situated in the residential area and wards 9 and 10 were situated in the hospital area. Typically the wards had about 3 streets under their supervision. For some streets, the western part fell under a different ward than the eastern part of the street. The Strand Road (night) Market was not under the responsibility of the township, but was managed by the YCDC Market Department (Tun Lin Aung, personal communication, April 4, 2017). All ten wards had their own administrative office and were responsible for implementing parts of the YCDC's activities. The wards were overseen by the General Latha Township Office, which was responsible for the Latha township as a whole. Weekly meeting with the General Township Officer and all ten Ward officers allowed for planning and coordination.

For this research the most important departments were the YCDC EDRB and the Yangon City Development Committee Pollution Control and Cleansing Department (YCDC PCCD). The YCDC EDRB was responsible for the drainage system, cleaning and maintenance of the drainage system and operation of the FGSs. The YCDC PCCD was responsible for the waste container collection and for cleaning the streets. Both departments had representatives at each institutional level till township level (thus not at ward level).

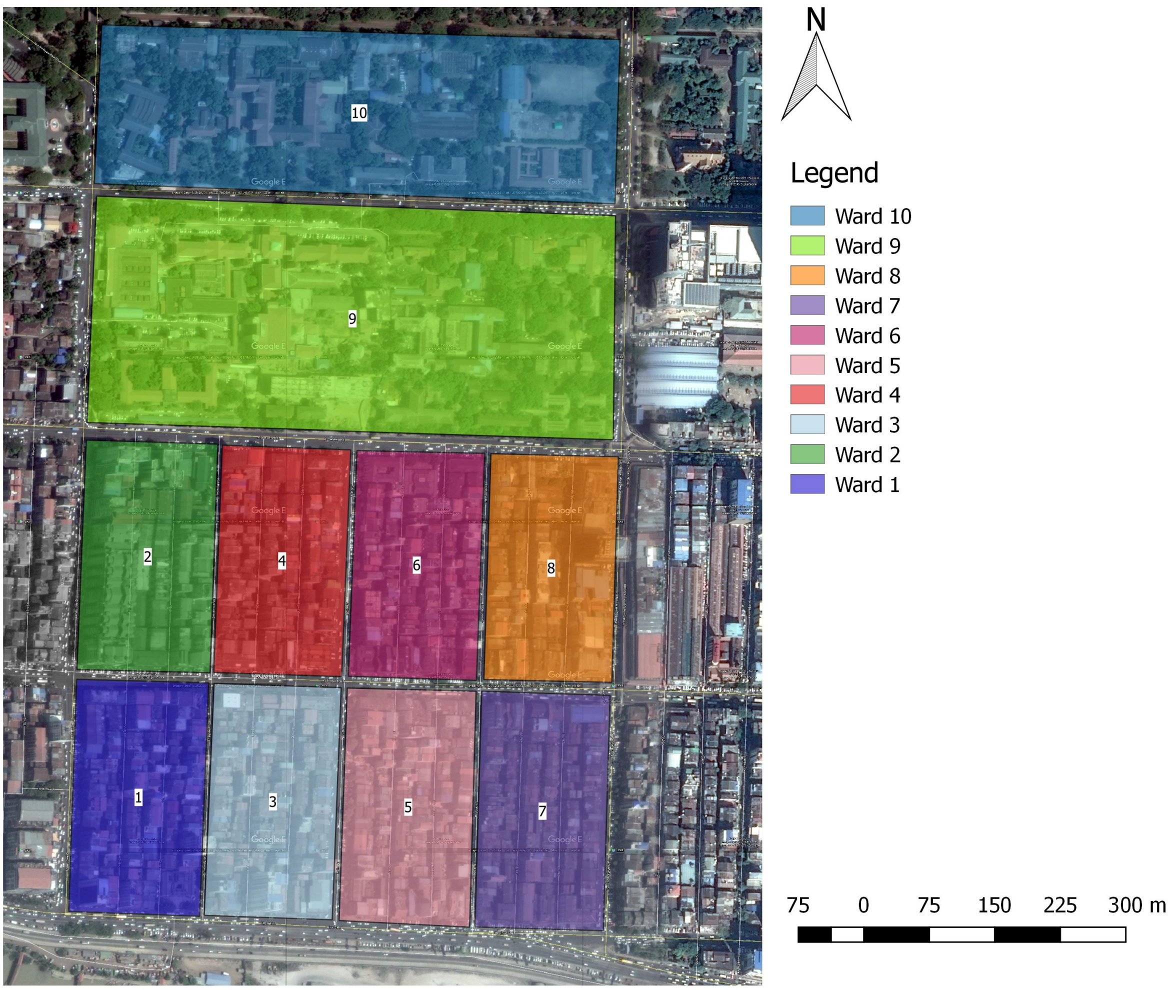


Figure 2.12: The Latha Township consists of 10 wards. These ten wards all have their own administrative office and are responsible for implementing parts of the YCDC's activities. The wards are overseen by the General Latha Township Office, which is responsible for the Latha township as a whole.

2.3. Research Constrains

This research was only focussed on the human-water system (HWS) of Latha's residential area (see Figure 2.9) for the rainy season during July 2014. The hospital area had too high ground level elevations to be flooded. Moreover, this area had a lot more unpaved areas compared to the residential area and the hospital area's population density was much lower. Therefore, the rainfall runoff and dry weather flow from the hospital area was modelled as an upstream boundary condition. The Strand Road market was only opened recently and did not exist before January 2017. The 2014's rainy season month July was selected since this yielded the most high-quality datasets for hydrological and hydraulic data.
The human-water system and flood dynamics of Latha were in reality more complex than just urban (pluvial) flooding. Given its position so close to the shore, the big river mouth and several rivers (and tributaries) that surround the city, Latha's floods could have multiple origins. For this research only urban pluvial flooding and high Yangon River water levels were considered. These two possible flood causes were selected as rainfall can result in direct flooding and high river water levels can affect the discharge capacity of the UDS. Direct or indirect flooding as a consequence of river bank over-topping, levee failure or storm surges (such as the cyclone Nargis (IFRC, 2011) of 2008) were out of the scope of this research. Groundwater flooding as a result of a groundwater excess was also disregarded.
For the human actions and interactions, only activities, policies and practices within Latha's residential area (both from citizens and the YCDC) were considered. City wide, national, regional and/or global (political) dynamics were ignored. Historic socio-economic data for 2014 was hard to find. Therefore, this research collected data between January 1, 2017 and April 8, 2017 that served to approximate the data of 2014.

2.4. Hypothesis

At the start of this research a hypothesis was formulated for the Latha case study. It was constructed to serve as a framework that provided guidance in this study since the hypothesis could be evaluated based on the results of this research. At the time that it was shaped, hardly any case specific data and insights were present. Therefore this hypothesis was the result of a tiny amount of studied literature, common sense, gut feelings and personal perceptions. Its creation served as a framework that provided guidance for the focus of this research and to provide a basis for reflection and evaluation of the obtained results and insights.

The hypothesis for Latha, was that human actions such as waste production and poor waste management resulted in a strongly limited urban drainage capacity. This was a consequence of increased friction losses in the drains, blocked culverts and blocked sewer inlets by solid waste that resulted in lower drainage discharges.
Moreover, the urban expansion resulted in higher run-off coefficients and faster hydrological responses due to the increased impervious area (e.g., more houses/roofs, more infrastructure such as asphalt roads or parking lots). The population growth that accompanied the urban expansion resulted in higher water consumptions with higher dry weather flows. As a consequence of the increased water demand, more ground water was extracted. This resulted in subsidence, making more people vulnerable to flooding.
The urban pluvial flooding could have slowed down urban expansion (in specific areas) and increased nuisance and damage experienced by citizens. This could have had the effect that flood protection constructions were build and the drainage capacity was increased.
However, since people were not aware of their interaction with the UDS, they kept producing waste, thereby reducing the effectiveness of structural measures which resulted in an increased flood vulnerability.

Figure 2.13 shows the hypothesized conceptual socio-hydrological model of the urban pluvial flooding human-water system for the Latha Township residential area. More detailed overviews are shown in Figure F.2, Figure F.3a, Figure F.3b) and Figure F.4. In the now following sections the hypothesis is elaborated from three perspectives to touch upon all components of the hypothesized model concept.

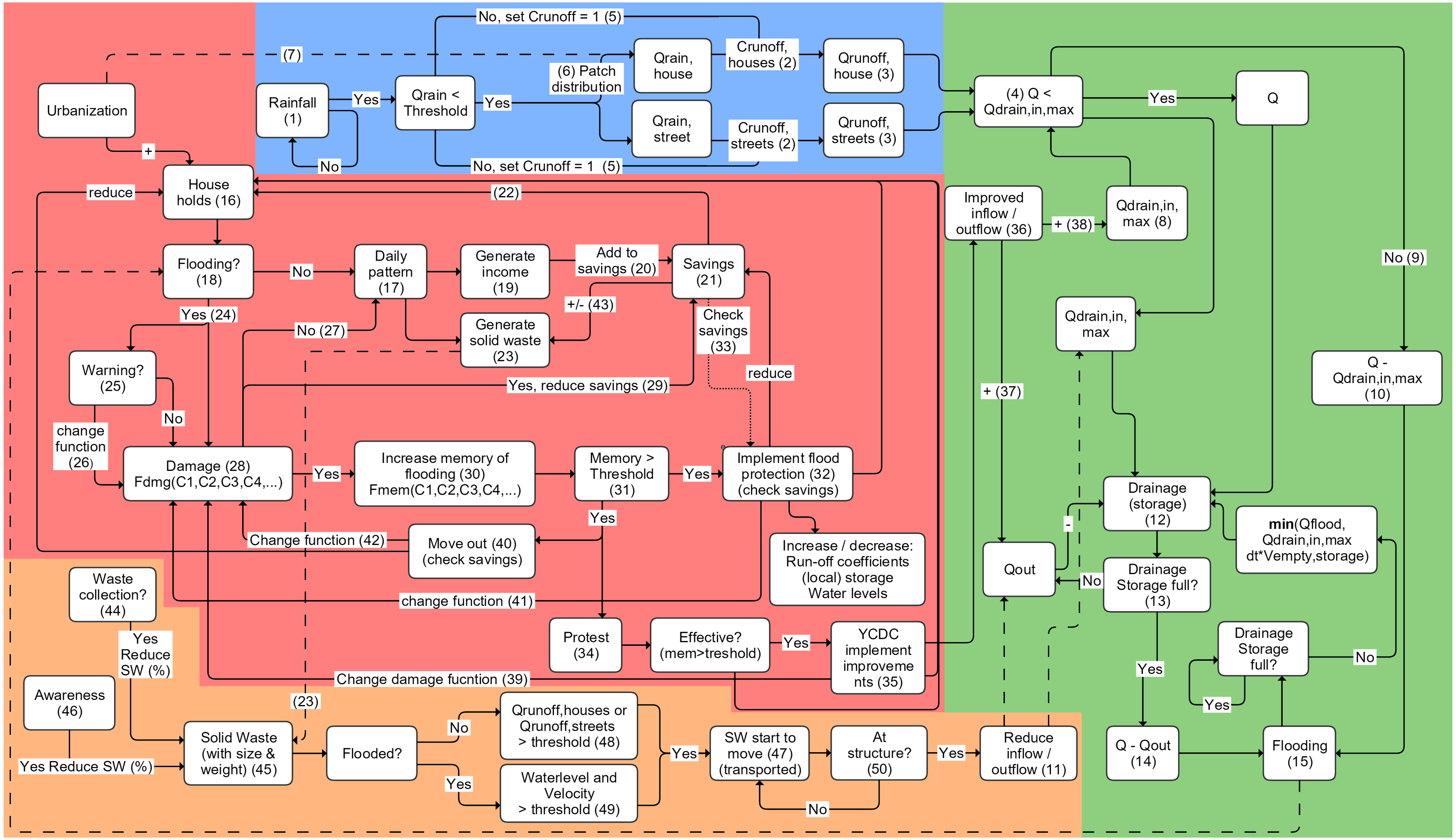


Figure 2.13: Hypothesis of the human-flood interaction. The red section represents the citizens' daily activity patterns (Detail in Figure F.2), responses to a flood and other related processes while the orange section is focussed on solid waste production, solid waste management and solid waste in the drains (Detail in Figure F.3a). Together these two parts represent the human activities. The right side represents the hydrological and hydraulic processes: with the blue section for the rainfall (runoff) (Detail in Figure F.3b) and the green section for the UDS's (flood) processes (Detail in Figure F.4).

2.4.1. Perspective from Rain/of a Raindrop

When it rains above Yangon (1), the water that falls down will partially be intercepted or infiltrate into the ground (2). The remaining part of the rain will runoff (3) and eventually end in the drainage (4). However, in the case of really intense events, the interception will be full and the infiltration processes are too slow thus resulting in a 100% runoff (5). The amount of runoff created depends on the type of surface the rain falls on. A distinction is made between no buildings, houses and street surfaces, each having their own rainfall-runoff formula (6). The distribution of these surfaces (represented by the grid cells) can change over time due to urbanization (7). Also the amount of runoff generated (2) is potentially under change e.g., because of changing brick roads into asphalt, or because of coupling a roof to a drain or by uncoupling it. For each surface the runoff drains towards one of the drains (4). The inflow into the sewer has a maximum, limited by the size of the openings of the drains (8). If the runoff is higher than the maximum inflow (9), part of the runoff will not flow into the drainage (10), but will be water that floods the streets. The maximum inflow of the drainage is not only effected by the size of the inlet, but also by its maintenance status. (solid) Waste may block (parts of) the inflow (11), reducing the actual inflow and potentially resulting in floods. Rain is not the only source of inflow to the drainage. Households also produce a waste water flow, adding up to the drain's total inflow discharge. However, this is small compared to the storm weather flow and is thus disregarded for now. Within the drainage system there is some storage (12). Once the storage is fully filled up (13) and the inflow is higher than the outflow, the sewer will start to spill water to the streets (14), resulting in a flood volume (15). The outflow of the sewer is also affected by its maintenance status (11), since better maintained sewers have less friction losses and thus higher outflow discharges. The outflow is determined by the size and the gradient of the drain.

2.4.2. Perspective of a Household

Households (16) have a daily pattern (17) that they will perform in case that there is no flooding (18). They potentially generate income (19) by working and are adding (20) this to their savings (21). If at the end of the day, the households have sufficient savings, they will keep active in the model (22). If a household is bankrupt, the household will become inactive. Within their daily pattern, the households purchases products that which will result in (solid) waste (23). Depending on their habits a part of their waste is not ending up in a collection system but on the streets or directly into the drainage (11) with its respective consequences (see above). If during a long period of rain or during high intensity rain events the streets and houses are being flooded, a household stops its daily pattern if the flood reaches the household (24). In case of a flooding a household can receive a warning (25), allowing it to reduce the (potential) damage/nuisance from the flood (26). The earlier a household is warned of a (potential) flood, the more the damage can be reduced. If there is no damage the household will continue with its daily patterns (27). In the case that there is damage (28), this will reduce the savings (29) of a household and thus may threaten its subsistence. At the same time different memories are increased (30). A household may have a memory that keeps track of the damage by flooding to evaluate (31) if it would like to implement flood protection measurements (32). In order to do so, a household must also have sufficient savings (33) in order to be able to invest in flood protection. Another possible memory can be keeping track off the will to protest (34) for improved management/maintenance (35). The improved maintenance has the potential to result in less frequent flooding because of higher inflows and outflows (36, 37, 38) and/or less damage (39). A final memory could be a memory that keeps track of the will to relocate (40) in the city to a less flood prone area (this could require even more savings). It is also important to find out how many people move out because they only work in Yangon during specific seasons. These memories could also be affected by the memories of neighbouring or related (e.g. family) households. Flood protection (41) or relocation (42) may also affect the damage function of a household resulting in less damage.

2.4.3. Perspective of a Piece of Waste

Waste is being produced by a household (23). Depending on the wealth of a household (43) more or less waste will be produced. A part of the waste is not collected (44) but ends up on the street or directly into the drainage system (45). The percentage is effected by the household's awareness (46). The more a household is aware of what impact throwing away waste on the streets has on the flooding, the less waste actually will be thrown on the streets and the more waste will be collected and processed. If waste ends up in the streets, it may only be transported (47) if there is sufficient flow (48) or in case of flooding sufficient water depth and if the water has a high enough velocity (49). If this is the case a piece of waste will start to move. The problems start to arise once one or multiple pieces of waste are ending up in front of a drain inlet or by a bridge/culvert, reducing the maximum inflow (50). Or if pieces of waste get into the sewer/canals affecting the roughness/friction losses and thereby reducing the outflow (11). Due to this inflow blockage or reduced discharge capacity the storages will fill up and eventually start to spill as a flood volume. At the same time, waste can be removed off the streets by the YCDC (or a responsible partner) if a proper collection system is present. The same applies for waste blocking the inlets and hydraulic structures. This waste management may result in less high water levels. However the amount of maintenance is determined by the political will, capabilities and available budget.

3

Materials and Methods

A mixed-method research methodology was developed to study the interaction between solid waste management (SWM) and urban flooding (UF) of a human-water system (HWS) and to develop a socio-hydrological model (SHM) of the interactions. The Latha Township (see Chapter 2) was selected as a case study that provided a basis for this research. For the HWS of Latha, a hypothesis of a conceptual SHM was constructed (Section 2.4). In order to answer the research question and to evaluate the hypothesis, socio-economic data was collected and analysed to identify the relevant human SWM activities that affected UF. At the same time a flood model was made based on hydrological and hydraulic data that was collected for Latha. The flood model was used to study which hydrological and hydraulic processes played a dominant factor for the occurrence of UF in the township. The socio-economic results and flood model results were then used to evaluate the initially constructed hypothesis and to come up with an improved hypothesis that was implemented in a SHM.

The rest of this chapter discusses the details of the data, tools and methods used for this research. The chapter is divided into two sections of which the first describes the used materials: the used data and used software. The second section explains how these materials were modified and combined to obtain the results of this research.
The mixed-method approach of this research has resulted in a large amount of used materials and methods. In order to keep a good overview and provide sufficient clarity, this chapter only discusses the main materials and methods. Additional information about the used materials and methods can be found in appendices.

3.1. Materials

3.1.1. Data Collection

For this research a lot of different datasets had to be collected and constructed. Some of these datasets served as direct results of this study (e.g. questionnaire results), whereas other datasets were required as an input to some of the used methods (e.g. rainfall data for the flood model). This made it hard to decide what belonged in this report's materials section and what in the results section. Moreover, the large number of datasets would also reduce this main report's readability. Therefore, Appendix C provides an overview of most datasets.

As mentioned in the research constraints (Section 2.3) this research is focussed on the rainy season of 2014. The month July 2014 yielded the most complete hydrological and hydraulic dataset (urban drainage network properties and layout data, ground level elevation (GLE) data, flood records data, river water levels data and rainfall data) for the selected case. Therefore, most of the collected data was presented in such a way that especially the data for the month July 2014 was shown. Some datasets also contained data for other time frames, but this data was omitted for clarity. Using the month July 2014 had two other benefits. Namely, this month was within Latha's rainy season and there actually were flood records of that period. Thus using this month made sense from an urban flooding perspective.
Some of the socio-economic data could not be obtained for July 2014 and thus other datasets were used to approximate the relevant data.

3.1.2. Socio-Economic Data

For this study, socio-economic data was collected in order to model socio-economic processes. This data was collected through questionnaires (Section 3.2.2), interviews (Section 3.2.4) and observations (Section 3.2.3). Census data provided a reference that was used to cross-check the results from the questionnaires, interviews and field observations. Moreover, it served as an additional data source for modelling socio-economic processes of the socio-hydrological model (Section 3.2.7).
In some of the statistics the census report differentiated between conventional households (CHH) and institutions (INST): hotels, hospitals and police/prison cells (MIP - DP, 2015, p.7). Also note that Yangon here refers to the Yangon Region, not only to the city.
The census report (MIP - DP, 2015) was produced by the Ministry of Immigration and Population's Department of Population in 2015 and was obtained from JICA on March 28, 2017.

The median age for the Yangon Region was 28.3 years (MIP - DP, 2015, p.1) and the age distribution is shown in Figure 3.1. Table 3.1 provided more additional information about the age distribution of Latha. Latha had a relative high age and a predominantly female population, compared to Yangon. The high age could also be an indicator that people lived for long durations in the Township. In the scientific relevance section (see Section 1.2) it was mentioned that flood awareness has a relation with the time of residence of individuals (Burningham et al., 2008). Thus it could be that Latha's citizens have a high awareness.
Table 3.2 provided data about the household sizes in Latha and Yangon. It also provided data about the number of people that were living in institutions and thus provided some details about the population of the hospital area (see Figure 2.9). In general Latha had on average a smaller household compared to Yangon. This dataset was used to allocate the dry weather flow (DWF) in the flood model.
Table 3.3 was collected since it provided data about the education level of Latha. In the scientific data (see Section 1.2) it was also mentioned that flood awareness has a relation with an individuals social class (Burningham et al., 2008). A higher education level could be an indicator of a higher social class. Based on the data, it was concluded that Latha had a higher average education level than Yangon. In Yangon the average university grade was 17.3% whereas for Latha it was 42.3 %.
Similar to the previous paragraph, a citizen's occupation could also be an indicator of a social class. For example, an entrepreneur with a private company could be part of a relatively high social class. Data about Latha's employment status was provided in Table 3.4. The employment rate of Latha was high, but did not show extreme deviations compared to Yangon as a whole.

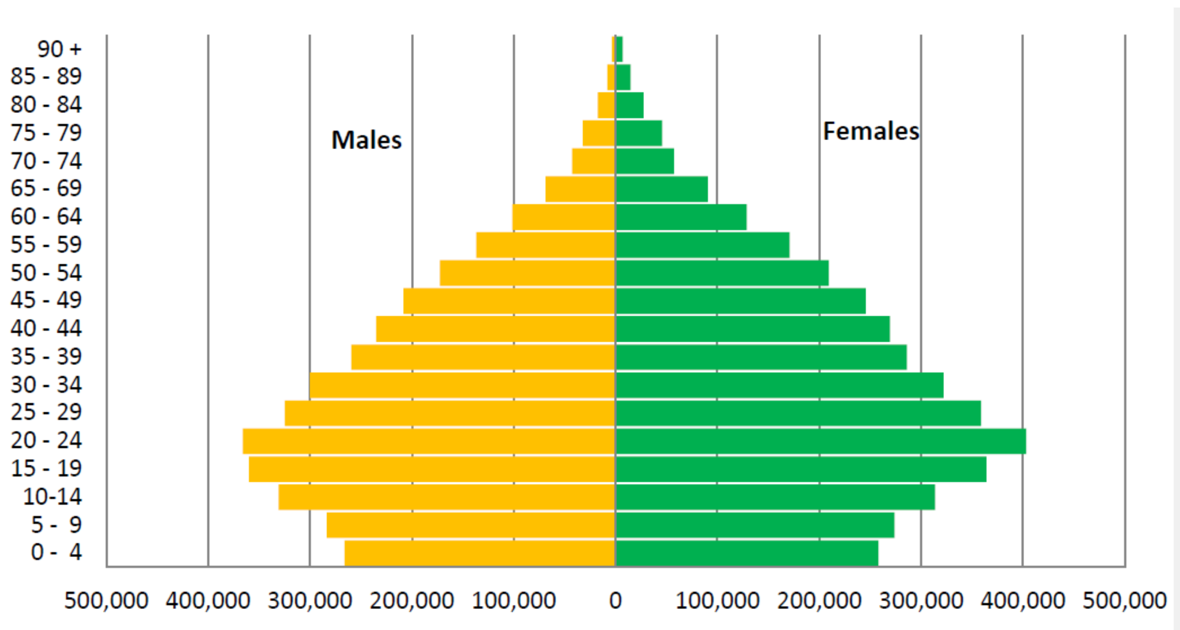


Figure 3.1: The age distribution for the Yangon Region (MIP - DP, 2015, fig.4).

Table 3.1: Statistics for population of Latha Township compared to Yangon. Based on the statistics it was conclude that the citizens of the Latha Township were relatively older. In this table, age group (AG) was abbreviated for readability. Data from MIP - DP (2015).

Population Groups	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Total Population	25,057	100.0	7,360,703	100.0
Male	10,728	42.8	3,516,403	47.8
Female	14,329	57.2	3,844,300	52.2
AG 0 – 14 years old	2,735	10.9	1,725,416	23.4
AG 15 – 64 years old	19,986	79.8	5,219,941	70.9
AG 65+ years old	2,336	9.3	415,349	5.7
AG age ≥ 10	23,592	94.2	6,279,629	85.3
Population in CHH	18,161	100.0	6,949,440	100.0
AG age in CHH ≥ 15	15,686	86.4	5,271,946	75.9
AG age in CHH ≥ 25	12,454	68.6	3,949,139	56.8

Table 3.2: Statistics for households in Latha and Yangon. Based on the statistics it was concluded that relatively more people households were female headed and on average households were a bit smaller. What was also striking is the difference in the relative population in institutions, which was a lot higher for the Latha Township. Data from MIP - DP (2015).

Households Data	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
CHHs	4,473	100.0	1,582,944	100.0
Households Data	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Population	25,057	100.0	7360703	100.0
Population in INST	6,896	27.5	411,263	5.6
Population in CHHs	18,161	72.5	6,949,440	94.4
CHHs of 1 person	506	11.3	68,073	4.3
CHHs of 2 persons	708	15.8	216,707	13.7
CHHs of 3 persons	865	19.3	325,983	20.6
CHHs of 4 persons	830	18.6	338,953	21.4
CHHs of 5 persons	606	13.5	249,425	15.8
CHHs of 6 persons	376	8.4	158,136	10.0
CHHs of 7 persons	241	5.4	95,117	6.0
CHHs of 8 persons	141	3.2	63,475	4.0
CHHs of ≥ 9 persons	200	4.5	67,075	4.2
Male-headed CHHs	2,679	60.0	1,199,003	75.7
Female-headed CHHs	1,794	40.0	383,941	24.3
Mean CHH size	4.1	N.A.	4.4	N.A.

Table 3.3: Statistics for education in Latha and Yangon. The statistics were for people older than 25 years old and living in conventional households only. From the statistics it was concluded that the average degree of education was a lot higher for the Latha Township when compared to the whole of Yangon. This might be a good indicator of relative wealth and awareness as mentioned in Section 1.2. Data from MIP - DP (2015).

Age Group	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Age ≥25 CHH	12,454	100.0	3,949,139	100.0
Highest Grade for Age ≥25 CHH	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
None	529	3.6	231,473	5.9
Primary school	2,493	12.4	1,280,979	32.4
Middle school	3,529	18.9	936,383	23.7
High school	5,006	20.5	712,985	18.1
Diploma	152	0.2	14,503	0.4
University	11,330	42.3	684,333	17.3
Post-graduate	678	1.8	39,750	1.0
Other	163	0.3	48,733	1.2
Age Group	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Age in CHH ≥ 15	15,686	86.4	5,271,946	75.9
Literacy	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Literate (age ≥ 15)	15,325	97.7	5,092,700	96.6

Table 3.4: Statistics for employment in Latha and Yangon. The statistics were for people older than 10 years old and living in conventional households and institutions. There did not seemed to be a big difference in the employment status distribution. Data from MIP - DP (2015).

Age Group	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Age group age ≥ 10	23,592	100.0	6,279,629	100.0
Employment status for Age ≥ 10	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Employee government	1,071	4.5	258,151	4.1
Employee private sector	7,601	32.2	1,784,656	28.4
Employer	1,074	4.6	128,576	2.0
Own account worker	2,978	12.6	887,821	14.1
Unpaid family worker	931	3.9	209,537	3.3
Sought work	545	2.3	142,701	2.3
Did not seek work	133	0.6	28,733	0.5
Full time student	2,872	12.2	853,726	13.6
Household worker	3,699	15.7	1,255,087	20.0
Pensioner, retired, elderly	1,896	8.0	401,484	6.4
Disabled	220	0.9	47,164	0.8
Other work	572	2.4	281,993	4.5

3.1.3. Hydrological & Hydraulic Data

For the flood model in this research (see Section 3.2.5), a lot of different datasets were collected, analysed, assimilated and used (see Figure 3.8). For clarity and readability the complete datasets are presented in Appendix C. This appendix also contains information about the collection and provides additional analyses and more details about pre-processing and post-processing. Table 3.5 provides an overview of where the different complete datasets can be found in the appendix.

Table 3.5: Figure 3.8 shows that for the SOBEK model a lot of different datasets were collected and used. For clarity and readability of this report, a lot of this data is presented in Appendix C. This table provides an overview of where the different datasets and dataset analyses can be found.

Materials	**Location**
Urban Drainage Network Data	Section C.3.7
Ground Level Elevation Data	Section C.3.8 & Section C.3.10
Flood Records for Latha	Section C.3.9
Yangon River Water Level Data	Section C.3.11
Operation Rules Flood Gate Structures Data	Section C.3.12
Rainfall Data	Section C.3.13
Storm Weather Flow	Section C.3.14 & Section C.3.14.1
Dry Weather Flow	Section C.3.14 & Section C.3.14.2

In order to make the flood model, more detailed information about the drainage system's properties were required. A map (Figure 3.2) was obtained that contained details about the location of the drains, sizes of the drain, flow direction in the drains, GLEs, flood gate structure (FGS) locations and culvert locations.
This map together with field observations (see appendix, Section C.3.7 & Figure C.10) made it possible to classify the drains in the township. Three types of drains were identified: canal drains uncovered, canal drains covered and pressurized drains (see Figure 3.3).
The flood model used a Manning's roughness for the friction component of the Saint-Venant (S-V) Equation. Field observations (Figure C.10) revealed that the drains were constructed from concrete and bricks. Therefore a Manning's roughness of $m = 0.015\,\mathrm{s/m^{1/3}}$ was used (Oregon State University, 2006).
A 5x5 meter GLE grid of Latha was created with the GLE point data from Figure 3.2. This was used in the flood model for the overland flow computations. The grid was constructed by a third order inverse distance weighting interpolation (see Section C.3.8). The resulted dataset is shown in Figure 3.4. From a recent study by Van der Horst (2017) it was concluded that Latha did not have any significant subsidence in the past few years.
However, the GLE data lacked a reference that multiple attempts were not able to solve (read Section C.3.10). Therefore, three artificial ground level reference (GLR) systems were constructed and used in the flood model. Table 3.6 provides the used ground level references with respect to mean sea level (MSL).
The GLR systems were constructed using flood records (Section C.3.9) that were present on FGS 7 (see Figure 3.3 for the location of FGS 7). Scratch marks made by Yangon City Development Committee Engineering Department of Roads and Bridges (YCDC EDRB) employees recorded past flood events, together with a water level. The data is presented in Table 3.7. This dataset was also used to verify the results of the flood model.

Table 3.6: Data conversion that linked ground level values from the drainage map (Figure C.8) to MSL, by means of the scratch marks (see Section C.3.9).

GL Reference	Scratch Mark (Date)	Scratch Mark (m MSL)	GL (m GLR)	GL (m MSL)
GLR 1	22-08-2015	+7.22	0.00	+5.22
GLR 2	14-07-2014	+6.81	0.00	+4.83
GLR 3	13-07-2014	+6.72	0.00	+4.77

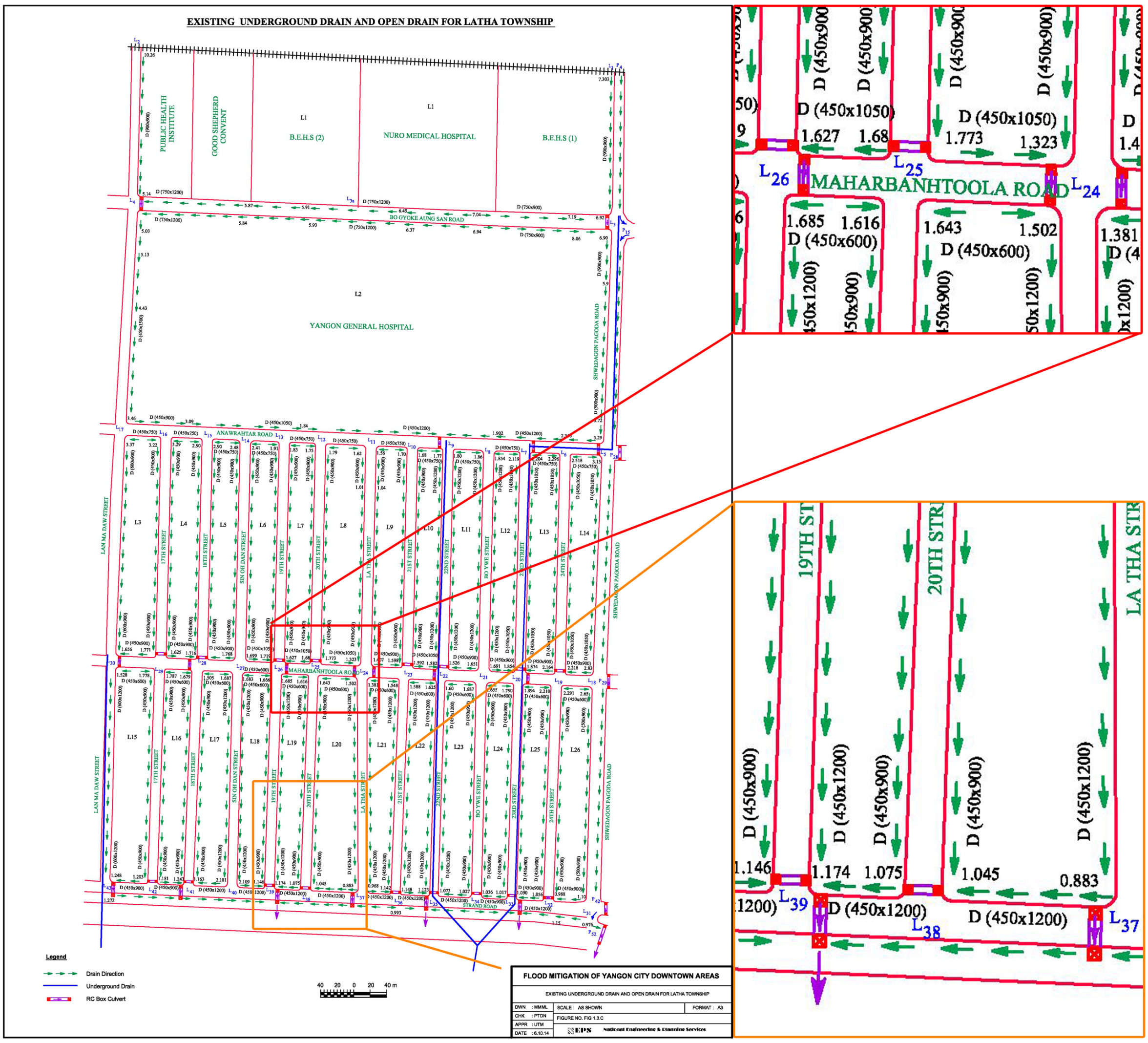


Figure 3.2: Overview map of the urban drainage system of the Latha Township in 2014 (for more details see appendix, Figure C.8). The map provided GLE data, e.g. the top right detail for example shows a GLE of 1.323 m. Moreover, the detail also shows that the map provided dimensions and positions of the drains. For example 450x1050mm and the direction of flow through the drains (green arrows). Furthermore, the map indicated culverts (magenta with red shapes), drain flow directions (green arrows), FGS locations and underground drains (flat blue lines, not relevant for this study). Modified from the original map titled: "Existing Underground Drain and Open Drain for Latha Township", created by NEPS on October 6 2014 and obtained from YCDC EDRB on April 4 2017.

Table 3.7: Flood record scratch marks measurements, for different flood events. For more details see Section C.3.9, Figure C.15, Table C.3 and Figure C.16. Data collected on April 6, 2017.

Date of Record	Recorded Water Level (m MSL)	WL above GL outside of gate (m)
22-08-2015	+7.22	0.95
14-07-2014	+6.81	0.93
13-07-2014	+6.72	0.90

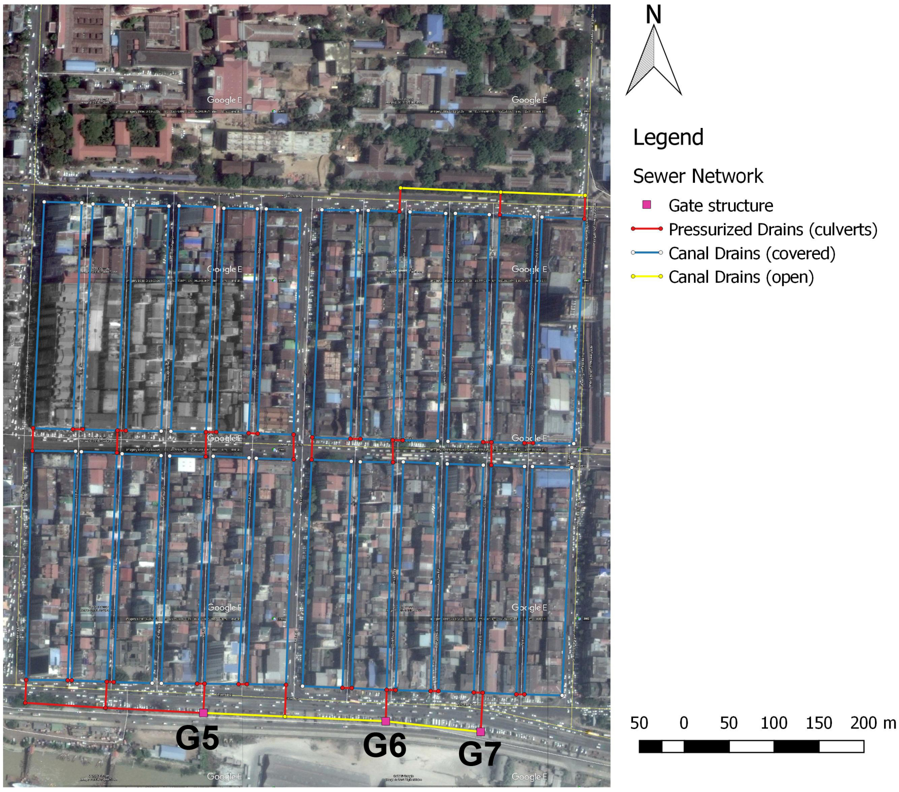


Figure 3.3: Overview of type of drains. The drains that were classified as a covered canal are indicated in blue while open canals are displayed with yellow. Culverts and pressurized drains are depicted with red. The 3 gate outlet structures are indicated by the magenta squares (gate 5, 6 and 7). Data obtained by field observations between 01-03-2017 and 30-03-2017. See Figure C.11 for an enlargement.

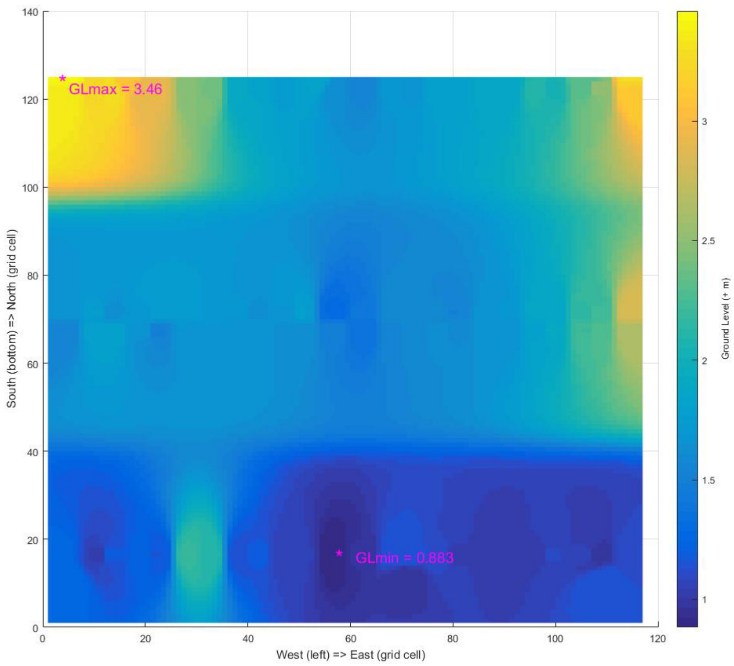


Figure 3.4: GLEs for the Latha Township. The township was divided into 5x5 meter cells. The GLEs were estimated by a 3rd order inverse distance interpolation based on known elevations in the Latha Township (see Section C.3.8). The highest value was in the north-west corner 3.46m and the lowest value was 0.883m. See Figure C.14 for a larger figure.

Latha's urban drainage system (UDS), discharged under gravity flow into the tidal Yangon River (see Figure 2.9 for the location of the Yangon River) through a total of 3 FGSs. No pumps were installed to discharge any total weather flow (TWF) (see Section C.3.14). The FGSs were closed if the water level (WL) in the Yangon River was too high. Therefore, the Yangon River water level (YRWL) was considered a downstream boundary condition, since it had an effect on the UDS's discharge. High water and low water YRWL data was collected from a study by De Koning and Janssen (2015) and approximated to an hourly time series by means of a combination of sinuses (see Section C.3.11). The resulted time series is shown in Figure 3.5. The hourly time step was chosen since the rainfall data had a temporal resolution of one measurement per hour.
The operation of the FGSs (for an example, see Figure 3.6) had no clear operational rules (see Section C.3.12). The gates were manually operated by YCDC EDRB employees, most of the times the gates were closed about 2 to 4 hours before high water (Kyaw Mein Oo, personal communication, April 6, 2017).
An important input for the flood model was rainfall. Figure 3.7 shows the hourly rainfall volumes for Yangon in July 2014.
However, this rainfall did not all end up in the drains. Therefore for most flood model cases, rainfall runoff coefficients (see Section C.3.14.1) of C = 0.8 were used for the residential area (for the areas See Figure A.14) and around C = 0.4 for the hospital area (U Khin Lat (NEPS), personal communication, 09-03-2017).
Latha had a combined sewer system and thus besides rainfall there was also a DWF (see Section C.3.14.2). For Yangon, the water consumption was 94 L/capita/day in 2011 (JICA and YCDC, 2013, p.95). This data was used in the flood model combined with peak-factors and temporal variations.

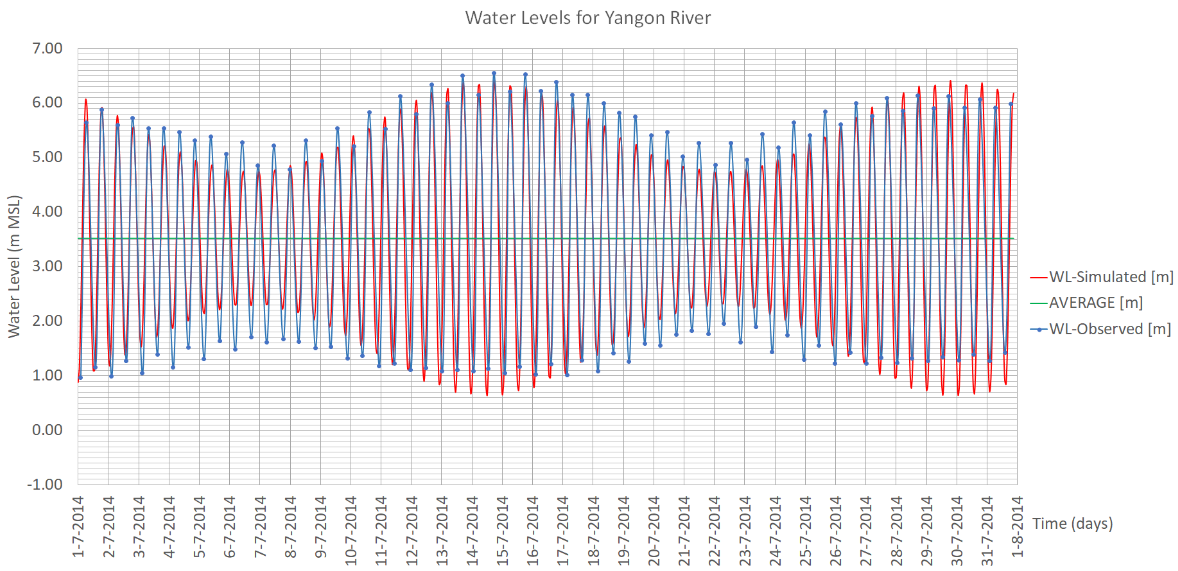


Figure 3.5: Water Levels for the month of July 2014. The blue point was the actual discrete data from the original dataset. The blue line was sketched through the points but had no mathematical representation. Based on the blue line it was observed that there was a fast tidal influence with a period of about 12 hours and that there was a slow tidal influence of about 15 days. The red line was a simulated water level which was a combination of sinuses as in Equation C.2 (Section C.3.11). The green line was the average water level of the observations. Data obtained and modified from (De Koning and Janssen, 2015).

Figure 3.6: Flood gate structure (FGS 6) along Strand Road. Picture taken on March 19, 2017.

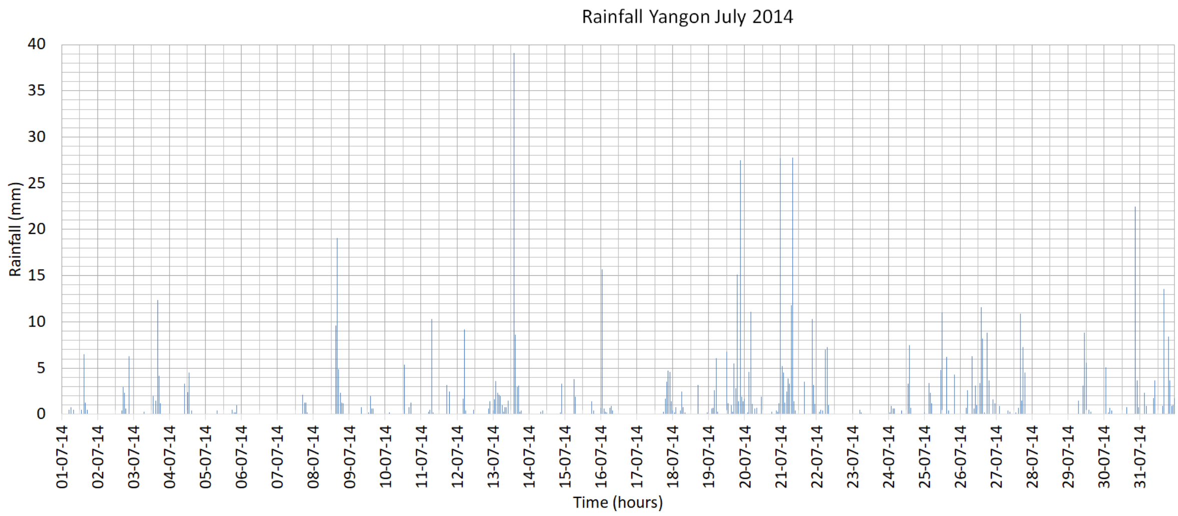


Figure 3.7: Hourly precipitation from Kaba Aye Station (See Figure 2.5) for the month of July 2014. Observe that the total hourly precipitation did not exceed 40mm per hour, which was relatively low. Also, there were no extreme cases of rainfall events with long durations or with a relatively high (average) intensity (see Figure C.25). Obtained from Dorien Honingh on September 15, 2016.

3.1.4. Software

Part of this research consisted of questionnaires (Section 3.2.2). The questionnaires lay-out and first post-processing steps were made with Google Forms (Google, 2017).

Microsoft Office Excel 2013 was used for the analysis of questionnaire results. The software was used to create histograms (e.g. Figure 4.1a), pie-charts (e.g. Figure 4.1b) and pivot-tables (e.g. Figure B.5).

In this research SOBEK 2.13 Rural (Deltares, 2013) was used to make a flood model (Section 3.2.5) and to do the hydrodynamic calculations on the drainage network. SOBEK uses the complete S-V Equations and a self-created numerical computation grid called Delft-scheme that is numerical stable and ensures a closed water balance. For this model the following modules were used: 1DFLOW (Rural), 1DFLOW (Urban), Overland Flow (2D) and RR.
Other versions than SOBEK 2.13 Rural should treat the flood model with care, as it turned out that SOBEK 2.15 Rural runned with a bug for the real time controller of the gates (orifice structures). This bug did not occur in SOBEK 2.13 Rural, but other versions than SOBEK 2.13 Rural were not tested on this bug.

Netlogo (Wilensky, 1999*a*) was used as an agent based modelling (ABMing) platform for the socio-hydrological model. For this study, version NetLogo 6.0.1 was used together with the extensions *network* (Wilensky, 1999*b*) and *csv* (Wilensky, 1999*c*).

Matlab 2016a and Matlab 2017a were used for the pre-processing and post-processing of data. An example was the interpolation of the raw GLE dataset to obtain GLEs for the whole of Latha's residential area, see Section C.3.8.

The QGIS 2.14.9 (Essen) with GRASS version was used in order to structure and organize spatial data by creating maps. It was also used for spatial analysis and spatial calculations. Examples of results from QGIS were: Figure C.7, Figure 3.11 and Table C.6.

3.2. Methods

Figure 3.8 shows the most important methods and which materials were used for each method. For this research the case study of Lahta was used, as introduced in Chapter 2. The socio-economic data of section 3.1.2 was used as a basis for additional socio-economic data collection and analysis on the Latha Township. This was done by means of field observations (Section 3.2.3), interviews (Section 3.2.4) and questionnaires (Section 3.2.2). The results of these separate parts were also used to cross-check each other and to provide a better understanding of the most important human SWM actions that contributed to UF. With the hydrological and hydraulic data (Section 3.1.3) a flood model (Section 3.2.5) of the Latha Township was made in SOBEK (see Section 3.1.4). This provided insights in the hydrological and hydraulic dynamics of Latha's UDS.
The results of the socio-economic data collection and analyses combined with the results of the flood model were used to evaluate the initial hypothesis (Section 2.4) and to come up with an improved hypothesis of a conceptual SHM (Section 3.2.7) that was modelled in NetLogo (see Section 3.1.4).

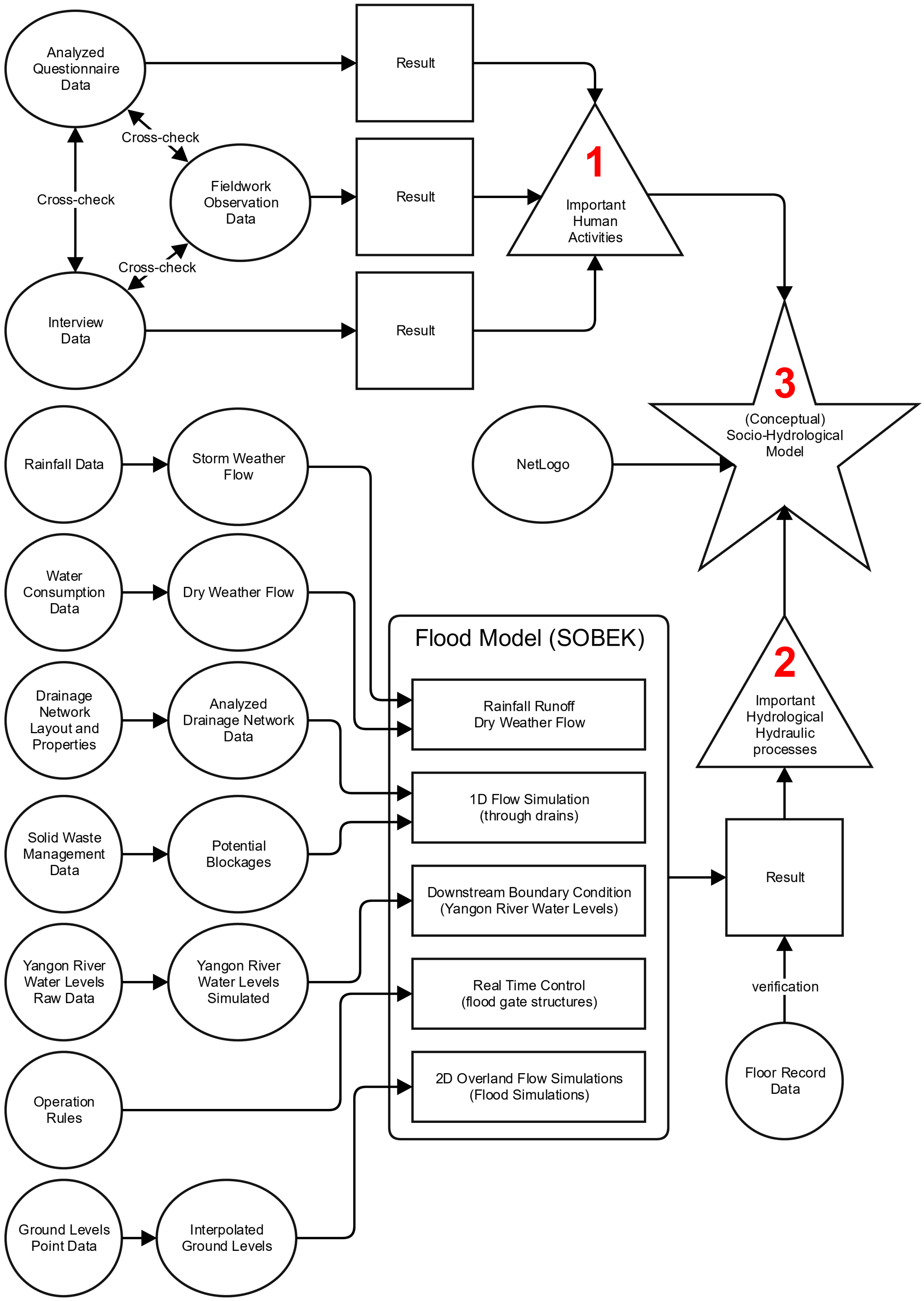


Figure 3.8: For this research a lot of data was collected, analysed, modified and combined to obtain the results that answer the research question. This is sometimes referred to as a mixed-method approach. A divide was made between socio-economic data (1) that answered the first research sub-question. Data for the flood model (SOBEK) (2) that answered the second research sub-question. Together the data and methods were used with additional data and methods to produce a social-hydrological model (3) that answered the third research sub-question.

3.2.1. Case Study

Latha was used as a case study (see Chapter 2) to research the interaction between solid waste management and urban flooding and to test the research methodology. This specific township was used since it is one of Yangon's most flood prone downtown areas (Kyaw Mein Oo, personal communication, April 6, 2017), see Figure 2.2. Moreover, its location in Yangon's business district (see Section 2.2.3) made it an economic important area on which floods had a large impact. Furthermore, due to the high degree of commercial activities and high population density (see Section 2.2.4) there was a high waste production probability with the potential for interactions between SWM and UF.
The results for Latha were used as comparison to see which results and conclusions might be generalized and which results were case specific.

3.2.2. Questionnaires

For this research two questionnaires were conducted, one amongst households (the *household questionnaire*) and one amongst shop owners, restaurant owners and market salesmen (the *shop questionnaire*). The questionnaires served to get an explorative non-representative dataset about the household's and shop's: composition/situation, solid waste production and solid waste cleaning habits, flood experience, flood awareness and flood protection. The dataset was used to evaluate the initial hypothesis and to estimate model parameters, inspire what processes should be modelled in the SHM, validate assumptions and interpret model results.
Using a questionnaire had the benefit that all questions were asked in the same order, under the same conditions and a large group could be researched efficiently. However, the number of respondents for the shop questionnaire was so low that the results were not published.

3.2.2.1. Design & Preparations

The questionnaires were made and designed with the help of a local junior environmental engineer. Once the first draft was completed, the questionnaires were tested in the field (see Figure B.1) and improvements implemented. These improvements included the addition of extra explanations for the questions, added answering options, new questions and the removal of questions. The questionnaires were also translated into Myanmar language in order to take away a possible language barrier and to make filling in the questionnaires easier for the respondents. Another round of testing was completed and with some small new improvements this eventually yielded the final version. Figure 3.9 shows two example questions from the final (untranslated) version. The entire questionnaire is presented in Appendix B (Section B.5).
The questionnaire consisted primarily of closed-ended questions, so that the respondent's answers were comparable. The close-ended questions were *one answer per question* and *multiple possible answers per question*. Some of the close-ended questions had the option of allowing a respondent to provide an additional answer option.

16. **On average, how big is your garbage bag of waste per time that you throw away your waste in a YCDC container?** *
(select one answer)
Mark only one oval.

- Large, about this size (70X45X30 cm)

- Medium, about this size (35X30X30)

- Small, about this size (25X25X20)

17. **How many of these bags do you throw away per day?** *
(select one answer)
Mark only one oval.

- more than 10 bags per day
- between 6 and 10 bags per day
- 5 bags per day
- 4 bags per day
- 3 bags per day
- 2 bags per day
- 1 bag per day
- 1 bag every 2 days
- 1 bag every 3 days or more days

(a) Example questions about solid waste (management).

31. **Flooding: On average, how long does a flood last?** *
(select one answer)
Mark only one oval.

- Just a few minutes
- 5 till - 29 minutes
- Between 30 minutes - 59 minutes
- Between 1 hour - 1 hour 59 minutes
- Between 2 hours - 2 hours and 59 minutes
- Between 3 hours - 3 hours and 59 minutes
- Between 4 hours - 4 hours and 59 minutes
- Between 5 hours and 7 hours and 59 minutes
- Between 8 hours - 11 hours and 59 minutes
- Between 12 hours - 23 hours and 59 minutes
- Longer than 24 hours

32. **On average when it floods, most of the times the water level gets:** *
(select one answer)
Mark only one oval.

- Just a few centimeters high (5 cm and less)
- To ankle height (10 cm)
- To the height of halfway of my calves (25 cm)
- To the height of my knees (40 cm)
- To the height of halfway my upper leg (60 cm)
- To the height of my hips (80 cm)
- To waist height and above (100 cm and more)

33. **When it starts to flood, I am often warned by others (e.g. YCDC, family, friends and/or colleagues):** *
(select one answer)
Mark only one oval.

- Yes (Go to question 34) *Skip to question 34.*
- No (Go to question 35) *Skip to question 35.*

Urban Flooding [3/10]

(b) Example questions about urban flooding.

Figure 3.9: Example questions from one of the questionnaires. For the full questionnaires, see Section B.5.

The questionnaire could be divided into three parts. The first part was mainly focussed on acquiring general information about the respondents. The second part of the questionnaire was focussed on solid waste management. The third part focussed on UF. The questionnaire participants were asked to describe when they experienced the most recent flood. This provided information how likely a respondent was to ever experience a flood. Appendix Section B.2 provides an overviews of all the reasons behind the questions of the questionnaire (which itself is in Section B.5).

3.2.2.2. Distribution & Collection

The questionnaires were distributed throughout the administrative offices of the different wards within the Latha Township's residential area (See section 2.2.5). Initially the wards were not willing to cooperate and the general administrative office of the township was not willing to give permission to distribute the questionnaires. However, after multiple conversations with the general township officer and mediation through some of Latha inhabitants a permission request was issues to the responsible Yangon Directorate office and under this pending permit the questionnaire was distributed through the administrative offices of wards 1 till 8. Each ward got a number of questionnaires they thought they could find respondents for. This meant that a total of 15 household questionnaires and 6 shop questionnaires were given to each ward's administrative office.
Agreements about the collection were made with the administrative offices. After one week, the questionnaires should have been ready for collection. However, after one week, none of the administrative offices had the results in and several new arrangements were made. Eventually there were 48 filled in household questionnaires and 16 filled in shop questionnaires collected (of the 150 distributed household questionnaires and 60 shop questionnaires).

3.2.2.3. Results Evaluation

The results of the questionnaires were statistically evaluated for the closed-ended questions. Histograms, pie-charts and pivot-tables were created with Microsoft Excel to present the collected data. Matlab was used for Monte-Carlo sampling of the census data and compared to the questionnaire results. QGIS was used to create spatial maps that organized the findings.
The open-ended questions were analysed qualitatively.

3.2.3. Field Observations

Unstructured direct field observations were conducted in the period of January 1, 2017 till April 8, 2017 in the Latha Township. The data was collected and recorded by taking notes, taking pictures and making maps.
The fieldwork observations served to obtain information on human SWM practices and information about Latha's UDS. Moreover, it provided additional information that was used to verify the data from the questionnaires and interviews.

3.2.4. Interviews

Semi-structured interviews were used to acquire data from the Yangon City Development Committee (YCDC). There was one meeting with the Yangon City Development Committee Pollution Control and Cleansing Department (YCDC PCCD) Latha Office on March 28, 2017 with mister U Myot Soe Thein. With the YCDC EDRB General Office two meetings took place on March 30, 2017 and April 6, 2017 with mister Kyaw Mein Oo.
The interviews with the YCDC PCCD served to get a better understanding of Latha's SWM, for example how often containers were collected and where all the containers were situated (Section C.3.3).
The interviews with the YCDC EDRB were used to gather additional datasets and knowledge that could be used for the creation of a flood model, for example on the operational rules of the FGSs (Section C.3.12) and flood records (Section C.3.9).

In addition to the semi-structured interviews, short unstructured interviews and conversations were held with various people e.g., Latha citizens and Latha salesmen, officials from different Latha wards and Dutch solid waste experts. The *mini-interviews* were conducted in the period of January 1, 2017 till April 8, 2017 primarily in the Latha Township. Unfortunately no complete transcripts or complete notes were made from these mini-interviews. However, these mini-interviews sometimes did provide useful information. Therefore the most important results and conclusions of these conversations were summarized into one transcript overview.

The interview data was analysed qualitatively. However, since the limited number of interviews and the relative short transcripts no (label) coding (Bryman, 2012, pp. 298-304) and categorization of the coding was applied.

3.2.5. Flood Model

A flood model was made in SOBEK 2.13 (see Section 3.1.4) based on the hydrological and hydraulic data (Section 3.1.3). To reduce computation times, the SOBEK simulations were runned from 07-07-2014 (00:00) till 28-07-2014 (00:00). Outside this time frame there was no significant rainfall and the flood records also did not show any actual flooding.
Figure 3.8 shows what different inputs were used in the SOBEK model and Figure 3.10 shows a snapshot of the SOBEK model. In order to deal with the uncertainties of the used data, different cases were modelled (see Table 3.8 and appendix Section E.3.1.1 to Section E.3.1.10). To results of the flood model, will be evaluated using different indicators (see Section 3.2.5.2).

With the collected hydrological and hydraulic data (Section 3.1.3) a SOBEK flood model was made (Figure 3.10). The observations of the drain types (Figure 3.3) were used to model the various drains and culverts, with the dimensions and invert levels from the UDS map (Figure 3.2). For the friction component of the S-V Equations, a Manning's roughness was used for all drains and culverts.
The interpolated GLE data (Figure 3.4) was used for the 5x5 meter 2D overland flow computation raster and *2D history points* recorded data from the overland flow calculations. The elevation was colour mapped by a brown gradient scale. Some locations had no elevation data, the grey cells (because of buildings on that location and not defining these cells improved the computation time).
The YRWL was modelled as a downstream boundary condition with the hourly time series of Figure 3.5. Measurement nodes, measured the modelled YRWL. The FGSs were modelled as orifices, with real time control. The real time control used the WL measurements from the measurement nodes, to either set the FGSs open or closed based on different YRWLs (see Section E.3.1.3). SOBEK did not allow to set the gate position on a time basis. Even if it would have been possible, the exact timing of the FGS operational rules were unknown (see Section 3.1.3).

For the rainfall, the hourly rainfall volumes of Figure 3.7 were used. For the rainfall runoff, the contributing areas to the different drains were modelled as shown in Figure 3.11 (for more details see Section C.3.14). The runoff for each drain was modelled as an inflow at the upstream end of the drains. In most cases the rainfall runoff was crudely simplified, making no differentiation between paved areas, unpaved areas, roofs, etcetera. The lumped areas of Figure 3.11 were used with C = 0.8 used for the residential area and C = 0.4 for the hospital area (U Khin Lat (NEPS), personal communication, 09-03-2017). However, in some cases the effect of this simplification of the runoff, infiltration, interception and evaporation were studied (see Section E.3.1.10).
For the DWF of Latha's population a DWF of 120 L/d was used. This is about 25% more than the literature reported (see Section 3.1.3). In some cases the DWF was increased with a peak factor or a temporal pattern of high DWFs during the day and lower DWFs during the night (see Section E.3.1.6). Latha's population was divided into 2 groups: 21,000 for the residential area and 3500 for the hospital area and distributed relative to the contributing areas (see Section C.3.14.2 and Table C.6 for more details).
For the SOBEK model some settings were kept constant for every case. The used time step was 30 seconds for computations (to ensure numerical stability and efficient computation speeds) and 5 minutes for output generation (this ensured comprehensible datasets with sufficient detail while limiting the size). The initial water level was set at 0.1 meter water depth in all drains, to ensure that the model did not run into numerical stability issues at the start of the calculations.
Inflow from the surrounding areas (e.g. the neighbouring townships) were assumed to be zero and were therefore disregarded.

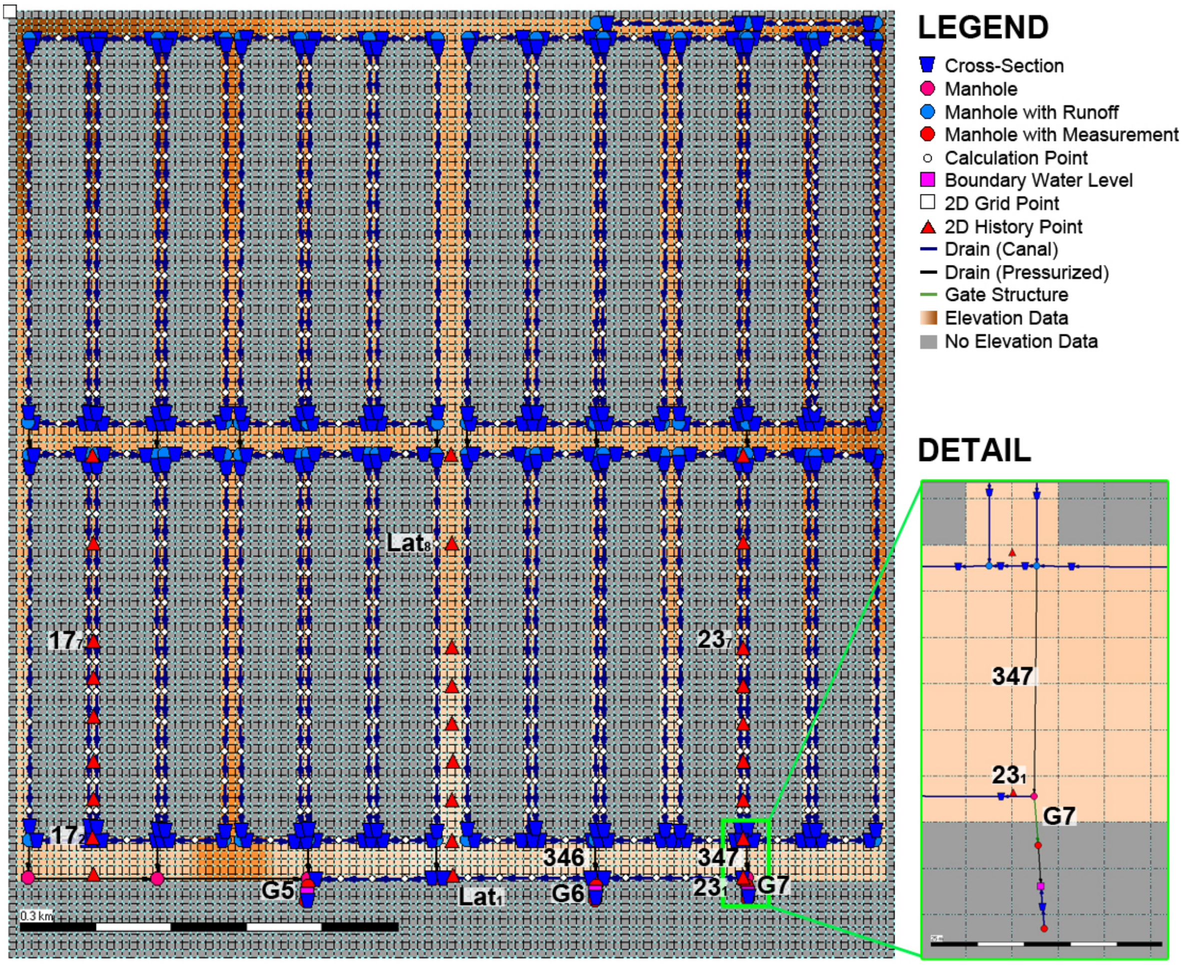


Figure 3.10: SOBEK Model Schematization. In the legend the various model components are named. There were different type of connection nodes, connecting canals and pipes. Eventually the system drained into the river, the downstream boundary nodes. To model the overland flow during a flood, a 5x5 meter 2D raster and other modelling components were defined. See Section E.3 for an full explanation. The six 2D History Points (17_2, 17_7, Lat_1, Lat_8, 23_1 and 23_7) were used to evaluate the results (see Section 3.2.5.2), 346 and 347 were the culverts that were modelled to be (partially) blocked for some cases and G5, G6 and G7 are Gates 5, 6 and 7. For a complete explenation of all the model components, see appendix Section E.3.

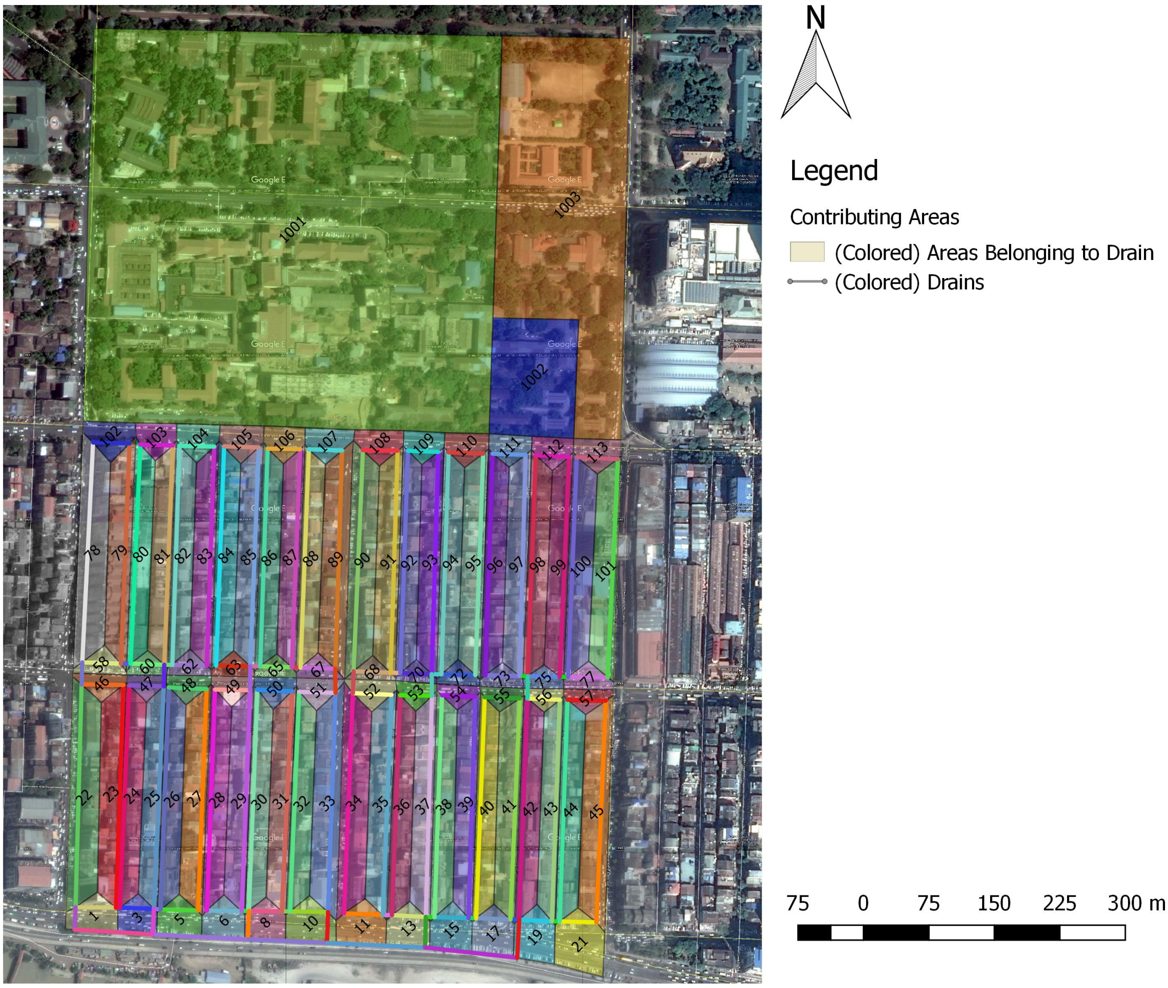


Figure 3.11: Contributing areas per drain. There were a total of 104 individual areas that contributed to the total area of roughly 645,000 m^2. The areas 1001, 1002 and 1003 were modelled as upstream boundary conditions. They drained to the top 3 (pressurized) drains that are connected by an open drain along the north side of Anarwrahta Road, see Figure 3.3. The surface area of the different sections is shown in Table C.6. Data obtained by field observations between 01-03-2017 and 30-03-2017 and from Figure C.8.

3.2.5.1. Scenario Based Flood Modelling

In order to deal with uncertainty in the hydrological and hydraulic data, different cases were modelled in the flood model. In total 42 cases of the flood model were runned to evaluate the drainage system's behaviour. Table 3.8 shows an overview of all the different 42 cases. For an extensive overview and explanation of all the cases, see Appendix E Section E.3.1.

Table 3.8: An overview of all the different cases that will be modelled. Different: ground level references (GLR), roughness (Manning), real time control (RTC) of the FGSs, runoff coefficients, (partial) blockages of drains, dry weather flow (DWF), Leakage of the FGSs, timing of tide in the Yangon River (shift WL), more detailed storage, infiltration, evaporation and runoff (improved S, I, E, C) and combined cases. See Table 3.9 for an explanation of the headers.
* Culvert running under Strand Road at the 22nd Street, ** Culvert running under Strand Road at the 23rd Street, *** 90 L/capita/day (19:00-07:00) and 240 L/capita/day (07:00-19:00), **** See Table E.3 for used values. NA means not available, as this setting/variable might not apply to this case.

	Case	Cr	Ch	RTC open	RTC closed	Leakage gap	Gap loc.	GLR	YRWL dt	DWF	m	Blckg. loc. 1	Blckg %	Loc. Descript.	Blckg. loc. 2	Blckg %	Loc. Descript.
GLR	1	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.015	NA	NA	NA	NA	NA	NA
	2	0.8	0.4	-0.1	0.0	0	NA	4.83	0	120	0.015	NA	NA	NA	NA	NA	NA
	3	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
Roughness	4	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.005	NA	NA	NA	NA	NA	NA
	5	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.010	NA	NA	NA	NA	NA	NA
	6	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.020	NA	NA	NA	NA	NA	NA
	7	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.025	NA	NA	NA	NA	NA	NA
	8	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.060	NA	NA	NA	NA	NA	NA
RTC	9	0.8	0.4	0.1	0.2	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	10	0.8	0.4	0.0	0.1	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	11	0.8	0.4	-0.2	-0.1	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	12	0.8	0.4	-0.3	-0.2	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	13	0.8	0.4	-0.5	-0.4	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
Runoff	14	0.9	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	15	0.7	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	16	0.8	0.5	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	17	0.8	0.3	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	18	0.9	0.5	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	19	0.7	0.3	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
Blockages	20	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	346	25	*	NA	NA	NA
	21	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	346	50	*	NA	NA	NA
	22	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	346	75	*	NA	NA	NA
	23	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	346	100	*	NA	NA	NA
	24	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	346	50	*	347	50	**
DWF	25	0.8	0.4	-0.1	0.0	0	NA	4.77	0	180	0.015	NA	NA	NA	NA	NA	NA
	26	0.8	0.4	-0.1	0.0	0	NA	4.77	0	240	0.015	NA	NA	NA	NA	NA	NA
	27	0.8	0.4	-0.1	0.0	0	NA	4.77	0	***	0.015	NA	NA	NA	NA	NA	NA
Leakage	28	0.8	0.4	-0.1	0.0	0.05	Gate 7	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	29	0.8	0.4	-0.1	0.0	0.10	Gate 7	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	30	0.8	0.4	-0.1	0.0	0.20	Gate 7	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
RTC 2	31	0.8	0.4	0.2	0.3	0	NA	5.22	0	120	0.015	NA	NA	NA	NA	NA	NA
	32	0.8	0.4	0.9	1.0	0	NA	5.22	0	120	0.015	NA	NA	NA	NA	NA	NA
Shift WL	33	0.8	0.4	-0.1	0.0	0	NA	5.22	3	120	0.015	NA	NA	NA	NA	NA	NA
	34	0.8	0.4	-0.1	0.0	0	NA	5.22	6	120	0.015	NA	NA	NA	NA	NA	NA
	35	0.8	0.4	-0.1	0.0	0	NA	5.22	9	120	0.015	NA	NA	NA	NA	NA	NA
Shift WL	36	0.7	0.3	0.9	1.0	0	NA	5.22	3	120	0.015	NA	NA	NA	NA	NA	NA
& RTC	37	0.7	0.3	0.9	1.0	0	NA	5.22	6	120	0.015	NA	NA	NA	NA	NA	NA
& Crunoff	38	0.7	0.3	0.9	1.0	0	NA	5.22	9	120	0.015	NA	NA	NA	NA	NA	NA
Improved	39	****	****	-0.1	0.0	0	NA	5.22	0	120	0.015	NA	NA	NA	NA	NA	NA
S, I, E, C	40	****	****	-0.1	0.0	0	NA	5.22	0	120	0.015	NA	NA	NA	NA	NA	NA
RTC, Shift WL, S, I, E, C	41	****	****	0.9	1.0	0	NA	5.22	6	120	0.015	NA	NA	NA	NA	NA	NA
Open Gate	42	0.8	0.4	NA	NA	1.20	Gate 7	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA

Table 3.9: The headers of Table 3.8 are explained in this table.

Description	Explenation	Units
Case	Case number	NA
Cr	Runoff Coefficient Residential Area	(-)
Ch	Runoff Coefficient Hospital Area	(-)
RTC open	Water Level at datum for which the gate is 100% open	m GLR
RTC closed	Water Level at datum for which the gate is 100% closed	m GLR
Leakage gap	Opening size gate gap from the bottom	m
GLR	Ground Level Reference , 0.00 m GLR in m MSL	m MSL
WL dt	Water Level boundary condition time shift	hours
DWF	Dry Weather Flow	L/capita/day
m	Manning friction value	$s/m^{1/3}$
Blckg. loc. 1	Location of blockage 1	NA
Blckg %	Part of the drain blocked	(%)
Loc. Descript.	Description of the location	NA
Blckg. loc. 2	Location of blockage 2	NA

3.2.5.2. Results Evaluation Criteria

For each cluster of cases, a comparison was made to a reference case, which was one of the cases with a different ground level reference (cases 1–3). For the evaluation of the cases, different indicators were used for six locations in the township. The locations used for evaluation are indicated in Figure 3.10 and were selected on the basis that they provided the most representative and clear results. For indicator 1 an increase or decrease of 2 or more number of floods was considered significant. For indicators 2–9 an increase or decrease of ±15% was considered significant. The used indicators were:

1. Number of floods
   The number of times the location experienced a flood
2. Total duration (Tot.Duration):
   The aggregated duration of water on the street for all the flood events at the specified location
3. Maximum duration (Max.Duration):
   The duration of the flood event that lasted longest at the specified location
4. Total maximum depth (Tot.max.Depth):
   The aggregated maximum water depths for all the flood events at the specified location
5. Maximum maximum depth (Max.max.depth):
   The maximum water depth of the most extreme flood event at the specified location
6. Minimum duration:
   The shortest duration of a flood event at the specified location
7. Average duration:
   The average duration of all flood events at the specified location
8. Minimum maximum depth:
   The maximum water depth of the least extreme flood event at the specified location
9. Average maximum depth:
   The average maximum water depth of all the flood events at the specified location

3.2.6. Triangulation

Figure 3.8 shows that the field observations, interviews and questionnaires were used to cross-check each other. For this research a from of triangulation was applied. Although not explicitly shown in Figure 3.8 the socio-economic results were also used to verify the flood model results.

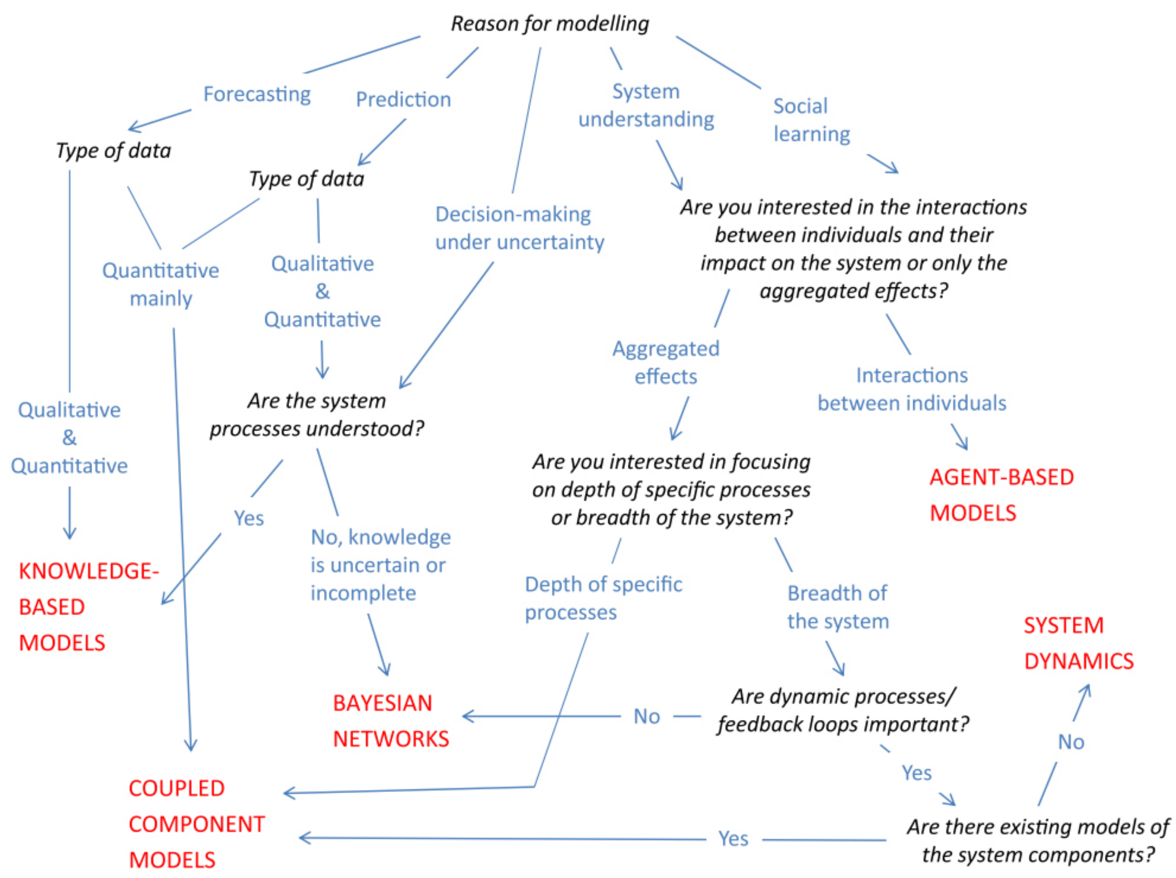


Figure 3.12: Based upon the reason for modelling, different physical models suit a model's objective best. In this case study we were especially interested in system understanding and social learning and the interaction amongst different agents. In order to serve this objective best, an agent based model (ABM) was a suitable approach. Figure from (Kelly et al., 2013, fig. 1).

"[...] Triangulation is supposed to support a finding by showing that independent measures of it agree with it or, at least, don't contradict it." (Miles and Huberman, 1984, p.235). "It is essentially a strategy that will aid in the elimination of bias and allow the dismissal of plausible rival explanations such that a truthful proposition about some social phenomenon can be made" (Mathison, 1988, p.13).
Triangulation was implemented since the limited duration and structure of field observations, the limited number of semi-structured interviews, the unstructured mini-interviews and the limited number of questionnaires potentially resulted in uncertainties, biases in the data and an insufficient statistical significant basis. Moreover, some of the applied methodologies lacked an adequate social scientific framework.

3.2.7. Socio-Hydrological Model

With the socio-economic results and flood model results, the initial hypothesis was evaluated and an improved hypothesis was formulated that served as a conceptual SHM. The model concept was then synthesized into a physical SHM with the results, the collected data and made assumptions.

The physical model was used to study the actions of households (HHs), their actions' impacts on the system and how the state changes of the system were being translated into impacts on the other HHs, evoking reactions to this system response by the other HHs which, in turn impacted the system and other HHs again. To serve this physical model's objective best an agent based model (ABM) was used, see Figure 3.12.
The ABM itself was build in the ABMing platform NetLogo (see Section 3.1.4). The results were evaluated using histograms for the number of times a flood occurred.

In the traditional approach of agent based models (ABMs) the agents are individuals i.e. people (Deadman,

1999; Teodorovic´, 2003). The individuals are living and interacting with other individuals (agents) and their surroundings (the environment). They react (change their state) to inputs from other agents, inputs from the environment and/or inputs from themselves, according to a set of rules and based on their own state. The (re)actions of the individual may change themselves, the environment and/or other individuals. A schematization is shown in Figure 3.13. Note that not (re)acting is also an action.
However, for this model, an agent was not necessarily a human actor. An agent was defined as *a thing that does things to other things*. Therefore, a container was also considered an agent. For example, a container (a thing) had a maximum capacity of waste units (the number of bags that fitted in the container, a state). If a container was full, this could affected the behaviour (doing things) of a household (an other thing). Sometimes a household disposed its waste on the streets, instead of going to the container since the container wa full (for more details see Section 4.3.3). Thus the container adhered to the used definition of an agent.

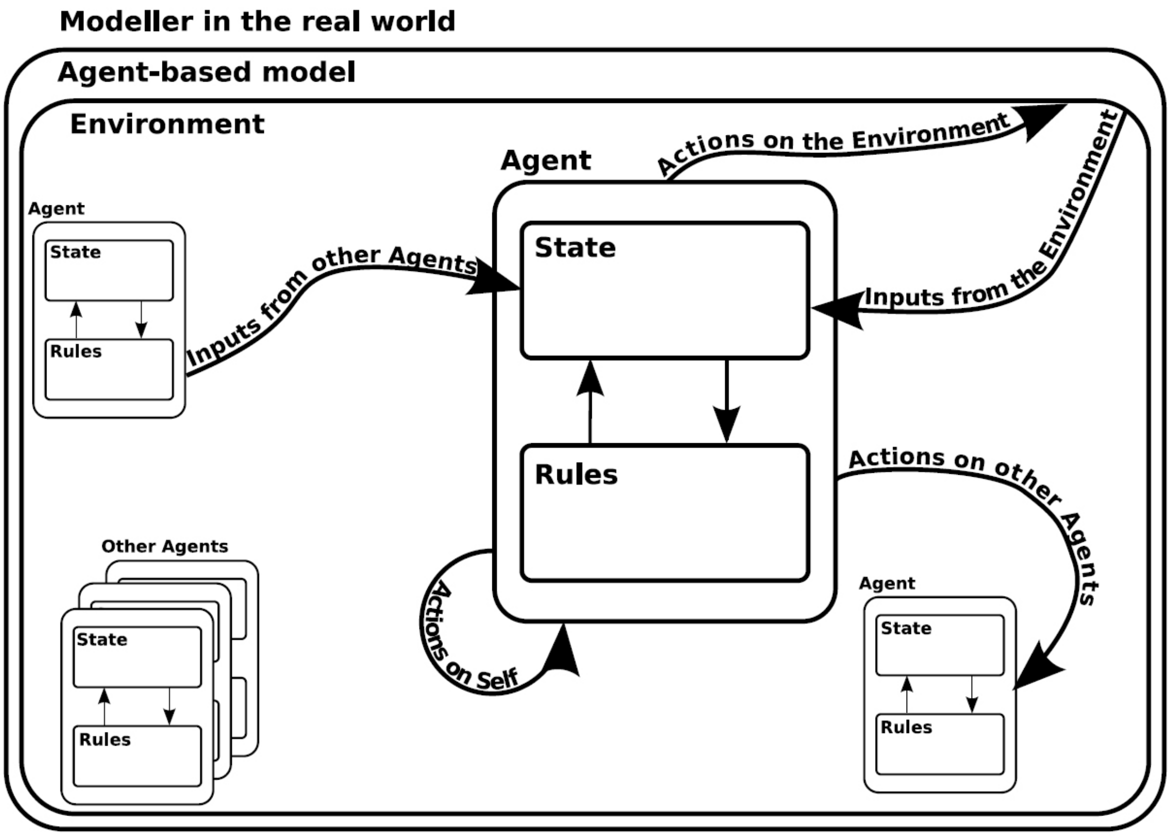


Figure 3.13: In an ABM, agents are acting (or not acting!) in an environment with other agents. Each agent has a state, that changes by inputs from other agents and/or the environment based on internal rules. Their actions (or lack of action) may have an impact on themselves, on the environment and/or on other agents. Figure from (Van Dam et al., 2013, fig. 2.6).

4
Results

This chapter shows the most essential results of this research. The results are split up in three main sections, the first showing the most important results from the questionnaires, interviews and observations. The second section shows the results from the flood model simulations and finally the results from the socio-hydrological model. However, for each of these topics, there were much more results for which the reader is referred to Appendix B (for questionnaire results), Appendix D (for interview results), Appendix C (for additional field observations results), Appendix E (for flood model results) and Appendix F (for socio-hydrological model results).

4.1. Socio-Economic Results

In order to research what human activities played an important factor with regards to urban flooding, questionnaires were conducted together with fieldwork and interviews. This section elaborates on the most important findings and results and the triangulation of the different results

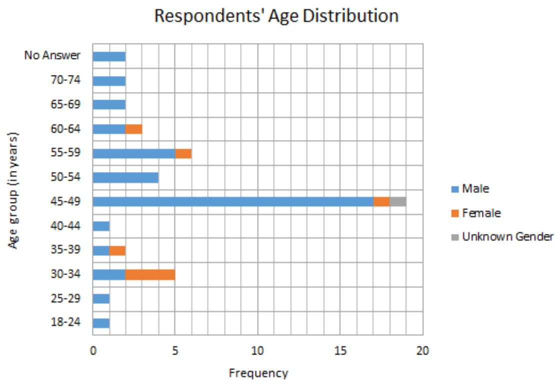
4.1.1. Questionnaire Results

In this section only the most important results of the Questionnaire for households will be discussed. For the all the results of the Household Questionnaire and for the results of the Shops Questionnaires the reader is referred to Appendix B.

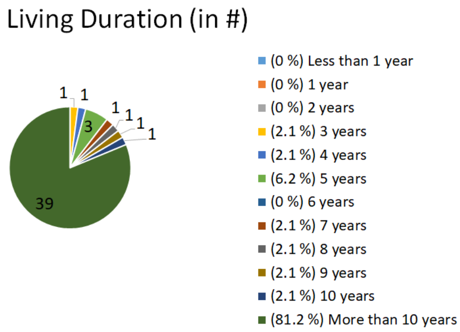
4.1.1.1. Respondents' Profile Results

The majority of the 48 respondents was male (Figure B.3a), around 45 to 49 years of age (Figure 4.1a), lived in the Latha Township permanently (Figure B.3e) and had been living there for long durations (Figure 4.1b). The average age of the respondents was 47.7 years old with a standard deviation of $\sigma = 11.8$ years. From comparing Figure 4.1a with Figure 3.1 it was concluded that the age distribution was somewhat skewed. The respondents were distributed throughout the Latha Township, see Figure B.4c. However, quite a few respondents (21 respondents) only provided the street where they lived in but not their house number. The majority of the respondents did not live on ground level but on higher floors (Figure B.4a). The most respondents' households were composed of 5 people, averaging to an above average household size of 5.1 people per household (See Figure B.4b and Table 3.2).
The sample population was educated to an above average grade, with the majority of the respondents having a university grade (See Figure 4.3a). For the Latha Township only 42.3% had a university grade, see Table 3.3. The majority of the respondents were self employed or working for the military or government (Figure 4.3b). This was higher than one might expect from the census data (Table 3.4), whereas the expected number of respondents to be employed for wages in the private sector should have been be a lot higher (6.3% of the respondents versus 32.3% in Latha). Most respondents could be considered to have be part of an above average social class, as the majority of the respondents was self employed and had at least a completed university

grade.
Interestingly, the results showed that flood protection nor solid waste management was a primary concern for the respondents (Figure 4.4). Reliable power supply seemed to be the biggest issue the respondents would have liked to see improvements being made upon, followed by more job opportunities and thirdly improved health care. The average age (AA) of people did not seem to play a role in their problem priority. You might have expected that for example the elder people responded that *improved health care* was most important and young people *improved internet connection* but this seemed not to be the case. There was one person who opted for his own answer that was "Achieve the Rule of Law".



(a) The most respondents were around 45 to 49 years old. The average age of the respondents was 47.7 years old. The respondents were relatively older than average for Latha (see Figure 3.1 and Table 3.1).



(b) Answer to Question (6): *How long have you lived on your current apartment in the Latha Township?*

Figure 4.1: Almost all respondents lived permanently in the Latha Township and most respondents were living in the Latha township already for a long time.

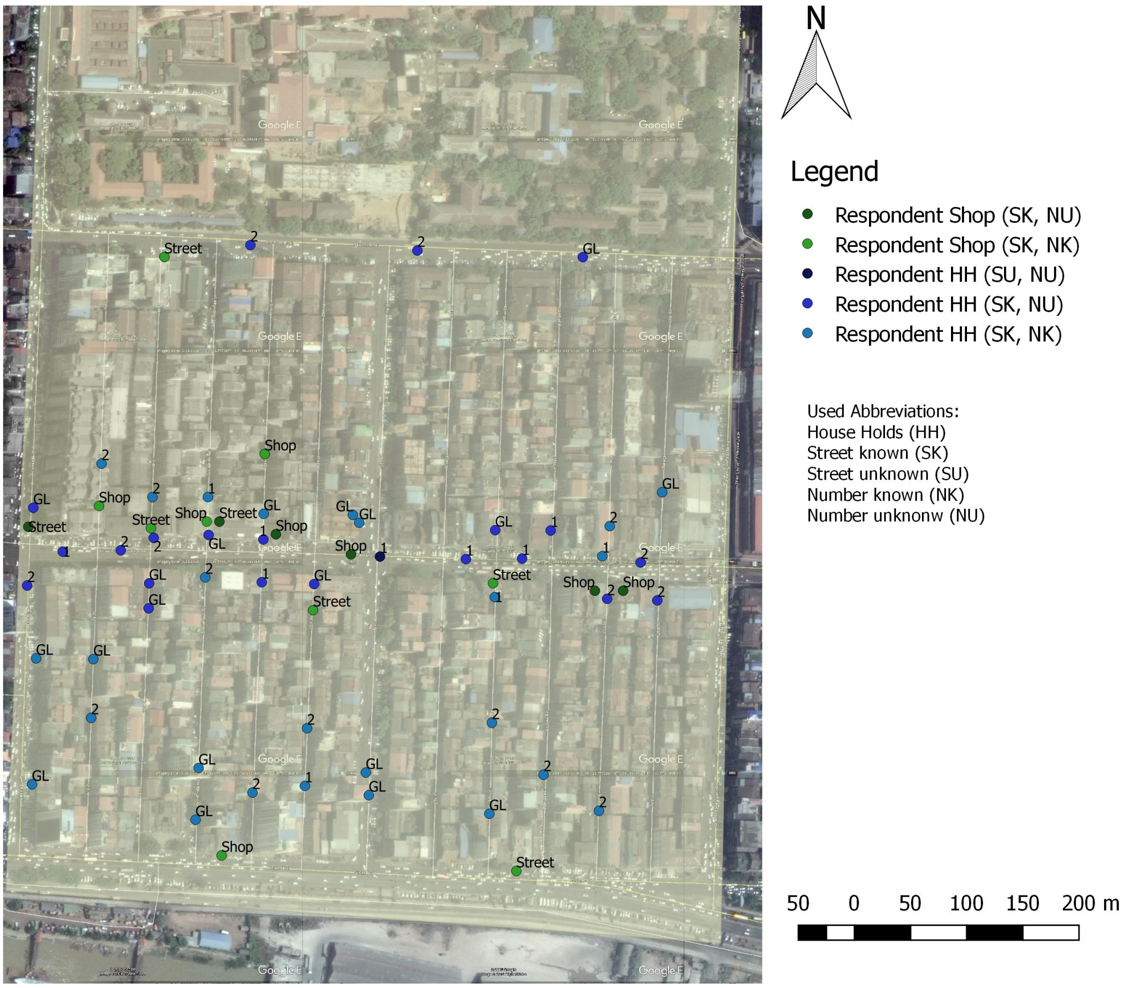
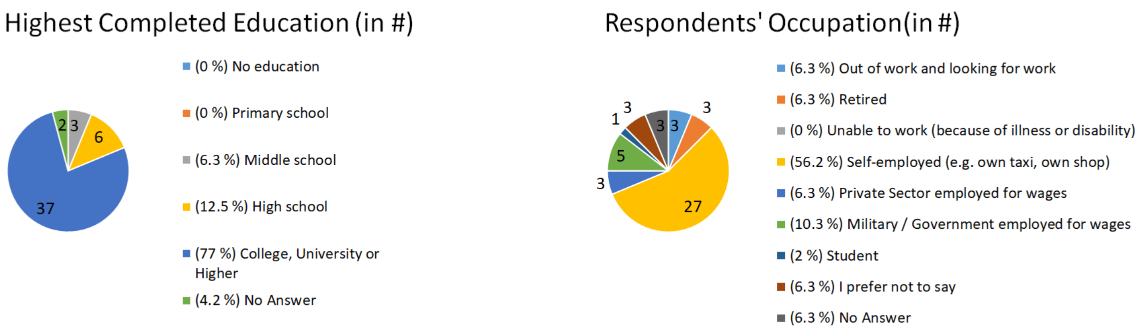


Figure 4.2: The locations of the respondents The blue colours represent respondents to the questionnaires for households and the green colours represent respondents to the questionnaires for shops. Some respondents only provided their street and thus were allocated at random along that street. The labels indicate on what floor the household was situated, where 2 indicates 2^{nd} floor or higher and ground level (GL). For the shops the label indicates if the commercial activity was in a building (labelled: shop) or on the street, labelled: street.



(a) Answer to Question (11): *Within your household, what is the highest level of education someone has?* The majority of the respondents were high educated. The respondents had an above average university grade ratio, as the fraction of citizens with a university grade for Latha was 42.3% (See Table 3.3).

(b) Answer to Question (12): *What is your current employment status?* The majority of the respondents was self-employed. This was higher than the average for the Latha township. The opposite applied to the number of people that were employed for wages in the private sector, which was much lower amongst the respondents than on average in Latha (6.3% to 32.2%). See Table 3.4 for the data of the Latha Township.

Figure 4.3: Most respondents could be considered to have a medium to high social class, as the majority of the respondents is self employed and has at least a completed university grade.

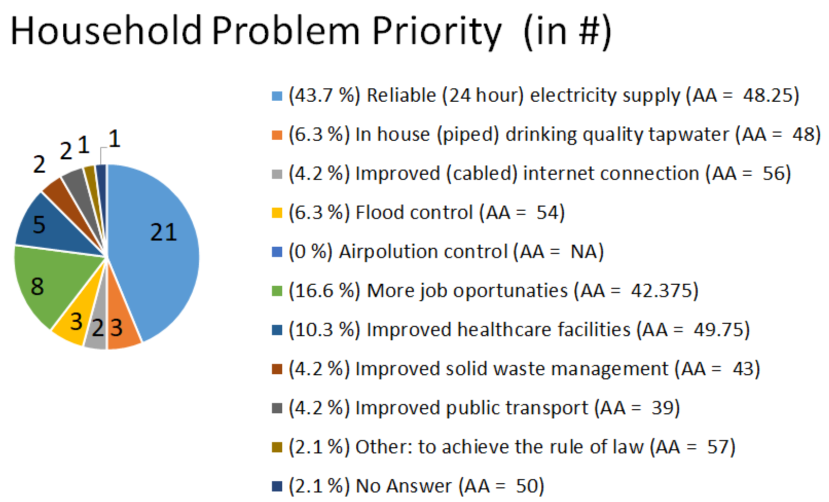


Figure 4.4: Answer to Question (14): *If I can decide what problem should be solved first, I first would like to solve...* Reliable power supply seemed to be the biggest issue the respondents wanted to be improved upon, followed by more job opportunities and thirdly improved health care. Flood protection and solid waste management were apparently not the most pressing problems to the respondents. The average age (AA) of people who gave a specific answer was also shown per answer.

4.1.1.2. Solid Waste Management Results

The first question of the *solid waste management* part of the questionnaire was an open question, that asked the respondents to describe what they typically do with their solid waste. The majority answered that they bag their solid waste, and throw away their waste in a container. None of the respondents mentioned that they sell part of their waste to recycling companies, or that private companies come and collect their waste. Table B.6 shows all responses.

Most households used a small bag (Figure B.6a, see Figure 4.5 for an idea of the different bag sizes) that was being disposed once every day (Figure B.6b). Table 4.1 shows how the responses related to the household size. It could be observed that the larger households did use more often larger bags and disposed more frequent. However, there did not seem to be a real strong relation between the household size and the frequency of waste disposal or the size of garbage bags being used. This could be the result of a too small sample size. When the used bag size and disposal frequency was compared against the floor on which the household lived it could be observed that the households who lived on ground level disposed more often (see Table 4.2). There seemed to be no clear relation between household floor level and bag size (Table B.8).

Most households had a container not further away than half a block's length (half a block is about 125 meter), see Figure B.7a. The majority of the households always disposed their waste in the designated containers. However, in total about 35.5% of the respondents reported that they themselves or others did not dispose their waste in a container. The disposal behaviour did not show a clear relation between the distance to a container or the floor on which household a lives (Table 4.3).

The responses yielded a pretty clear answer to the question how frequent the containers were collected, which was once a day (Figure B.8a). A closer look into the response also did not show a relation between the location and the collection frequency of two times per day. Most respondents were not satisfied with the number of times waste was being collected (Figure B.8b) and from these respondents the majority would have liked to see the collection being 2 times per day (Figure B.8c).

The questionnaire provided a clear answer to the question if people had to pay tax for their solid waste. The majority of the people paid tax (Figure B.10a), and the majority paid 600 Kyats per month(Figure B.10b). From the people who did not pay tax, the majority was aware that they have to pay tax but they just did not know where they had to pay or did not have the money for it (Figure B.10c).

Figure 4.5: For the question about the size of their waste, this picture was shown. The red outlined bag is the small bag (about 25x25x20 cm). Picture taken on March 17, 2017.

Table 4.1: Most households threw away a small bag once a day. However, some households threw away their small waste even less frequent. A minor portion of the respondents produced a lot of waste both in terms of the size of the bags used for waste disposal and the frequency of waste disposal. Observe that the household size did not show a strong relation to the size of the used bag size or to the frequency of waste disposal. However, it could seen that the larger bags were used by larger households and that the larger households might have had a bit higher waste disposal frequency.

		Garbage Bag Size				Household Size									
		Small	Medium	Large	No Answer	1	2	3	4	5	6	7	8	9	≥10
Frequency of Waste Disposal	3 bags per day	-	-	-	1	-	-	-	-	-	-	-	-	1	-
	2 bags per day	4	4	1	1	-	1	1	3	1	-	2	1	-	1
	1 bag per day	13	2	2	-	-	-	2	5	6	1	2	-	-	1
	1 bag every 2 days	8	-	-	1	1	2	1	2	1	1	-	-	1	-
	1 bag every ≥ 3 days	8	-	-	2	-	-	2	4	-	1	1	-	1	1
	No Answer	-	-	-	1	-	-	-	1	-	-	-	-	-	-
Household Size	1	1	-	-	1										
	2	3	-	-	-										
	3	5	-	-	-										
	4	12	1	-	-										
	5	5	1	-	1										
	6	3	-	-	2										
	7	1	2	2	-										
	8	-	1	-	-										
	9	1	-	1	1										
	≥10	2	1	-	-										

Table 4.2: The households that lived on ground level disposed their waste more frequent. The size of the used bags did not show a clear relation with the floor level of the households.

		Household Floor Level		
		≥2nd floor	1st floor	Ground Level
Size of Garbage Bag	Small	12	6	15
	Medium	2	2	2
	Large	1	1	1
	No Answer	3	1	2
Frequency of Waste Disposal	3 bags per day	-	-	1
	2 bags per day	2	2	6
	1 bag per day	6	4	7
	1 bag every 2 days	4	3	2
	1 bag every ≥3 days	5	1	4

Table 4.3: There seemed to be no clear relation between the distance to the nearest container or the on what floor the household was situated and the household's waste disposal behaviour. You might expect that the further people had to walk to a container and/or the higher they lived the more tempting it was to not always go to a container or know neighbours who did not go to the container.

		Distance to Container						Household Floor		
		<25m	≥25 & <50m	≥50 & <100m	≥ 100 and & <150m	≥ 150 & ≤200m	>200m	≥ 2nd floor	1st floor	Ground Level
Waste Disposal Behaviour	*	-	3	-	-	-	-	2	-	1
	**	1	4	2	-	-	-	1	2	4
	***	-	-	-	-	-	-	-	-	-
	♦	-	-	-	-	-	-	-	-	-
	♦♦	2	11	9	2	4	1	13	7	9
	♦♦♦	3	1	2	1	-	-	2	1	4
	No Answer	1	-	-	-	1	-	-	-	2

* I sometimes throw away my solid waste not in the container, but on the street.

** I sometimes throw away my solid waste on a spot where my neighbours have already thrown away their waste

*** I sometimes throw away my solid waste in the drain

♦ I sometimes throw away my solid waste in the inlets of the drains

♦♦ I don't think that the container is too far away and I always go to the container, even when it is always full

♦♦♦ I don't think that the container is too far away, but I know others who don't go to the container because it is too far away or always full

4.1.1.3. Urban Flooding Results

It did flood in the Latha township as could be concluded from the answers shown in Table B.10. Note that the people who answered that it never flooded (Question 30 of the questionnaire and Figure 4.7a) were omitted from this point on which resulted in 43 respondents.
According to the majority of the responses it flooded on average less than four times per year (Figure 4.7a), the floods were of a short duration (Figure 4.7c) and the water depth during a flood was mostly around 10 cm (Figure 4.7b). This is generally speaking in line with the results from the interviews with the Yangon City Development Committee Engineering Department of Roads and Bridges (YCDC EDRB) (see Table D.2).
During interviews the question: "Do you receive a warning before it floods?", was a guaranteed moment of laughter and no one ever replied that they receive a flood warning. However, some respondents indicated that they did sometimes received a flood warning from others (Figure B.12a). Often this was between zero to ten minutes before the flood reached them (Figure B.12b).
About one third of the respondents answered that the blockages (almost) always occurred at the same location. (Figure B.12c). With Strand Road mentioned the most often (Figure 4.6).
About 30% of the respondent's building/house had a form of flood protection (Figure B.13a). In most cases this flood protection consisted of a concrete slab in the (door) opening of their building (Figure B.13b). In Figure 4.14b an example of a concrete slab is shown. The slabs are multi-purpose as they also serve to prevent rats from walking into the property.
The majority of the respondents replied that they do not change their daily pattern/activities in case of a flood (Figure 4.7d). The large majority of respondents answered that they never had any damage from floods Figure B.14a), and people who did had any damage did not answer how much damage they had (Figure B.14b) and what type of damage it was (Figure B.14c).
The majority of the respondents indicated that the drains were maintained once per year, followed by a group of 30% that answered that the drains were maintained 2 or 3 times per year (Figure 4.7e) and the most likely reason for maintenance was because the rainy season was approaching (Figure 4.7f).
The questionnaire made clear that the YCDC implemented some improvement in the last 5 years to reduce (the consequences) of floods. Sixteen people responded that the sizes of drains had been increased and 14 people mentioned that the road was raised (Figure B.15c).
It seemed that the majority of the respondents had relative good knowledge/awareness about the flood causes (Figure 4.8) and the majority would have liked to see that the floods are resolved by increasing the capacity of the urban drainage system (UDS) (Figure 4.9).

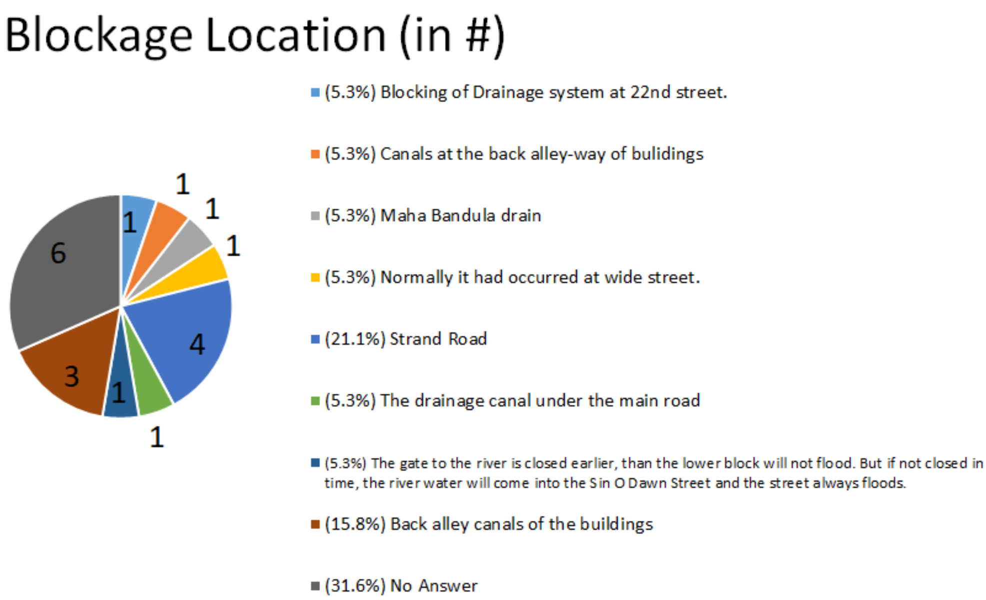
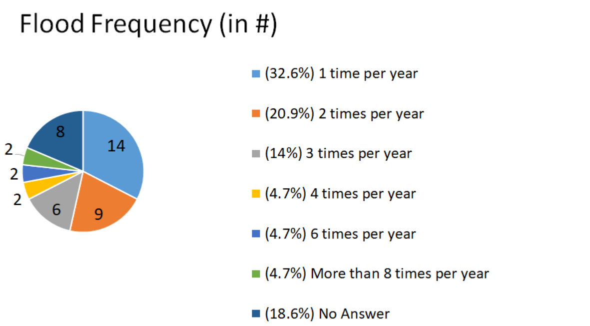
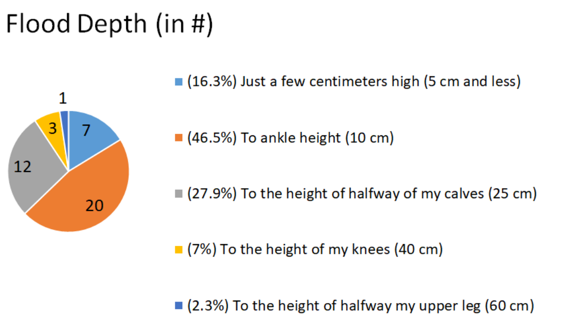


Figure 4.6: Answer to Question (36): *Where (at what location) does the blocking and flooding most of the times/always start?*

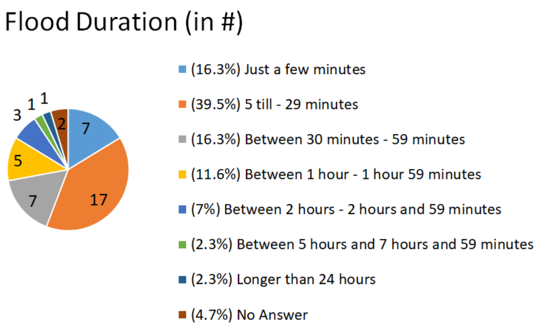
Strand road was often mentioned as the location where the blockages often occurred. What is interesting is that one person also answered that the blockages often happen around 22nd Street, as confirmed by YCDC EDRB (Kyaw Mein Oo, personal communication, April 6, 2017). Also note the response that talked about the FGSs, this is in line with the results from the SOBEK model (see Section 4.2). Finally a group responded that the flooding always starts from the back alley drains. The back alley drains were not researched, since there was too little information available about them.



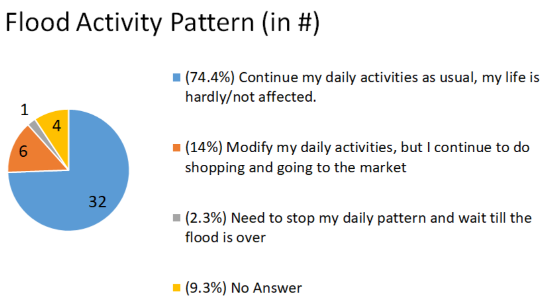
(a) Answer to Question (30): *On average, how often do you experience flooding in your street/house?* Most respondents said that it floods once, twice or three times per year on average.



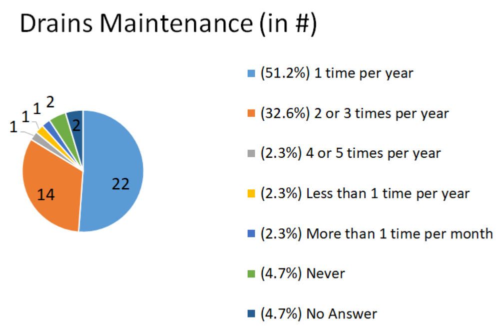
(b) Answer to Question (32): *On average when it floods, most of the times the water level gets:* Most respondents said that if it floods the water depth is about 10 cm. Also observe that most respondents do not experience severe flooding as hardly any one experiences floods with a water depth above 40 cm.



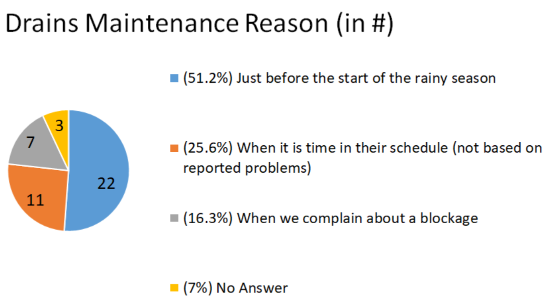
(c) Answer to Question (31): *On average, how long does a flood last?* Most respondents replied that the floods last between a few minutes to one hour.



(d) Answer to Question (39): *When it is flooded, I...* In case of a flood, a very large majority said that they did not change their daily pattern/activities. Some people said that they will actually modify their activities slightly but will continue to do their business.



(e) Answer to Question (43): *How often get the drains in your street get cleaned/maintained?* The questionnaire showed that the drains were most likely to be cleaned only once a year or otherwise 2 or 3 times a year.



(f) Answer to Question (44): *They clean the drains...* Most of the times the moment that the drains got cleaned was just before the start of the rainy season, according to the respondents.

Figure 4.7: Answers from household respondents to questions about flooding in Latha.

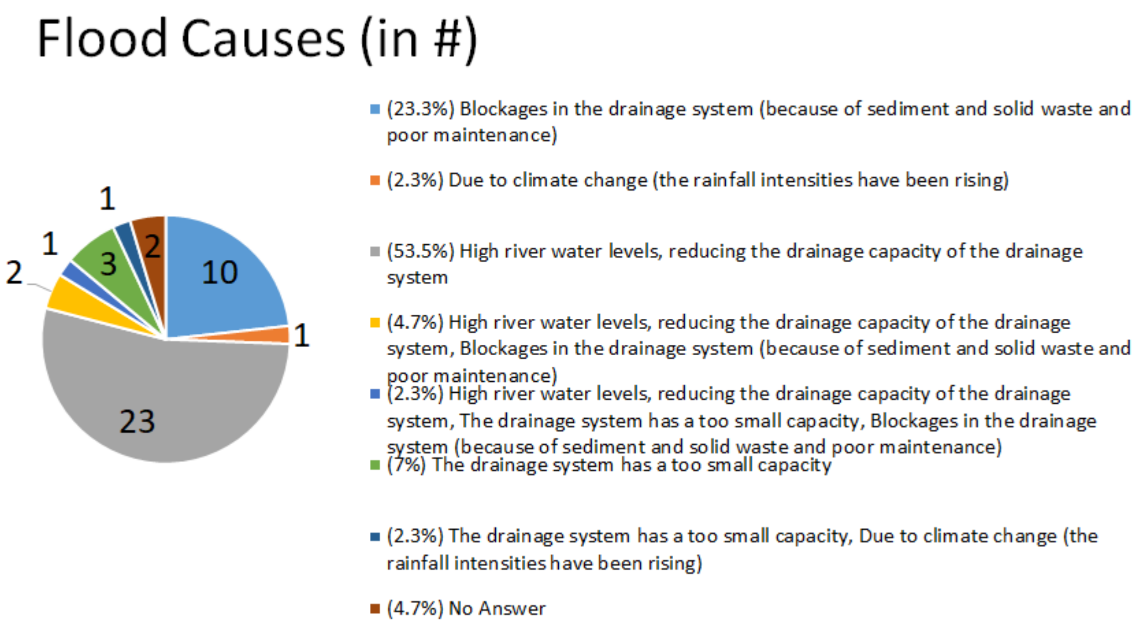


Figure 4.8: Answer to Question (46): *What do you think causes the flooding?* The majority of the respondents thought that the floods were the result of high river water levels that reduced the drainage capacity of the drainage system and/or that the flood was caused by blockages in the drainage system.

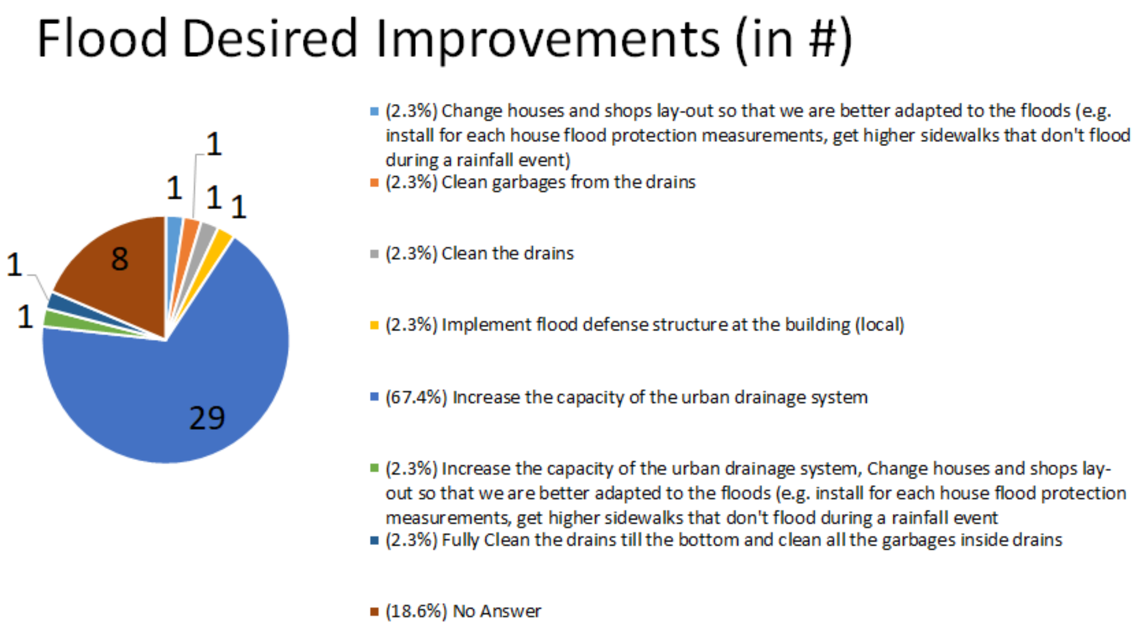


Figure 4.9: Answer to Question (47): *How should the flooding be solved?* Increasing the capacity of the UDS was by far the most popular desired improvement to reduce the flood probability.

4.1.2. Field Observation Results

This section shows some fieldwork observations that were characteristic for human actions (or the results of human activities) that might contributed to urban flooding. First of all, citizens cleaning their house, shop or street with water from a hose and a broom: swiping all their waste in the drains was an often observed practise (See Figure 4.10).
Over-topped containers, with waste littered all around it and waste dumps with no container nearby were frequently observed (Figure 4.11). This also fitted the results from Section 4.1.1.2, where respondents indicated that there were insufficient containers for the collection frequency. More illegal local dump sites were observed if the nearest container had been moved to a different location than its usual spot, which was not an exception.
The questionnaire results already showed that people had some flood awareness (Figure B.16a). Another example of citizens' flood awareness is shown in Figure 4.12a.
A general observation was that the maintenance state of a lot of the drains was not 100%. Often drain covers were cracked or bits were broken off, as the example of Figure 4.12b shows.
Figure 4.13 shows two situations where the waste had clearly found a way to enter the drainage system. Situations with this waste amount were not excessive or abnormal compared to other observed situations.

(a) Citizen cleaning the street with water from a hose and a broom. In the middle of the picture it could be observed that the a cover of the drain was removed. Picture taken on March 2, 2017.

(b) This person was cleaning its doorstep by forcing all the rubbish and waste through the cracks of the drain covers with his broom. Picture taken on April 3, 2017.

Figure 4.10: Cleaning practices of citizens that resulted in fouling of the drains.

(a) A location with a large number of containers and yet waste was littered everywhere. Picture taken on March 12, 2017.

(b) An example of a local waste dump location. For this specific time and location the nearby container that usually stood at the end of the street was missing. Picture taken on March 3, 2017.

Figure 4.11: Full containers, missing containers and locally unofficial dump locations were no exception.

(a) A local initiative of citizens from the 20th Street upper block. The sign asked passer-bys to not throw their waste on the street or in the drains, but to be aware of the consequences of such an action and therefore dispose their waste in the small bin. Several of these bins were placed in this street. Picture taken on March 17, 2017.

(b) For a lot of locations the maintenance state of the drains was not 100%. Such cracks and openings were often used as a place to dispose waste, as could be observed by the amount of waste in the drain around and under the opening. Picture taken on March 5, 2017.

Figure 4.12: Citizens' awareness and a typical partially broken drain cover.

(a) A drain that was broken open for reconstruction provided a nice insight in the amount of waste that can be present in a drain. The drain was not situated in Latha, but this was not out of the ordinary for the drains in the busiest streets of Latha. Picture taken on January 8, 2017.

(b) This was an example of the waste and deposits that were removed from a culvert that was cleaned on a monthly basis (outside of Latha though). The amount of waste was from one half of the culvert and the cleaning operation was still under way when the photo was taken. Picture taken on March 15, 2017.

Figure 4.13: Waste that was ended up in the drains and culverts of Yangon.

(a) The inside of the FGS under low water level conditions. It could be observed that even without a rainfall event flushing a lot of waste to the gate structure there is a significant amount that is stuck within the structure. Moreover, the observation also shows a pipe or cable that runned through the structure. This could potentially increase the probability that waste gets stuck. Picture taken February 8, 2017.

(b) This was an example of the a building with flood protection. The concrete slab also functions to keep out rats. Picture taken on January 21, 2017.

Figure 4.14: Waste that was ended up in the drains and culverts of Yangon.

4.1.3. Interview Results

This section provides the most important questions and answers from the interviews. Appendix D provides additional information.

Table 4.4: Summary of the transcript from the semi-structured interview with the Yangon City Development Committee Pollution Control and Cleansing Department (YCDC PCCD) Latha Office

Date:	*28-03-2017*
Organisation:	*YCDC PCCD Latha Office*
Name:	*U Myot Soe Thein*
Q:	*How much household waste is collected per day for Latha?*
A:	For Latha the waste production was 36,000 kg per day. Waste from the hospital area was collected separately and that was about 4,000 kg/day.
Q:	*How often is the waste collected per day for Latha?*
A:	One time per day at 6 AM a truck collected all the waste from the containers and brings it to the transfer collection point. Moreover, twice a day YCDC PCCD employees collected small garbage with a cart. They collect especially recyclable waste. Eventually all the waste goes to the Htein Bin Final Disposal Site.
Q:	*How many containers are there in Latha and what are their locations?*
A:	In total there were 120 containers in the area and a map was provided with the locations of the containers. Each container could contain 660 Liters.
Q:	*How much is the waste production variation from day to day?*
A:	The waste production was relatively stable. Almost every day the YCDC PCCD collected about the same amount of waste, even Sundays did not show a large deviation compared to the other days of the week (Myanmar is thought to have a six day economy).
Q:	*How often do the streets get cleaned?*
A:	The streets were cleaned every day by YCDC PCCD employees that went around with a cart. The streets were broomed and the collected waste was disposed in the cart.
Q:	*How often do the drains get cleaned?*
A:	Open (uncovered) drains got cleaned every day. Covered drains got cleaned one or two times per year just before the start of the rainy season. If the YCDC PCCD received complaints about a blockage, incidental maintenance was executed. The drains of 17th and 18th Street got cleaned three or four times, as they got blocked more often. This was probably related to the market at 17th and 18th Street.
Q:	*What was recently updated on the drainage system?*
A:	In 2015 some drains were upgraded, resulting in no floods for 2016.

Table 4.5: Summary of the transcripts from from the two semi-structured interviews with the YCDC EDRB General Office

Date:	*30-03-2017 & 06-04-2017*
Organisation:	*YCDC EDRB General Office*
Name:	*Kyaw Mein Oo*

Q: *Why does the Latha Township flood?*

A: The Latha Township was one of the lowest areas in the central business district and was most flood prone. Lanmadaw sometimes also experienced floods. However the other 4 townships of the central business district had higher ground level elevations and hardly had floods.
The floods themselves were caused by heavy rainfall events. In some cases drains were blocked, causing floods. Another issue was that sometimes the flood gates could not be fully closed because of blockages. Finally, high water levels in the Yangon River often resulted in having to close the FGSs. If it rained the drains would become full since the could not drain to the river, eventually resulting in floods.

Q: *How long does a flood typically last?*

A: Floods because of blockages often lasted for 20 to 30 minutes. After this time frame, often a YCDC EDRB employee arrived on the scene to clear the blockage by using long bamboo sticks. However, really heavy floods could last up to 3 to 4 hours or so.

Q: *What is the water depth during a typical flood?*

A: The water depth is typically somewhere between a few centimetres to about 20 centimetres. However, during a sever flood the water depths might be over half a meter at Strand Road.

Q: *How frequent are there floods during a typical year?*

A: There are about 4 floods during the rainy season, although the severity differs from time to time.

Q: *Which areas can be flooded during a flood in the Latha Township?*

A: Often Strand Road and the lower blocks were flooded first. Especially around Latha Street, 22nd and 23rd Street. The floods never extended further than the south side of the Hospital terrain.

Q: *Who is responsible for cleaning the inlets, drains and structures in the drainage system?*

A: The YCDC EDRB was responsible for all the waste in the drainage system, waste in the inlets and waste in the flood gate structures. Cleaning the streets and containers was the responsibility of the YCDC PCCD . Scheduled maintenance to the inlets by YCDC PCCD was not possible as this is a different Yangon City Development Committee (YCDC) department with different responsibilities. "Cleaning the drains and inlets was our responsibility".

Q: *How often are the drains cleaned and when?*

A: The drains were cleaned once per year, just before the start of the rainy season.

Q: *What causes blockages in the drains?*

A: Citizens who disposed their waste in the drains or on the street. Eventually this waste got stuck in some of the culverts and sometimes prevented the FGSs to not be fully closed by a YCDC EDRB employee. Waste might also got stuck behind water pipelines, electrical wires and telecommunication lines that runned through the drains. This was a problem that could not be prevented by the YCDC EDRB . The pipelines, electrical wires and telecommunication lines were under the responsibillity of other YCDC departments. There used to be a lack of communication and coordination between the different YCDC departments. However, recently the coordination improved and new connections are now made as much as possible outside of the drains, aside of the road.

Q:	*At which location do the floods start most of the times?*
A:	The gate at 22nd and 23rd street (this is gate 7) often had the worst blockages. Also the culverts close to this drain got blocked relatively frequent. The junction of Latha Street and Strand Road was also a problem area, which often was one of the first places to be flooded.
Q:	*How often do the gates get blocked?*
A:	In the past the gates used to be leaky along the side walls. Therefore the gates were upgraded in 2013. However, sometime waste still gets stuck in the gate not allowing them to be fully closed. The same applied to the high water valves that were at the other end of the drain that connected the gate with the Yangon River.
Q:	*Does Latha experience subsidence?*
A:	In the last few years Latha did not experience any significant subsidence.

Table 4.6: Transcript summary of the unstructured mini-interviews with Latha citizens.

Date:	*28-02-2017 till 08-04-2017*
Organisation:	*Latha Township*
Name:	*Latha Township Citizens*
Q:	*How much waste do you produce per day?*
A:	Most of the people said that they produced about one plastic bag of waste per day.
Q:	*How often do you dispose your waste and where do you dispose it?*
A:	The majority of the interviews mentioned that they disposed their waste once a day in a container of the YCDC. However, a small number of people also mentioned that there were small companies who offered services of waste collection at the door.
Q:	*What should be improved on Latha's solid waste management?*
A:	An often heard answer was that one of the problems was that the YCDC PCCD did not have sufficient employees cleaning the streets. As a result, not all the waste that lied around on the streets got cleaned. Moreover, some of the street cleaners were reported to be too focussed on recyclable materials like plastic bottles and cans, but did not clean other types of waste. The collection of waste close to containers was better than waste on the streets (especially in the smaller streets).
Q:	*What do you think about the number of containers?*
A:	There were insufficient containers. Some interviewees also mentioned that there was a problem with the location of the containers. Most containers were almost everywhere positioned at the beginning and end of a street. This was done so that the YCDC PCCD was able to collect the containers fast. However, some people felt that this distance was too far. They asked to the YCDC if additional containers could be placed halfway of the street, but the YCDC did not want to cooperate, because it would be disruptive to their collection procedure. Also most respondents complained that they felt they paid enough tax, but that the containers were always full. They said that more containers were required or collection should be more frequent. However, when asked how the interviewee would feel about additional containers in front of their house, most people answered negative. There seemed to be some kind of not in my backyard opinion.
Q:	*How often does it happen that the containers in your street are missing?*
A:	People said that it did happen, but not too often. In most cases a container was placed back a few days later.

Q: *What do you do if a container is full or if the container(s) in your street are missing?*
A: Most of the people said that they would still go to the container and just make a pile next to the container or on the spot of the missing container. However, some people also said that they made piles in front of their houses. But since this waste was not always collected the next day, some citizens mentioned that it was best to still go to the location of the container, since there the collection was better.

Q: *What do you think is the biggest problem in solid waste management (SWM) from the side of citizens?*
A: Not all shops pay waste taxes and do not throw away their waste in the containers. Most shops are often cleaned with water, flushing all the garbage and dirt in the drain. Another problem is that sometimes households on the higher floors just throw their waste out of the window, especially in the back alley drains. Therefore security cameras were placed in some streets and back alleys behind the buildings to prevent illegal waste dumps. However, there were still too little cameras (especially in the back alleys) and some cameras got deliberately obstructed and destroyed.

Q: *How often does it flood in Latha?*
A: According to most respondents short floods that lasted about 30 minutes occurred a few times per year. During these floods, the water depth was to about ankle height and most people said they would continue their daily business as usual. Long floods only happen once or twice a year with durations of a few hours and water depths of about half way the calves to knee height.

Q: *Where do these floods occur?*
A: Most of the times it flooded especially around Strand Road and the south end of Latha street, because these were the low laying areas.

Q: *Why do you think floods occur in the Latha Township?*
A: Most interviewees said that they thought that the floods were the results of blockages in the drains. The blockages were the results of people disposing waste outside of containers and the streets and drains were cleaned insufficient.
Another often heard reason was that the drainage system was too small for heavy rainfall events. But there were some recent improvements made to the drainage system and some streets were slightly raised.

Q: *Does your property you have flood protection measures and if so what?*
A: A lot of people who lived on ground level had a concrete slab in the (door) opening of their building. However, this concrete slab was multi-functional. It also served as a measure to prevent rats from entering the property.

Q: *How often do the drains get cleaned and when do they get cleaned?*
A: The large majority indicated that the drains only got cleaned once a year, just before the start of the rainy season. Most of these people also complained that they would like to see that the drains would be cleaned more often during the entire year.
Around the market of 17^{th} and 18^{th} street (see Figure) people complained more often about blocked drains and reported that drains were cleaned more often, sometimes even 4 times per year and not only just before the start of the rainy season.
Multiple times, interviewees also complained about the maintenance state of the drains. At a lot of locations the concrete drain covers were partially broken. This was a dangerous situation as people could hurt themselves. Moreover, they said that sometimes people also dispose waste through these openings into the drains.

Q: *How do you think the flood problems should be resolved?*
A: Almost all respondents mentioned increasing the size of the drains as the main solution. In addition a large group suggested more frequent cleaning of the drains before and during the rainy season.

4.2. Flood Simulation Results

Simulating all the cases from Table 3.8 provided a clear insight of the effects of different parameters, processes and urban hydrological dynamics on the manifestation of flood events in Latha.
For the six evaluated locations, the indicators and criteria of Section 3.2.5.2 were used for each case. For clarity indicators 6 to 9 were omitted from the results presented in Table 4.7. In the table the used reference case per cluster of cases (see Table 3.3) was highlighted grey. Recall that for indicator 1 an increase or decrease of 2 or more number of floods was considered significant. For indicators 2–5 an increase or decrease of $\pm 15\%$ was considered significant. If a case's indicator resulted in an significant improvement the indicator was highlighted green and for a significant deterioration it was highlighted red.
Observe from Table 4.7 that the cases researching the effects of: runoff coefficients, blockages and different dry weather flows were omitted. These settings showed no significant impact (see Table E.4 for the results). Case 42 was only used for Figure 4.17, no statistics were made.

The two recorded flood events on July 13, 2014 and July 14, 2014 (Section 3.1.3, Table 3.7 and Section C.3.9 for more details) resulted in a water depth of about 90 cm. This data was used as comparison of the simulated results.
All the cases with the normal timing of the Yangon River water level (YRWL) (all cases but cases 33–35) resulted in the most intense floods on 13 July 2014, which was in line with the collected flood records. However, do observe that none of the cases showed any flooding on 14 July 2014, whereas the flood records clearly showed a flood recorded on 14-07-2014 (e.g. see Case 1, Figure 4.15). This anomaly will be addressed at the end of this section and in Section 4.3.

Table 4.7: Overview of all cases and their results. Grey is the reference case, green indicates an improvement, red indicates a deterioration for a $\pm 15\%$ deviation or a deviation of ≥ 2 number of flood events. For the used indicators see Section 3.2.5.2. Number of floods: The number of times the location experienced a flood. Tot.Duration: The aggregated duration of water on the street for all the flood events at the specified location. Max.Duration: The duration of the flood event that lasted longest at the specified location. Tot.max.Depth: The aggregated maximum water depths for all the flood events at the specified location. Max.max.depth: The maximum water depth of the most extreme flood event at the specified location.

		Point 17_2					Point 17_7					Point Lat_1					Point Lat_8					Point 23_1					Point 23_7				
	Case	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth
GLR	2	14	2611.5	492.0	3.86	0.68	2	436.0	328.5	0.25	0.19	19	2938.5	428.5	5.29	0.79	3	546.0	339.5	0.43	0.24	14	1863.0	394.0	3.20	0.66	1	259.5	259.5	0.13	0.13
	1	14	2170.5	459.5	3.33	0.63	1	270.5	270.5	0.14	0.14	16	2245.0	400.0	4.33	0.74	4	409.5	311.0	0.34	0.20	13	1404.5	362.0	2.37	0.61	1	168.5	168.5	0.08	0.08
	2	14	2611.5	492.0	3.86	0.68	2	436.0	328.5	0.25	0.19	19	2938.5	428.5	5.29	0.79	3	546.0	339.5	0.43	0.24	14	1863.0	394.0	3.20	0.66	1	259.5	259.5	0.13	0.13
	3	14	2722.5	498.5	3.96	0.69	2	481.5	339.5	0.28	0.20	19	3400.0	435.0	5.57	0.80	3	572.0	345.5	0.45	0.25	12	1954.0	403.0	3.24	0.67	1	274.0	274.0	0.14	0.14
Roughness	1	14	2170.5	459.5	3.33	0.63	1	270.5	270.5	0.14	0.14	16	2245.0	400.0	4.33	0.74	4	409.5	311.0	0.34	0.20	13	1404.5	362.0	2.37	0.61	1	168.5	168.5	0.08	0.08
	4	11	1660.0	387.0	2.73	0.60	1	228.0	228.0	0.12	0.12	16	2205.5	391.0	4.22	0.71	3	252.5	245.5	0.23	0.17	27	1441.5	365.5	2.96	0.58	1	110.5	110.5	0.05	0.05
	5	14	1900.5	429.0	3.06	0.62	1	254.0	254.0	0.13	0.13	16	2221.5	403.0	4.26	0.73	2	316.0	287.5	0.22	0.18	12	1396.5	369.0	2.38	0.60	1	141.0	141.0	0.07	0.07
	6	14	2413.0	491.0	3.53	0.64	1	289.5	289.5	0.15	0.15	16	2276.0	398.0	4.38	0.75	4	517.5	321.0	0.47	0.21	13	1374.0	357.0	2.35	0.62	1	195.5	195.5	0.09	0.09
	7	16	2733.5	528.5	3.83	0.65	1	312.0	312.0	0.16	0.16	16	2354.5	405.0	4.46	0.76	4	570.5	331.0	0.58	0.22	10	1381.0	360.5	2.31	0.63	1	210.0	210.0	0.10	0.10
	8	15	5700.5	1025.0	4.25	0.69	3	880.0	477.0	0.41	0.20	16	3551.0	536.5	4.96	0.80	10	1191.5	404.5	1.30	0.26	13	2025.0	477.0	3.04	0.67	2	292.0	268.5	0.17	0.14
RTC	3	14	2722.5	498.5	3.96	0.69	2	481.5	339.5	0.28	0.20	19	3400.0	435.0	5.57	0.80	3	572.0	345.5	0.45	0.25	12	1954.0	403.0	3.24	0.67	1	274.0	274.0	0.14	0.14
	9	14	2506.0	484.0	3.75	0.67	2	364.5	314.5	0.22	0.18	17	2632.5	421.0	5.01	0.78	3	518.5	332.0	0.39	0.23	13	1764.0	383.5	2.99	0.65	1	242.0	242.0	0.12	0.12
	10	14	2604.5	491.5	3.85	0.68	2	430.5	327.0	0.25	0.19	18	2874.5	428.0	5.24	0.79	3	543.5	338.5	0.42	0.24	11	1855.0	393.0	3.08	0.66	1	258.5	258.5	0.13	0.13
	11	15	3265.5	506.0	4.13	0.70	2	528.0	351.0	0.31	0.21	17	3615.5	441.5	5.53	0.81	3	606.5	352.5	0.48	0.26	17	2425.0	413.0	3.56	0.68	2	296.0	288.5	0.18	0.15
	12	14	3565.5	512.5	4.19	0.70	2	572.5	362.5	0.34	0.22	17	3782.0	448.0	5.68	0.82	4	653.0	359.5	0.55	0.27	13	2795.5	421.5	3.61	0.69	2	398.5	299.5	0.21	0.15
	13	14	3881.0	525.0	4.40	0.71	2	636.5	380.5	0.39	0.23	17	4073.0	462.5	5.99	0.83	4	732.5	372.0	0.63	0.28	14	3114.5	435.5	3.89	0.70	2	512.5	315.5	0.26	0.16
Leakage	3	14	2722.5	498.5	3.96	0.69	2	481.5	339.5	0.28	0.20	19	3400.0	435.0	5.57	0.80	3	572.0	345.5	0.45	0.25	12	1954.0	403.0	3.24	0.67	1	274.0	274.0	0.14	0.14
	28	15	2850.5	496.5	4.02	0.68	2	449.0	336.0	0.25	0.20	19	3486.5	433.5	5.57	0.80	3	564.5	344.5	0.42	0.25	14	2060.0	401.5	3.31	0.67	1	268.0	268.0	0.13	0.13
	29	16	2981.0	495.0	4.10	0.68	1	333.0	333.0	0.20	0.20	26	3725.5	432.0	6.04	0.79	3	556.5	343.0	0.41	0.25	14	2128.5	400.0	3.34	0.66	1	263.0	263.0	0.13	0.13
	30	22	3755.5	491.5	4.60	0.68	1	327.0	327.0	0.20	0.20	29	4962.5	429.0	7.25	0.79	3	474.5	340.5	0.40	0.25	19	2709.5	397.5	3.70	0.66	1	251.0	251.0	0.13	0.13
RTC 2	1	14	2170.5	459.5	3.33	0.63	1	270.5	270.5	0.14	0.14	16	2245.0	400.0	4.33	0.74	4	409.5	311.0	0.34	0.20	13	1404.5	362.0	2.37	0.61	1	168.5	168.5	0.08	0.08
	31	12	1695.5	432.0	2.70	0.58	1	192.0	192.0	0.09	0.09	16	1802.0	376.5	3.58	0.69	2	263.0	217.5	0.26	0.14	8	995.0	339.0	1.63	0.56	0	0.0	0.0	0.00	0.00
	32	12	1695.5	432.0	2.70	0.58	1	192.0	192.0	0.09	0.09	16	1802.0	376.5	3.58	0.69	2	263.0	217.5	0.26	0.14	8	995.0	339.0	1.63	0.56	0	0.0	0.0	0.00	0.00
Shift WL	1	14	2170.5	459.5	3.33	0.63	1	270.5	270.5	0.14	0.14	16	2245.0	400.0	4.33	0.74	4	409.5	311.0	0.34	0.20	13	1404.5	362.0	2.37	0.61	1	168.5	168.5	0.08	0.08
	33	10	1531.5	309.5	2.72	0.68	1	164.5	164.5	0.19	0.19	10	1598.0	288.5	3.33	0.79	3	181.5	148.5	0.34	0.24	10	869.5	219.0	1.99	0.66	1	89.5	89.5	0.13	0.13
	34	11	1498.0	229.5	2.46	0.42	0	0.0	0.0	0.00	0.00	12	1438.5	242.5	2.87	0.38	1	41.5	41.5	0.12	0.12	10	859.0	210.0	1.25	0.24	0	0.0	0.0	0.00	0.00
	35	14	1818.0	248.0	2.72	0.43	0	0.0	0.0	0.00	0.00	16	1874.0	264.5	3.56	0.57	2	51.5	41.0	0.15	0.12	15	1131.0	222.0	1.67	0.44	0	0.0	0.0	0.00	0.00
Shift WL	1	14	2170.5	459.5	3.33	0.63	1	270.5	270.5	0.14	0.14	16	2245.0	400.0	4.33	0.74	4	409.5	311.0	0.34	0.20	13	1404.5	362.0	2.37	0.61	1	168.5	168.5	0.08	0.08
& RTC	36	9	854.5	270.0	2.1	0.6	1	113.0	113.0	0.2	0.2	12	742.0	207.5	2.2	0.8	1	101.0	101.0	0.2	0.2	5	269.5	173.0	0.9	0.6	1	38.0	38.0	0.1	0.1
& Crunoff	37	7	815.0	185.5	1.9	0.4	0	0.0	0.0	0	0	15	1042.0	134.5	2.3	0.4	1	41.5	41.5	0.1	0.1	6	279.5	95.5	0.8	0.3	0	0.0	0.0	0	0
	38	10	1023.5	185.0	2	0.4	0	0.0	0.0	0	0	16	1158.0	157.0	2.4	0.4	1	41.5	41.5	0.1	0.1	6	334.5	90.5	0.6	0.2	0	0.0	0.0	0	0
Improved	1	14	2170.5	459.5	3.3	0.6	1	270.5	270.5	0.1	0.1	16	2245.0	400.0	4.3	0.7	4	409.5	311.0	0.3	0.2	13	1404.5	362.0	2.4	0.6	1	168.5	168.5	0.1	0.1
S, I, E, C	39	14	2027.0	458.0	3.1	0.6	1	268.5	268.5	0.1	0.1	14	1935.5	398.5	4	0.7	3	414.5	310.0	0.3	0.2	11	1286.0	361.5	2.2	0.6	1	164.0	164.0	0.1	0.1
	40	13	1890.0	456.5	2.9	0.6	1	264.5	264.5	0.1	0.1	13	1818.0	395.5	3.7	0.7	2	355.0	291.5	0.2	0.2	12	1225.0	364.0	2.2	0.6	1	157.5	157.5	0.1	0.1
RTC, WL shift	1	14	2170.5	459.5	3.3	0.6	1	270.5	270.5	0.1	0.1	16	2245.0	400.0	4.3	0.7	4	409.5	311.0	0.3	0.2	13	1404.5	362.0	2.4	0.6	1	168.5	168.5	0.1	0.1
S, I, E, C	41	7	793.5	183.5	1.9	0.4	0	0.0	0.0	0	0	14	853.0	133.5	2.1	0.4	1	40.5	40.5	0.1	0.1	6	267.0	90.0	0.8	0.3	0	0.0	0.0	0	0

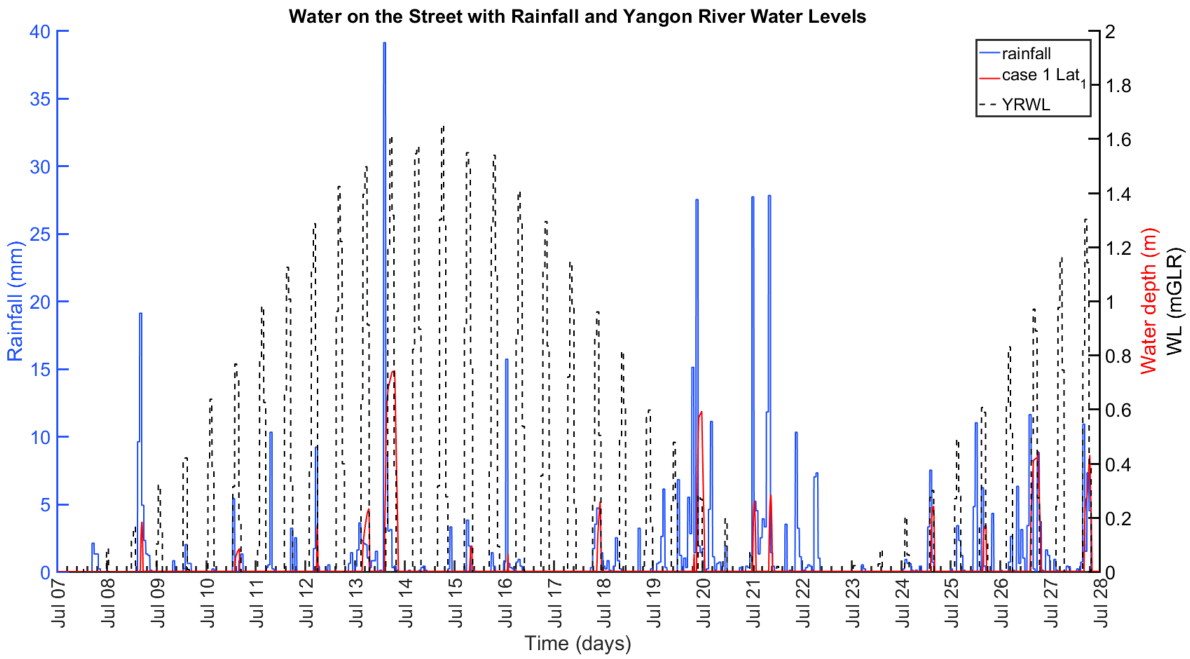


Figure 4.15: A plot of the data for Case 3 at the point Lat_1 (see Figure 3.10), for the entire model simulation time. On the left y-axis: the rainfall in millimetres for the blue line. On the right y-axis: water depth in meters for the red line, and the Yangon River water levels in meters Ground Level Reference (GLR) for the black line. Most flood events coincided when a high water level in the Yangon River occurred simultaneously with a rainfall event. Also note that on 14 July 2014 there was no flood simulated and this applied to the results of all cases.

The flood dynamics of the flood model simulation reflect the reported data. The most flood prone areas seemed to be Strand Road, Latha Street and the streets in the lower block (see Figure 4.16), as was mentioned by the YCDC EDRB (Table 4.5), the mini-interviewees (Table 4.6) and to some extent the questionnaire respondents (Figure 4.6).
Apart from the mentioned anomaly (of July 14, 2017) the flood depth results of the different simulated cases (Table 4.7) were in general comparable to the reported and observed flood record data. Although some cases underestimated the water depth at Strand Road, cases 1—30 showed water depths that were quite reasonable for the maximum flood event (Location 23_1 is very near to the location of gate 7).
Moreover, when the average maximum depth (Table 4.7) for the locations: 17_7, Lat_8 and 23_7 was compared to the answer provided by the questionnaire respondents (Figure 4.7b) and mini-interviewees (Table 4.6), the flood depths were also plausible.
However, the simulated results from all cases showed that the flood frequency was overestimated in general and especially for the areas on and close to Strand Road. Based on the flood records (Section 3.1.3), the reported flood frequencies by the respondents from the questionnaires (Figure 4.7a) and the interviews with the YCDC EDRB (Section 4.5) a typical flood frequency of about once or twice per year was to be expected. Even in the case with the least flooding (case 41, Table 4.7) the number of simulated floods was still 6 to 14 times for the areas close to Strand Road. For the locations further away from Strand Road the flood frequencies were lower and thus the differences were smaller but in general still too large.
A similar observation applies to the flood duration of the simulated floods, which in general lasted too long (compare Table 4.7, with Figure 4.7c and Table 4.5).

There are a number of reason that could have resulted in the performance of the model and the observed deviations from reality. The appendix Section E.5.1 discusses how the uncertainties of the used data and the model simplifications might have affected the model's results.

Despite the flood model's weaknesses and imperfections to accurately replicate the flood records (Table 3.7) and reported interview data (Table 4.5 and Table 4.6), it provided an improved understanding on which hydrological and hydraulic processes were dominant for the induction of the number flood events and their *severity* (the combination of duration and water depth).

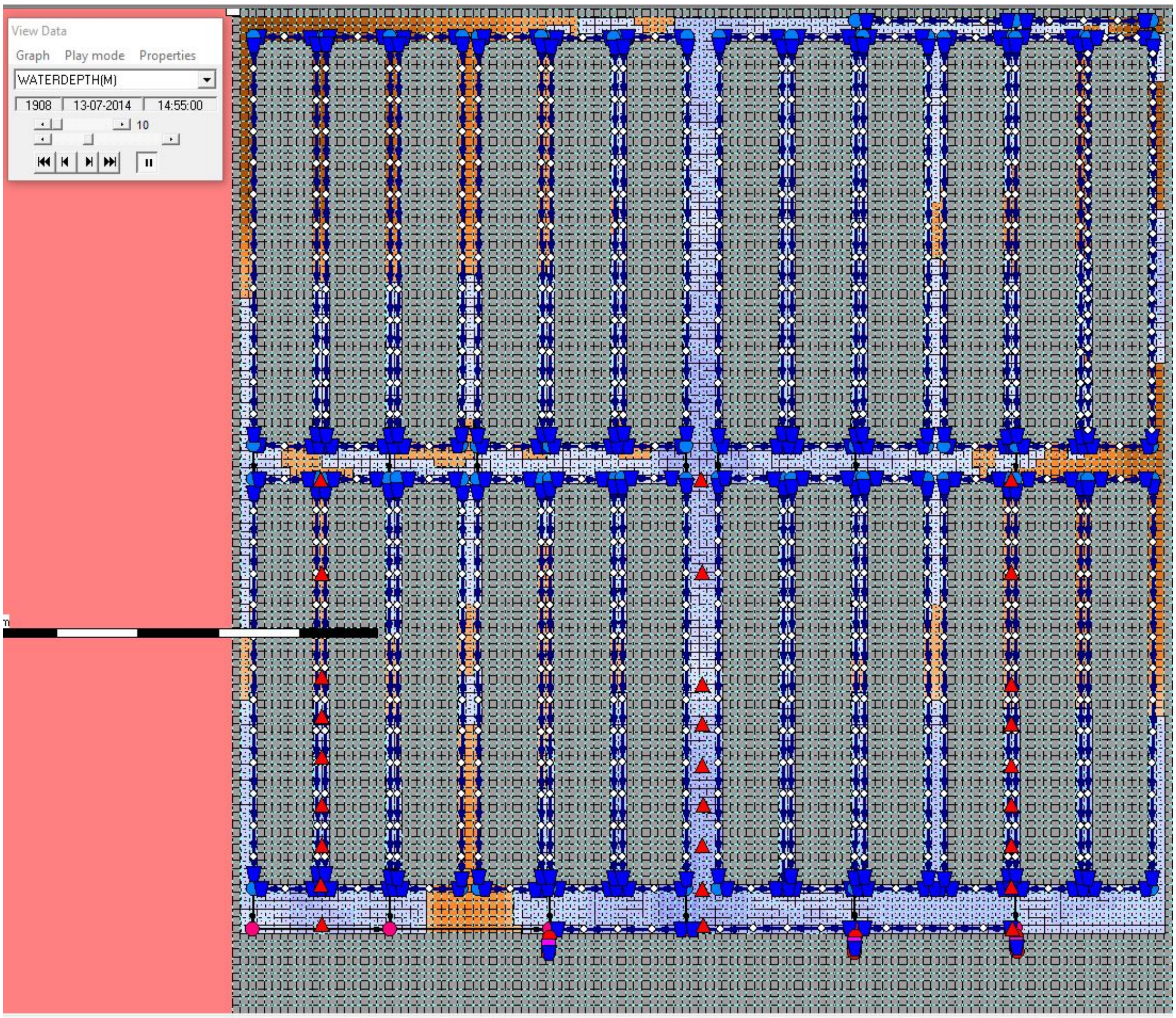


Figure 4.16: A snapshot from the SOBEk overland flow model results of Case 8 during the most severe flood on 13 July 2014, around 03:00 PM (UTC/GMT +6:30 hours). In general all cases showed that Strand Road, (lower) Latha Street and the south side of the streets in the lower block were most flood prone.

The results showed that the downstream boundary condition of the YRWL determined to a great extent if a flood occurred. When the YRWL became too high the FGSs had to be closed in order to prevent flooding caused by Yangon River water flowing into the UDS (Case 42, see Figure 4.17).

When rainfall coincided with a high YRWL, forcing the closure of the FGSs, the system often had too little storage to store all the runoff. The drains were full and spilled to the streets, causing floods before the YRWL became sufficiently low enough to allow for the FGSs to be reopened and discharge the rainfall fast enough. For example Figure 4.15 shows the rainfall, YRWL and the flood depth for Case 1 at the junction of Latha Street and Strand Road. The small rain events such at 18 July together with a high YRWL resulted in a similar flood depth as a more intense rainfall event with a low YRWL such as on 21 July. Moreover, most floods only occurred if the rainfall fell just before, during or just after high YRWLs.

The operational management of the FGS also affected the manifestation of flood events (cases 9–13, 31, 32). Lowering the target water level (WL) that was used to determine if the FGSs had to be closed, resulted in higher flood frequencies and more severe floods. Raising the target WL yielded opposite results.
Closing the FGSs later and opening them earlier might resulted in less flooding as the system was able to discharge for longer durations leaving more storage available. Moreover, the probability of rainfall just before, during or just after a gate closure was reduced. However, closing the gates too late or opening them too early might resulted in floods by Yangon River water as was mentioned before.

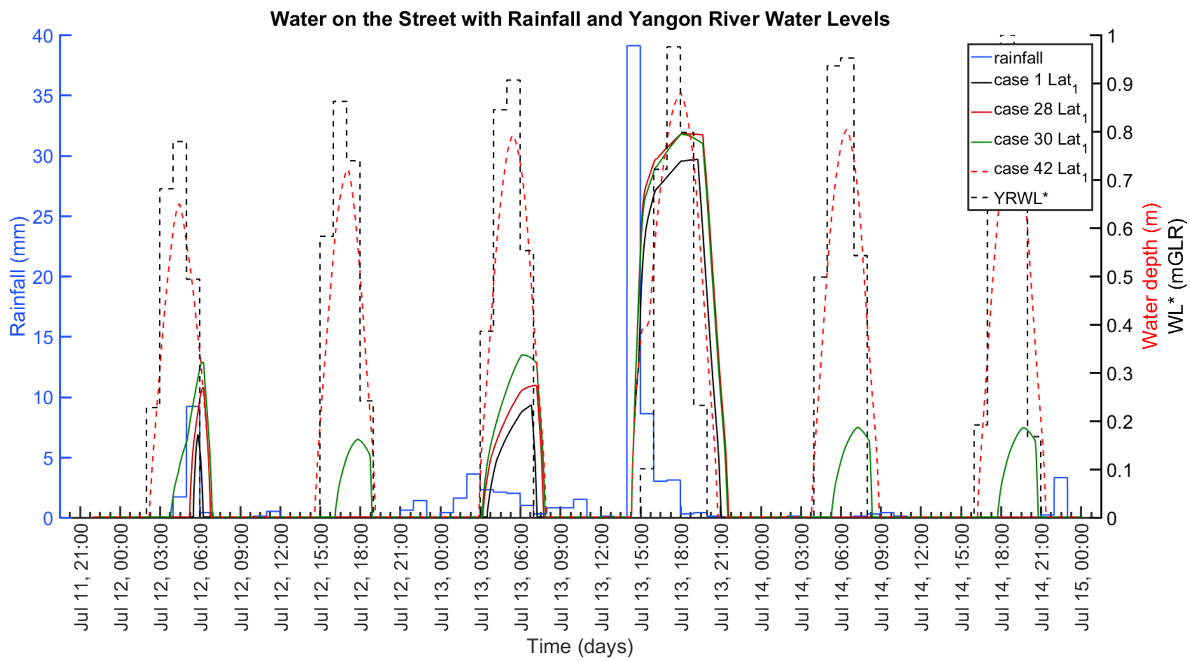


Figure 4.17: The plots show the water depths at the Lat_1, in case of a leaky and not closed gate 7. Case 1 shows only floods during rainfall, however the other cases all show floods during high water levels. The larger the gap, the larger the water depth. A large gap or fully opened gate can even cause major flooding without rainfall (e.g. on July 14, 2017), as Case 30 and Case 42 show. Note that the plot has two y-axis (left and right) and that in this plot the YRWL was scaled (by a factor 1/1.6505) to YRWL* for readability.

Not being able to close the gates completely (cases 28–30) or not closing them at all (Case 42) proved to be troublesome as the results showed. A small 5 cm gap did not have a too big impact (Case 28), but a 20 cm opening at just 1 gate (Case 30) or a completely opened FGS (Case 42) had disastrous consequences (see Figure 4.17). This was especially true for areas close to the Yangon River and FGSs (e.g. Points: 17_2, $Latha_1$ and 23_1).

The results of cases 9–13 and 28–32 already showed the importance of the downstream boundary condition to the induction of flood events. Moreover, Cases 33–35 showed that the same water levels with a different timing resulted in significantly less flooding, both in frequency and severity.

The effects of an increased dry weather flow (DWF) with or without a daily temporal pattern (cases –27 were negligible . Therefore on its own an increase in water consumption from population growth was expected to have no significant direct effect.

Lowering or raising the GL relative to MSL (cases 1–3) hardly affected the number of floods . However, there was an effect on the duration and water depth (the severity) of the flood events. Thus any significant subsidence from natural processes or (in)direct human activities (e.g. from ground water extraction) increases citizen's flood vulnerability and the negative effects of a flood event. The YCDC EDRB interview (Table 4.5) and a study by Van der Horst (2017) (see Section 3.1.3) revealed no recent significant subsidence.

There was hardly any effect on Latha's flood dynamics as a result of lower and higher runoff coefficients that simulated a decreased and increased storm weather flows (SWFs) that entered Latha's UDS. Thus urbanization was thought to play no significant role.

The simplifications for the hydrological processes such as interception, infiltration and runoff hardly affected the results, as cases 39 & 40 showed. The flood frequency was somewhat affected but the dominant flood events still occurred with a similar severity.

Combining some simulation settings resulted in a strong reduction of Latha's flood events . If the operation of the FGSs was set to close only at high YRWLs, if the hydrological processes were incorporated more detailed and if the Yangon River water levels had a different timing than the flood frequency and water depths for the Latha Township showed a significant improvement (see Table 4.7, cases 36–38 and Case 41).

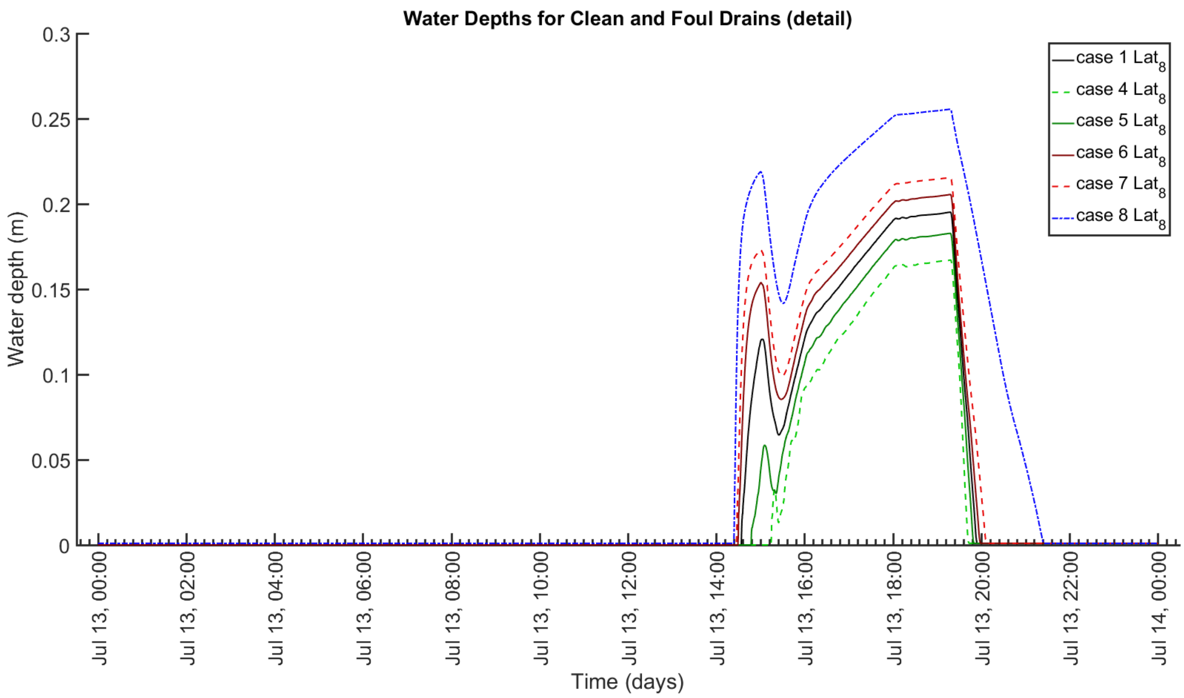


Figure 4.18: Water depth at the location Lat_8, for the most extreme flood event (on 13-07-2014). The black solid line is the reference case (Case 1), The two cases with cleaner drains resulted in a shorter duration and lower water depths, whereas the more foul drains resulted in higher water depths and longer durations. The top line represents the data from Case 8, which modelled the foulest drains.

Surprisingly the roughness of the drains (cases 4–8) had just a minor impact. Only when the drains were modelled as very foul, an overall deterioration was observed (Case 8). Figure 4.18 shows a detail of the flood depths for the $Latha_8$ location during the most extreme flood event. The peak water depth was about 5 cm higher compared to the reference case and had a duration that was two hours longer. However, the pattern of the flood dynamics showed similarities.

Another example of the importance of the downstream boundary condition (the YRWL) is revealed by a closer look at the results of Case 8. The case's very fouled drains did not result in severe flooding or a significant different flood behaviour of the drainage system, when the drains were able to discharge through the FGSs under free flow conditions (see Figure 4.19). Observe that for 20 July 2014, the fouled drains (Case 8) showed a similar flood pattern compared to the drains with a normal Manning's roughness (case 1), albeit with a higher peak water level and a longer duration. On this particular day, the rainfall coincided with a high YRWL. However, none of the rainfall that fell during a low YRWL did result in flooding for Case 8 but did not result in flooding for Case 1. For example, the rainfall on July 19, 2014 and July 21 (evening), 2014 did not result in flooding for both cases.

Even more surprising was the limited effect of the (partial) blocked culverts (cases 20–24). In none of the modelled cases, the hydrological and hydraulic response of the system deviated significantly compared to the drainage system without any blockages (see Figure 4.20).

A similar reasoning as for the limited effect of the roughness applied. The effects of a blocked drain were minimal when the FGSs were open and discharging into the Yangon River. Only when a high YRWL forced the closure of the FGSs and rainfall coincided with this moment, severe floods occurred.

Coming back to the anomaly of the *"flood mystery"* on July 14, 2014. The flood simulation results of cases 28–30 and Case 42 (Figure 4.17) already showed the flood potential of a not (fully) closed gate. Moreover, the questionnaires (Figure 4.6), field observations (Figure 4.14a) and the interview with YCDC EDRB (Table 4.5) learned that some floods might have been the result of a (partially blocked), not (fully) closed FGS.

Thus a possible explanation of the flood mystery was that there actually was a malfunctioning FGS during a high YRWL on July 14, 2014.

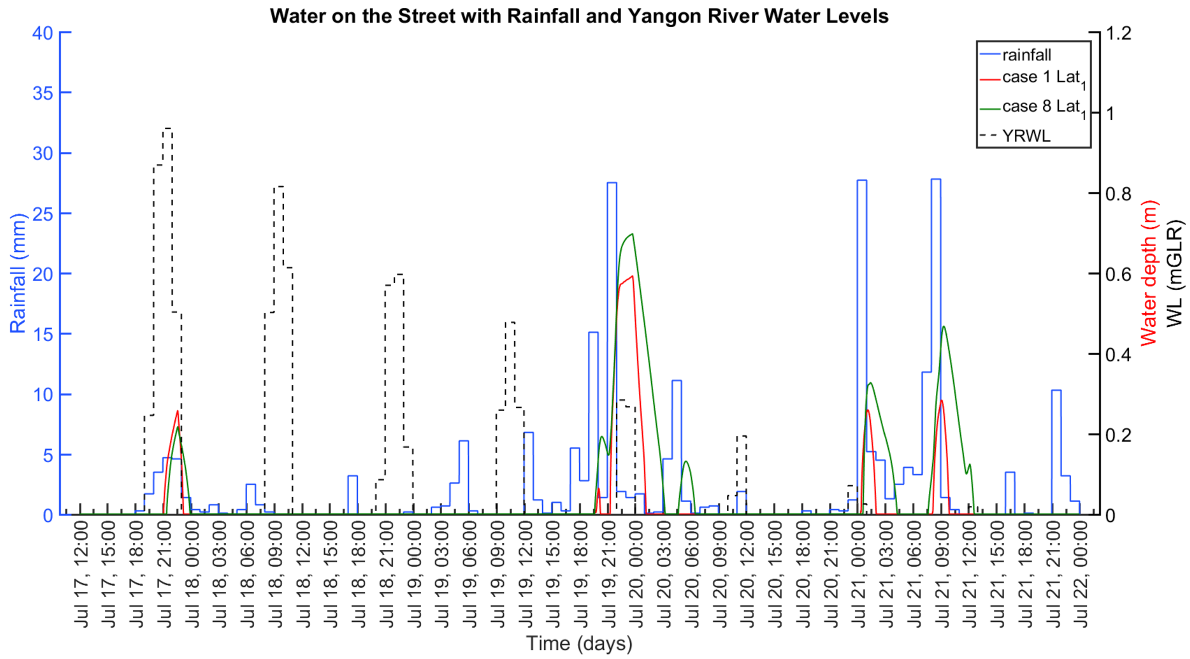


Figure 4.19: This figure shows the modelled water depths at the junction of Latha Street and Strand Road for cases 1 and 8. Observe that rainfall that coincided with high river water levels resulted in a similar flood pattern, albeit that the case with foul drains had a slightly higher water depth and a longer duration of the flood events. However, rainfall that fell during lower river water levels did not result in any flooding for any of the two cases. Apparently the effects of the foul drains' increased resistance did not result in any flooding under these flow conditions. This shows the dominance of the YRWL in the occurrence of flood events. Note that the figure has two y-axis (left and right) with different scales.

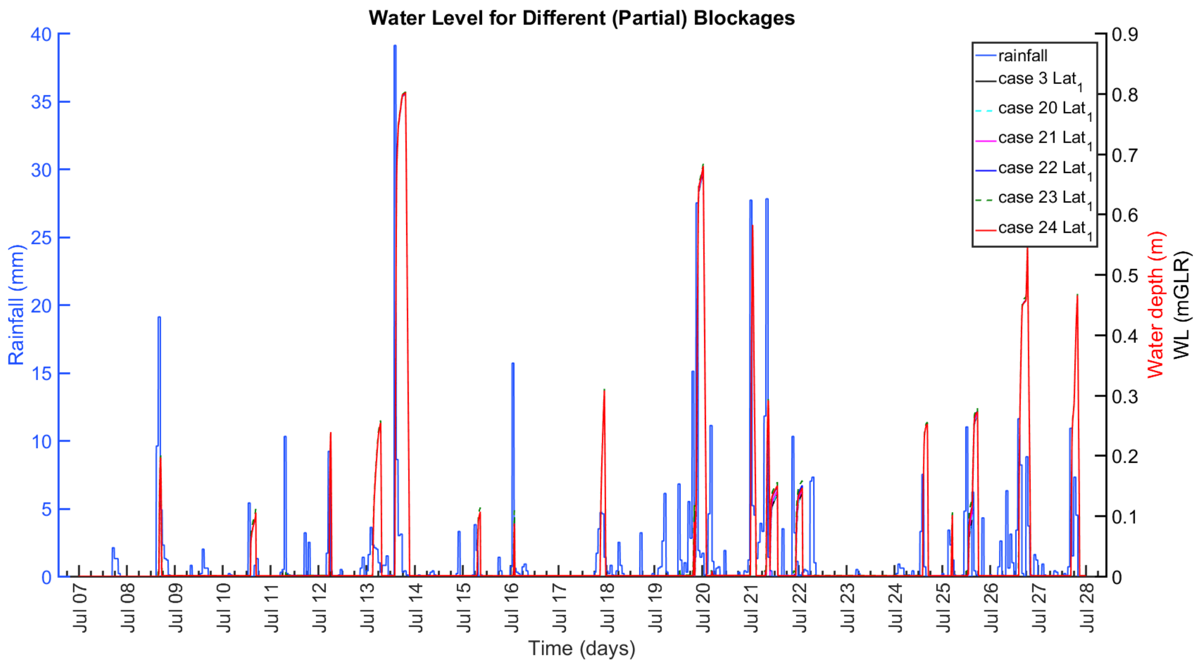


Figure 4.20: The plots show the water depths at the Lat$_1$, in case of different blockages (cases 20–24). Observe that there were no additional floods as a result of the blockages. Also the dynamics of all blockage cases showed no significant variations (also see Table E.4). Note that the plot has two y-axis (left and right) with a different scale.

4.3. Socio-Hydrological Model Results

4.3.1. Triangulation

The questionnaires (Section 4.1.1), field observations (Section 4.1.2), interviews (Section 4.1.3) and flood model (Section 4.2) results provided sufficient understanding and insights to evaluate the initial hypothesis (Section 2.4 and Figure 2.13) and to come up with an improved hypothesis (Section 4.3.3 and Figure 4.21).

The results from the questionnaires seemed to suggest that there was a strong coupling between human SWM activities and urban flooding (UF). However, the results from the flood model contradicted this coupling.

The often reported blockages that were thought to be responsible for Latha's floods, did not produce any significantly different UF dynamics when compared to simulations without any blockages modelled.
Moreover, the flood simulations that modelled increased friction loses for fouled drains did not result in an increased flood frequency when compared to clean drains. Only for very fouled drains the simulated flood durations and water depths increased, but the flood frequency and dynamics remained similar.
Other human activities and interactions with Latha's human-water system (HWS) were also considered to have no coupling or a weak coupling with UF. A processes like urbanization that results in a higher runoff (coefficient) for the SWF showed no signs of a strong coupling. The simulations for a population growth or economic growth that resulted in an increased water consumption with a higher DWF also did not resulted in a strong direct coupling.

Instead, the flood model results disclosed that Latha's downstream boundary condition, the Yangon River (YR), was responsible for dominant hydrological and hydraulic processes that caused UF.
A flood occurred when a high YRWL coincided with an average intense rainfall event, e.g. the rainfall event on July 13, 2014 (see Figure 3.7) which had a return period of T = 2 years (see Figure C.21). The UDS simply had too little storage to sufficiently store all the rainfall while the FGSs were closed. The FGS had to be closed to prevent any YR water from flowing into Latha's drainage system which otherwise would have caused floods in the first place.
Therefore, a shifted relative timing of rainfall and high YRWL resulted in a completely different flood dynamic. Moreover, the operational management of the FGSs also showed a clear link with Latha's UF dynamics.

The flood simulations showed that any significant subsidence as a result of natural processes or as an (in)direct result of human activities (such as an increased ground water extraction) did have a coupling with the UF dynamics and resulted in an increased flood vulnerability. Although the interview with YCDC EDRB and the study by Van der Horst (2017) revealed no recent significant subsidence for the Latha Township.
However, the flood model results and socio-economic results did discover a weak coupling between SWM and UF that actually could have occurred in the past and exists in the present. The questionnaires (Figure 4.6), field observations (Figure 4.14a) and the interview with YCDC EDRB (Table 4.5) learned that some floods might have been the result of a (partially blocked), not (fully) closed FGS. The flood simulation results (Figure 4.17) also showed the flood potential of a not (fully) closed gate. Such an event might provide an explanation of the anomaly of July 14, 2017.

The found weak coupling between SWM and UF served as the basis for the socio-hydrological model (SHM) that was made in this research. In the next section the initial hypothesis is evaluated in detail. Section 4.3.3 elaborates on an improved hypothesis that incorporated floods that result from a blockage of a FGS that prevents it from fully closing, resulting into floods.

4.3.2. Evaluation Hypothesis

First the human activities (see Section 2.4, Figure 2.13 and Figure F.2) were evaluated. Although there might be future urbanisation (7) (e.g. by an urbanisation development of the hospital area) the impacts will most likely be relatively small. The additional DWF was insignificant compared to the SWF (see Section E.5.1.7) and an increase in the runoff coefficient as a consequence of less green areas, less pervious surfaces and less unpaved areas hardly showed any effect during the flood simulations (Section 4.2, Section E.4: cases 11–19).
Floods (18) did occur (Table 3.7, Figure 4.7a, Table 4.5 and Figure C.15), however the majority of Latha's citizens did not change their daily activities (17) during a flood (Figure 4.7d). Furthermore, the majority (Figure B.14a) seemed to not experience damage from floods (28) and this made the fact that some people (Figure B.12a) did receive a flood warning (25) an irrelevant process, since the flood warning would be used to

reduce a household (HH)'s experienced damage during a flood.
This research was unable to provide sufficient data (Figure B.5c, Section B.6.1.3) about a citizen's daily income (19) and how this was spent (20) or saved (21), nor how much was used for the implementation of flood protection measures (33). However, field observations (Figure 4.14b), interviews (Table 4.6) and the questionnaires (Figure B.13a) showed that flood protection measures (32) were implemented by some citizens. The research did not reveal which criteria (31) citizens used to decide to implement flood protection measures.
It was likely that people had some sort of flood memory (30) (Table B.10). However, moving out of Latha (40) was an irrelevant/uncommon action, as the majority of the respondents permanently lived in the Latha Township for long durations (Figure B.3e & Figure B.3f). Therefore, such actions should not be modelled.
Urban flooding and solid waste management were not the most pressing issues for households, based on the questionnaire sample's responses (Figure B.5d). Despite the respondents dissatisfaction about the waste collection (Figure B.8) and memories of recent flood events (Table B.10). This might be the result of past improvements made by the YCDC EDRB (35) (Table 4.5, Figure B.15c). Therefore, Protests (34) were disregarded for now.
The questionnaire provided insights in the waste production of households (23) and disposal practices (Figure B.6 and Figure B.7). Field observations and interviews showed that not only households were important for waste production but also shops, restaurants and markets/street shops (Figure 4.10a, Table 4.4 and Section C.7).

Taking a closer look to the (human) waste activities (Section 2.4 and Figure F.3a), the research provided a better understanding about solid waste (45) in the Latha Township (e.g. Figure 4.10, Figure 4.11 and Figure 4.13) and about the waste collection (44) (Table 4.4, Figure B.8a and Figure C.6). Although hard to quantify, Latha's citizens did had some *solid waste management - urban flood* awareness (46), see Figure B.16a, Figure 4.12a. Unfortunately, this study (nor other relevant published studies known to this author) provided any details on how solid waste moves over the street and through the drains (47, 48, 49) and eventually gets stuck at a structure (50). The interviews (Table 4.5), questionnaires (Figure B.12c) and field observations (Figure 4.14a) together with the SOBEK results (Section 4.2, cases 28 –30) have made clear that there was a coupling between waste getting stuck at structures (50) and causing floods. Floods might be induced by (partially) blocked FGSs. Not because of a reduced inflow through the inlets or a reduced outflow through the gates (11), but because of river water flowing filling up the system under high water levels. Although inlets do get blocked ((4) in Figure F.3b), the water will only pond a little and then flows through the cracks of the concreted *drain covers* that seal of the drains (Table 4.5 and Table 4.6). Foul drains or partially blocked drains/culverts only have a minor impact (Section 4.2).
The rainfall processes (1, 2, 3, 5 in Figure F.3b) were modelled and studied by the flood model (see Section 4.2), but proved to be a too big challenge to be incorporated directly in the agent based model. The same applies to most hydrological and hydraulic processes of the UDS (Figure F.4).
In the initial hypothesis, the dry weather flow was disregarded as it was considered small compared to the storm weather flow. This assumption was justified by the results of the flood model, see Section E.5.1.7.

4.3.3. Improved Hypothesis

Based on the evaluation and conclusions of the previous sections, the hypothesis was updated to a new conceptual model that represents the weak coupling between solid waste management and urban flooding. The floods caused by blockages of the FGSs were conceptualised and shown in Figure 4.21. Because of data limitations, an incomplete/insufficient understanding and practical (technical) limitations (such as the coupling of a hydrodynamic model with(in) the agent based model) this model should be considered a toy model, strongly inspired by reality.

Figure F.6 shows a detail of the human activities and waste related processes. A household (1) produces waste (2) with a waste production rate (3). The observed waste production rate was one small bag per HH per day, based on the questionnaire results (Figure B.6a & Figure B.6b). Because of the waste production (2), the HH (1) has a new current amount of waste (5). If the HH has not yet produced the amount of waste it disposes every day (6) it continues its daily activities. This threshold for disposal is between 1 bag every two days and 2 bags per day, based on the results of the questionnaire (Figure B.6a).
If a HH has produced its daily waste amount (6) it checks where the nearest container is situated (7) and it compares this to the maximum distance a HH is willing to walk (8) to dispose its waste. The questionnaire provides an indication of what a reasonable maximum distance (8) could be (Figure B.7a). If the container is

close enough (7) and not full (9) the HH will dispose its waste in the container (10) (Table B.6). However, if there is no container close enough and/or the container is full (9) with no capacity left (18), there is a probability (12) that a specific household will not go to the container anyway (11).
The questionnaire (Figure B.7b), field observations (Figure 4.11) and interviews (Table 4.6) showed that indeed not all households go to a container (12) and dispose their waste on the streets or in the drains. However, the study results did not allow for an exact quantification of this probability (12). The questionnaire (Figure B.7b) and interviews (Table 4.6), also revealed that there were households that still go to a container even if the containers are not on their usual spots nearby and/or if the containers are already full, these households will be referred to as *tidy households*. Such a tidy household will still dispose its waste in the container (10).
An improper HH (opposite of a tidy household) will first check if there is any waste on the street close enough (12) by applying the same maximum walking distance as for a container (8). If there is no waste on the street close enough the HH will dispose its waste in front of its own building (14), creating an opportunity for other HHs to dispose there waste there too (e.g. Figure 4.11b). If there is already waste on the street nearby, the HH will dispose its waste at that location (15) (picking the closest spot in case of multiple locations that are within the maximum distance limit). Any waste on the street becomes *street waste* (16).

If waste is disposed in a container, the waste is considered to be *container waste* (17), filling up the container reducing the container's (19) remaining capacity (18). Each container has a location (20), a maximum capacity (21) and there is a probability that the container is collected and emptied by the YCDC (22). The exact collection probability is thought to be high, but not 100% as field observations showed that containers were not always collected (Figure 4.11b). A reasonable collection probability could be between 80% and 99%.
The location of the container (20) is used by a household to determine which container is closest and if this container is close enough (7). The maximum capacity ((21), see Table D.1) is used to calculate the remaining container capacity (18), such that if the container is full (23) the excessive waste in the container becomes street waste too (16). Street waste has a lower probability of collection (27) and a chance to end up in the drain (30).
An interview with the YCDC PCCD (Table 4.4) and the questionnaires (Figure B.8a) have showed that the waste collection frequency (26) is collected once per day. Thus if it is collection time (25) the waste in containers and on the streets will be collected. However, not all the waste gets collected (24), as there is a probability that the waste in containers is collected (22) and waste on the streets is less likely to be collected (27). Based on field observations and interviews (Figure 4.11b), street waste has a smaller collection probability since YCDC employees do not clean the streets on a structural basis.
If waste is collected successfully (24), the container waste is removed (17) and the remaining container capacity (18) becomes the maximum container capacity (21). Field observations and interviews have shown that there is a probability that a container will be relocated to a new place after it is collected (28), the exact probability (29) is unknown but is estimated to be at most 50% as none of the interviewed citizens reported that this is a major problem (Table 4.6). If the container is relocated, the container's location (20) will be updated. If waste on the streets (16) is collected successfully (24) the pile of waste will be removed.
Waste on the streets (16) has a probability (31) that it (eventually) will end up in the drains (30), becoming *drain waste* (32) (Figure F.7). This study has not been able to quantifying this probability (31). Waste in the drains (32), will move through the drains (33) because of water (DWF and SWF) flowing through the drains, changing its location (35). Since it was impossible to link hydrodynamic calculations with (sufficiently) realistic solid waste propagation dynamics this transport behaviour is simplified to a stochastic model, where each piece of drain waste has a probability (31) that it moves from one drain section to the next drain section (34). This probability is synthetic, as there was insufficient data about the properties of the waste in the drains and no adequate literature found that provided any scientific basis for plausible assumptions.
The drain waste unit (32) keeps moving downstream (36) through the drains (33) till it gets at a location (37) of one of the FGSs (40). Once the waste is at the FGS (36), the FGS has a probability that waste will get stuck (39) as sometimes happens based on interviews (Table 4.5), the questionnaires (Figure B.12c) and observations (Figure 4.14a). However this study was not able to quantify the probability that the drain waste will get stuck (39) and therefore a crude assumption of P(stuck at gate) = 0.05 will be used. If the waste does not get stuck, it will flow out of the drainage system into the Yangon River (40) and is no longer considered in the model.
If the drain waste unit does get stuck, the number of drain wastes stuck at the gate (42) will be increased (41). The FGSs (43) have a maximum number of drain waste units (45) that might be stuck at the gate, before the gate is considered to be blocked (46). Once the gate has more stuck drain waste units (42) than the maximum number of stuck waste units (45) the drain becomes blocked (44). The exact number of drain waste units

that are required to get stuck (45) to result in a blockage (46) is unknown and will be synthesized at 50 waste units. Moreover, the exact size of the opening caused by the blockage is also unknown, although the size of the opening does matter for the severity of a flood (53) as the flood model results have shown (Section 4.2, cases 28–30).
The FGSs are cleaned (47) according to a cleaning schedule (48), with a cleaning frequency (49). Interviews (Table 4.5) and the questionnaires (Figure B.15a & Figure B.15b) provided insights that this is most likely between once every year to a maximum of 4 times per year. If the gate is cleaned (47) all the drain waste units stuck at the gate (42) are removed (and if applicable, the blocked gate becomes clear again).
If there is waste stuck at the gate (50), the probability that new waste will get stuck (39) is increased (51) to a new, higher probability (52). This is a synthetic process as there is no exact knowledge and data available about these processes (51, 52), nor is it possible to accurately model this within the agent base modelling platform even if this was known.
If the gate is blocked (44), and the Yangon River water levels (54) are higher than a critical water level (55) that might result in a flood if the gates are blocked, a flood might occur (53). If this happens, the number of floods (56) is increased by one. The critical water level (55) is hard to determine, as the flood extent also depends on rainfall, the size of the leaking opening and as a result of the unknown ground level elevations related to the Yangon River water levels (see Section 4.2). If there has been no flood for a while, HHs become less tidy and more and more HHs will dispose their waste on the street, modelled by an increase of that probability (12). A recent flood will result in an increased awareness, resetting (decreasing) the probability that a HHs will dispose waste on the street (12). However, it is unknown to what extend the waste disposal patterns are changing over time and how they change after a flood event.

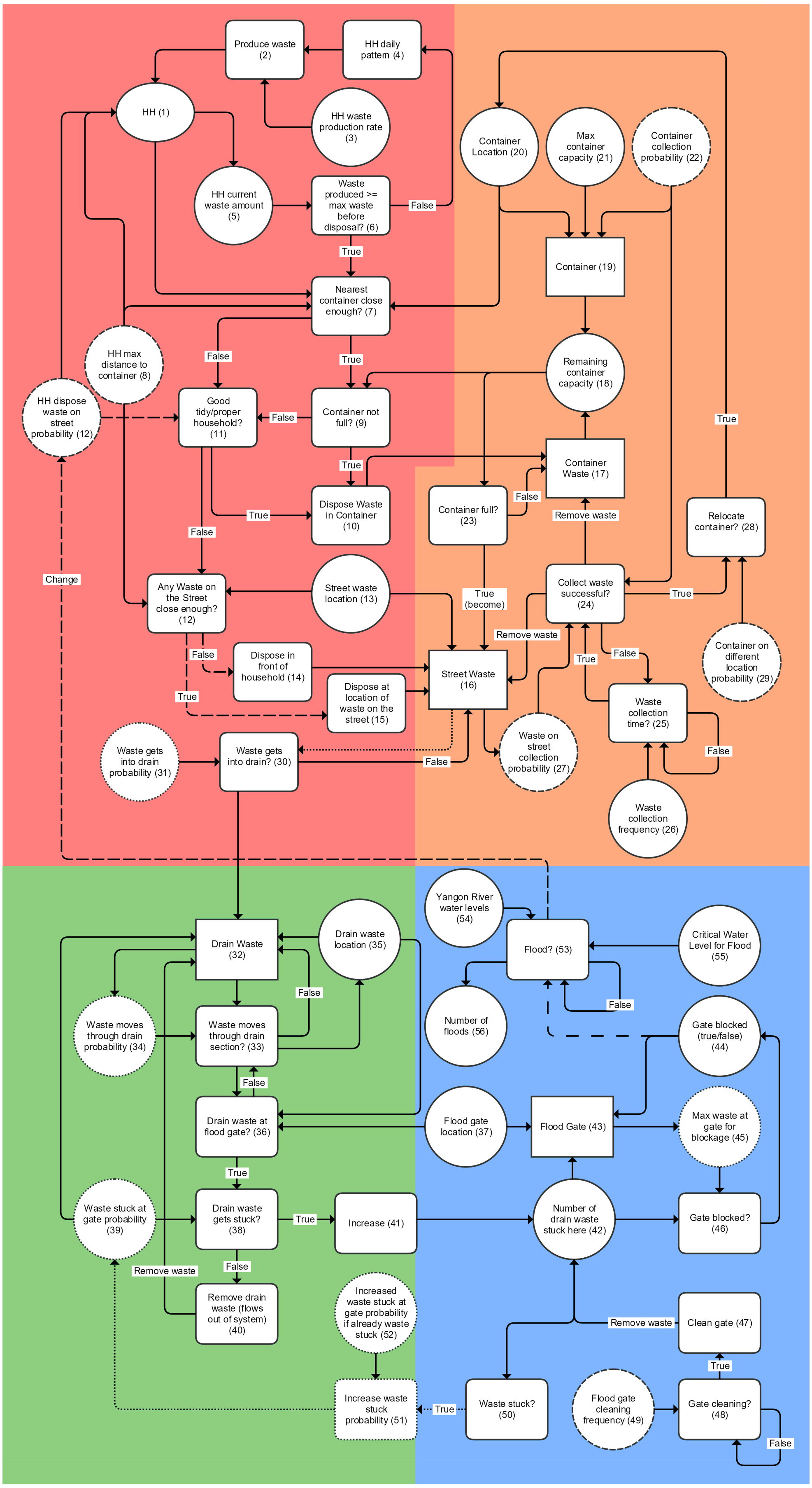


Figure 4.21: Renewed hypothesis of the human-flood interaction. The red section represents the citizens' daily activity patterns producing waste and making decisions about their waste disposal practices. The orange section models the waste in and around the waste containers and waste on the streets with its collection and cleaning (by the YCDC). For a detail of the red and orange section see Figure F.6. The green section represents waste that *found its way into the drains* and moves through the drains to the FGSs. The blue section conceptualizes the FGS and potential blocking of the FGS that results in a flood. For a detail of the blue and green section see Figure F.7.

4.3.4. Socio-Hydrological Model

Since the conceptual model is so weak and has such a large degree of essential simplifications only two toy-set-ups were implemented for this study. The conceptual model of Figure 4.21 was made in a agent based model (ABM) with NetLogo (see Figure 4.22). The model was runned for two cases. In the first case, there was no feedback between recent floods and a HH's probability to throw waste on the streets (the relation from 53 to 12 was taken away). In the second set-up this relation was included in the model. The model was runned 100 times, with an hourly time step for a duration of 3 year per simulation. The water levels (50) where simulated with the function of Section C.3.11. For the other used parameters see Table 4.8.

Table 4.8: The used parameters for the two cases. In the first case the waste disposal on street probability increase is 1% per day if there is no flood and the most recent flood is longer ago than a households flood memory. Not available (NA).

Model Parameter	Process	Lower Bound	Upper Bound	Units	Case 1 Used	Case 2 Used
Simulation Time	NA	0	∞	years	3	3
Waste disp. on street prob. Increase	53 to 12	0	1	(-)	NA	0.01
Waste production rate	3	0.5	2	WU/day	1	1
Waste amount for disposal	6	1	1	WU	1	1
Max distance to container	8	50	150	m	125	125
Waste dispose on street probability	12	0	50	%	35	35
Max container capacity	21	20	175	WU	135	135
Container collection probability	22	50	100	%/day	95	95
Waste collection frequency	26	0.33	2	days	1	1
Street waste collection probability	27	0.33	5	%/day	80	80
Container different location probability	29	0	50	%/day	10	10
Waste gets into drain probability	31	0	100	%	15	15
Waste through drain propagation probability	34	0	100	%/day	60	60
Waste gets stuck at gate probability	39	0	100	%	5	5
Max waste at gate for a blockage	45	0	∞	WU	70	70
Flood gate cleaning frequency	49	90	365	1/days	100	100
Increase waste gets stuck at gate probability 1	52	0	100	%	10	10
Increase waste gets stuck at gate probability 2	52	0	100	%	30	30
Increase waste gets stuck at gate probability 3	52	0	100	%	50	50
Waste stuck at gate before probability increases 1	52	0	∞	WU	10	10
Waste stuck at gate before probability increases 2	52	0	∞	WU	30	30
Waste stuck at gate before probability increases 3	52	0	∞	WU	50	50
Yangon River water levels	54	0.00	7.00	m MSL	f(t)	f(t)
Critical water level for flood	55	3.00	7.50	m MSL	6.00	6.00

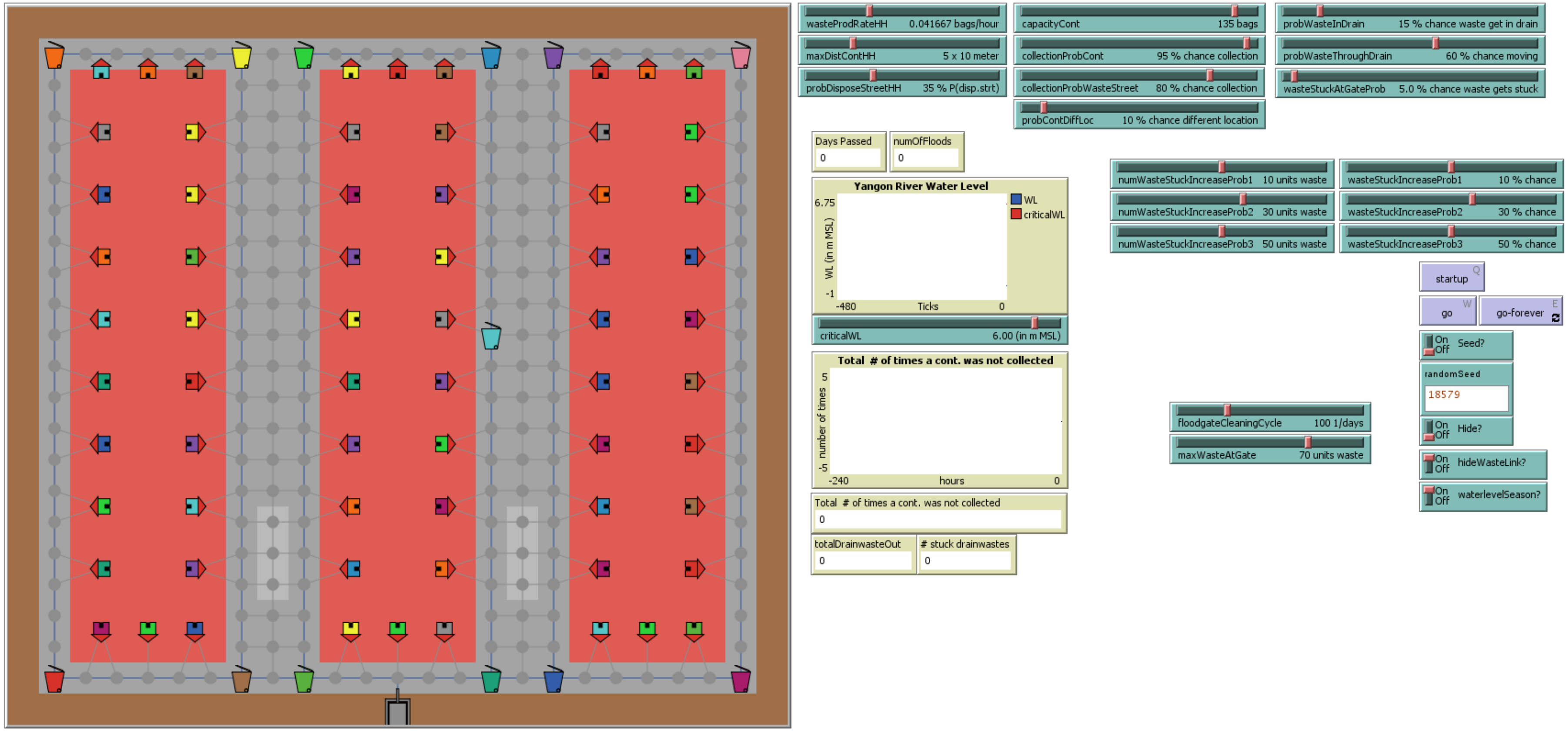


Figure 4.22: This figure provides a visual overview of the socio-hydrological model's user interface. The different sliders and switches might be used to vary parameters and settings of the model. There are also some components that report modelled values

The number of floods that occurred for both scenarios is shown in Figure 4.23 and Figure 4.24. It should be observed that the model set-up without feedback seemed to produce a stable dynamic with an average of about 3 floods per simulation time frame. However, if the feedback is included, a more threshold type of behaviour was observed. In some cases the number of floods was very lower whereas much more extreme number of floods were also possible.
Unfortunately this research has not been able to analyse the reasons for this behaviour and this should be part of future research.

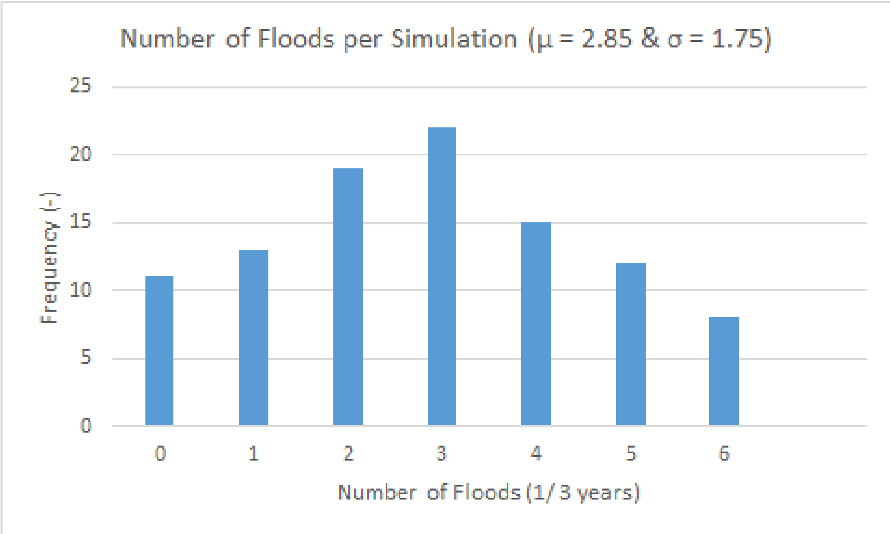


Figure 4.23: This figure show the number of floods for 100 simulations with a combination of parameter settings without feedback from flood events to the probability that a household disposes its waste on the street and not in a container if the nearest container is too far away (or became to far away after the location of the nearest container changed). There seems to be a normal distribution in the results.

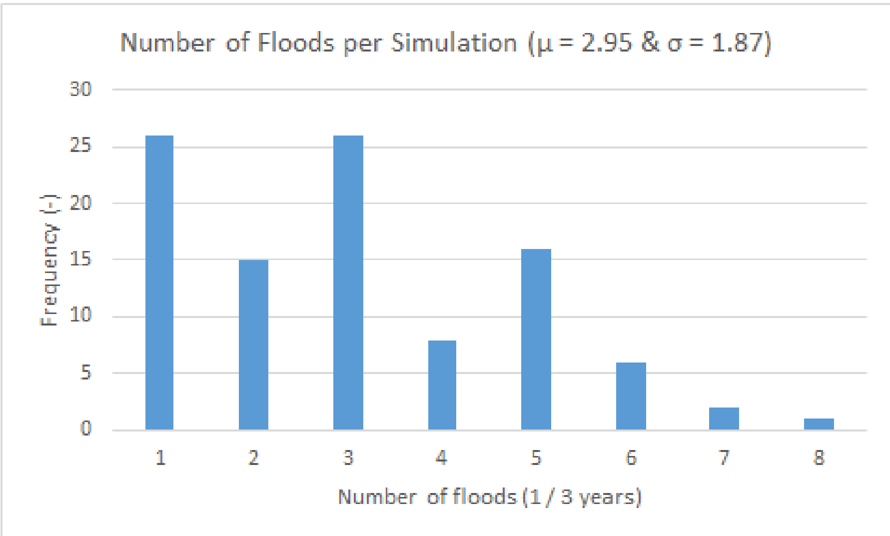


Figure 4.24: This figure show the number of floods for 100 simulations with a combination of parameter settings **with** feedback from flood events to the probability that a household disposes its waste on the street and not in a container if the nearest container is too far away (or became to far away after the location of the nearest container changed). The results of these 100 simulations show that the feedback probably resulted in threshold/non-linear behaviour.

5

Discussion

In this chapter we will reflect on the weaknesses of this research and evaluate the impacts of these weaknesses. Moreover, possible improvements will be suggested. The discussion is split up according to the different results and methodologies.

5.1. Results Discussion

5.1.1. Socio-Economic Data

The questionnaires (Section 4.1.1), field observations (Section 4.1.2) and interviews (Section 4.1.3) results provided sufficient understanding and insights to evaluate the initial hypothesis (Section 2.4 and Figure 2.13) and to come up with an improved hypothesis (Section 4.3.3 and Figure 4.21).

In general the results from the questionnaires were in line with the fieldwork observations and interviews. All together the data provided useful insights. First of all, it may be concluded that the citizens had some flood awareness (Figure B.16a and Figure 4.12a) as was to be expected based upon the profiles of the respondents (Section 4.1.1.1) while recalling from Section 1.2 that: *It was concluded that "class is the most influential factor in predicting flood risk awareness, followed by flood experience and length of time in residence" (Burningham et al., 2008, p. 216). With class was meant social class.*
However, despite this awareness, their dissatisfactions (Figure B.8b, Figure B.9b) towards the current solid waste management policies and implementations and desires that YCDC reduces the floods (Figure B.16b), only a small group responded that either flood management or improved solid waste management was their priority issue (Figure B.5d). One of the possible explanations could be that Latha's citizens are so used to the flooding, that they have become resilient to flooding. This could be supported by the fact that people hardly change their activities during a flood (Figure B.13c), do not experience any damage (Figure B.14a) and the fact that some respondents reported that they had flood protection measures (Figure B.13a) for their house/building

Important human activities are the disposal patterns and cleaning habits from citizens. Insufficient containers, insufficient container collection frequencies, missing containers and neighbours that threw their waste on the street all have an impact on how likely a citizen is to not properly dispose its waste. The maintenance state of the drains, cleaning actions by the YCDC are also important human activities that change the state/condition of the drains affecting the probability that waste get in the drain and gets stuck or propagates to the flood gate structure (FGS).

5.1.2. Flood Model

Although the simulation results were not perfect, the results still provided useful insights about Latha's flood dynamics. First we will elaborate on why the model's performance is not necessarily a problem for answering the research sub-question. This is followed by a discussion on how the results differed from the hypothesis and why there is no strong coupling between urban flooding an human activities for Latha.

The modelled results from all cases showed that the flood frequency was over estimated in general and especially for the areas on and close to Strand Road. Based on the flood records (Section C.3.9), the reported flood frequencies by the respondents from the questionnaires (Figure 4.7a) and the interviews with the YCDC EDRB (Section 4.1.3) a typical flood frequency of about once or twice was to be expected. However, even in the case with the least flooding (case 41, Table 4.7) the number of floods is still 6 to 14 times for the areas close to Strand Road. For the locations further away from Strand Road, there differences are smaller but in general still too high. The number of reported floods by YCDC and questionnaires could be the result of a different perception of when water on the street is a flood, and when it is not. Table 5.1 shows the same type of statistics as the results in Table 4.7, but now only incorporating flood events that resulted in a peak water depth of at least 25 cm and a minimum flood event duration of 30 minutes. An example of how this works out is shown in Figure 5.1. Based on these results, it could be concluded that a less strict flood perception still results in too frequent flooding at Strand Road.
A similar discussion as for the flood frequency applies to the duration of the floods, which in general last too long (Table E.4), even when a less strict flood perception is applied (Table 5.1).
For the flood depths of the different cases, the results are closer to the reported and observed data. If we recall Table 3.7, the two flood events in 2014 resulted in a water depth of about 90 cm. Although some cases under estimate the water depth at Strand Road, cases 1—30 showed water depths that are quite reasonable for the maximum flood event (Location 23_1 is almost at the location of gate 7). Moreover, when the average maximum depth (Table E.4) for the locations: 17_7, Lat_8 and 23_7 is compared to the answer provided by the questionnaire respondents (Figure 4.7b), the flood depths are reasonable.
There are a number of reason that could result in the performance fo the model to differ from reality. Section E.5.1 discusses how the uncertainties of the used data and model simplifications might have had an affect on the model's results.

The model's weaknesses do not have a big impact on the conclusions that could be drawn. Despite the model's imperfections to accurately replicate reality, it provided an improved understanding on what processes are dominant for the realisation of flood events. The results proved that the downstream boundary condition of the Yangon River water level determines to a great extent if other hydrological and hydraulic processes will result in a flood. For example extremely fouled drains will not result in severe flooding or a significant different flood behaviour of the drainage system, if the drains would be able to discharge through the FGSs under free flow conditions. Figure 4.19 provides an example that backs this claim. Taking a closer look at 20 July 2014, we see that the fouled drains (case 8) showed a similar flood pattern as the clean drains (case 1) albeit with a higher peak water level an a longer duration. For this day, high water coincides with the rainfall. However, none of the rainfall that falls during low Yangon River water levels (e.g. the rainfall on July 19^{th} or July 21^{st}) did result in flooding for case 8 but did not cause flooding for case 1.

For this study it would be interesting to further investigate how the different combinations of input and parameter settings affect the urban flooding process. For example to what extent does a combination of foul drains with a few (partially) blockages in the drains result in flooding? Another thing to research is how the system behaves under more extreme rainfall conditions, as the month July 2014 proved to be an ordinary month (see Section C.3.13).
If an improved model performance is desired it is crucial to acquire more accurate Yangon River water level data with a known reference. Just as important is improved understanding and better data about the operation of the FGSs, as this will also result in more reliable results. For ground level elevation data applies the same as for Yangon River water levels, although less of a priority. Improved estimations of rainfall intensities with a higher temporal resolution and measured at a location closer to the township, combined with better rainfall runoff relations may also result in more reliable results.

Coming to the second part of the SOBEK model discussion: how did the results differed from the hypothesis? As it turned out, Latha's urban flooding was in particular the result of the downstream (hydrological/hydraulic) boundary condition and not so much the result of human activities. The past increased urbanization and future new urbanization was most likely not to be the largest cause or threat for the increased urban flooding events. A higher rainfall runoff (coefficient), a higher DWF and more waste in the drains will probably only have a little effect. However, if due to an increased demand for (drinking) water, more ground water is extracted which induces subsidence this will have a negative effect on the urban flood extent.

Table 5.1: Overview of all cases and their statistics with flood events that had a peak of at least 25 cm and a minimum flood event duration of 30 minutes. Grey is the reference case, green indicates an improvement, red indicates a deterioration for a ±15% deviation or a deviation of ≥ 2 number of flood events. See Figure 5.1 for an example of a case.

		Point 17_2					Point 17_7					Point Lat_1					Point Lat_8					Point 23_1					Point 23_7				
	Case	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth	Num of Floods	TotDuration	Max Duration	Tot.max. Depth	max.max.depth
GLR	2	6	1325.0	494.0	2.75	0.68	0	0.0	0.0	0.00	0.00	9	1283.0	431.0	3.57	0.79	0	0.0	0.0	0.00	0.00	5	886.5	395.5	2.34	0.66	0	0.0	0.0	0.00	0.00
	1	6	1056.0	461.5	2.40	0.63	0	0.0	0.0	0.00	0.00	7	987.5	402.0	2.50	0.74	0	0.0	0.0	0.00	0.00	4	652.5	366.0	1.69	0.61	0	0.0	0.0	0.00	0.00
	2	6	1325.0	494.0	2.75	0.68	0	0.0	0.0	0.00	0.00	9	1283.0	431.0	3.57	0.79	0	0.0	0.0	0.00	0.00	5	886.5	395.5	2.34	0.66	0	0.0	0.0	0.00	0.00
	3	6	1373.0	500.5	2.82	0.69	0	0.0	0.0	0.00	0.00	10	1458.5	437.5	3.92	0.80	1	52.0	352.0	0.25	0.25	5	933.5	405.0	2.41	0.67	0	0.0	0.0	0.00	0.00
Roughness	1	6	1056.0	461.5	2.40	0.63	0	0.0	0.0	0.00	0.00	7	987.5	402.0	2.50	0.74	0	0.0	0.0	0.00	0.00	4	652.5	366.0	1.69	0.61	0	0.0	0.0	0.00	0.00
	4	4	769.5	388.5	1.71	0.60	0	0.0	0.0	0.00	0.00	7	1015.0	393.5	2.46	0.71	0	0.0	0.0	0.00	0.00	7	642.5	367.0	1.63	0.58	0	0.0	0.0	0.00	0.00
	5	6	922.0	430.5	2.04	0.62	0	0.0	0.0	0.00	0.00	7	1013.5	406.0	2.48	0.73	0	0.0	0.0	0.00	0.00	4	656.0	373.5	1.66	0.60	0	0.0	0.0	0.00	0.00
	6	6	1177.5	493.0	2.48	0.64	0	0.0	0.0	0.00	0.00	7	970.5	401.0	2.52	0.75	0	0.0	0.0	0.00	0.00	4	651.0	360.5	1.72	0.62	0	0.0	0.0	0.00	0.00
	7	7	1335.0	531.0	2.55	0.65	0	0.0	0.0	0.00	0.00	6	981.0	408.5	2.56	0.76	0	0.0	0.0	0.00	0.00	4	658.0	363.0	1.74	0.63	0	0.0	0.0	0.00	0.00
	8	6	3172.0	1032.0	2.97	0.69	0	0.0	0.0	0.00	0.00	8	1539.5	539.5	3.76	0.80	1	84.0	415.5	0.26	0.26	5	892.5	480.0	1.93	0.67	0	0.0	0.0	0.00	0.00
RTC	3	6	1373.0	500.5	2.82	0.69	0	0.0	0.0	0.00	0.00	10	1458.5	437.5	3.92	0.80	1	52.0	352.0	0.25	0.25	5	933.5	405.0	2.41	0.67	0	0.0	0.0	0.00	0.00
	9	6	1265.0	485.5	2.67	0.67	0	0.0	0.0	0.00	0.00	8	1231.0	423.5	3.45	0.78	0	0.0	0.0	0.00	0.00	5	831.5	387.0	2.22	0.65	0	0.0	0.0	0.00	0.00
	10	6	1320.0	493.0	2.75	0.68	0	0.0	0.0	0.00	0.00	9	1287.0	430.5	3.57	0.79	0	0.0	0.0	0.00	0.00	5	882.5	395.0	2.33	0.66	0	0.0	0.0	0.00	0.00
	11	6	1426.0	507.5	2.89	0.70	0	0.0	0.0	0.00	0.00	10	1568.0	444.0	4.53	0.81	1	123.5	359.0	0.26	0.26	5	985.0	415.0	2.49	0.68	0	0.0	0.0	0.00	0.00
	12	6	1480.0	514.5	2.96	0.70	0	0.0	0.0	0.00	0.00	10	1671.5	450.5	4.62	0.82	1	149.5	365.5	0.27	0.27	5	1036.0	424.0	2.55	0.69	0	0.0	0.0	0.00	0.00
	13	7	1631.0	526.5	3.07	0.71	0	0.0	0.0	0.00	0.00	11	2438.5	465.0	5.13	0.83	1	189.0	378.0	0.28	0.28	5	1129.5	438.5	2.65	0.70	0	0.0	0.0	0.00	0.00
Leakage	3	6	1373.0	500.5	2.82	0.69	0	0.0	0.0	0.00	0.00	10	1458.5	437.5	3.92	0.80	1	52.0	352.0	0.25	0.25	5	933.5	405.0	2.41	0.67	0	0.0	0.0	0.00	0.00
	28	6	1372.0	498.5	2.79	0.68	0	0.0	0.0	0.00	0.00	9	1440.0	435.5	3.91	0.80	0	0.0	0.0	0.00	0.00	5	932.5	403.5	2.38	0.67	0	0.0	0.0	0.00	0.00
	29	6	1367.0	496.5	2.76	0.68	0	0.0	0.0	0.00	0.00	9	1491.0	434.5	4.19	0.79	0	0.0	0.0	0.00	0.00	5	930.5	402.0	2.34	0.66	0	0.0	0.0	0.00	0.00
	30	6	1353.0	493.0	2.70	0.68	0	0.0	0.0	0.00	0.00	10	1648.5	431.5	4.49	0.79	0	0.0	0.0	0.00	0.00	5	927.0	399.5	2.28	0.66	0	0.0	0.0	0.00	0.00
RTC 2	3	6	1373.0	500.5	2.82	0.69	0	0.0	0.0	0.00	0.00	10	1458.5	437.5	3.92	0.80	1	52.0	352.0	0.25	0.25	5	933.5	405.0	2.41	0.67	0	0.0	0.0	0.00	0.00
	31	6	742.5	433.5	2.06	0.58	0	0.0	0.0	0.00	0.00	6	752.5	379.0	2.07	0.69	0	0.0	0.0	0.00	0.00	2	300.5	343.0	0.56	0.56	0	0.0	0.0	0.00	0.00
	32	6	742.5	433.5	2.06	0.58	0	0.0	0.0	0.00	0.00	6	752.5	379.0	2.07	0.69	0	0.0	0.0	0.00	0.00	2	300.5	343.0	0.56	0.56	0	0.0	0.0	0.00	0.00
Shift WL	3	6	1373.0	500.5	2.82	0.69	0	0.0	0.0	0.00	0.00	10	1458.5	437.5	3.92	0.80	1	52.0	352.0	0.25	0.25	5	933.5	405.0	2.41	0.67	0	0.0	0.0	0.00	0.00
	33	5	661.0	311.0	2.09	0.68	0	0.0	0.0	0.00	0.00	6	641.0	250.5	2.43	0.79	0	0.0	0.0	0.00	0.00	3	260.0	223.5	1.32	0.66	0	0.0	0.0	0.00	0.00
	34	4	274.5	188.0	1.34	0.42	0	0.0	0.0	0.00	0.00	6	336.5	165.5	1.35	0.38	0	0.0	0.0	0.00	0.00	0	0.0	0.0	0.00	0.00	0	0.0	0.0	0.00	0.00
	35	5	417.0	218.5	1.77	0.43	0	0.0	0.0	0.00	0.00	7	560.0	266.5	1.78	0.57	0	0.0	0.0	0.00	0.00	1	72.0	148.5	0.44	0.44	0	0.0	0.0	0.00	0.00
Shift WL	3	6	1373.0	500.5	2.82	0.69	0	0.0	0.0	0.00	0.00	10	1458.5	437.5	3.92	0.80	1	52.0	352.0	0.25	0.25	5	933.5	405.0	2.41	0.67	0	0.0	0.0	0.00	0.00
& RTC	36	4	366.0	271.5	1.6	0.6	0	0.0	0.0	0	0	4	225.0	210.5	1	0.8	0	0.0	0.0	0	0	1	121.0	177.0	0.6	0.6	0	0.0	0.0	0	0
& Crunoff	37	5	323.5	187.5	1.6	0.4	0	0.0	0.0	0	0	5	217.5	137.0	1.1	0.4	0	0.0	0.0	0	0	1	25.5	0.0	0	0	0	0.0	0.0	0	0
	38	4	272.0	187.0	1.3	0.4	0	0.0	0.0	0	0	4	143.0	137.0	0.7	0.4	0	0.0	0.0	0	0	0	0.0	0.0	0	0	0	0.0	0.0	0	0
Improved	3	6	1373.0	500.5	2.8	0.7	0	0.0	0.0	0	0	10	1458.5	437.5	3.9	0.8	1	52.0	352.0	0.3	0.3	5	933.5	405.0	2.4	0.7	0	0.0	0.0	0	0
S, I, E, C	39	6	1025.0	460.0	2.4	0.6	0	0.0	0.0	0	0	6	931.5	401.5	2.5	0.7	0	0.0	0.0	0	0	4	639.5	365.0	1.4	0.6	0	0.0	0.0	0	0
	40	6	977.5	458.0	2.1	0.6	0	0.0	0.0	0	0	5	887.0	398.5	2.4	0.7	0	0.0	0.0	0	0	4	620.5	367.5	1.4	0.6	0	0.0	0.0	0	0
RTC, WL shift	3	6	1373.0	500.5	2.8	0.7	0	0.0	0.0	0	0	10	1458.5	437.5	3.9	0.8	1	52.0	352.0	0.3	0.3	5	933.5	405.0	2.4	0.7	0	0.0	0.0	0	0
S, I, E, C	41	5	289.0	185.5	1.3	0.4	0	0.0	0.0	0	0	5	202.5	136.0	1.1	0.4	0	0.0	0.0	0	0	1	12.5	0.0	0	0	0	0.0	0.0	0	0

The characteristics of Latha's urban drainage system (UDS), provide a possible explanation for the weak coupling found from the results of the SOBEK model. A closer look at the system lay-out (see Figure C.8) showed a system that was looped to a large degree. A reduction of a drain's cross-sectional area as a consequence of a (partial) blockage, will result in raised water levels and an increase of pressure build up upstream of the blockage. The higher water level and the accompanying increased (water) pressure allows for larger flow velocities through the remaining cross-section (albeit with more friction losses). Simultaneously this pressure build up also allows for a bigger discharge through alternative flow paths through the looped system. With these higher flow velocities in the system the friction losses are increased. However, due to the relative small system (spatially) the flow paths (the drains) are relatively short and thus the friction losses seem to stay within acceptable limits and do not cause any flooding. In line with the blockages, any increased friction from solid waste also becomes not dominant. The drains are relatively short as are the flow paths the water has to take before it discharges out of the system in to the Yangon River.
However, this implicates that a highly branched drainage systems with a large (spatial) scale is more susceptible to human activities with regards to maintenance of the drains and waste disposal patterns and habits, such that the system potentially becomes strongly coupled.

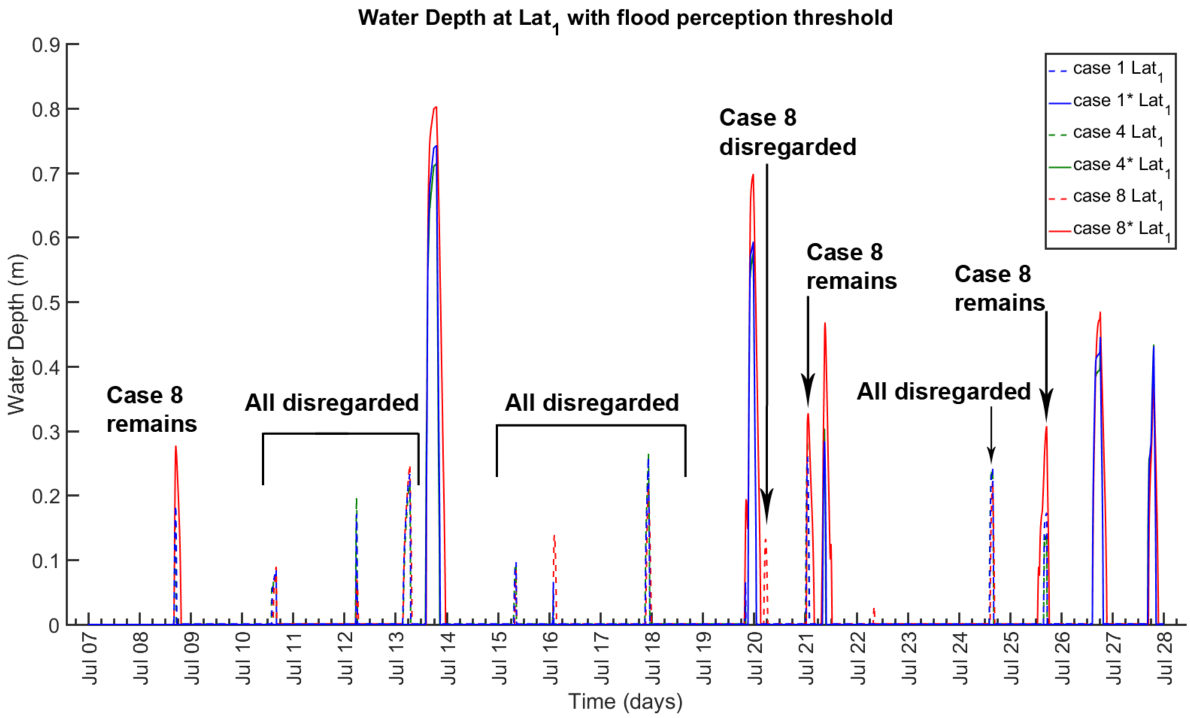


Figure 5.1: This figure shows an example of a few cases where a different flood definition was applied. In this case a flood was only considered a flood if the flood events had a peak of at least 25 cm and a minimum flood event duration of 30 minutes.

5.2. Socio-Hydrological Model

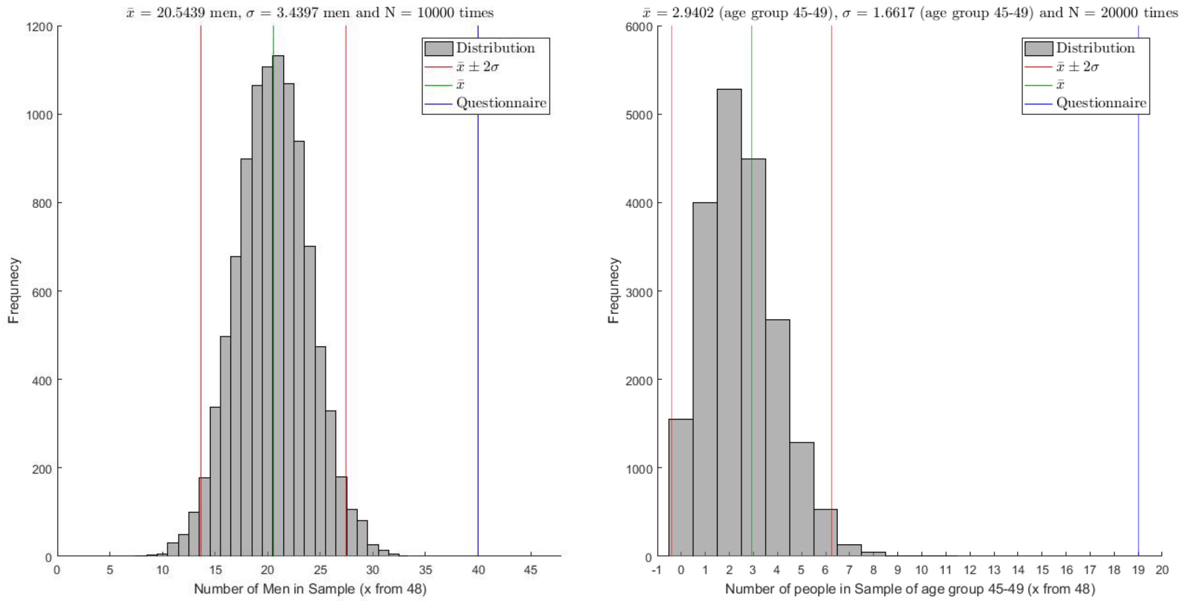
1. Questionnaire and observations provided a decent explorative basis
2. No scientific knowledge (that can be incoporated in the ABM platform NetLogo)
3. Weak coupling thus not that relevant
4. should be considered a toy model that could help the research community to go to the next step of modelling coupled human-water or human-nature systems.

5.3. Methodology

5.3.1. Questionnaires

The discussion of all results of the questionnaire is too elaborate and would be distracting too much from the main message of this section. Therefore, the result's anomalies were discussed straight after the presentation of the result itself in the appendix, Section B.6.

The obtained sample size was too small to be sufficiently representative for the entire Latha Township population of about 25,000 people. The required minimum sample size was more than 380 respondents for a margin of error of 5% ($p = 0.05$) and a confidence interval of 95% ($\alpha = 0.95$). Although the initially distributed 210 questionnaires (150 for households (HHs) and 60 for shops) were too little, the low response rate reduced the reliability even more. The sample contained just 48 respondents. The questionnaire results for the shops were not even considered in this research as there only were 16 respondents and triangulation provided insufficient additional data.
Moreover, the questionnaires were distributed by the wards. This could have been the cause of the bias that was observed in the questionnaire data. For example, the sample consisted of too much old male respondents (see Figure 5.2). This also might have had the effect that respondents were giving socially expected (e.g. fearing that a negative answer or critique could lead them into trouble with the Yangon City Development Committee (YCDC)) or untrue (e.g. not reporting the right HH income, because you do not pay all required



(a) Male distribution in a sample of 48 randomly selected persons per sample out of the general distribution for Latha, with 10,000 repetitions. The general distribution is based on the data from Table B.1.

(b) Age group 45 to 49 distribution in a sample of 48 randomly selected persons per sample out of the general distribution for Yangon, with 20,000 repetitions. The general distribution is based on the data from Figure B.2

Figure 5.2: The number of male respondents (40) was statistically significant over represented with a 95% confidence interval. A distribution was made based on 10,000 repetitions of randomly selecting 48 people from the entire Latha Township population. Moreover, the respondents were also statistically significant too old with a 95% confidence interval. A distribution was made based on 20,000 repetitions of randomly selecting 48 people from the entire Yangon Region population.

taxes for your actual income). Unfortunately there was no clear way to check this and YCDC permission was required for the distribution of the questionnaires.
Design errors, translation errors, interpretation errors also may have added to the uncertainty of the questionnaire results.
Finally, the questionnaires only provided a snapshot of the situation at that time. It may well be that the results of the questionnaires would have been completely different if the questionnaire was distributed right after a serious flood event.

The under-sampling may have resulted in observing results that were not there (type-I errors) or not being able to observe results that actually were there (type-II errors). For example, cross-tables (e.g.) were made to see if there were any relations between different behaviours and properties of HHs. In this case study there were no clear trends observed, whereas they might have been there but the sample size was just too small to detect this.
This uncertainty and the previously mentioned weaknesses resulted in errors and a dataset that was not a 100% reliable. However, the triangulation with the results of the field observations and interviews provided a method to still come up with truthful propositions about the results of the questionnaire. Moreover, one needs to remember that the objective of this study was to conduct an explorative study, acknowledging that the results would be not completely representative.

A possible improvement would be to do elaborate interviews with some of the respondents to ask additional questions that might provide more useful insights and allow for additional data that might be used for triangulation. A possible solution to get a larger sample size would be to distribute the questionnaire digitally. However, this does make it difficult to check if people actually live in the township.
Alternatively, different methods could have been applied that are less effected by a small sample size. A possible methodology could be the Q-Method (Stephenson, 1994).
For an improved statistical analysis of these larger samples other or additional tests may be required, for example a Chi-square test.
For a good example of an better designed research see for example Muñoz-Cadena et al. (2009, 2012).

5.3.2. Field Observations

One of the problems of field observations is the time and location dependency: *"Would you observe the same things if it were another time or location?"*. Intuitively the answer to this question must clearly be negative. To reduce this effect, the field observations were done over a long period of time, but maybe still too short. Moreover, there is the problem of perception and interpretation: *"Do you actually observe what is there or is there more or less to it?"*. To minimize this effect, most observations were also documented in pictures or videos. Moreover, the field work has not provided adequate details about the exact waste composition that was present in the drains.

It is highly likely that doing the same type of observations at a different location and time would have resulted in different results, for example during the rainy season. Unfortunately it remained unknown how large this uncertainty was. Quantifying this uncertainty was impossible since there was no baseline that could be used for comparison. The lack of knowledge on the exact composition of waste in the drains made it also very hard to estimate what type of dynamics need to be applied to the solid waste streams through the drains (if such knowledge actually exists).

The study of Spence et al. (2016) provides a good example of a possible monitoring set-up and methodology that might be applied to Latha to collect additional data on the waste composition and waste propagation through the drains.

5.3.3. Interviews

The semi-structured interviews that were conducted for this research yielded valuable additional data for triangulation or knowledge on where or how to collect extra information or data. To a large degree this data was consistent with the other data sources. However, it needs to be noted that the structured interviews result in subjective answers. There is the potential of a bias as a consequence of the framing of question and the order in which questions were asked. Moreover, the interviews with the YCDC were both conducted with one official. It might be that different interviewees would have answered the same question differently.
This same weakness applies to the mini-interviews with Latha's citizens. The unstructured character made it hard to report exact transcripts of all the conversations. Moreover, a large number of these conversations were not in English but were from questions asked in English (by the researcher) translated into Myanmar Language and the answer had to be translated back from Myanmar Language to English by means of a translator. Despite the fact that this researcher has a great faith in the accuracy of the interpretor, this might have been a source for uncertainties and biases. For example, biases might have been caused by a (slight) deviation of the questions that was originally asked and a misunderstanding and misinterpretation of the answers. Due to the short character of most conversations it was hard to implement similar questions in other wordings at a later time to cross-check the initial answer.

However, since this was an explorative study the impact of the potential biases were limited. Furthermore, the answers of the interviews were mostly in line with the results of the unstructured mini-interviews with citizens and vice-versa. The answers were also consistent with the other sources that were used for triangulation.

For future research, it could be useful to voice-record all conversations with the citizens. This allows for a second interpreter to verify the questions asked and the answers that were given. This might also allow for a more structural reporting of the results. Such recorded results might then also be used to apply coding and categorizations for a more scientific methodology. A good example of using interviews in water management with the usage of coding and analysis might be Junier (2017).

5.3.4. Flood Model

The usage of the scenario based flood model was considered appropriate. Although the results deviated from the recorded historical events and reported results (from questionnaires and interviews) the flood model did allow for a sensitivity analysis of the UDS. Despite the large number of cases, there were still plenty of additional cases possible. Especially combining cases such as multiple blockages with and increased wall roughness could provide additional understanding.

Since the impacts of the model's inaccuracy is limited and making the perfect hydrological model was not the primary objective no additional action is required for this study. However, for other studies that might not have an as clear hydrological response as Latha's urban drainage system, a more accurate method might be required. In such a case, a calibration of the model, e.g. by means of a Monte-Carlo simulation might be useful.

5.3.5. Socio-Hydrological Model

Although other studies showed the great potential of agent based modelling (ABMing) to recreate realistic scenarios that could truly be used for policy development (e.g. flood evacuation policies (Dawson et al., 2011)), the current agent based model (ABM) of this model cannot be used for such objectives. Never the less, the creation of the initial hypothesis, its evaluation and the creation of a new hypothesis was a useful tool on its own. However, it has to be noted that even a perfect working ABM is only able to recreate dynamics that have actually been coded into the model. Whereas the whole purpose of an ABM is to study the effects of interactions and how they might change over time, it is kind of contradictory to study this with a fixed model that does not allow for the creation of spontaneous new interactions that might actually be formed in reality. Another weakness is the inability of the used ABMing platform to incorporate advanced models that describe physical processes such as the rainfall runoff processes, flow through drains and solid waste transport.

It is unknown to what extent the simplifications of the physical processes and fixed dynamics effect the model's capability to accurately model reality.
Therefore it would be interesting to build an ABM for a well understood subject and build different ABMs with various degrees of complexity to study the effects of the added complexity. It might be that an ABM that uses a simple formula with a correlation coefficient works just as good as a model that runs a hydrological/hydraulic model parallel with an ABM. Unfortunately such studies have not been completed and maybe this shows the weakness of applying an ABM in general.

6 Conclusions and Recommendations

This chapter provides answers to the four research sub-questions, which all together answer the central research question of this thesis. This is followed by recommendations to the Latha Township and YCDC on how to reduce Latha's urban flooding problems. Finally recommendation for future research are introduced.

This research started out with the central research question:
To what extent is a human-water system a coupled system for solid waste management and urban flooding and how could a social-hydrological model help to understand this human-water system interaction for the case of urban flooding?

Which will be answered by answering the following research sub-questions:

1. What are the most relevant human solid waste management activities that contribute to urban flooding and how does urban flooding affect human activities?
2. What are the most dominant urban drainage system (UDS) properties and processes that cause urban flooding from a hydrological and hydraulic perspective?
3. What could be a possible social-hydrological model for the coupling between solid waste management and urban flooding and how could this be used to better understand a human-water system?
4. What is an appropriate methodology to study the interactions between human solid waste management activities and urban flooding?

For the first sub-question, the socio-economic results of the case study suggest that a high flood awareness is no guarantee for adequate solid waste management (SWM) actions. If a human-water system (HWS) has insufficient disposal locations and waste collection is not frequent enough, people develop waste disposal practices at undesignated sites.
A too ad hoc cleaning schedule of the streets results in waste ending up in the drainage system before the waste is successfully collected of the streets. Moreover, cleaning practices where water is commonly used to sweep waste in the drains results in an additional waste flux that enters the drainage system.
Insufficient maintenance to drain covers and drain inlets increases the probability of fouling of the UDS. Moreover, limited maintenance and cleaning of the drains also adds to the build-up of waste in the drains and structures.
A long history of frequent flood experiences results in both acceptance of flood events or adaptation to flood events. Signs of acceptance and adaptation for Latha are the large number of people who reported to not have experienced any recent damage and said to continue their daily business in case of a flood event.
The implementation of flood protection measures shows that citizens indeed react and adapt to urban flooding (UF) and thereby change the HWS. Other forms of interaction with the HWS are structural improvements to the drainage system, as were reported for the case study.
For Latha, both blockages of the flood gate structures (FGSs) and even more so blockages of the drains were reported to be the cause of UF. This seems to suggest that there is a strong coupling between human SWM

activities and floods.

However, answering the second research sub-question for the case study results in a contradiction to the answer of the first question. To a large extent Latha's floods are the result of an unfortunate combination of events and system characteristics. A high Yangon River water level (YRWL) that coincides with a rain event forces the FGSs to be closed, preventing the drainage system to discharge the inflowing rainfall and the dry weather flow (DWF). The drainage system's storage is too little to temporarily store all this water and discharge it under gravity flow at a later stage, once the YRWL has become sufficiently low enough for the FGSs to be reopened.
The timing of the operation of the Latha FGSs also plays an important factor. Closing the FGS too late or not completely results in river water filling up the drainage system, eventually spilling to the lower laying streets. Waste that is stuck within the structure can result in situations where the gate does not fully close.
Drains that are fouling up and (partial) blockages of the drains only have a minor impact on Latha's drainage system. Rainfall runoff processes and urban waste water discharges have an even smaller impact. Thus there is no strong coupling between SWM and UF for Latha.
This is the result of Latha's UDS temporal and spatial scales, and its lay-out characteristics. The system has a lot of short drains, with a fast hydraulic response and limited friction losses. Moreover, the network is highly looped allowing for sufficient alternative flow paths under increasingly pressurised flow.
Generalizing the answer to this research sub-question results in a different conclusion for other types of systems. The combination of rainfall and high water levels might only play a minor role, or no role at all in systems with: sufficient storage, less dominant downstream boundary conditions and/or alternative discharges possibilities (such as pumping stations in a polder).
Spatially large, branched networks (opposite of looped networks), with small drains are more prone to the effects of fouled and blocked drains. The longer drain's lengths will result in significantly more friction losses. The lack of alternative flow paths does not allow for the pressure build up to result in higher discharges along different flow paths, but only results in an increase of the water level in the drains. Under such conditions, citizen's waste disposal patterns and flood awareness, the municipalities solid waste management practices and drainage system maintenance become much more relevant.

The answer to sub-question three comes from the evaluation of the initial hypothesis. For the case study a SWM was synthesized for the existing weak coupling between SWM and UF. The waste production and disposal patterns of Latha's households (HHs) are crudely modelled, as are the waste collection practices by the Yangon City Development Committee Pollution Control and Cleansing Department (YCDC PCCD) and the cleaning of a FGS by the Yangon City Development Committee Engineering Department of Roads and Bridges (YCDC EDRB). Waste can end up in the drains and potentially block the flood gated, before the waste is successfully collected. Too much waste stuck at the FGS results in a blocked gated that causes floods if a critical water level is exceeded. The absence of floods, results in an slow increase of the number of HHs that do not always dispose their waste in containers. The consequence is an increased probability of a blocked gate, since more waste enters the system. If a new flood occurs, a number of people reconsider their disposal patterns which results in a new different dynamic.
However, the large degree of simplified and not scientifically backed described processes and parameters makes the model's current predicting and explorative capabilities too weak.
This toy-model is far from complete and provides ample possibilities to add complexity and more realistic behaviour. Despite its weaknesses it can be used as an inspiration for new research steps and contains potential model concepts and building blocks for future models.
If this conclusion for the case study is generalized, it becomes clear that there is still a long way to go before a generalized socio-hydrological model (SHM) is able to describe the coupling between SWM and UF of any HWS.

The answer to sub-question four could be summarized as follows: The methodology used in this researched consists of a combination of social science methodologies: questionnaires, field observations and interviews and scenario based flood model simulations that are used to synthesize a SHM.
The used social sciences materials, collected datasets and obtained results on their own are biased and lack sufficient statistical significance. Moreover, the applied social sciences methodologies are subject to design flaws, lack a sound scientific framework and are executed imperfect. However, using multiple data sources and different methodologies allows for the implementation of triangulation on the collected datasets and obtained results. The triangulation results in the convergence of the different datasets, providing truthful

propositions about the relevant social SWM phenomena.
Although the flood model simulations are unable to accurately simulate historic flood events the scenario based approach with flood model cases results in sufficient system understanding. In this methodology the different cases serve to some extent as a form of sensitivity analysis that also allows for a crude analysis of the effects caused by input-data uncertainties.
Unfortunately the SHM is unable to go beyond the extend of a toy-model. However, the composition and evaluation of the initial hypothesis and the synthesis of an improved conceptual model provided directions and structure to the research strategy.
It should be concluded that the implemented research methodology is effective for a research that simultaneously: has an explorative character, has limited financial and human resources, has a high uncertainty in the available data and where multiple scientific disciplines meet.

To answer this research central question the answers of the four sub-questions are unified. It should be concluded that there are HWS with an coupling between SWM and UF. However, the significance of this relation is subject to location specific characteristics. In general, large drainage systems with long drains and a highly branched network are expected to have a stronger coupling. In these systems, friction losses and blocked cross-sections caused by waste have a larger effect.
The current SHM is not able to provide additional understanding of this interaction since the modelled processes are too simplified. However, attempts to make an accurate model do provide insight in the scientific knowledge gaps that can help to advance this research area.

In general, it is important to research which degree of added complexity is required to increase the usefulness of an agent based model (ABM) and to research the performance improvement of this added complexity. Do we need complex parallel or integrated hydrological and hydraulic models to describe the natural processes, or can we make smart assumptions, correlations or simplifications that provide sufficient detailed dynamics? Moreover, future research should focus on finding the similarities and differences of other types and other scales of drainage systems compared to this system. Is there indeed is a stronger coupling for systems with a larger scale, smaller drains and a more branched network?
Finally the dynamics of the transport of consumables solid waste trough an UDS has not been studied in great detail. Although a lot of studies have focussed on deposits and large particles, larger items as plastic bottles, package cartons and plastic bags is limited. Moreover, what is the probability of different of these items to enter the UDS? Additional knowledge might help to improve a SHM that describes the relation between SWM and UF.

Considering the results of this case study, the Latha Township and YCDC EDRB are advised to prioritize additional research on the drainage system's storage capacity, (outflow) discharge capacity and alternatives to the discharge under gravity flow. An improved operational management of the FGSs, with additional storage within the system and other backup options (such as a pumping station) might result in a reduction of the number of annual floods, flood durations and water depths.
It is also strongly advised to improve and intensify the solid waste management system. This reduces the probability of floods (albeit small) and contributes to a more sustainable environment. Moreover, public health will be increased and the appreciation of the Yangon City Development Committee (YCDC) by Latha's citizens might be increased.

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A

Mayanmar, Yangon & Latha Township

This appendix provides additional information about Myanmar, Yangon and Latha that was omitted from the main report (Chapter 2) to improve the lay-out and readability. Therefore, a part of this appendix will be a repetition but it will also provide additional information and figures.

A.1. Myanmar, Yangon and Latha

A.1.1. Myanmar

Myanmar, or by its old name Burma, is officially known as the Republic of the Union of Myanmar and is situated in south east Asia (see detail Figure A.2). The country's area totals to about 765,000 km^2 (CIA, 2016) and is bordering the Andaman Sea, the Bay of Bengal, Bangladesh, India, China, Laos and Thailand, see Figure A.2. In Myanmar live about 56.3 million people, with 34 % of the population in urban areas (CIA, 2016). The official capital is Naypyidaw, but the largest city in Myanmar is Yangon (also known as Rangoon). The largest ethnic groups are the Burman (about 68 %), followed by the Shan (about 9 %) and Karen (7 %) (CIA, 2016). The median age of people is 28.3 years and its population structure is shown in Figure A.1 (CIA, 2016). Myanmar has a GDP of US$ 283.5 billion estimated for 2015 (CIA, 2016). As a result of democratic reforms in 2011, Myanmar has transformed tremendously over the past few years from a dissolved military junta to a fast growing economy (Asian Development Bank, 2016).

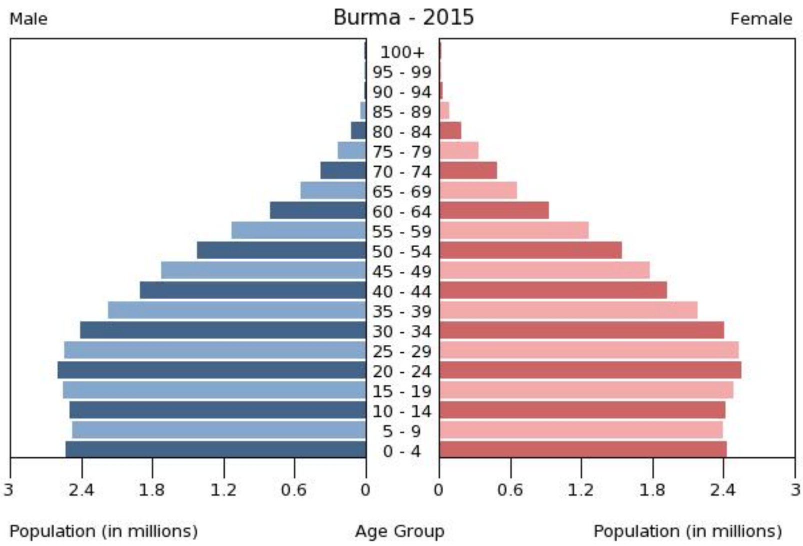


Figure A.1: Population pyramid of Myanmar.

Figure A.2: Map of the Republic of the Union of Myanmar (modified from : UN Cartographic Section (2012)). Water levels in Myanmar are with respect to mean sea level (MSL) at Kyaikkami (JICA and Ministry of Forestry - Myanmar Survey Department, 2004). Kyaikkami was formerly known as Amherst.

A.1.2. Yangon Region

Yangon could be used to refer to the independent Yangon Region or to the city Yangon (see Figure A.3). Apart from this section, Yangon will be used to describe the city Yangon unless specifically stated otherwise. The Yangon Region has an area of about 10,000 km^2, a population of about 7.4 million people and it is the most developed region of Myanmar (MIP - DP, 2015, p.1).

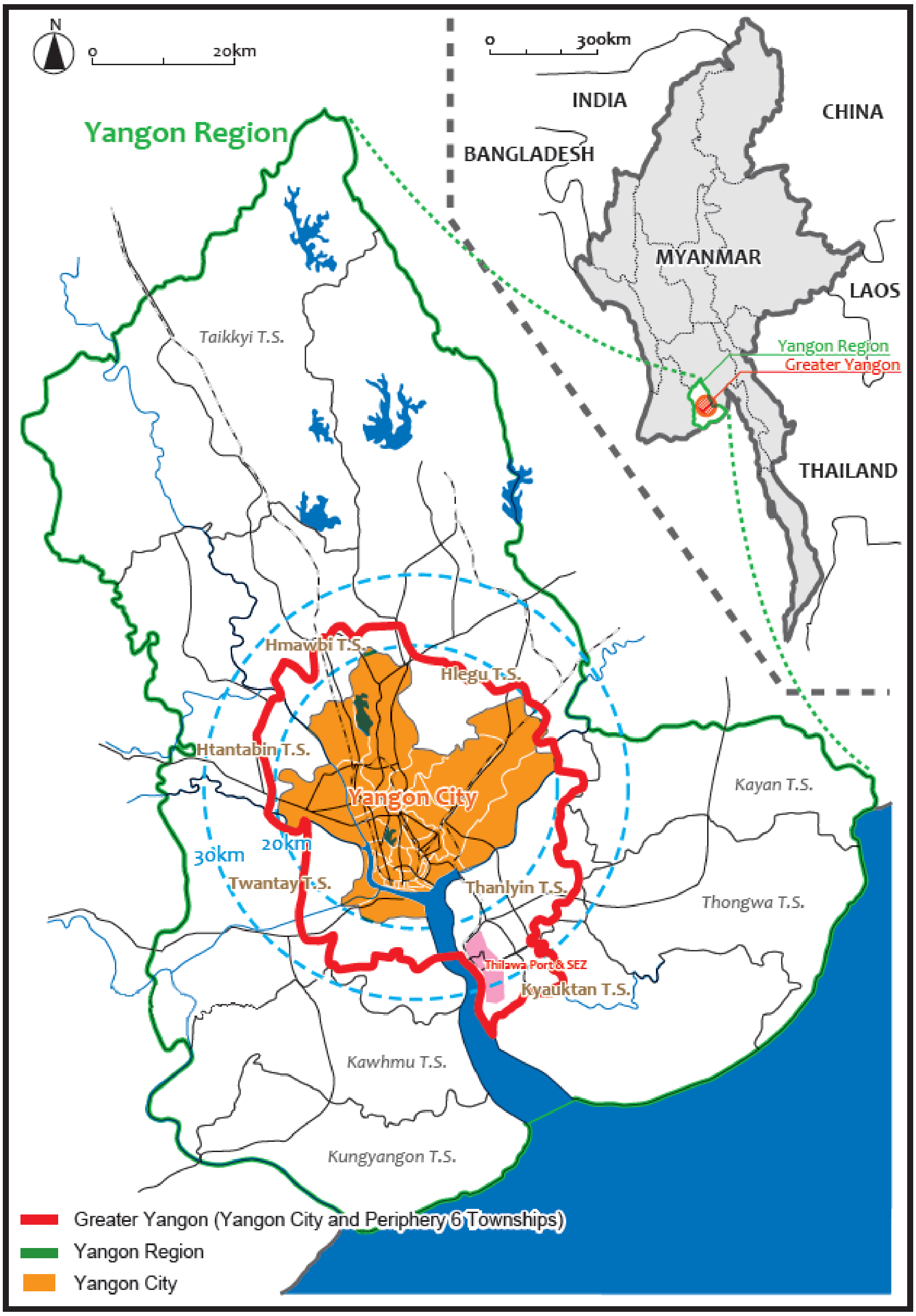
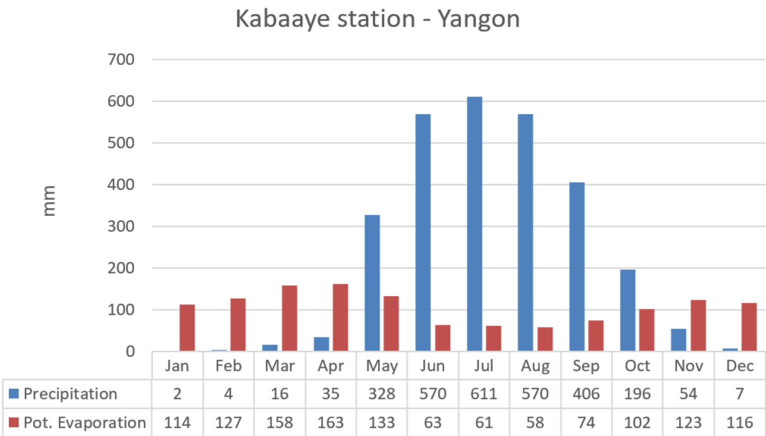
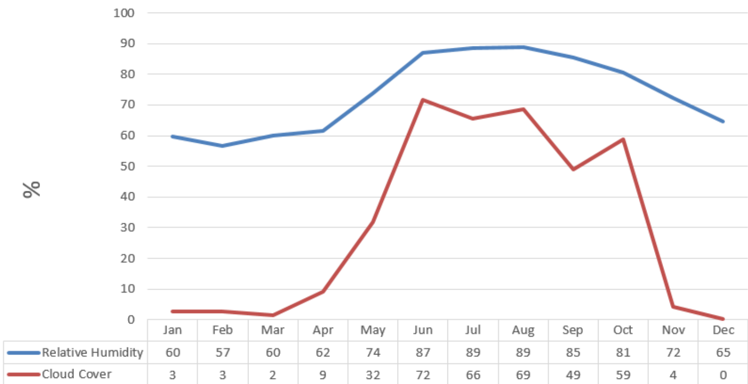


Figure A.3: Map of Myanmar and Yangon. The map shows the location of Yangon within Myanmar. A differentiation should be made between the Yangon Region, Greater Yangon and Yangon City. Modified from (JICA and YCDC, 2013).

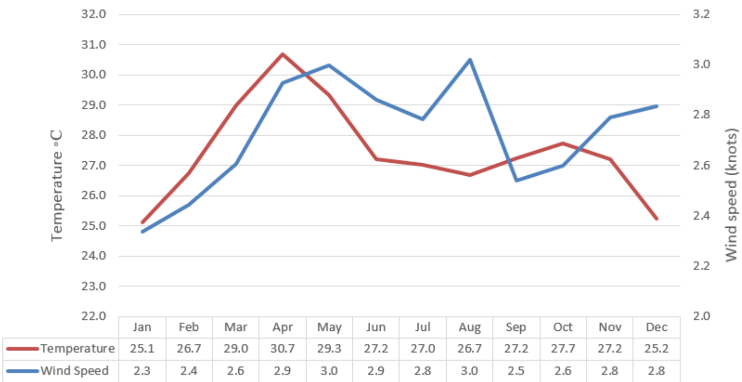
The region has a climate with 3 seasons: cold season (roughly from November to February), hot season (roughly from March to May) and a rainy season (roughly from June to October), as could be seen from Figure A.4. During the rainy season large monsoon weather fronts (Sen Roy and Kaur, 2000) reach the coast of the Yangon region. Figure A.4a shows the monthly average rainfall for the Yangon Region. On average July is the wettest month of the year for Yangon, with a long term monthly averaged precipitation of 602 mm/month (as much as in a very dry year for the Netherlands). Climate change in the past few years has resulted in upwards trends for the annual total precipitation of Myanmar's coastal areas (Win Zin and Rutten, 2017) and thus an increase in future annual rainfall might be expected.



(a) Long term monthly averaged precipitation and evaporation, values in mm/month



(b) Long term monthly averaged relative humidity and cloud cover data



(c) Long term monthly averaged temperature in °C and wind speed in kn

Figure A.4: Climatologic parameters of Kaba Aye Weather Station, Yangon City (See Figure A.5). Obtained from (Van der Horst, 2017, p.10).

A.1.3. Yangon

The city Yangon (Figure A.5) is the former capital of Myanmar. It is situated at the (south) coast of Myanmar in the Yangon Region (see Figure A.3), 34 km upstream from the mouth of the tidal Yangon River (JICA and YCDC, 2013). Apart from the Yangon River, Yangon is also adjacent to the Hlaing and Bago rivers and the Nga Moeyeik Creek and Panzyndaung Creek flow through the city (see Figure A.6).
Figure A.5 shows the location of the Latha Township within Yangon, which will be introduced in the next section. The figure also shows 3 points of interest that are sometimes referred to within this report and appendices. The first point is the Kaba Aye Rain Station, situated roughly 13 km away from the Latha Township. This is Yangon's only rainfall station and data from this station was used for this research (see appendix, Section C.3.13). The second point is the Yangon Port, and the third point is Monkey Point. Both points are relevant when considering the Yangon River water levels (see appendix, Section C.3.11).

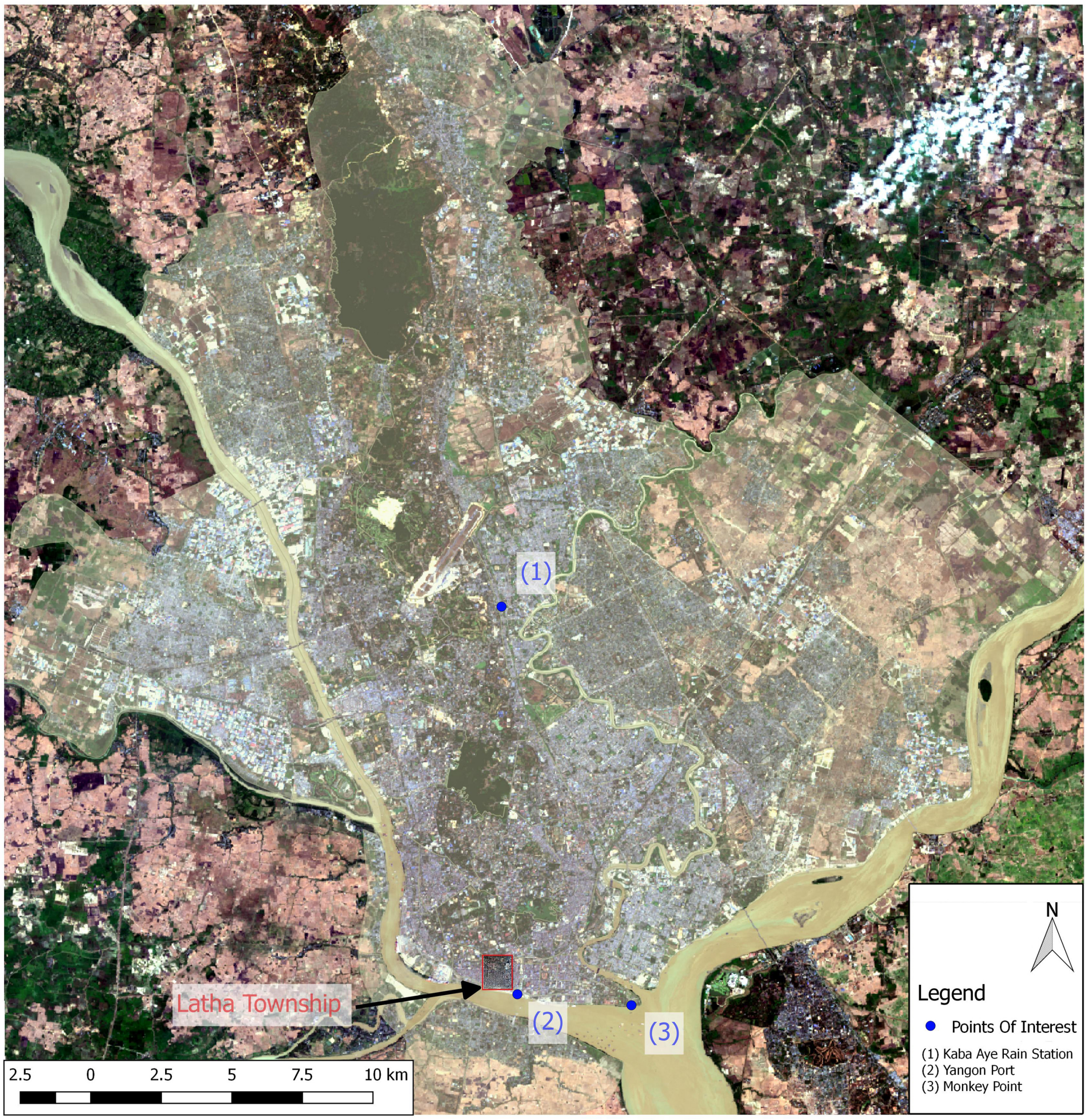


Figure A.5: Map of the city Yangon. The Yellow overlay gives the boundaries of the city. The red rectangle indicates the location of the Latha Township. Furthermore, there are 3 points of interest indicated on the map that may be referred to at later stages. The first is the location of the meteorological station that records the rainfall for Yangon. It is about 13 km as the crow flies from the meteorological station to the centre of the Latha Township. The second location is the Yangon Port Area, that starts at the south east corner of the Latha Township. The third location is Monkey Point, at this location the water levels of the Yangon River are modelled/measured (see Section C.3.11). Monkey point is about 5 km downstream of the outlets for the Latha Township

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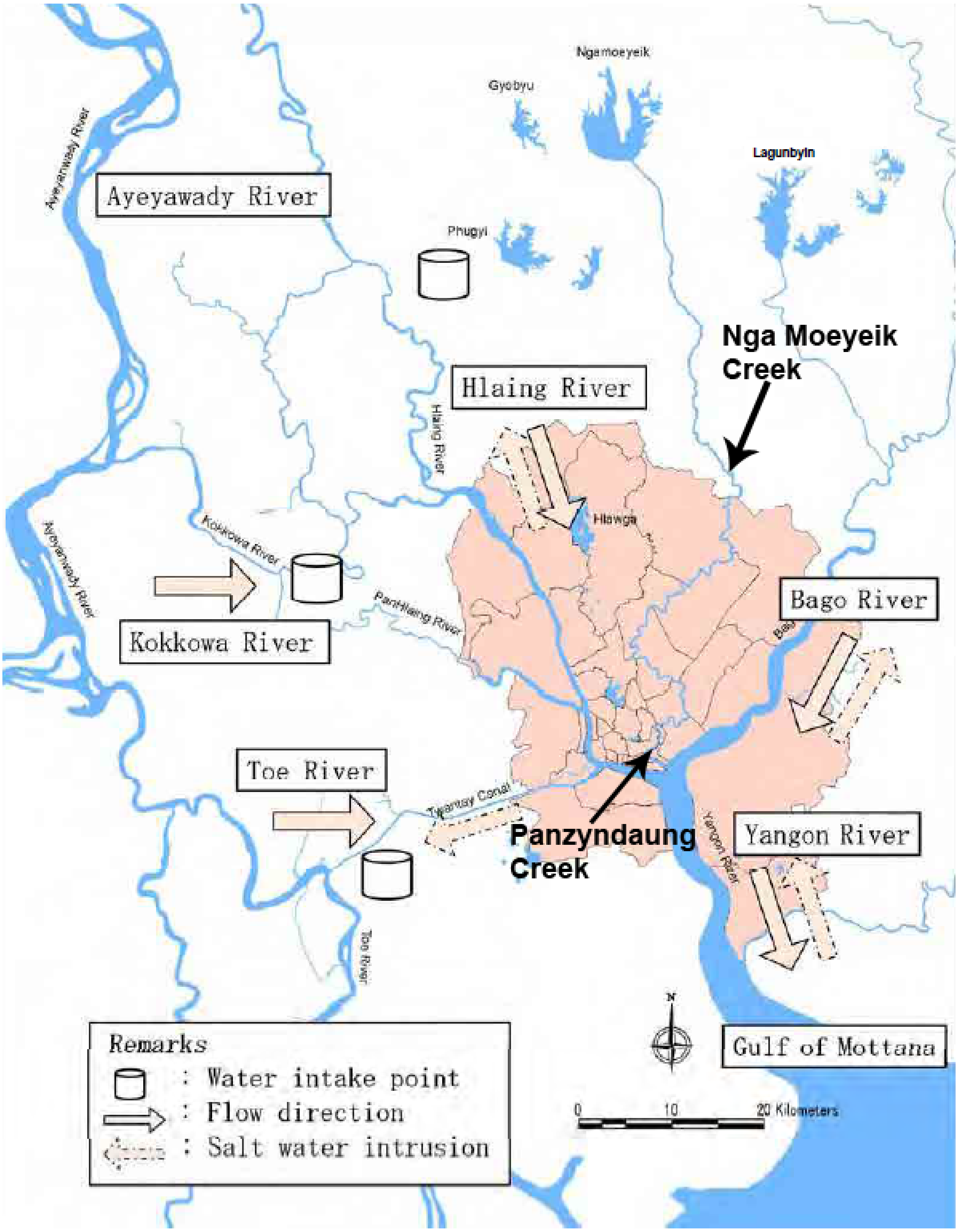


Figure A.6: Yangon is 34 km upstream from the mouth of the tidal Yangon River (JICA and YCDC, 2013). Apart from the Yangon River, Yangon is also adjacent to the Hlaing and Bago rivers and the Nga Moeyeik Creek and Panzyndaung Creek flow through the city. Modified from (JICA, 2014*b*, fig.2.11).

The city has an area of almost 600 km^2 and is divided into 33 different townships (see Figure A.7) which all are administered by the Yangon City Development Committee (YCDC) (YCDC, 2017). The 6 downtown townships: Lanmadaw, Latha, Pabedan, Kyauktada, Pazudaung and Botataung (JICA and YCDC, 2013, p.ix) make up the central business district (Figure A.8).
From Myanmar's 56.3 million inhabitants about 5.16 million people live in Yangon city's urban areas (MIP - DP, 2015, p.16). "The city is very densely populated with an average of 8500 p/km^2 and local peaks up to 70000 p/km^2." (Van der Horst, 2017, p.7). These high population densities are in particular in the central business district and central townships (see Figure A.9).

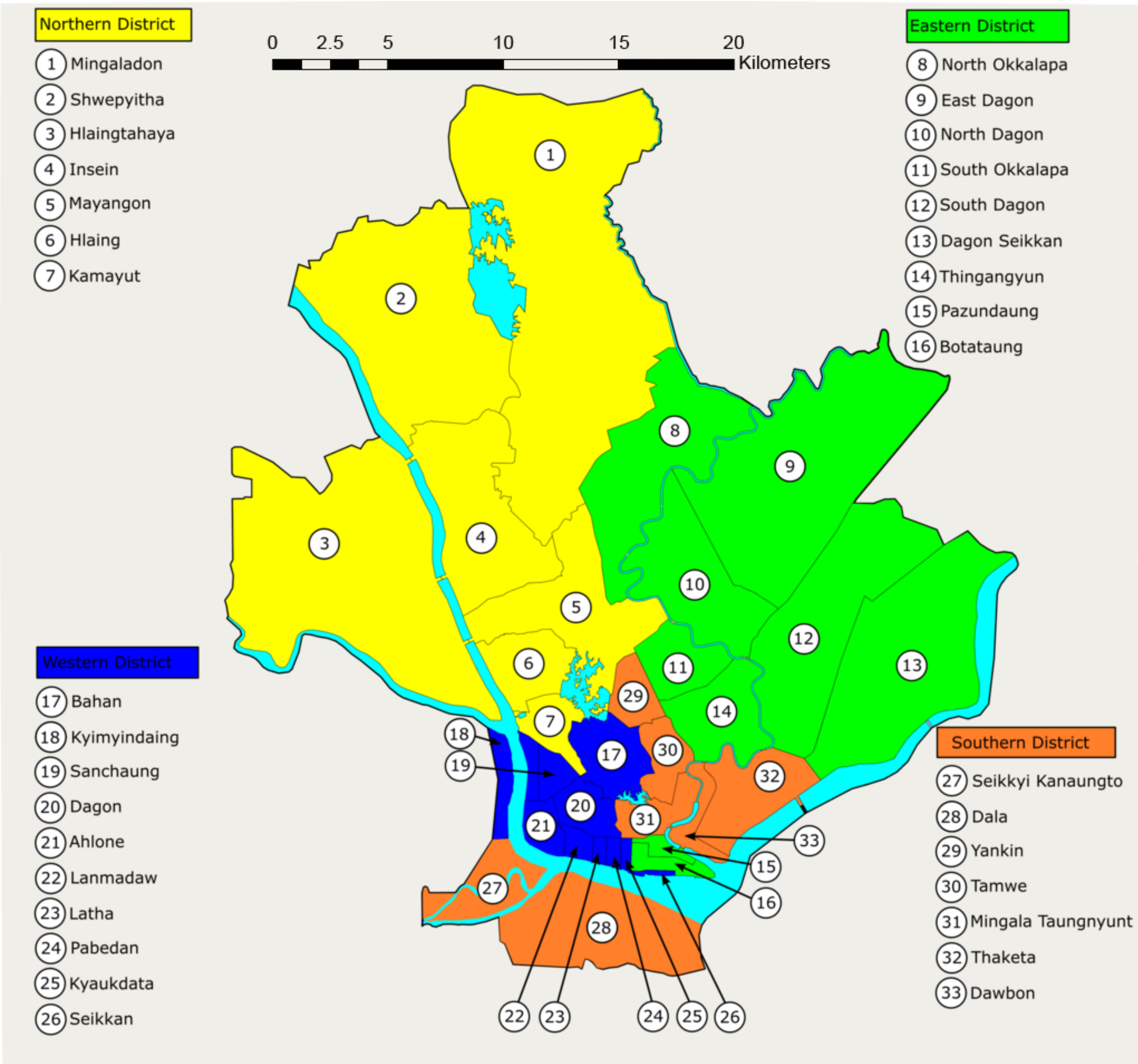


Figure A.7: Yangon is divided into 33 townships (Wikipedia, 2016). Each township represents a separate institutional layer within the city's governance.

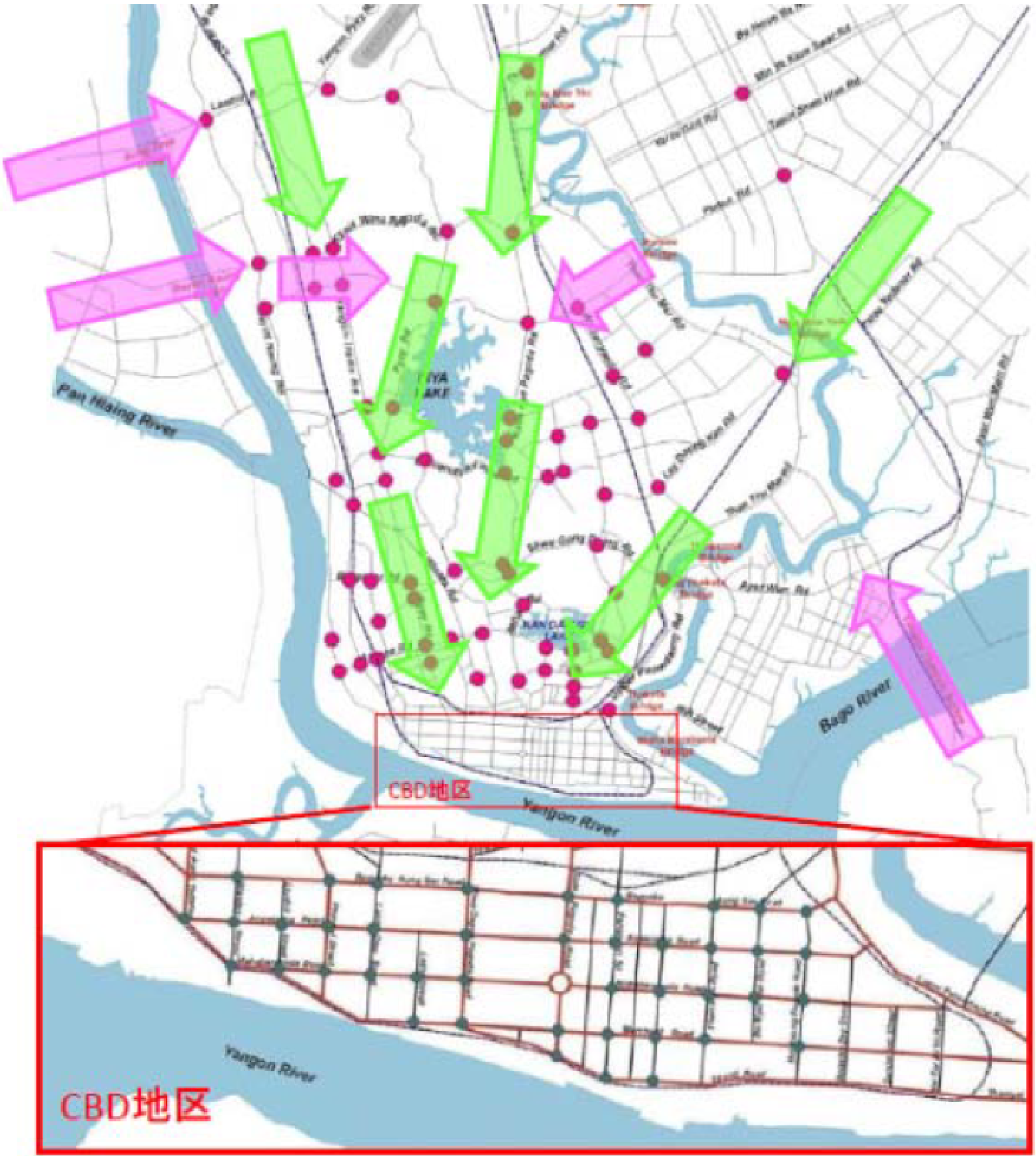


Figure A.8: The central business district (CBD) area of Yangon. The area consists of 6 townships: Lanmadaw, Latha, Pabedan, Kyaykdata, Pazundaung and Botataung (JICA and YCDC, 2013, fig.2.8). See Figure A.7 for the locations of the townships.

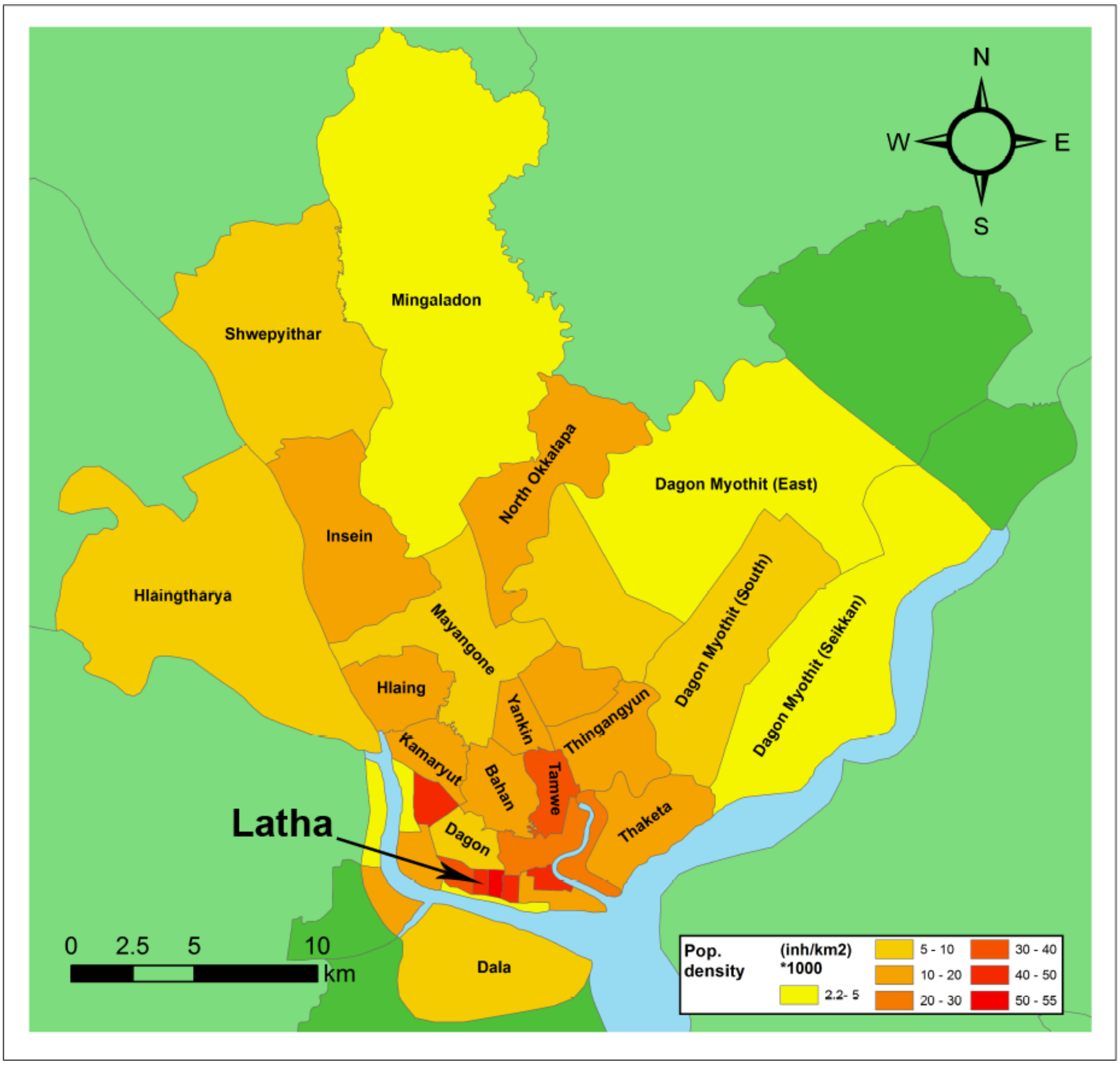


Figure A.9: Map of te population density in Yangon's different townships. Only the names that fit are shown together with Latha. The image shows that Latha is one of the most densely populated areas in the city. Modified from (Van der Horst, 2017, fig.2.3).

In the past decades, Yangon City has grown tremendously (Figure A.10). “Foreign investment in Burma, particularly from China, is on the rise”, “hitherto greenfield sites surrounding the city have been built upon”, the “demand for office space has grown, and construction taking place in the city centre is of an ever-enlarging vertical scale” (Morley, 2013, p. 601). “Burma’s largest city must be recognized as being in the midst of a process of environmental alteration, a reshaping that reflects the nation’s push for modernity and development” (Morley, 2013, p. 601), a process that will continue in the near future as there are plans to develop the city even further (JICA and YCDC, 2013, 2014).

Within the city there are ground level elevation variations. Foothills that originate from the Yangon Region’s low, long hills in the north-south direction which gradually transition into the delta plains west, south and eastwards (see appendix, Figure A.11). However, all urban areas close to the rivers (including Latha) are low laying areas with ground level elevations just a few meters above mean sea level (also see appendix Section C.3.8).

Figure A.10: Urban development of Yangon City throughout the years. The current township borders are highlighted in yellow in all images. Obtained from (Van der Horst, 2017, fig.2.7).

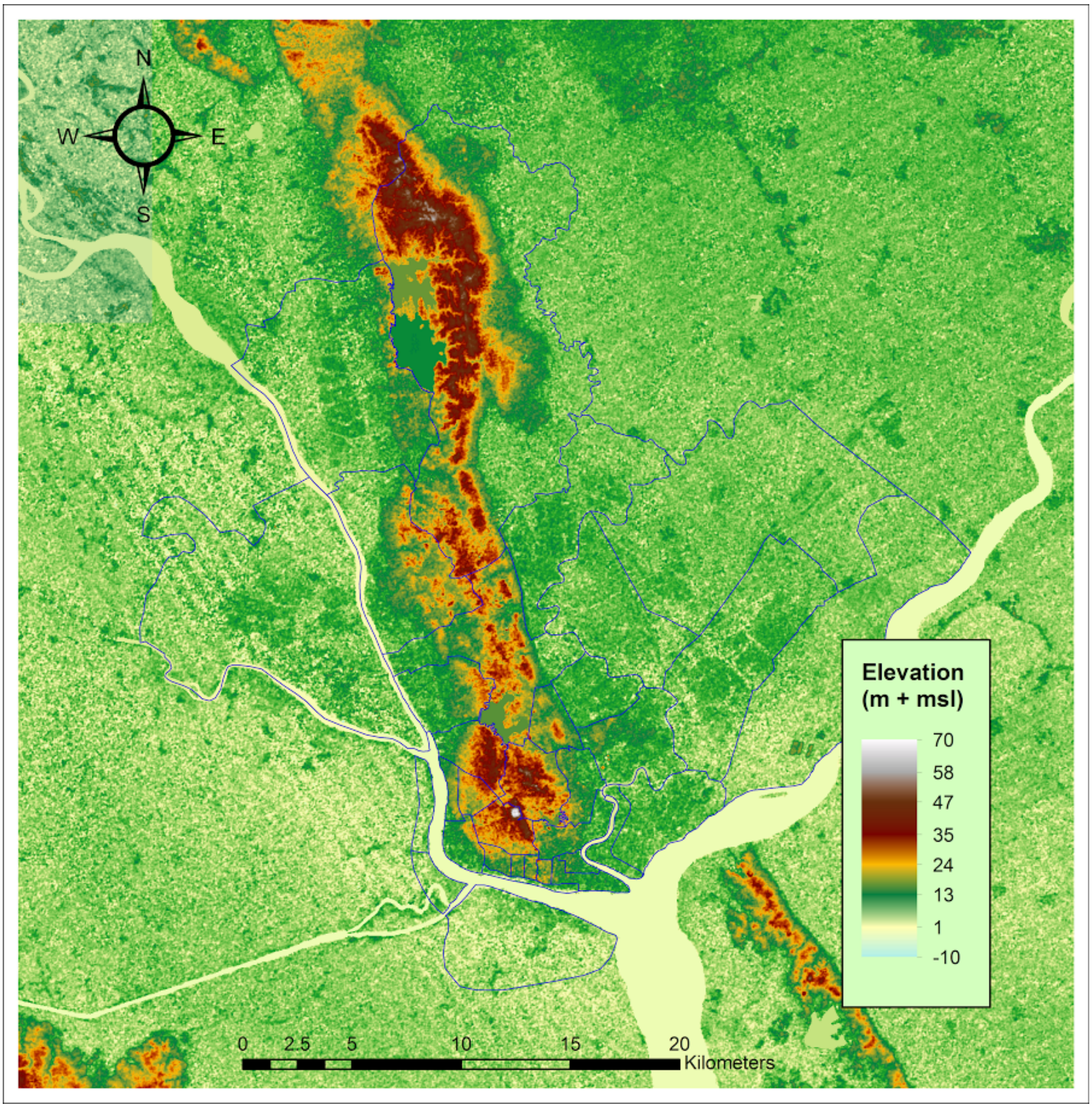


Figure A.11: DEM map of Yangon. It could be seen that within the city there are quite some elevation differences. The majority of the gradients run in a north-south direction. The elevations of the townships close to the rivers is on average close to mean sea level. Made by and obtained from Teije van der Horst.

A.1.4. Latha Township

The Latha Township (also known as Yangon's China Town, see Figure A.17) is one of six townships that together make up the so called central business district in downtown Yangon (see Figure A.8) . With an area of about 70 hectares and a population of just over 25,000 people (MIP - DP, 2015) it is one of the geographically smallest townships in area but with one of the highest population densities (see Figure A.9).
The township has a grid like structure with four main roads running from west to east (Bo Gyoke Road, Anarwrahta Road, Maha Bandula Road and Strand Road). Two main north-south oriented roads (Lanmadaw Street and Shwedagon Pagoda Road) together with the train tracks in the north and the Yangon River in the south confine the township (see Figure A.12 and Figure A.13).

Based on its land use characteristics found during field work the township was split up into three areas: the hospital area, the residential area and Strand Road (night) Market (see Figure A.14. In the northern hospital area the building density was relatively lower and the area was more unpaved and *green) (Figure A.15).* Along the south side of Strand Road a recently (early 2017) opened new (night) market area (Figure A.16) hosted a lot of food market stands. The residential area (Figure A.17), with its smaller north-south oriented streets, was where the majority of Latha's citizens live (MIP - DP, 2015) and where a large number of shops, restaurants and street shops sold their products.

An interview with the Yangon City Development Committee Engineering Department of Roads and Bridges (YCDC EDRB) made clear that the residential area and Strand Road market were Latha's flood prone areas. The hospital area had too high ground level elevations to be flooded and same applies to the neighbouring and other downtown townships, albeit for the Lanmadaw Township to a lesser extent (see Table D.2). Apart from the low elevation, the high ratio of paved to unpaved areas and the high building density also resulted in less infiltration, faster run-off processes and more nuisance to Latha's citizens. Since the area was one of the most commercially active areas the damage to entrepreneurs and the nuisance for costumers was high and the group of people being affected large. Moreover, in case of a flood of (one of) the three main roads (Anarwrahta Road, Maha Bandula Road and Strand Road) the transport of numerous commuters and passer-bys was affected.
Figure A.19 provides an illustrative cross-section of the Latha residential area. There was a small gradient in the ground level elevation, from high in the north to low in the south. In the west-east direction the outskirts of the township were in general higher then the centre of the township around Latha Street. For more information about the ground levels see Section C.3.8.
At the north side of Anarwrahta Road an open drain connected the hospital area to the residential area (dark green drains). Underneath the three main roads, culverts connected the different drains (red dashed lines). Covered off, concrete drains made up the large majority of the township's drainage system. Running parallel on both sides of the small north-south streets (light blue dashed lines) and parallel to the main roads (dark blue lines). A drain along the south side of Strand Road (mostly open) eventually connected the drainage network to three gate outflow structures that discharged into the tidal Yangon River. For more information about the drainage network see Section C.3.7. For more information about the gate outflow structures see Section C.3.9, Section C.3.12 and the previously referred sections about the urban drainage system. For more information about the Yangon River water levels, see Section C.3.11.
Just south of Strand Road, the ground level elevation had a sharp increase (see Figure A.19d and Figure A.19a). Here was *Raised Strand Road* (see Figure A.13, officially also called Strand Road), for the transport of trucks with containers to the different terminals of the Yangon Port. Due to the large elevation difference (~2 meter, see Figure A.18) this road acted somewhat like a large dike, separating Latha's southern boarder and the Yangon River (see Figure A.19d).

As earlier mentioned in this section, the residential area was a mix of households and commercial activities. In general the majority of the shops were situated along the main roads or the beginning of the smaller side streets, however there were some exceptions. There was also a difference to be made between shops and restaurants who operate their business from a building or from a market stand on the street. For more details see Section C.3.4.

Latha's citizens were relatively high educated, had a high employment rate and in general were older than Yangon's citizens in general (MIP - DP, 2015). Moreover, Latha was part of the downtown central business district. Here the living prices were one of the highest through out the city and thus on average Latha's citizens were more wealthy (Kyaw Mein Oo, personal communication, April 6, 2017). For more socio-economic data about Latha see Section 3.1.2.

Figure A.12: Satellite image from the Latha Township. The image shows train tracks at the north boundary, a large street (Strand Road) on the south boundary. Even further south, outside of Latha's boundaries are Yangon Port terminals on the Yangon River's quay. The west boundary is Lanmadaw Street and the east boundary is Shwedagon Pagoda Road. The top part area has a lower building density and shows more signs of vegetation compared to the central and lower part of Latha. These areas have a grid like structure. For more details about the names of different areas see Figure A.13. Modified from Google Maps.

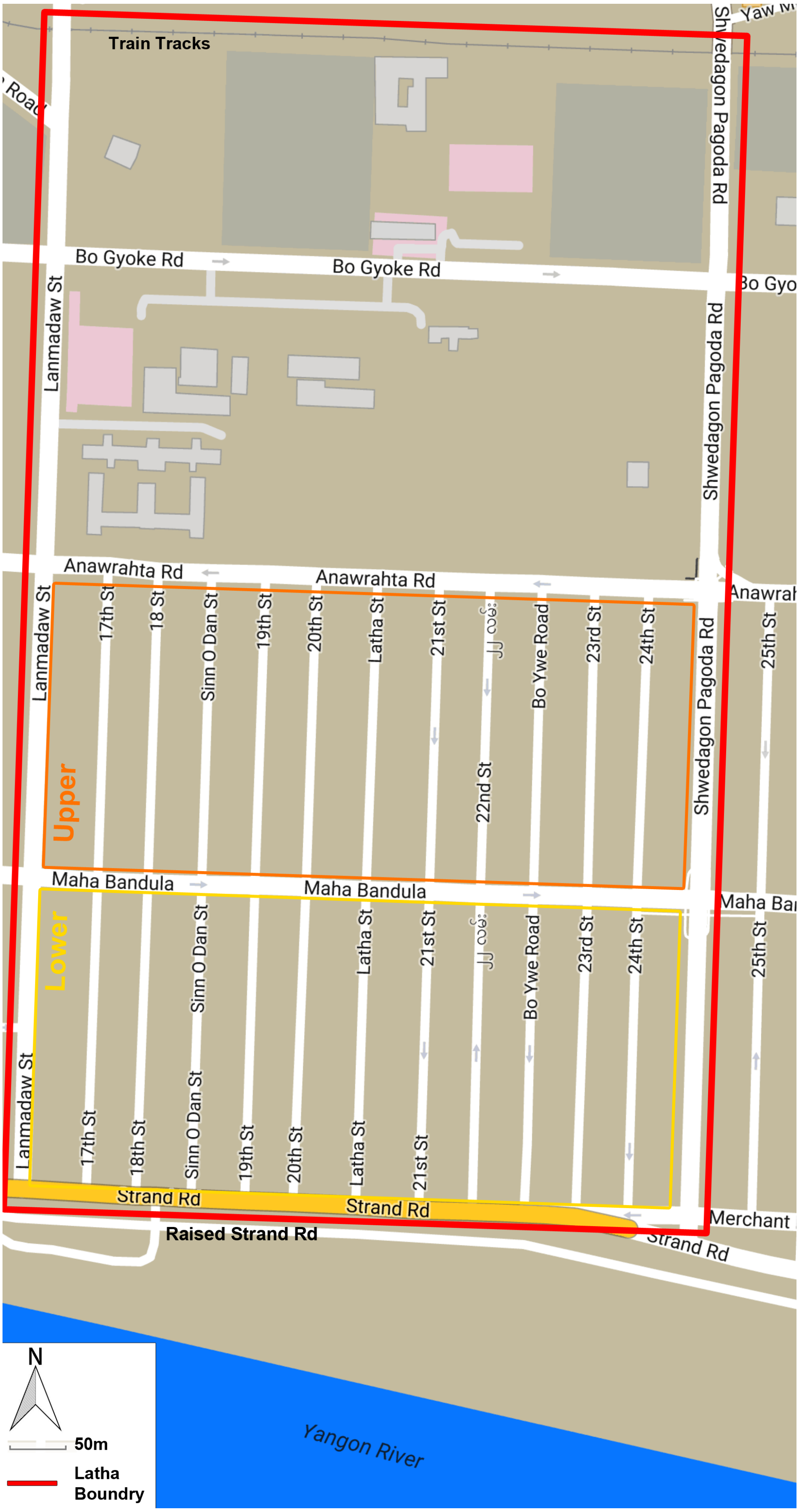


Figure A.13: This report sometimes refers to streets and/or locations within the Latha Township. This map provides an overview of the streets and locations. The Latha township is confined by the Train tracks at the north of the area, Strand Road at the south of the area, Lanmadaw Street at the west of the area and Shwedagon Pagoda Road at the east of the area. Latha might be split up in a upper block between Anarwrahta Road and Maha Bandula Road (orange) and a lower block between Maha Bandula Road and Strand Road (yellow). Modified from Google Maps.

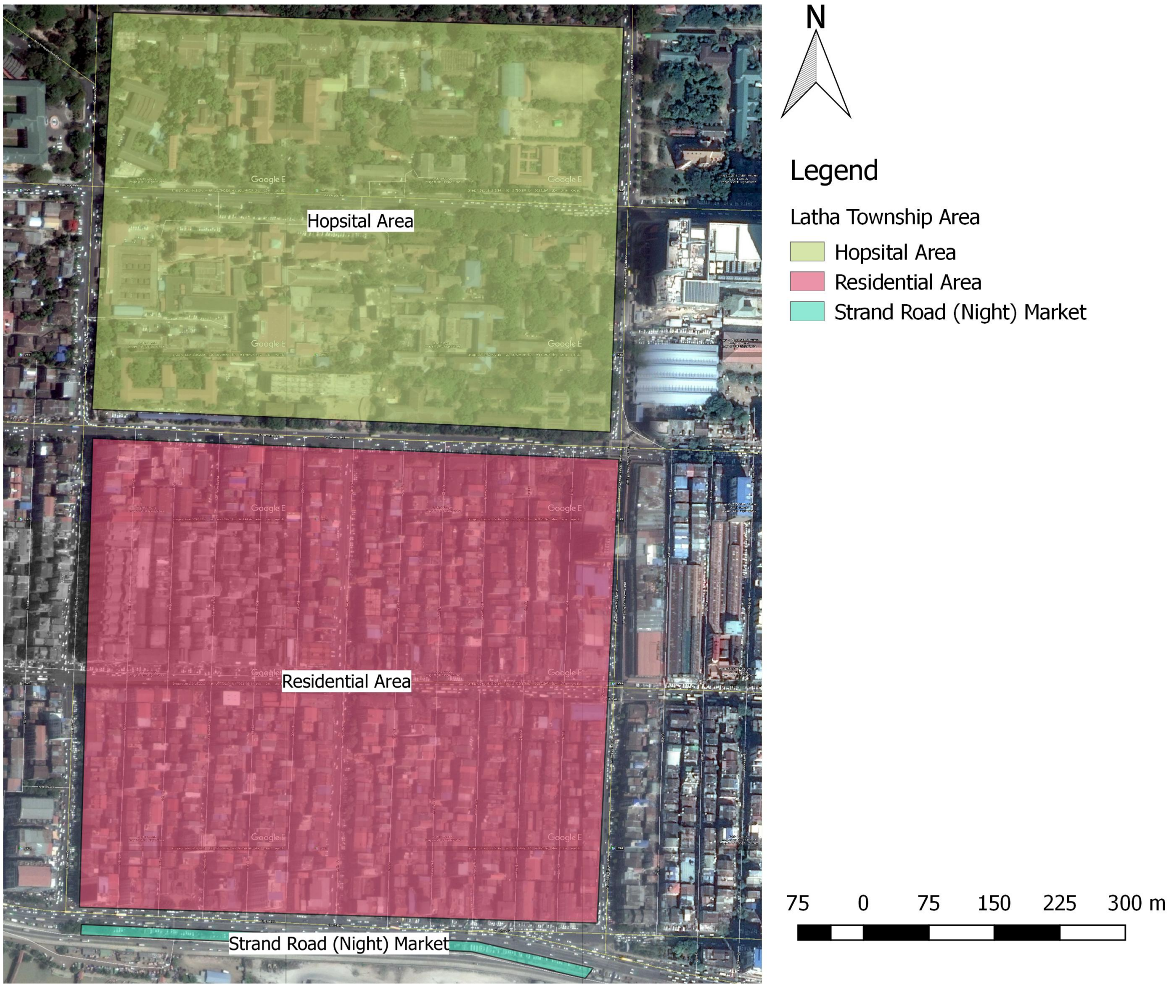


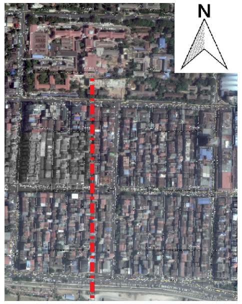
Figure A.14: The Latha township may be divided into 3 parts with each an individual character. In the north there is the hospital area. This is a relatively green area with scattered hospital departments. There is a relative high proportion of unpaved areas. In the middle part of the township consists of a typical Yangon Central Business District residential area with a north-south grid-like/block lay-out. This area will be referred to as the residential area. At the southern edge of Latha, early 2017 (January) a (night) market area was permitted.

Figure A.15: Hospital area on the left and the residential area on the right. Seen from the junction between Lanmadaw Street and Anarwrahta Road, looking in north-east direction. Picture taken on February 8, 2017.

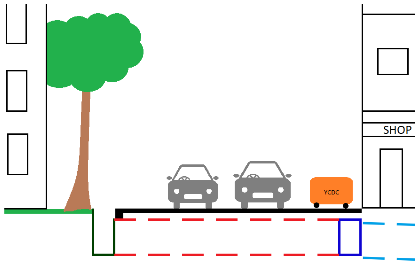
Figure A.16: Strand Road (night) market at the south side of Strand Road between 20^{th} Street and Latha Street, looking in east direction. In this area a lot of salesmen sold their products. Picture taken on April 3, 2017.

Figure A.17: Maha Bandula Road in the Latha Township during Chinese new year, seen from the junction with Maha Bandula Road and Shwedagon Pagoda Road looking to the west. Picture taken on January 28, 2017.

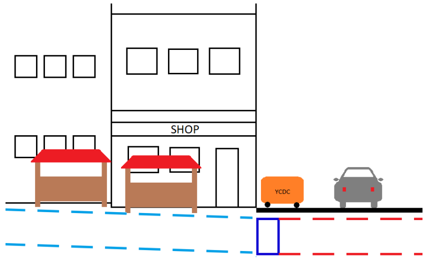
Figure A.18: At the south side of Strand Road there was a sharp increase in the ground level elevation. Here a road referred to as *Raised Strand Road* (see Figure A.13, officially also called Strand Road), was elevated and used for trucks to transport containers to the various Yangon Port terminals. The elevation difference was around 2 meters. Therefore the raised Strand Road acted as a sort of large dike, separating the Latha Township and the Yangon River. View from the south side of Strand Road, looking to the west. Left the Raised Strand Road, right Strand Road. In the middle an open drain that runned along the south side of Strand Road, see Figure C.11. Picture taken on March 19, 2017.



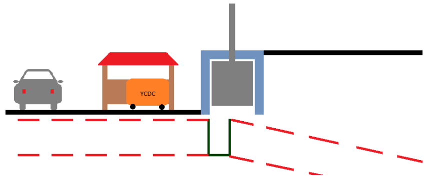
(a) The red line gives the direction of the cross section for Figure A.19e. Although the exact location is not relevant as Figure A.19e is only illustrative.for what a typical cross-section looks like through the Latha Township.



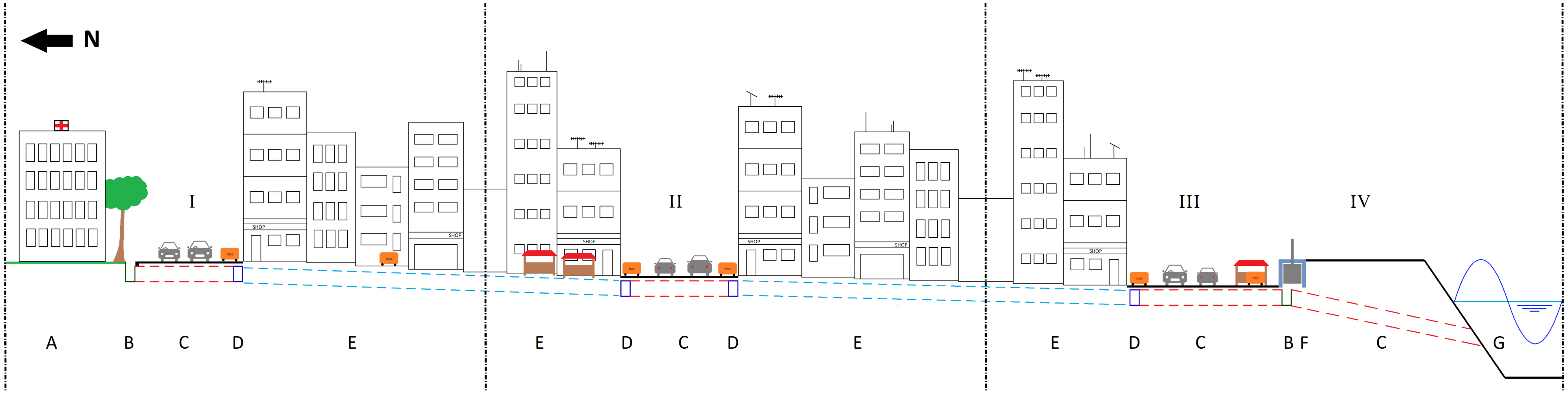
(b) Detail of Figure A.19e, that shows the *green* hospital area, the open drain along the north side of Anarwrahta Road and a closed one on the south side, with a culvert connecting them underneath Anarwrahta Rd.



(c) Detail of Figure A.19e, that shows a shop in the street, 2 market/street shops a container and a car driving along a main road. The blue dashed lines are covered drains running north-south on both sides of the street.



(d) Detail of Figure A.19e, showing a market at Strand Rd., together with the open drain that runs parallel to the majority of Strand Rd. The drains come together at one of the 3 FGSs that drain to the Yangon River.



(e) Indicative cross-section (not to scale) for the Latha Township, illustrating a typical street in the Latha Township. The cross-section has no specific location as the exact distribution of building layers, shop and market locations and container locations does not represent an actual location. The northern part of the township consists of the hospital area (A), which is a relative pervious area. Parallel to Anarwatha Road (I) is running an open drain (B) and a covered drain (D), that is connected through an underground culvert (C). Covered drains run along the houses (E) and drain towards Maha Bandula Road (II). Eventually the drains go underneath of Strand Road (III) and joined by the open drain that runs along the southern side of Strand Road to a FGS (F) and eventually discharges into the tidal Yangon River (G). Raised Strand Road (IV) and a small strip of the Yangon Port have higher GLEs and serve somewhat like a wide dike, separating the southern Latha border and the Yangon River.

Figure A.19: This figure provides an indication of a typical cross-section of the residential area of the Latha Township.

A.2. Institutional Set-Up of Yangon & Latha Township

Yangon has a very hierarchical institutional set-up. For Yangon city there is the YCDC, which has a large number of departments working on different agendas YCDC (2017). The city is divided into multiple districts, consisting of several townships. Each township is divided into wards that make out the smallest institutional unit/administrative areas. Within the Latha Township there are ten wards (Figure A.20), numbers 1 to 8 are situated in the residential area and wards 9 and 10 are situated in the hospital area. Typically the wards have about 3 streets under their supervision. For some streets, the western part falls under a different ward then the eastern part of the street.
All ten wards have their own administrative office and are responsible for implementing parts of the YCDC's activities. The wards are overseen by the General Latha Township Office, which is responsible for the Latha township as a whole. Weekly meeting with the General Township Officer and all ten Ward officers allows for planning and coordination.

For this research the most important departments are the YCDC EDRB and the Yangon City Development Committee Pollution Control and Cleansing Department (YCDC PCCD). The YCDC EDRB is responsible for the drainage system, cleaning and maintenance of the drainage system and operation of the flood gate structures (FGSs). The YCDC PCCD is responsible for the waste container collection and for cleaning the streets. Both departments have representatives at each institutional level till township level (thus not at ward level).

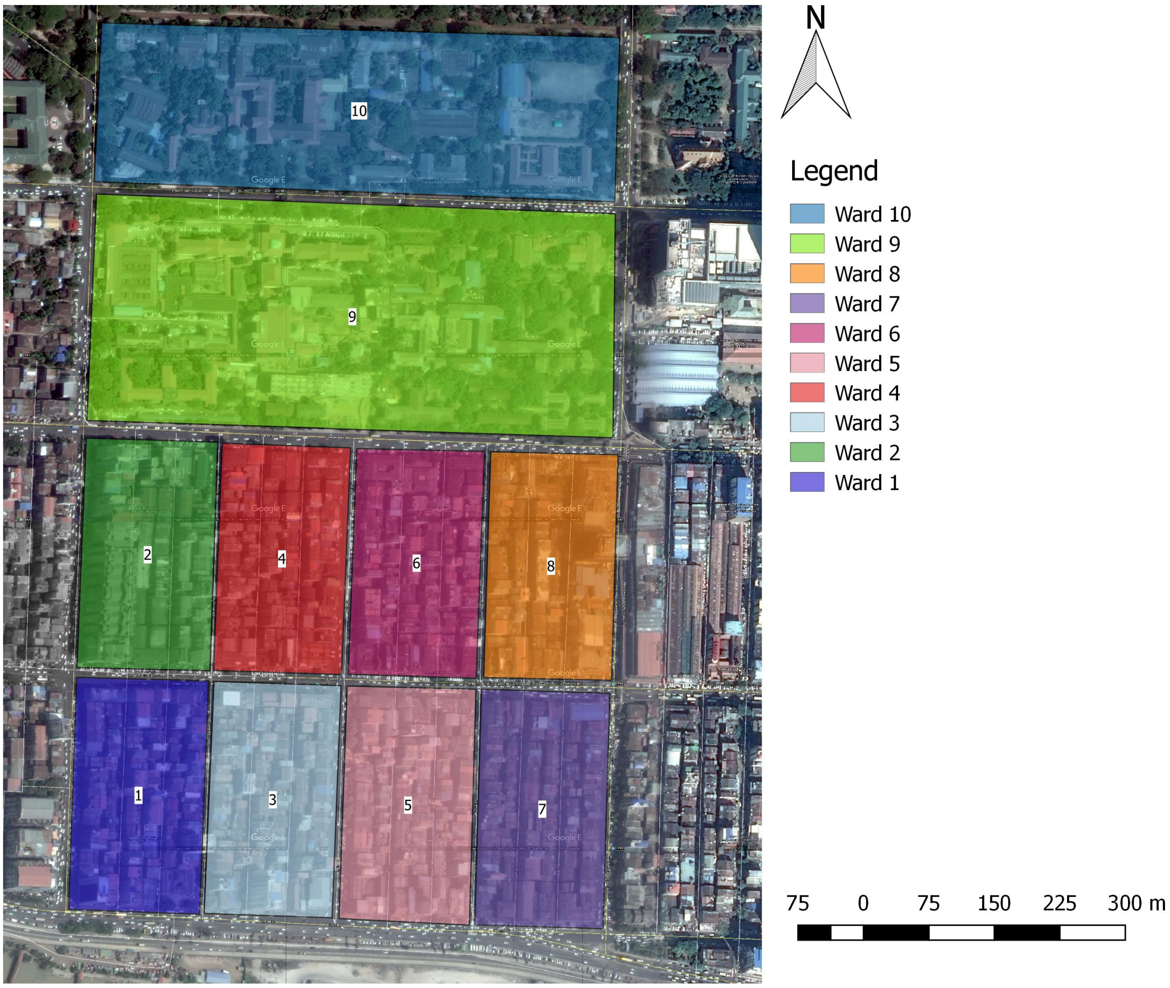


Figure A.20: The Latha Township consists of 10 wards. These ten wards all have their own administrative office and are responsible for implementing parts of the YCDC's activities. The wards are overseen by the General Latha Township Office, which is responsible for the Latha township as a whole.

B

Questionnaires

For this research two questionnaires were conducted, one amongst households (the *household questionnaire*) and one amongst shop owners, restaurant owners and market salesmen (the *shop questionnaire*). The questionnaires served to get an explorative non-representative dataset about the household's and shop's: composition/situation, solid waste production and solid waste cleaning habits, flood experience and flood protection. The dataset was used to estimate model parameters, inspire what processes should be modelled, validate assumptions and interpret model results. However, the number of respondents for the shop questionnaire was so low that the results were not published.
This appendix elaborates on the types of questionnaires (Section B.1), design and preparations of the questionnaire (Section B.2), distribution and collection of the questionnaire (Section B.3) and used census data (Section B.4), before the actual questionnaire is presented (Section B.5 followed by the results of the the household questionnaire (Section B.6), the discussion of the results (Section B.7) and finally the conclusions and recommendations (Section B.8).

B.1. Questionnaire Types

For this research there were two different questionnaires distributed. One questionnaire focused on households (QHH, Section B.5) and one questionnaire focused on shops, restaurants and (street) market salesmen. This distinction was made since the characters of these groups and their activities and interactions with the environment differ. For example, (almost) all shops are either on street or ground level and thus are on average much more susceptible to a flood. Moreover, the waste production is likely to be higher and solid waste management practices might differ. As a final example, households do not have customers that might be affected by floods. However as mentioned in the introduction, there only was a very small group of respondents and thus these results are not used.

B.2. Design & Preparations

Using a questionnaire had the benefit that all questions were asked in the same order, under the same conditions and a large group could be researched efficiently. The questionnaires were made and designed with the help of a local junior environmental engineer. Once the first draft was completed, the questionnaires were tested in the field (see Figure B.1) and improvements implemented. These improvements included the addition of extra explanations for the questions, added answering options, new questions and the removal of questions. The questionnaires were also translated into Myanmar language in order to take a way a possible language barrier and to make filling in the questionnaires easier for the respondents. Another round of testing was completed and with some small new improvements this eventually yielded the final version. The entire questionnaire is presented in (Section B.5).
The questionnaire consisted primarily of closed-ended questions, so that the respondent's answers were comparable. The close-ended questions were *one answer per question* and *multiple possible answers per*

question. Some of the close-ended questions had the option of allowing a respondent to provide an additional answer option.

The questionnaire could be divided into 3 parts. The first part was mainly focussed on acquiring general information about the respondents. It consisted of questions about the respondent's gender and the respondent's age that allowed for a comparison to the census dataset. The respondent's household (HH) address was collected to study the spatial patterns of the data.
Questions about the HH's temporal residence pattern and the HH's residence duration were used to analyse how long a respondent lived in Latha. A long residence time during each season, could be an indicator of an increased flood awareness (Burningham et al., 2008).
A HH's solid waste management (SWM) activities and urban flooding (UF) experiences could be related the floor on which a HH was situated and thus this data was collected. For example, a HH that lived on the 6th floor might dispose waste less frequent and never had any damage to any of its properties, compared to a HH that was situated on ground level. A similar reasoning applied to the HH size. For example, the larger the HH the more frequent waste could be disposed or the more likely a HH was to receive a flood warning.
The HH's highest education, respondent's employment status and the HH's income were collected as it provided information about a HH's social class, which could be an indicator of a high flood awareness (Burningham et al., 2008).
The respondents were asked which problem they would like be solved first, to find out if SWM or UF was a priority. Although the questionnaire form had an opening page that stated the purpose and usage of the questionnaire (mentioning SWM and UF) this question was asked before the sections on SWM and UF, to minimize a bias in the answer of this question towards any of these two problems. A few example answer options were: reliable electricity supply, in house (piped) drinking quality tap water and improved public transport. Respondent's were also allowed to come up with their own priority issue.

Part two of the questionnaire was focussed on solid waste management. The questionnaire data was used to analyse HHs' waste production rates, waste disposal patterns and HHs' SWM perceptions. Moreover it provided alternative and additional data about the Yangon City Development Committee Pollution Control and Cleansing Department (YCDC PCCD)'s SWM practices.
Observations showed that the township and Yangon as a whole had quite some small companies that were collecting (solid) waste for recycling purposes. Moreover, mini interviews on the streets learned that some households (especially on higher floors) used the services of these companies to have their waste collected. Therefore, the respondents were asked to describe what they did with their HH's solid waste.
To make a socio-hydrological model (SHM), data about a HH's waste production was required. Since people are bad at estimating weights (Weber, 1978; Charpentier, 1891), it was decided to not specifically ask for a weight but to work with crude garbage bag sizes that were shown on pictures in the questionnaire. Besides the size of the bags, respondents were asked how much of these bags they produced per day. This served as a rough estimation of the waste production. Additionally questions were asked about the HH's disposal frequency of the waste that the HH produced. This data was later used in the SHM to model household disposal patterns.
In order to get an idea of what maximum distances citizens had to walk to a container, the respondents were asked what the distance to their nearest container was. This data was used for the human agents in the SHM to estimate a threshold for a maximum distance to a container. If the nearest container in the model was further away than this threshold the agent might not disposed its waste in a container but on the streets.
Observations and mini interviews revealed that not all citizens disposed their waste in the YCDC PCCD containers. Thus there was a probability that citizens disposed their waste on the streets, in the inlets or in the drains. In order to get an estimation of this probability a question asked if the respondent always went to the container and if they knew others that did not go to the container.
In order to analyse citizen's their SWM awareness and perceptions, questions were asked about the number of containers and the collection frequency. This data was also used to compare the information of the YCDC PCCD. The questions provided also an indication of how satisfied the respondents were with the SWM by the YCDC PCCD. The initial hypothesis included a form of protest from citizens, that was tested by the answers. If all respondents were satisfied, protests might not be a realistic behaviour of Latha's citizens.

The third part focussed on UF. The questionnaire participants were asked to describe when they experienced the most recent flood. This provided information how likely a respondent was to ever experience a flood.
To get an idea of the flood frequency, the respondents were asked how often it floods during an average year. A question about the average duration and a question about the average water depth provided additional

details for the flood events. This data was used to compare the flood records and interview data. Moreover, the data could be used to model floods in the SHM.
The initial hypothesis had a flood warning component. To test if citizens received a flood warning, questions were asked about if they received a warning and if so, how long in advance of the flood.
Interviews with the Yangon City Development Committee Engineering Department of Roads and Bridges (YCDC EDRB) and mini interviews mentioned that sometimes drains were blocked by solid waste. A question asked if there were any locations that were blocked frequently. This data was used to cross-check data from the interviews and to decide which locations would be modelled as partially blocked in the flood model.
Field observations showed signs of flood protection measures at some of the properties. A question asked if the respondents had a from of flood protection, to estimate this probability. The next question asked what kind of flood protection measure the HH had if any flood protection was available.
In the initial hypothesis, human agents could experience nuisance and damage from floods that could be expressed in monetary units. In order to estimate the damage probability, the amount of damage (in monetary units) and to get an improved understanding of what was damaged, three questions were asked about these topics.
To obtain more data about the maintenance on the drains the respondents were asked how often the drains in their streets get cleaned. Another question asked about the reason for cleaning of the drains. This data was used in addition to the data from YCDC PCCD to model the cleaning of the drains and the flood gate structures (FGSs) in the SHM.
Improvements to the urban drainage system made by Yangon City Development Committee (YCDC) were part of the initial hypothesis. To test this, a question asked if any recent improvements were implemented by the YCDC to reduce UF.
To directly test the respondents flood awareness, the questionnaire also contained a question that asked directly what the respondents thought that caused UF. Moreover, the respondents were asked how they thought the flooding should be solved.

Figure B.1: Testing a draft version of the questionnaire for shops and market salesmen.

B.3. Distribution & Collection

The questionnaires were distributed through the administrative offices of the different wards within the Latha Township's residential area (See section 2.2.5). Initially the wards were not willing to cooperate and the general administrative office of the township was not willing to give permission to distribute the questionnaires. However, after multiple conversations with the general township officer and mediation through some Latha inhabitants a permission request was issues to the responsible Yangon Directorate office and under this pending permit the questionnaire was distributed through the administrative offices of wards 1 till 8. Each ward got a number of questionnaires they thought they could find respondents for. This meant that a total of 15 household questionnaires and 6 shop questionnaires were given to each ward's administrative office.
Agreements about the collection were made with the administrative offices. After one week, the questionnaires would be ready for collection. However after one week, none of the administrative offices had the results in and several new arrangements had to be made. Eventually there were 48 filled in household questionnaires and 16 filled in shop questionnaires collected (of the 150 distributed household questionnaires and 60 shop questionnaires).

B.4. Census Data

For this study, socio-economic data was collected in order to model socio-economic processes. This data was collected through questionnaires, interviews and observations. Census data provides a reference that was used to cross-check the results from the questionnaires. Moreover, it served as an additional data source for modelling socio-economic processes.
In some of the statistics the census report differentiates between conventional households (CHH) and institutions (INST): hotels, hospitals and police/prison cells (MIP - DP, 2015, p.7). Also note that Yangon here refers to the Yangon Region, not only to the city.
The census report (MIP - DP, 2015) was produced by the Ministry of Immigration and Population's Department of Population in 2015 and was obtained from JICA on March 28, 2017.

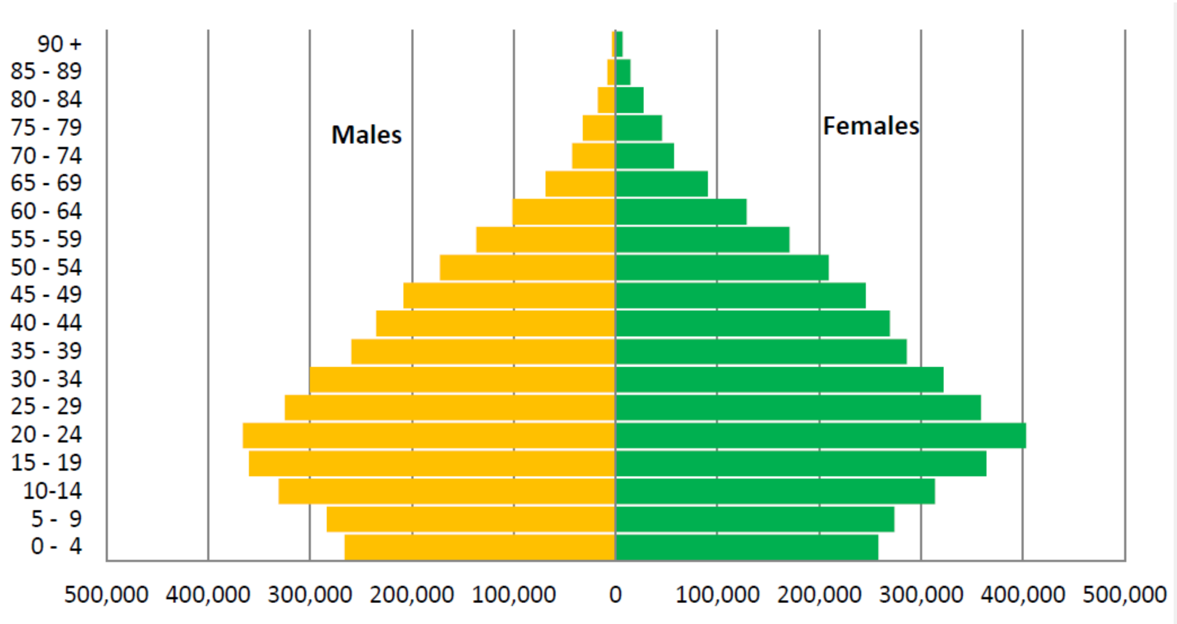


Figure B.2: The age distribution for the Yangon Region (MIP - DP, 2015, fig.4).

Table B.4: Statistics for employment in Latha and Yangon. The statistics were for people older than 10 years old and living in conventional households and institutions. There does not seem to be a big difference in the employment status distribution.
Data from MIP - DP (2015).

Age Group	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Age group age ≥ 10	23,592	100.0	6,279,629	100.0
Employment status for Age ≥ 10	**Number of People Latha (-)**	**Part of Latha Population (%)**	**Number of People Yangon (-)**	**Part of Yangon Population (%)**
Employee government	1,071	4.5	258,151	4.1
Employee private sector	7,601	32.2	1,784,656	28.4
Employer	1,074	4.6	128,576	2.0
Own account worker	2,978	12.6	887,821	14.1
Unpaid family worker	931	3.9	209,537	3.3
Sought work	545	2.3	142,701	2.3
Did not seek work	133	0.6	28,733	0.5
Full time student	2,872	12.2	853,726	13.6
Household worker	3,699	15.7	1,255,087	20.0
Pensioner, retired, elderly	1,896	8.0	401,484	6.4
Disabled	220	0.9	47,164	0.8
Other work	572	2.4	281,993	4.5

Table B.1: Statistics for population of Latha Township compared to Yangon. Based on the statistics we could conclude that the citizens of the Latha Township are relatively older. In this table, age group (AG) was abbreviated for readability.
Data from MIP - DP (2015).

Population Groups	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Total Population	25,057	100.0	7,360,703	100.0
Male	10,728	42.8	3,516,403	47.8
Female	14,329	57.2	3,844,300	52.2
AG 0 – 14 years old	2,735	10.9	1,725,416	23.4
AG 15 – 64 years old	19,986	79.8	5,219,941	70.9
AG 65+ years old	2,336	9.3	415,349	5.7
AG age ≥ 10	23,592	94.2	6,279,629	85.3
Population in CHH	18,161	100.0	6,949,440	100.0
AG age in CHH ≥ 15	15,686	86.4	5,271,946	75.9
AG age in CHH ≥ 25	12,454	68.6	3,949,139	56.8

Table B.2: Statistics for households in Latha and Yangon. Based on the statistics we may conclude that relatively more people households were female headed and on average households were a bit smaller. What's also striking is the difference in the relative population in institutions, which was a lot higher for the Latha Township.
Data from MIP - DP (2015).

Households Data	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
CHHs	4,473	100.0	1,582,944	100.0
Households Data	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Population	25,057	100.0	7360703	100.0
Population in INST	6,896	27.5	411,263	5.6
Population in CHHs	18,161	72.5	6,949,440	94.4
CHHs of 1 person	506	11.3	68,073	4.3
CHHs of 2 persons	708	15.8	216,707	13.7
CHHs of 3 persons	865	19.3	325,983	20.6
CHHs of 4 persons	830	18.6	338,953	21.4
CHHs of 5 persons	606	13.5	249,425	15.8
CHHs of 6 persons	376	8.4	158,136	10.0
CHHs of 7 persons	241	5.4	95,117	6.0
CHHs of 8 persons	141	3.2	63,475	4.0
CHHs of ≥ 9 persons	200	4.5	67,075	4.2
Male-headed CHHs	2,679	60.0	1,199,003	75.7
Female-headed CHHs	1,794	40.0	383,941	24.3
Mean CHH size	4.1	N.A.	4.4	N.A.

Table B.3: Statistics for education in Latha and Yangon. The statistics were for people older than 25 years old and living in conventional households only. From the statistics we may conclude that the average degree of education was a lot higher for the Latha Township when compared to the whole of Yangon. This might be a good indicator of relative wealth and awareness as mentioned in Section 1.2. Data from MIP - DP (2015).

Age Group	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Age ≥25 CHH	12,454	100.0	3,949,139	100.0
Highest Grade for Age ≥25 CHH	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
None	529	3.6	231,473	5.9
Primary school	2,493	12.4	1,280,979	32.4
Middle school	3,529	18.9	936,383	23.7
High school	5,006	20.5	712,985	18.1
Diploma	152	0.2	14,503	0.4
University	11,330	42.3	684,333	17.3
Post-graduate	678	1.8	39,750	1.0
Other	163	0.3	48,733	1.2
Age Group	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Age in CHH ≥ 15	15,686	86.4	5,271,946	75.9
Literacy	Number of People Latha (-)	Part of Latha Population (%)	Number of People Yangon (-)	Part of Yangon Population (%)
Literate (age ≥ 15)	15,325	97.7	5,092,700	96.6

B.5. Questionnaire Households

(H) Latha Township Solid Waste Management and Urban Flooding (for households)

This questionnaire is conducted for a study by Mr. B-S. van der Sterre, a master student Water Resources Management from Delft University of Technology in the Netherlands. This questionnaire is intended to research solid waste management and urban flooding in the Latha Township. For this research we would like to know some general information about you and your household, get some information about your solid waste management (practices) and personal experiences with urban flooding.

The results of this questionnaire will be used to determine model parameters. The results from this questionnaire and the model results will be published in a publicly available report. All information provided through this survey will be handled confidentially. Results from this research will not mention your name, specific location, day of birth or any other form of information that might leed to you. Results will be presented generalized and anonymous.

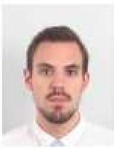
* By filling in my name and phone number, I confirm that I consent to participate in this questionnaire, that can be terminated early by not finishing the questionnaire.*
** By filling in my name and phone number, I agree that the information I will provide in this questionnaire will be made anonymous and is used for the research of Mr. B-S. van der Sterre, which will be made available in a publicly accessible report. **
*** By filling in my name and phone number, I confirm that I have read this declaration, I understand the declaration and I'm willing to cooperate on my own initiative. ***

* Required

1. **My name is:** *

2. **My phone number is:** *

TU Delft



Name: Boy-Santhos van der Sterre
Position: MSc Graduation Student

General Information

In this section we would like you to answer some basic questions.

3. **Gender: What is your gender?** *
   (select one answer)
   Mark only one oval.
   - Male
   - Female

4. **Age: How old are you? (answer in years)** *

   ____

5. **Household situation: Do you live permanently in the Latha Township?** *
   (select one answer)
   Mark only one oval.
   - Yes (I live here in the cold, hot and rainy season)
   - No, I only live here in the cold season
   - No, I only live here in the hot season
   - No, I only live here in the wet season
   - No, I only live here in the cold season and hot season
   - No, I only live here hot season and rainy season
   - No, I only live here in the rainy season and cold season
   - Other: ____________________

6. **Household duration: How long have you lived on your current apartment in the Latha Township?** *
   (select one answer)
   Mark only one oval.
   - Less than 1 year
   - 1 year
   - 2 years
   - 3 years
   - 4 years
   - 5 years
   - 6 years
   - 7 years
   - 8 years
   - 9 years
   - 10 years
   - More then 10 years

7. **Household location: What street is your current address?** *
   (select one answer)
   Mark only one oval.
   - Lanmadaw Street
   - 17th Street
   - 18th Street
   - Sinn O Dan Street
   - 19th Street
   - 20th Street
   - Latha Street
   - 21st Street
   - 22nd Street
   - Bo Ywe Road
   - 23rd Street
   - 24 Street
   - Shwedagon Pagoda Road
   - Anawratha Road
   - Maha Bandula Road
   - Strand Road

8. **Address number: Which house number has your current address of your apartment? (1 to 999)** *

   ____

9. **Household situation: On what floor is your apartment?** *
(select one answer)
Mark only one oval.

- Basement
- Ground level (street level)
- 1st floor
- 2nd floor or higher

10. **Household size: With how many people do you live in your apartment?** *
(select one answer)
Mark only one oval.

- 1 (just me)
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10 or more

11. **Education: Within your household, what is the highest level of education someone has?** *
(select one answer)
Mark only one oval.

- No education (didn't finish primary school)
- Primary school
- Middle school
- High school
- College, University or Higher
- Other: ____________________

12. **Employment: What is your current employment status? I am ...** *
(select one answer)
Mark only one oval.

- Out of work and looking for work
- Retired
- Unable to work (because of illness or disability)
- Self-employed (e.g. own taxi, own shop/market stand, housekeeping)
- Private Sector employed for wages
- Military / Government employed for wages
- Student
- I prefer not to say

13. **My total household's monthly income is...** *
(select one answer)
Mark only one oval.

- Less than 300,000 Kyat
- Between 300,000 and 399,999 Kyat
- Between 400,000 and 499,999 Kyat
- Between 500,000 and 599,999 Kyat
- Between 600,000 and 699,999 Kyat
- Between 700,000 and 799,999 Kyat
- Between 800,000 and 899,9999 Kyat
- Between 900,000 and 999,999 Kyat
- More than 999,999 Kyat

14. **If I can decide what problem should be solved first, I first would like to solve...** *
(select one answer)
Mark only one oval.

- Reliable (24 hour) electricity supply
- In house (piped) drinking quality tapwater
- Improved (cabled) internet connection
- Flood control
- Airpolution control
- More job oportunaties
- Improved healthcare facilities
- Improved solid waste management
- Improved public transport
- Other: ____________________

Solid Waste Management [1/7]

In the now following sections, we would like you to answer some questions about solid waste management.

15. **What do you do with your households' waste?** *

____
____
____
____
____

This image is for the next question, look at the container and plastic bottle (1L) for scale/size.

16. **On average, how big is your garbage bag of waste per time that you throw away your waste in a YCDC container?** *
(select one answer)
Mark only one oval.

- [ ] Large, about this size (70X45X30 cm)

- [ ] Medium, about this size (35X30X30)

- [ ] Small, about this size (25X25X20)

17. **How many of these bags do you throw away per day?** *
(select one answer)
Mark only one oval.

- [ ] more than 10 bags per day
- [ ] between 6 and 10 bags per day
- [ ] 5 bags per day
- [ ] 4 bags per day
- [ ] 3 bags per day
- [ ] 2 bags per day
- [ ] 1 bag per day
- [ ] 1 bag every 2 days
- [ ] 1 bag every 3 days or more days

18. **What is the distance to your closest YCDC waste container?** *
(select one answer)
Mark only one oval.

- Less than 25 meters
- Between 25 and 50 meters
- Between 50 and 100 meters
- Between 100 and 150 meters
- Between 150 and 200 meters
- More than 200 meters

19. **I think the closest YCDC container is too far away or the container is always full, therefore I...** *
(multiple answers possible)
Check all that apply.

- Sometimes throw away my solid waste not in the container, but on the street.
- Sometimes throw away my solid waste on a spot where my neighbors have already thrown away their waste.
- Sometimes throw away my solid waste in the drain.
- Sometiems throw away my solid waste in the inlet of the drains.
- I don't think that the container is too far away and I always go to the container, even when it is always full.
- I don't think that the container is too far away, but I know others who don't go to the container because it is too far away or always full.
- Other: ____________________

20. **How often are the YCDC waste containers collected?** *
(select one answer)
Mark only one oval.

- Less then once every 2 days
- Once every 2 days
- 1 times per day
- 2 times per day
- 3 times per day
- More than 3 times per day

21. **The YCDC waste collection is frequently enough?** *
(select one answer)
Mark only one oval.

- No (Go to question 22) *Skip to question 22.*
- Yes (Go to question 23) *Skip to question 23.*

Solid Waste Management [2/7]

22. **I think the waste collection should be...** *
(select one answer)
Mark only one oval.

- 1 time per day
- 2 times per day
- 3 times per day
- 4 times per day
- More than 4 times per day

Solid Waste Management [3/7]

23. **Locations: How many YCDC waste containers are there in your street?** *
(select one answer)
Mark only one oval.

- None
- 1
- 2
- 3
- 4
- 5
- More than 5

24. **The number of YCDC waste containers is enough?** *
(select one answer)
Mark only one oval.

- No (Go to question 25) *Skip to question 25.*
- Yes (Go to question 26) *Skip to question 26.*

Solid Waste Management [4/7]

25. **For your street, how much extra YCDC waist containers do you feel are required?** *
(select one answer)
Mark only one oval.

- 1
- 2
- 3
- more than 3

Solid Waste Management [5/7]

26. **Taxation: Do you pay tax or a fee for solid waste collection/disposal?** *
(select one answer)
Mark only one oval.

- Yes (Go to question 27) *Skip to question 27.*
- No (Go to question 28) *Skip to question 28.*

Solid Waste Management [6/7]

27. **How much tax and/or fee for solid waste (collection) do you pay per month? (Answer in Kyat) (After this question, go to question 29)** *

Skip to question 29.

Solid Waste Management [7/7]

28. **Why do you not pay tax and/or fee?** *
(select one answer)
Mark only one oval.

- ( ) We do not have to pay for tax and/or fee.
- ( ) We have to pay it, but I don't know where to pay it.
- ( ) We have to pay it, but I don't have the money for it.
- ( ) We have to pay, but I don't think the money will be spend well. Therefore I don't pay.
- ( ) I never heard about taxes/fees for solid waste collection/disposal
- ( ) Other:

Urban flooding [1/10]

In the now following sections, we would like you to answer some questions about urban flooding in the Latha Township.

29. **When was the last flood in your street/house/building?** *

30. **Flooding: On average, how often do you experience flooding in your street/house?** *
(select one answer)
Mark only one oval.

- ( ) Never *Stop filling out this form.*
- ( ) 1 time per year
- ( ) 2 times per year
- ( ) 3 times per year
- ( ) 4 times per year
- ( ) 5 times per year
- ( ) 6 times per year
- ( ) 7 times per year
- ( ) 8 times per year
- ( ) More than 8 times per year

Urban Flooding [2/10]

31. **Flooding: On average, how long does a flood last?** *
(select one answer)
Mark only one oval.

- ( ) Just a few minutes
- ( ) 5 till - 29 minutes
- ( ) Between 30 minutes - 59 minutes
- ( ) Between 1 hour - 1 hour 59 minutes
- ( ) Between 2 hours - 2 hours and 59 minutes
- ( ) Between 3 hours - 3 hours and 59 minutes
- ( ) Between 4 hours - 4 hours and 59 minutes
- ( ) Between 5 hours and 7 hours and 59 minutes
- ( ) Between 8 hours - 11 hours and 59 minutes
- ( ) Between 12 hours - 23 hours and 59 minutes
- ( ) Longer than 24 hours

32. **On average when it floods, most of the times the water level gets:** *
(select one answer)
Mark only one oval.

- ( ) Just a few centimeters high (5 cm and less)
- ( ) To ankle height (10 cm)
- ( ) To the height of halfway of my calves (25 cm)
- ( ) To the height of my knees (40 cm)
- ( ) To the height of halfway my upper leg (60 cm)
- ( ) To the height of my hips (80 cm)
- ( ) To waist height and above (100 cm and more)

33. **When it starts to flood, I am often warned by others (e.g. YCDC, family, friends and/or colleagues):** *
(select one answer)
Mark only one oval.

- ( ) Yes (Go to question 34) *Skip to question 34.*
- ( ) No (Go to question 35) *Skip to question 35.*

Urban Flooding [3/10]

34. **When I receive a flood warning I know the flood is coming (times in HH:MM:SS):** *
(select one answer)
Mark only one oval.

- Less than 5 minutes in advance
- Between 00:05:00 and 00:09:59 in advance
- Between 00:10:00 and 00:14:59 in advance
- Between 00:15:00 and 00:19:59 in advance
- Between 00:20:00 and 00:24:59 in advance
- Between 00:25:00 and 00:29:59 in advance
- Between 00:30:00 and 00:39:59 in advance
- Between 00:40:00 and 00:49:59 in advance
- Between 00:50:00 and 00:59:59 in advance
- Between 01:00:00 and 01:14:59 in advance
- Between 01:15:00 and 01:29:59 in advance
- Between 01:30:00 and 01:44:59 in advance
- Between 01:45:00 and 02:00:00 in advance
- More than 2 hours in advance

Urban Flooding [4/10]

35. **Is there always a blockage at the same location when it floods?** *
(select one answer)
Mark only one oval.

- Yes (Go to question 36) *Skip to question 36.*
- No (Go to question 37) *Skip to question 37.*

Urban Flooding [5/10]

36. **Where (at what location) does the blocking and flooding most of the times/always start?** *

____
____
____
____
____

Urban Flooding [6/10]

37. **Does the building or house where you live in have any flood protection measurements? (like a pump, concrete slab/stairs that forms a small dam, sandbags or wooden boards that are placed in (door) openings)** *
(select one answer)
Mark only one oval.

- Yes (Go to question 38) *Skip to question 38.*
- No (Go to question 39) *Skip to question 39.*

Urban Flooding [7/10]

38. **My building has the following flood protection measurements...** *
(Multiple answers possible)
Check all that apply.

- [ ] Concrete slab in (door) opening
- [ ] Pump (to pump away water when flooded)

- [ ] Sandbags
- [ ] Wooden plate(s)
- [ ] Other: ______

Urban Flooding [8/10]

39. **When it is flooded, I...** *
Mark only one oval.

- Continue my daily activities as usual, my life is hardly/not affected.
- Modify my daily activities, but I continue to do shopping and going to the market
- Can hardly continue my dailly pattern normally
- Need to stop my daily pattern and wait till the flood is over

40. **Did you ever had any damage from flooding?** *
(select one answer)
Mark only one oval.

- Yes (Go to question 41) *Skip to question 41.*
- No (Go to question 43) *Skip to question 43.*

Urban Flooding [9/10]

41. **What was the total damage for the most recent time you had damage caused by flooding? (answer in Kyat)** *

42. **Please describe what was damaged?** *

Urban Flooding [10/10]

43. **How often get the drains in your street get cleaned/maintained?** *
(select one answer)
Mark only one oval.

- Never
- Less than 1 time per year
- 1 time per year
- 2 or 3 times per year
- 4 or 5 times per year
- Every 2 months
- Every month
- More than 1 time per month
- Other:

44. **They clean the drains...** *
(multiple answers possible)
Check all that apply.

- When we complain about a blockage
- Just before the start of the rainy season
- When it is time in their schedule (not based on reported problems)
- Other:

45. **In recent years (maximum of 5 years ago), YCDC has made the following improvements that reduced flooding:** *
(multiple answers possible)
Check all that apply.

- Raised the road
- Increased the size of the drains
- Done nothing
- Other:

46. **What do you think causes the flooding?** *
(multiple answers possible)
Check all that apply.

- High river water levels, reducing the drainage capacity of the drainage system
- The drainage system has a too small capacity
- Due to climate change (the rainfall intensities have been rising)
- Increase in the total impervious areas (more asphalt, concrete, roofs of houses)
- Blockages in the drainage system (because of sediment and solid waste and poor maintenance)
- Other:

47. **How should the flooding be solved?** *
(multiple answers possible)
Check all that apply.

- Increase the capacity of the urban drainage system
- Get less impervious surfaces (such as asphalt, concrete and houses) in my area, but replace this by pervious areas (e.g. brick roads, grass, green roofs)
- Change houses and shops lay-out so that we are better adapted to the floods (e.g. install for each house flood protection measurements, get higher sidewalks that don't flood during a rainfall event)
- Other:

Personal Note

48. **If you have any remarks, or would like to say something, please feel free to do that there:**

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B.6. Results Questionnaire Households

In this section the results of the questionnaire for households are presented. At the same time, oddities in the results are discussed. This results section is divided into 3 parts that focus on separate parts of the questionnaire: respondents profile, solid waste management and urban flood (management).

B.6.1. Respondents Profile Results

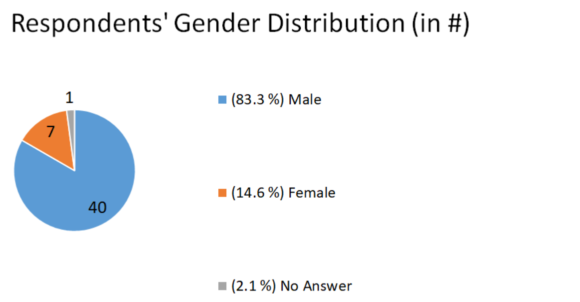
The first section of the questionnaire served to establish a better understanding of the profile of the respondents. Furthermore, it also provided insights in the respondents most pressing problems. In the now following sections the answers to questions 1 till 14 will be shown.

B.6.1.1. Respondents' Details

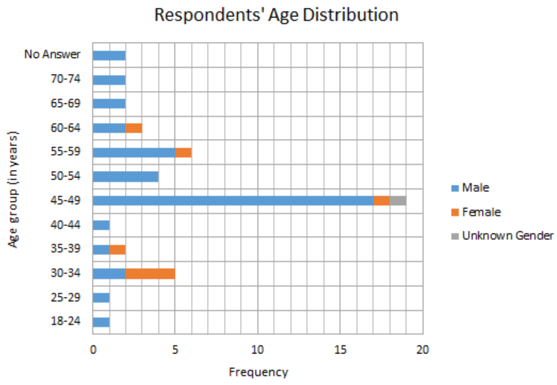
The majority of the 48 respondents was male (Figure B.3a), around 45 to 49 years of age (Figure B.3b) and lived in the Latha Township permanently (Figure B.3e) and had been living there for long durations (Figure B.3f).
A comparison of the sample's age distribution (Figure B.3b with the Yangon census age distribution (Figure B.2), results in the observation that the respondents' profile was too old. Moreover, the median age for the Yangon Region was 28.3 years (MIP - DP, 2015, p.1), whereas the sample's average age was 47.7 years old with a standard deviation of $\sigma = 11.8$ years. The number of male respondents (Figure B.3a) also seemed to high when compared to Latha's census data (Table B.1). With a 95% confidence interval it was concluded that the household questionnaire sample had statistically significant too many male respondents (Figure B.3c) and the sample's age profile was also statistically significant too old (Figure B.3d).

B.6.1.2. Household Situation

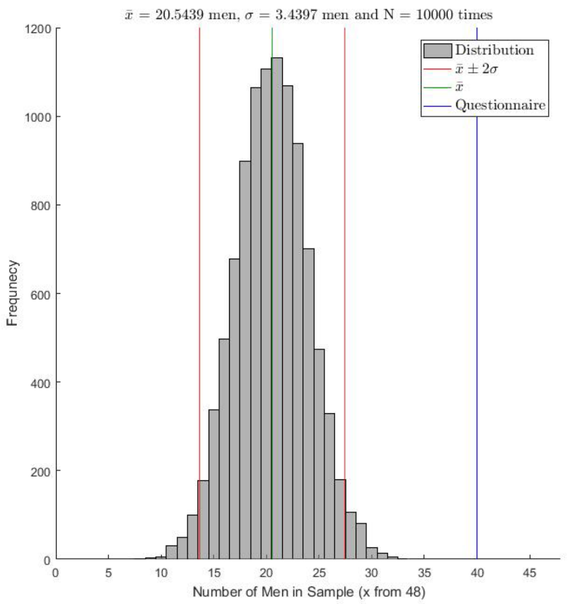
The respondents were distributed throughout the Latha Township, see Figure B.4c. However, quite a few respondents (21 respondents) only provided the street where they live in but not the house number. The majority of the respondents did not live on ground level but on higher floors (Figure B.4a). The most respondents' households were composed of 5 people, averaging to an above average household size of 5.1 people per household (See Figure B.4b and Table B.2).



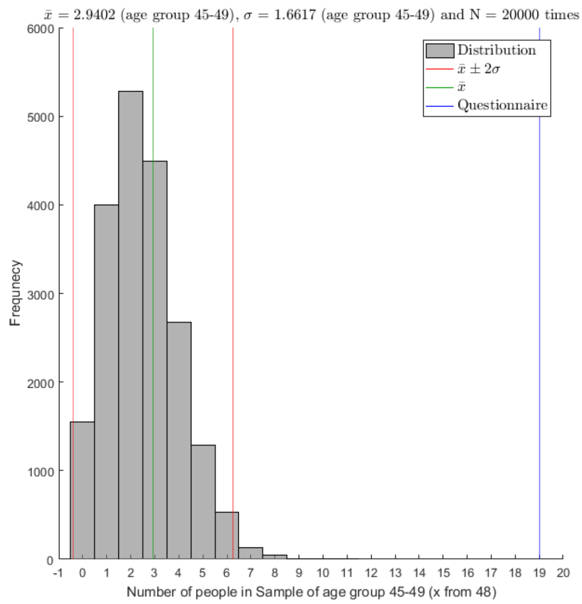
(a) Answer to Question (3): *What is your gender?* The majority of the respondents is male, whereas for Latha as a whole 57.2% is female (See Table B.1).



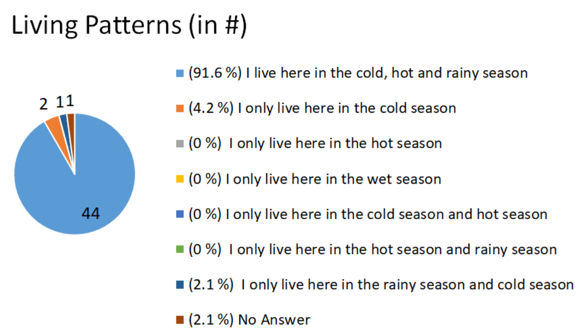
(b) Answer to Question (4): *How old are you? (answer in years)* The most respondents are around 45 to 49 years old. The average age of the respondents is 47.7 years old. The respondents are relatively older than average for Latha (see Figure B.2 and Table B.1).



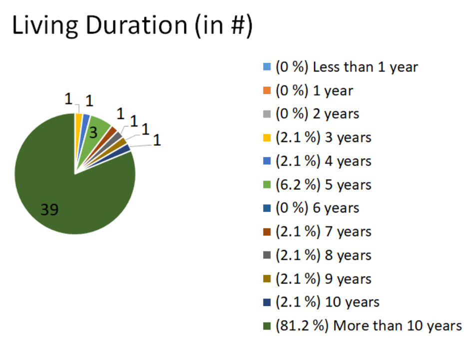
(c) Male distribution in a sample of 48 randomly selected persons per sample out of the general distribution for Latha, with 10,000 repetitions. The general distribution is based on the data from Table B.1.



(d) Age group 45 to 49 distribution in a sample of 48 randomly selected persons per sample out of the general distribution for Yangon, with 20,000 repetitions. The general distribution is based on the data from Figure B.2

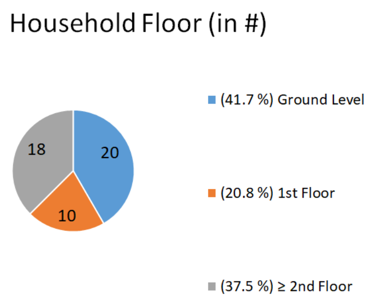


(e) Answer to Question (5): *Do you live permanently in the Latha Township?* The majority of the respondents lived permanently in the Latha Township.

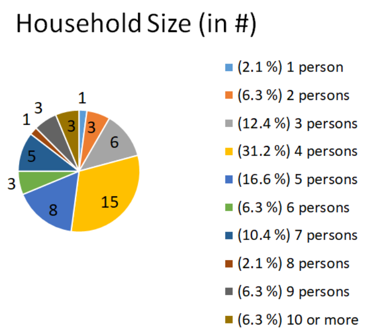


(f) Answer to Question (6): *How long have you lived on your current apartment in the Latha Township?* The most respondents lived for long durations in the Latha Township.

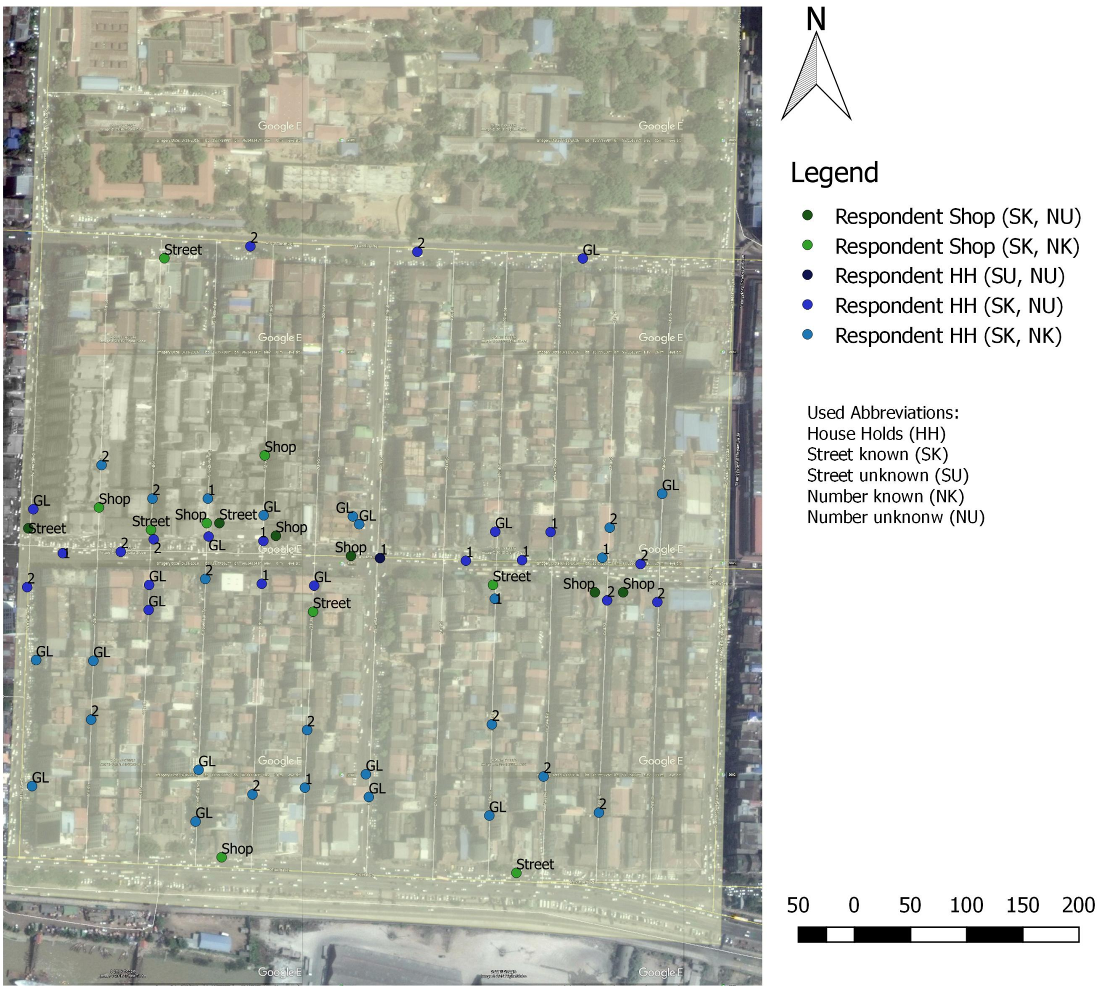
Figure B.3: The number of male respondents (40) was statistically significant over represented with a 95% confidence interval. A distribution was made based on 10,000 repetitions of randomly selecting 48 people from the entire Latha Township population. Moreover, the respondents were also statistically significant too old with a 95% confidence interval. A distribution was made based on 20,000 repetitions of randomly selecting 48 people from the entire Yangon Region population. Almost all respondents lived permanently in the Latha Township and most respondents were living in the Latha township already for a long time.



(a) Answer to Question (9): *On what floor is your apartment?* The households were primarily on the 1st floor and higher floors, although still a few of the respondents was living on ground level.



(b) Answer to Question (10): *With how many people do you live in your apartment?* Most households were composed of between 3 to 5 people and the average household size was 5.1 people per household (assuming 10 people for households with 10 or more people). The respondents' average household size was larger than the average household size for Latha, which was 4.1 people per household (see Table B.2).



(c) The locations of the respondents. The blue colours represent respondents to the questionnaires for households and the green colours represent respondents to the questionnaires for shops. Some respondents did only provide their street and thus were allocated at random along that street. The labels indicates on what floor the household is situated, where 2 indicates 2nd floor or higher and ground level (GL). For the shops the label indicates if the commercial activity is in a building (labelled: shop) or on the street, labelled: street.

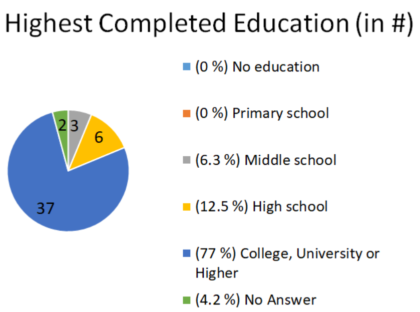
Figure B.4: The majority of the respondents lived not on ground level, with a household size of 5.1 persons per household on average. The distribution of the respondents through the area is also shown.

B.6.1.3. Respondents' Education, Occupation, Income

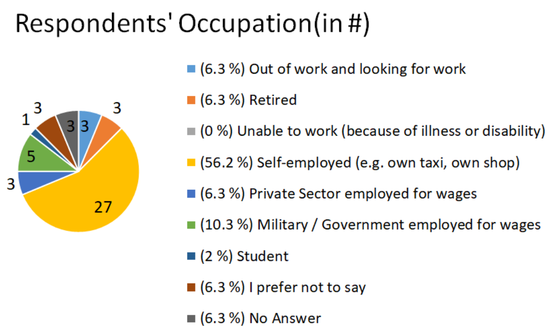
The sample population was educated to an above average grade, with the majority of the respondents having an university grade (See Figure B.5a). For the Latha Township only 42.3% had an university grade, see Table B.3. The majority of the respondents were self employed or working for the military or government (Figure B.5b). This was higher than might be expected from the census data (Table B.4), whereas it was expected that the number of respondents to be employed for wages in the private sector was a lot higher (6.3% of the respondents versus 32.3% in Latha). Interestingly it should be observed that the majority of the respondents' households had a total income of less than 300,000 Kyat per month (Figure B.5c), although only 25.2% was not working (out of work, retired, I prefer not to say and no answer together, Figure B.5b).
The results about the total monthly household income (Figure B.5c) seemed to be questionable. Especially when looked into the household sizes and their total monthly incomes (Table B.5).It should be seen that the bigger households not necessarily had a significant higher income, although this might be expected. Another unexpected result was the over representation of the lowest income, this was way higher than anticipated. Latha is a township in the central business district (CBD) one of the most expensive areas in Yangon. Moreover, a lot of the respondents had an university grade which could be an indicator that they are not poor. Altogether this could be a sign that the participants did not correctly interpreted this question and for example answered this question only for themselves, not for their aggregated income of all household members. Another thing that could have played a role is that people were not willing to (honestly) disclose their monthly income and thus filled in the lowest possibility or refrained from answering this question.
With question 13 (Figure B.5c) the idea was to get an understanding of the financial means of a household. As this might also be an indicator of how much damage an household may experience from a flood, or the financial means a household has to buy flood protection measurements. With this quality data it will be hard to make good assumptions.
Additional data should be acquired in order to make good assumptions. A new questionnaire or survey could be useful to acquire such data. In this new data it might be a good idea to ask to write down who are the household members and per household member ask for an monthly income. However, this might prove to be troublesome as people might be not willing to share such data or do not know the answer to the question. Alternative indicators might prove to be useful to estimate the wealth of a household. For example, does the household own a car? Does the household have a cleaning lady or do they clean themselves? Still it will be very hard to yield an useful dataset.
Finally the results show that flood protection nor solid waste management is a primary concern for the respondents (Figure B.5d). Reliable power supply seems to be the biggest issue the respondents would like to see improvements being made upon, followed by more job opportunities and thirdly improved health care. The average age (AA) of people does not seem to play a role in their problem priority. You might have expected that for example the elder people might responded that *improved health care* was most important and young people *improved internet connection* but this seems not to be the case. There was one person who opted for his own answer that was "Achieve the Rule of Law".

Table B.5: The table shows the number of households of a specific size with a specific total household income class. You would have expected that the smaller households had a lower monthly total income and that the the bigger households had a higher monthly total household income. Whereas the ≤ 300,000 Kyat category seemed to be over represented. This might be an indication that a majority of the respondents miss interpreted this question. A possible interpretation could be, that they answered about their own personal monthly income.

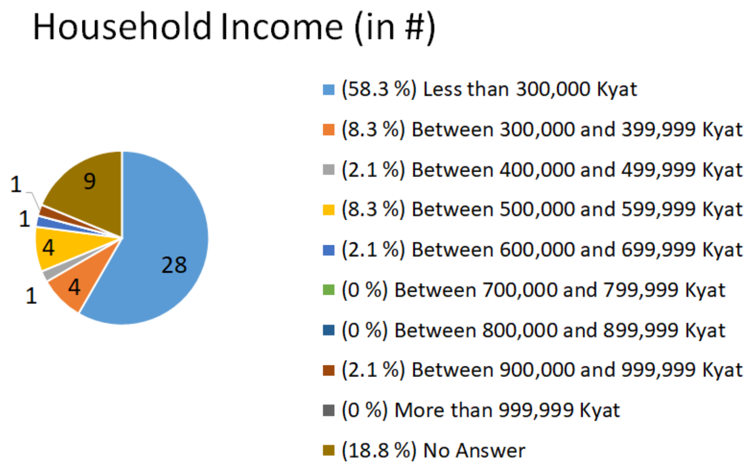
		Household Size									
		1	2	3	4	5	6	7	8	9	≥10
Total Household Income	Less than 300,000 Kyat	1	3	3	7	7	2	2	-	2	1
	Between 300,000 and 399,999 Kyat	-	-	1	1	-	-	1	1	-	-
	Between 400,000 and 499,999 Kyat	-	-	-	-	-	-	-	-	-	1
	Between 500,000 and 599,999 Kyat	-	-	1	3	-	-	-	-	-	-
	Between 600,000 and 699,999 Kyat	-	-	-	-	1	-	-	-	-	-
	Between 700,000 and 799,999 Kyat	-	-	-	-	-	-	-	-	-	-
	Between 800,000 and 899,999 Kyat	-	-	-	-	-	-	-	-	-	-
	Between 900,000 and 999,999 Kyat	-	-	-	-	-	-	1	-	-	-
	More than 999,999 Kyat	-	-	-	-	-	-	-	-	-	-
	No Answer	-	-	1	4	-	1	1	-	1	1



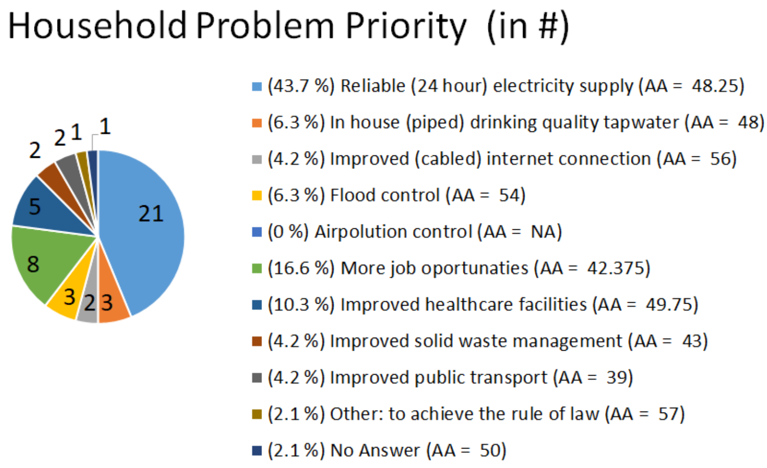
(a) Answer to Question (11): *Within your household, what is the highest level of education someone has?* The majority of the respondents were high educated. The respondents had an above average university grade ratio, as the fraction of citizens with an university grade for Latha is 42.3% (See Table B.3).



(b) Answer to Question (12): *What is your current employment status? I am ...* The majority of the respondents was self-employed. This was higher than the average for the Latha township. The opposite applied to the number of people that were employed for wages in the private sector, which was much lower amongst the respondents than on average in Latha (6.3% to 32.2%). See Table B.4 for the data of the Latha Township.



(c) Answer to Question (13): *My total household's monthly income is...* The majority of the households had a fairly low total monthly income. See Section B.7 for a possible explanation.



(d) Answer to Question (14): *If I can decide what problem should be solved first, I first would like to solve...* Reliable power supply seemed to be the biggest issue most respondents would have liked to see improvements being made upon, followed by more job opportunities and thirdly improved health care. Flood protection and solid waste management were apparently not the most pressing problems to the respondents. The average age (AA) of people giving specific answers is also shown per answer.

Figure B.5: This figure shows the results about the respondents' education grade, occupation, household income and household problem priorities.

B.6.2. Solid Waste Management Results

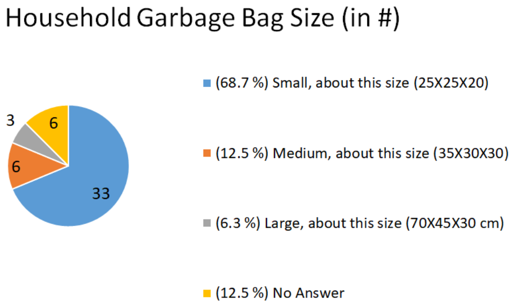
In this section, the results of the questionnaire focussed on solid waste management, cleaning practices and related topics are presented. This part of the questionnaire consists of question 15 till question 28. The first question of the *solid waste management* part of the questionnaire was an open question, that asked the respondents to describe what they typically do with their solid waste. The majority answered that they bag their solid waste, and throw away their waste in a container. None of the respondents mentioned that they sell part of their waste to recycling companies, or that private companies come and collect their waste. Table B.6 shows all responses.

Table B.6: Answer to question 15: *what do you do with your waste?* The majority of the people bagged their solid waste and threw it away in a (YCDC) container. Private waste collection companies or recycling companies that come and collect household waste were not mentioned.

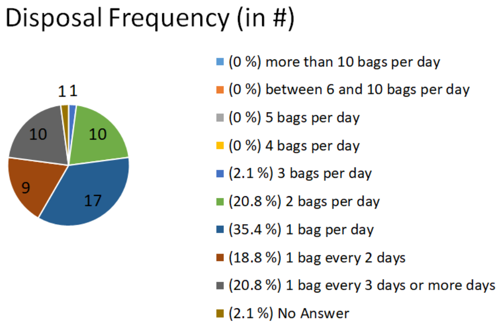
Respondent	What do you do with your households' waste?
1	Throw all garbage at waste container.
2	Put into the waste container.
3	Throw garbage with plastic bag.
4	I packed the waste with plastic bag and then dispose at the waste container.
5	Throw the waste daily at the container.
6	Throw at the waste container.
7	Garbage Bag
8	The garbage was collected with the waste bag putting on the household waste container and then dispose the garbage bag to the YCDC container.
9	No Answer
10	No Answer
11	No Answer
12	No Answer
13	I packed all my household waste with bag and dispose at the YCDC container.
14	Disposed with household waste bags.
15	The garbage are packed with plastic bags and then throw at the waste container.
16	Throw all the household wastes in the YCDC waste container.
17	Put into the household waste bag.
18	No Answer
19	No Answer
20	Garbage Bag
21	Disposed by waste disposal bag
22	Throw with Waste disposal bag
23	No Answer
24	Throw into the waste bag
25	Put the garbage into the waste bag.
26	Put the waste into the waste container.
27	Put the garbage into waste bag.
28	Throw the garbage with waste bag
29	Put the garbage into the waste bag
30	Put the garbage into the waste bag
31	Throw the garbage into the waste container
32	Garbage put into the waste bag and then throw at the waste container.
33	Put the garbage into the waste bags and throw in the waste carts.
34	There is household waste bin.
35	Put the garbage into the waste bag.
36	No Answer
37	Throw with waste bags
38	Throw with waste bags
39	Throw at the waste container
40	Put the garbage into waste container.
41	Put the wastes into waste bags and then throw.
42	Every day throw away waste in YCDC container
43	Separate dry and fresh waste. Throw into container at the start of the street.
44	Waste of whole day is put in a plastic bag. At 7pm throw away in YCDC container at start of the street.
45	Use waste bags and throw in YCDC containers
46	Pack in plastic bags and dispose at container
47	Throw waste in YCDC container
48	Plastic bag that I throw in container

B.6.2.1. Solid Waste Generation & Disposal

Most households used a small bag (Figure B.6a) that was disposed once every day (Figure B.6b). Table B.7 shows how the responses related to the household size. It could be observed that the larger households did use more often larger bags and disposed more frequent. However, there did not seem to be a real strong relation between the household's size and the frequency of waste disposal or the size of garbage bags being used. This could be the result of a too small sample size. If the used bag size and disposal frequency is compared against the floor on which the household lived we observe that the households that lived on ground level disposed more often (Table B.8). There seemed to be no clear relation between household floor level and bag size (see Table B.8).
Most households had a container not further away than half a block's length (one block is about 250 meters), see Figure B.7a. The majority of the households always disposed their waste in the designated containers. However, in total about 35.5% of the respondents reported that they themselves or others do not dispose their waste in a container. The disposal behaviour did not show a clear relation between the distance to a container or the floor on which household a lives (Table B.9).



(a) Answer to Question (16): *On average, how big is your garbage bag of waste per time that you throw away your waste in a YCDC container?* The most households use a small bag to throw away their waste.

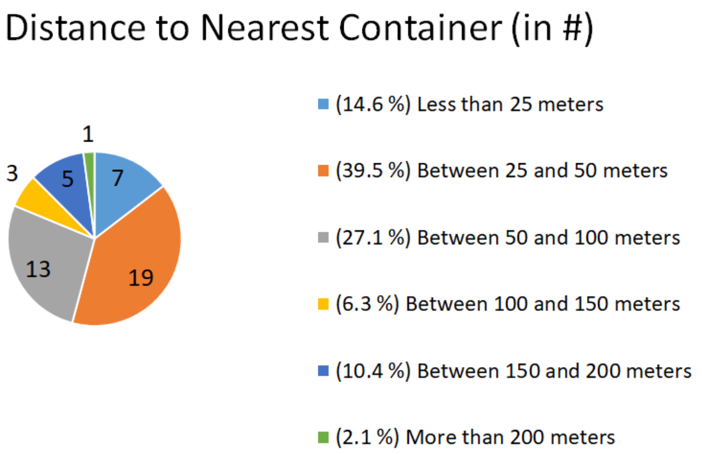


(b) Answer to Question (17): *How many of these bags do you throw away per day?* The most households use a small bag to throw away their waste.

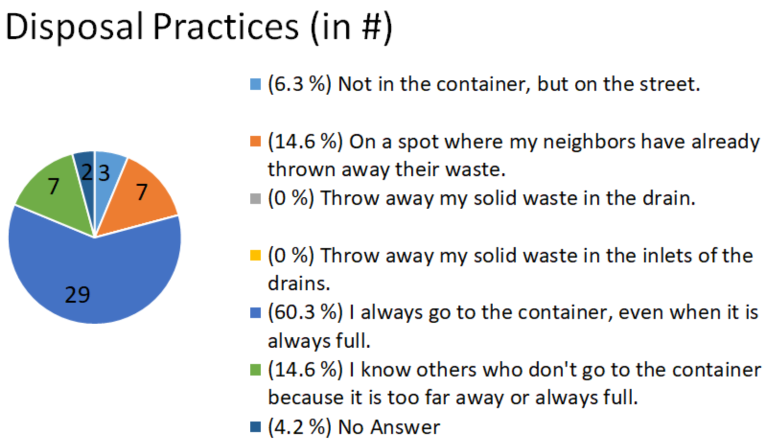
Figure B.6: This figure show the results of the used garbage bag size and disposal frequency (see Section B.6.2.1).

Table B.7: Most households disposed a small bag once a day. However, some households threw away their small waste even less frequent. A minor portion of the respondents produced a lot of waste both in terms of the size of the bags used for waste disposal and the frequency of waste disposal. It may be observed that the household size did not show a strong relation to the size of the used bag size or to the frequency of waste disposal. However, it could be see that the larger bags were used by larger households and that the larger households might have had a bit higher waste disposal frequency.

		Garbage Bag Size				Household Size									
		Small	Medium	Large	No Answer	1	2	3	4	5	6	7	8	9	≥10
Frequency of Waste Disposal	3 bags per day	-	-	-	1	-	-	-	-	-	-	-	-	1	-
	2 bags per day	4	4	1	1	-	1	1	3	1	-	2	1	-	1
	1 bag per day	13	2	2	-	-	-	2	5	6	1	2	-	-	1
	1 bag every 2 days	8	-	-	1	1	2	1	2	1	1	-	-	1	-
	1 bag every ≥ 3 days	8	-	-	2	-	-	2	4	-	1	1	-	1	1
	No Answer	-	-	-	1	-	-	-	1	-	-	-	-	-	-
Household Size	1	1	-	-	1										
	2	3	-	-	-										
	3	5	-	-	-										
	4	12	1	-	-										
	5	5	1	-	1										
	6	3	-	-	2										
	7	1	2	2	-										
	8	-	1	-	-										
	9	1	-	1	1										
	≥10	2	1	-	-										



(a) Answer to Question (18): *What is the distance to your closest YCDC waste container?* The most households had a container between 25 and 100 meter to their house, which is about half a block's length.



(b) Answer to Question (19): *I think the closest YCDC container is too far away or the container is always full, therefore I...* The majority of the households deposited its waste always in the container. However there was also a group who disposed their waste not in a container but in a location where others had already disposed their waste. A number of respondents threw away their own waste in containers, but did know other people who did not disposed their waste in a container. All together about 35.5% of the people reported about waste not being disposed in the containers.

Figure B.7: This figure show the results of the distance to the containers and the respondents' disposal practices (see Section B.6.2.1).

Table B.8: The households that lived on ground level disposed their waste more frequent. The size of the used bags did not show a clear relation between the floor level of the households.

		Household Floor Level		
		≥2nd floor	1st floor	Ground Level
Size of Garbage Bag	Small	12	6	15
	Medium	2	2	2
	Large	1	1	1
	No Answer	3	1	2
Frequency of Waste Disposal	3 bags per day	-	-	1
	2 bags per day	2	2	6
	1 bag per day	6	4	7
	1 bag every 2 days	4	3	2
	1 bag every ≥3 days	5	1	4

Table B.9: There seemed to be no clear relation between the distance to the nearest container and the floor on which a household was situated and the household's waste disposal behaviour. You might expect that the further people have to walk to a container and/or the higher they live the more tempting it is to not always go to a container or know neighbours who do not go to the container.

		Distance to Container						Household Floor		
		<25m	≥25 & <50m	≥50 & <100m	≥ 100 and & <150m	≥ 150 & ≤200m	>200m	≥ 2nd floor	1st floor	Ground Level
Waste Disposal Behaviour	*	-	3	-	-	-	-	2	-	1
	**	1	4	2	-	-	-	1	2	4
	***	-	-	-	-	-	-	-	-	-
	♦	-	-	-	-	-	-	-	-	-
	♦♦	2	11	9	2	4	1	13	7	9
	♦♦♦	3	1	2	1	-	-	2	1	4
	No Answer	1	-	-	-	1	-	-	-	2

* I sometimes throw away my solid waste not in the container, but on the street.

** I sometimes throw away my solid waste on a spot where my neighbours have already thrown away their waste

*** I sometimes throw away my solid waste in the drain

♦ I sometimes throw away my solid waste in the inlets of the drains

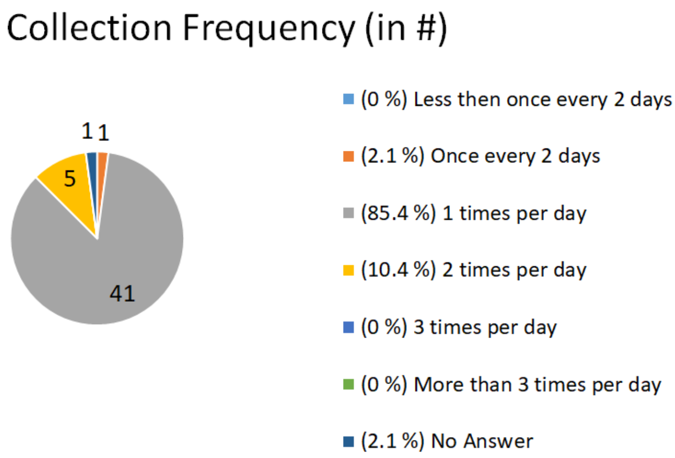
♦♦ I don't think that the container is too far away and I always go to the container, even when it is always full

♦♦♦ I don't think that the container is too far away, but I know others who don't go to the container because it is too far away or always full

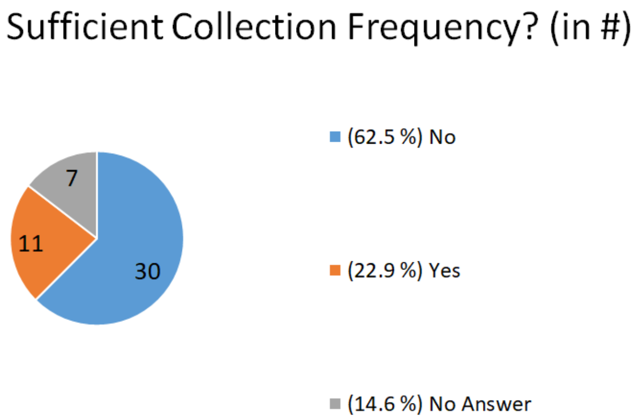
B.6.2.2. Solid Waste Collection (by YCDC)

The responses yielded a pretty clear answer to the question how frequent the containers were collected, which was once a day (Figure B.8a). A closer look into the response also did not show a relation between the location and the collection frequency of two times per day. All respondents lived in a different street and there were in some case others that lived in the same street and answered that the collection frequency was only once per day. Most respondents were not satisfied with the number of times waste was being collected (Figure B.8b) and from these respondents the majority would have liked to see the collection being 2 times per day (Figure B.8c).

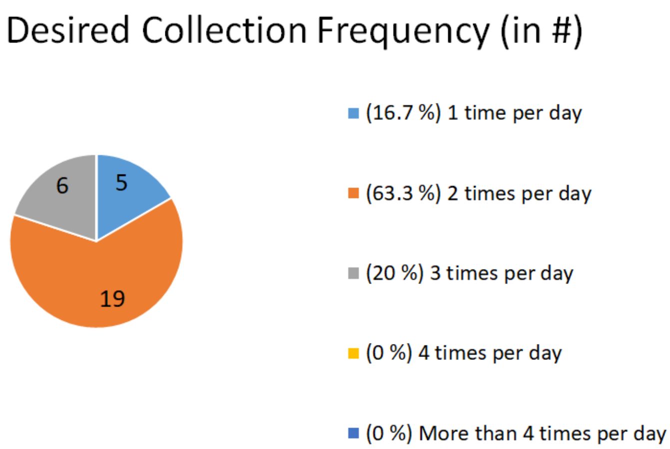
The question about the desired YCDC container collection frequency (Figure B.8a) yielded unexpected results. From the 30 respondents who said that the current collection frequency is too little, only one answered that the current frequency is *once every 2 days*. Yet, four other respondents also responded that they would like to see the collection frequency to be once per day. This could be an indication that not everyone rightly interpreted this question.
The impact of these inconsistent/unexpected responses is limited. This data serves to get an idea of what could be possible demands if a citizen protests against the poor solid waste management. It could still be concluded that if the collection frequency would be increased to twice a day, most respondents will probably expect the situation to improve.
Since the impact is limited no special/extra improvements or additional actions will be required for now.



(a) Answer to Question (20): *How often are the YCDC waste containers collected?* The majority of the households disposes its waste always in the drain. However there is also a group who throw away their waste not in a container but in a location where others have already disposed their waste. And a number of respondents throw away their own waste in containers, but do know other people who do not throw away their waste in a container. All together about 35.5% of the people report about waste not being disposed in the containers.



(b) Answer to Question (21): *The YCDC waste collection is frequently enough?* A large majority feels that the waste is not being collected frequently enough.



(c) Answer to Question (22): *I think the waste collection should be...* From the respondents that answered that the collection frequency is not frequent enough, the majority would like to see that the collection becomes twice a day.

Figure B.8: This figure show the results of the collection frequency, if the respondents deem the collection frequency sufficient and if not, how frequent they would like the collection to be (see Section B.6.2.2).

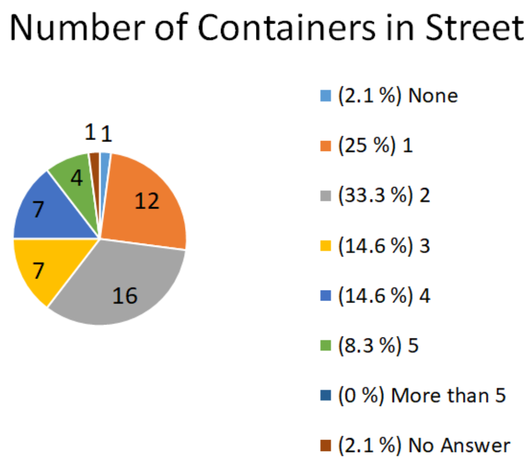
B.6.2.3. Solid Waste Containers

The most respondents reported that they had 2 containers in their street (Figure B.9a), and the average number of containers was 2.4 containers per street. This was a lot lower than the average number of containers available for the entire residential area of Latha, which was 6.3 containers/street on average (See Table C.2). However, there was one location (See Figure C.6) with a relative high number of containers that might skew the average. The majority of the respondents indicated that they thought the number of containers was too little (Figure B.9b) and from this group the majority wanted a lot of extra containers (Figure B.9c).

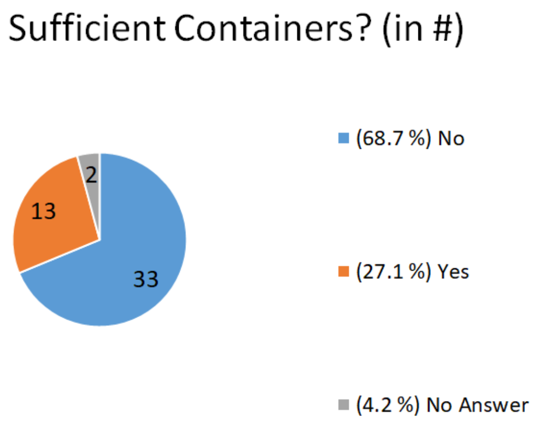
B.6.2.4. Solid Waste Taxation

The questionnaire provided a clear answer to the question if people had to pay tax for their solid waste. The majority of the people paid tax (Figure B.10a), and the majority paid 600 Kyats per month(Figure B.10b), especially when the people who answered 1800 Kyats per month also actually paid 600 Kyats per month (see next paragraph). The 600 Kyats per month was also in line with interview results (see Table D.1). From the people who did not pay tax, the majority was aware that they had to pay tax but they just did not know where they had to pay the tax or did not have the money for it (Figure B.10c). Thus there was a taxation of 600 Kyats per month per household.

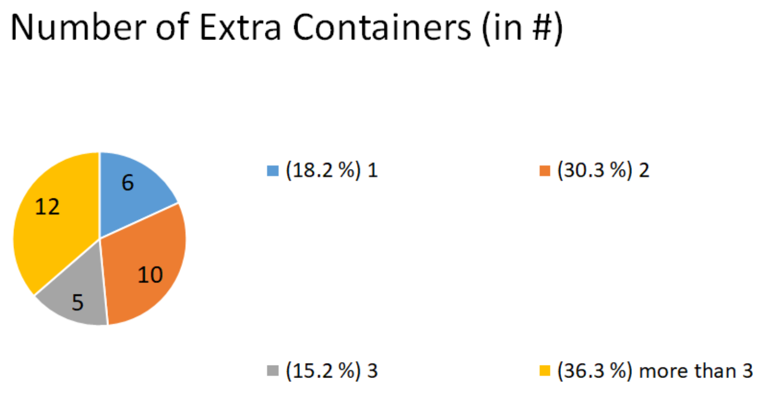
The data about the taxation tariffs (Figure B.10b) seemed to produce not as clear results as most likely was actually the case. A large group answered that the tax is 600 Kyat per month whereas another big group answered that the tax is 1800 Kyat per month. This was certainly a problem of respondents not answering the right question. Multiple interviewees mentioned that the tax was paid per 3 months and amounts 600 Kyats per month, equalling to 1800 Kyats per quarter. Thus about 60% of all respondents answered that the monthly tax was 600 Kyats per month. There were some others that gave different answers, it remains unclear why so.
The impact of the inconsistencies in this data is negligible. As combination with data from interviews allows for the good assumption that the taxation is 600 Kyats per month.
Since the impact is limited no special/extra improvements or actions will be required for now.



(a) Answer to Question (23): *How many YCDC waste containers are there in your street?* The average street had about 2 containers and the average number of containers was 2.4 containers per street. This was less than the average 6.3 containers per street (See Table C.2).

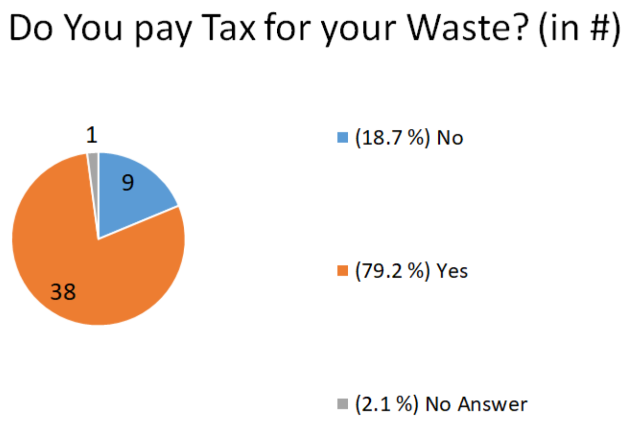


(b) Answer to Question (24): *The number of YCDC waste containers is enough?* A large majority of the respondents felt that there were too little containers in their street.

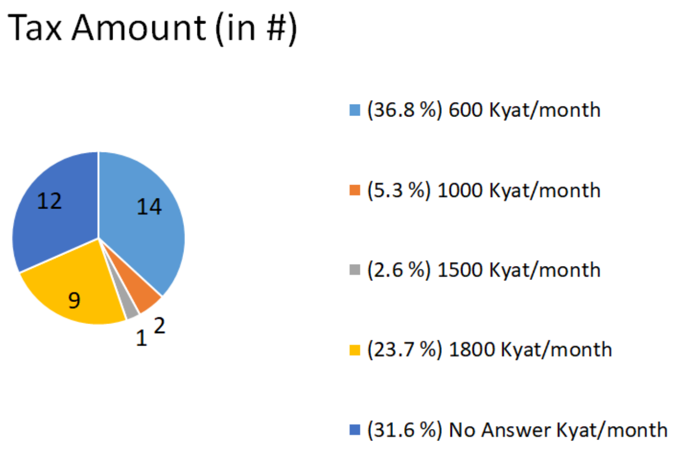


(c) Answer to Question (25): *For your street, how much extra YCDC waist containers do you feel are required?* For the respondents who liked to see extra containers the most would have liked to see a lot of extra containers.

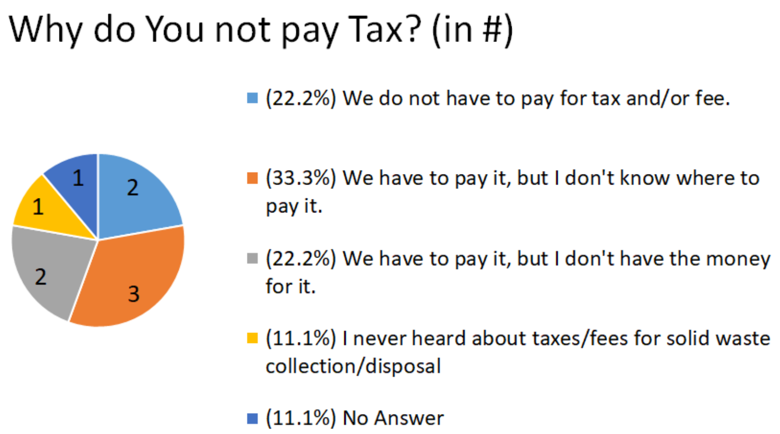
Figure B.9: This figure show the results about the number of containers in the respondent's street, if the respondents deem the number of containers sufficient and if not, how frequent they would like the collection to be (see Section B.6.2.3).



(a) Answer to Question (26): *Do you pay tax or a fee for solid waste collection/disposal?* Most households respond that they have to pay tax.



(b) Answer to Question (27): *How much tax and/or fee for solid waste (collection) do you pay per month? (Answer in Kyat) (After this question, go to question 29)* Most households responded that they had to pay 600 Kyats per month or 1800 Kyats per month (However, 1800 Kyats per month most likely was actually 1800 Kyats per three months and thus 600 Kyats per month, see discussion about this point in Section B.6.2.4).



(c) Answer to Question (28): *Why do you not pay tax and/or fee?* From most of the households who responded that they did not pay tax the majority was aware that they had to pay tax but they just did not know where they had to pay the tax or did not have the money for it

Figure B.10: This figure show the results about taxation, the amount of taxation and why some respondents did not pay tax (see Section B.6.2.4).

B.6.3. Urban Flooding Results

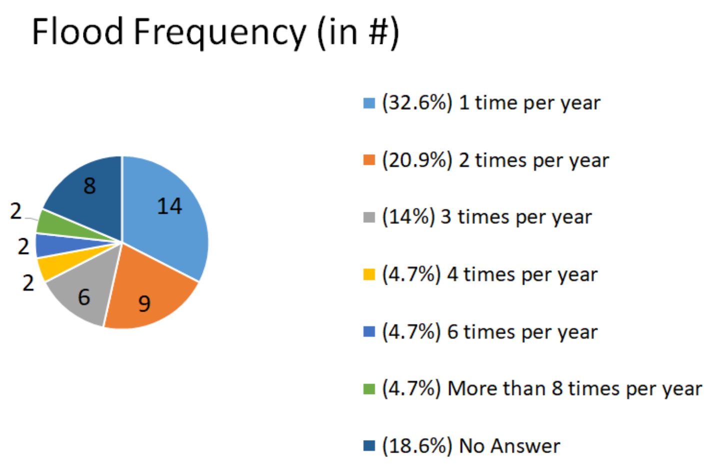
In this section presents the results of the questionnaire focussed on urban flooding (question 29 till question 47). It did flood in the Latha township as we may conclude from the answers shown in Table B.10. Note that the people who answered that it never floods (Question 30 and Figure B.11a) were omitted from this point on since they do not have any answer to all the following questions, this results in 43 respondents.

B.6.3.1. Floods: Frequency, Duration and Depth

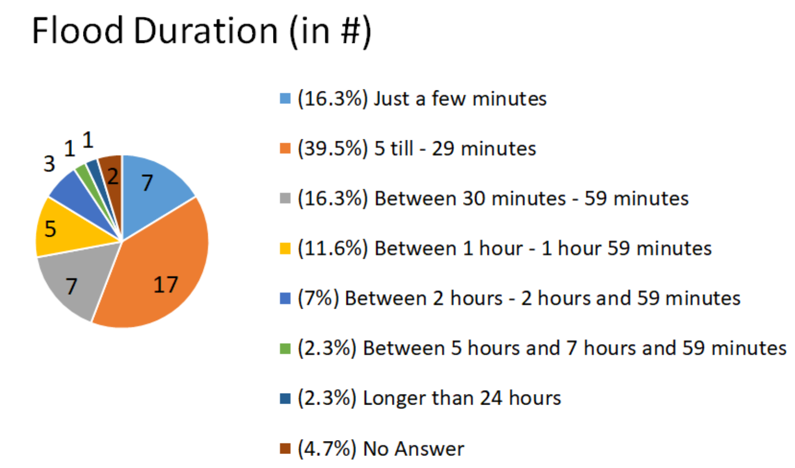
According to the majority of the responses it flooded on average less than four times per year (Figure B.11a), the floods were of a short duration (Figure B.11b) and the water depth during a flood was mostly around 10 cm (Figure B.11c). This is to a large extent in accordance with the interview with the YCDC EDRB, see Table D.2.

Table B.10: Answer to Question (29): *When was the last flood in your street/house/building?*

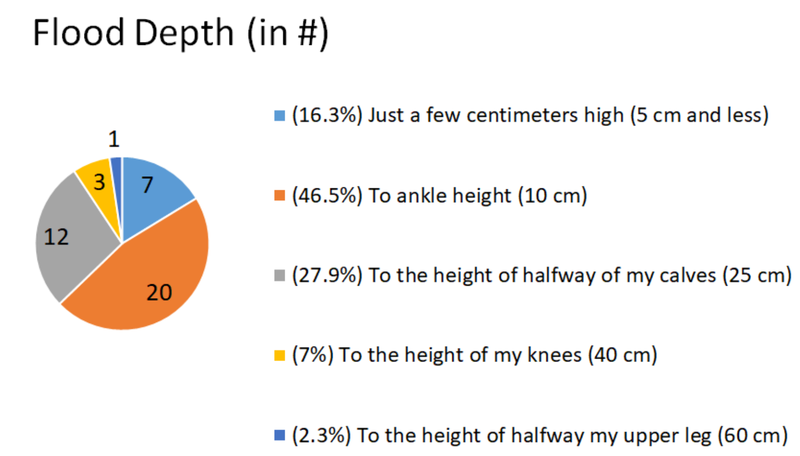
Respondent	When was the last flood in your street/house/building?
1	Flooding is more common in raining season and high tide.
2	Flood had occurred because of blockage of garbage.
3	2014, 2015
4	2016, raining season
5	None
6	No Answer
7	No Answer
8	2008
9	No Answer
10	No Answer
11	No Answer
12	No Answer
13	I did not remember
14	Raining Season
15	Raining Season
16	Last 10 years ago
17	Rainy Season
18	No Answer
19	No Answer
20	No Answer
21	During heavy rainfall of early raining season
22	During Heavy Rainfall
23	I have never experienced
24	No Answer
25	No Answer
26	No Answer
27	No Answer
28	Raining Season
29	No Answer
30	Hight tide during raining season
31	2015
32	No Answer
33	High tides during full moon day and raining season.
34	Raining Season
35	None
36	No Answer
37	Raining Season
38	Raining Season
39	Raining Season
40	Raining Season
41	Raining Season
42	During rainy season the water levels increase a little bit and small floods
43	Rainy season, during heavy rains, Tide (July, August)
44	Rainy season (June till August)
45	Every year rainy season
46	No flood
47	I do not remember
48	NA (back of the houses and basements + car parking flooded)



(a) Answer to Question (30): *On average, how often do you experience flooding in your street/house?* Most respondents said that it flooded once, twice or three times per year on average.



(b) Answer to Question (31): *On average, how long does a flood last?* Most respondents replied that the floods last between a few minutes to one hour.



(c) Answer to Question (32): *On average when it floods, most of the times the water level gets:* Most respondents said that if it floods the water depth is about 10 cm. We may also observe that most respondents do not experience severe flooding as hardly any one experiences floods with a water depth above 40 cm.

Figure B.11: This figure show the results about the flood frequency, flood duration and flood depths (see Section B.6.3.1).

B.6.3.2. Flood Warning

During interviews the question: "Do you receive a warning before it floods?", was a guaranteed moment of laughter and no one ever replied that they receive a flood warning. However, some respondents indicated that they do sometimes receive a flood warning from others (Figure B.12a). Often this is between zero to ten minutes before the flood reaches them (Figure B.12b).

Surprisingly the questionnaire showed that some people actually do receive a flood warning. This was unexpected as interviewees always responded negative to this question. But the majority of the respondents did not answer this question (Figure B.12a). And thus this question might have been not clear enough. Or the concept of receiving a flood warning is different for this research than for the respondents.
The fact that such a big group did not answer the question at all is unfortunate, as it could be that actually even more people receive a flood warning. More response will produce a better understanding and provide more insights in to the temporal variation between the flood and the warning. Never the less, this question has proven that it might be reasonable to model a short warning time, that might allow for households to anticipate the flood and divert or reduce the threat.
If a flood warning is modelled, different probabilities could be used in different scenarios to study the possible effect/influence of this human interaction. For the timing of the warning it makes sense to focus on the shorter warning times as these have been reported the most.

B.6.3.3. Drain Blockages

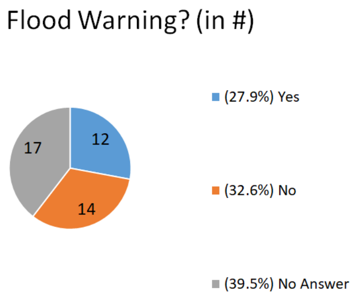
About one third of the respondents answered that the blockages (almost) always occurred at the same location. (Figure B.12c). With Strand Road mentioned the most often (Figure B.12d). This is in line with the results of the interview with the YCDC EDRB (see Table D.2). This data was used to select the location of blockages in the SOBEK cases that study the effect of blockages (see Section E.3).

B.6.3.4. Flood Protection

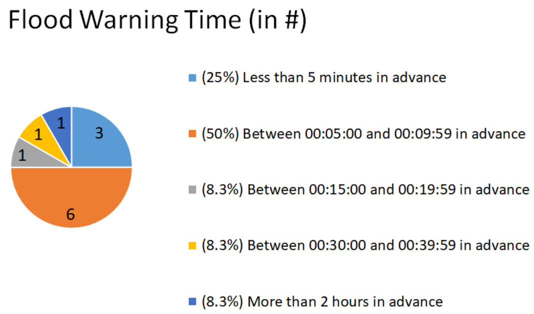
About 30% of the respondent's building/house had a form of flood protection (Figure B.13a). In most cases this flood protection consisted of a concrete slab in the (door) opening of their building (Figure B.13b). This is consistent with field observations. However, often these concrete slabs are multi-purpose, as they also serve to keep rats out of a households house/building as interviews with households revealed.

B.6.3.5. Flood Activity Pattern

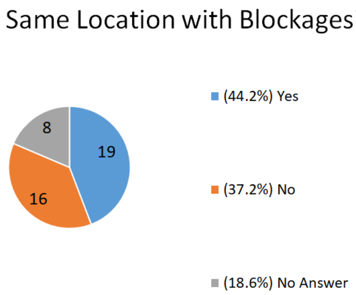
The majority of the respondents replied that they do not change their daily pattern/activities in case of a flood (Figure B.13c). This was somewhat unexpected, as the hypothesis was that people would change their daily activities during a flood. This might be an indication that the Latha citizens were (somewhat) flood resilient.



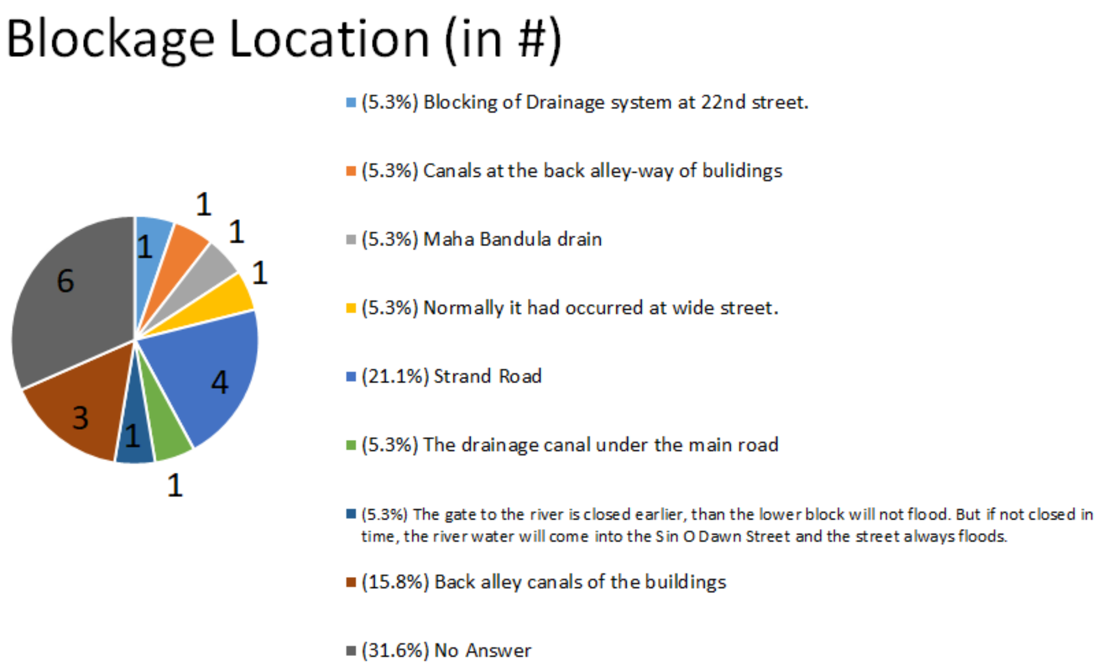
(a) Answer to Question (33): *When it starts to flood, I am often warned by others (e.g. YCDC, family, friends and/or colleagues):* It might be that this question was not as clear as it was during the testing, since a large group did not answer this question. However there is a group that did receive a flood warning before there was a flood.



(b) Answer to Question (34): *When I receive a flood warning I know the flood is coming (times in HH:MM:SS):* The most respondents who received a flood warning received this warning only shortly before the flood occurred.

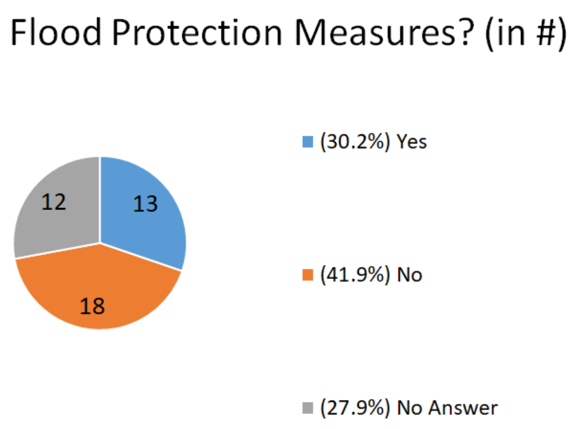


(c) Answer to Question (35): *Is there always a blockage at the same location when it floods?* About one third of the respondents answered that the if there are blockages, they occur (almost) always at the same location.

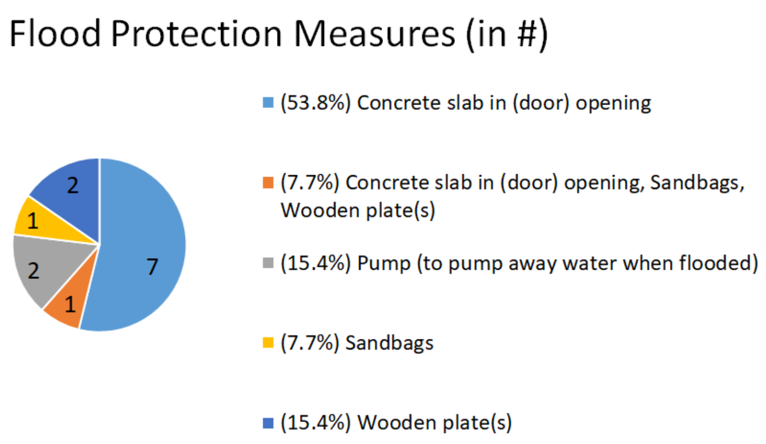


(d) Answer to Question (36): *Where (at what location) does the blocking and flooding most of the times/always start?* Strand road is often mentioned as the location where the blockages often occur. What is interesting is that one person also answered that the blockages often happen around 22nd Street, this was also mentioned by YCDC EDRB (Kyaw Mein Oo, personal communication, April 6, 2017). Another interesting thing is the response that talks about the FGSs, this is in line with the results from the SOBEK model. Finally a group responded that the flooding always starts from the back alley drains. The back alley drains were not researched, since there has been too little information available about it.

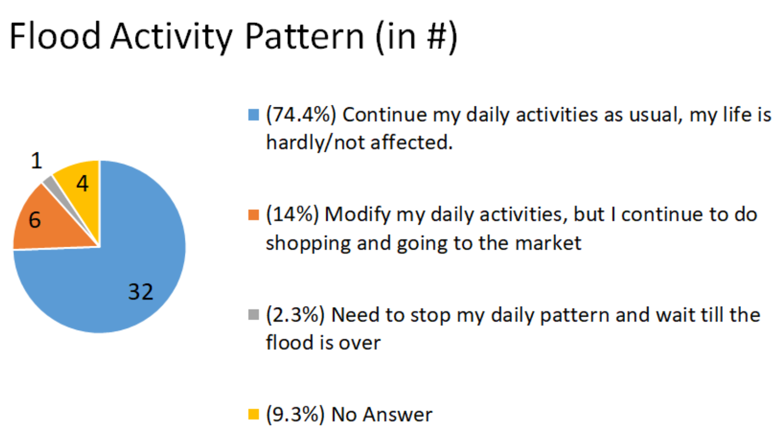
Figure B.12: This figure show the results about the flood frequency, flood duration and flood depths (see Section B.6.3.2) and the results about the occurrence of bloackages and the locations of such blockages (see Section B.6.3.3).



(a) Answer to Question (37): *Does the building or house where you live in have any flood protection measurements? (like a pump, concrete slab/stairs that forms a small dam, sandbags or wooden boards that are placed in (door) openings)* The majority of the respondents do not have any flood protection in the household or in the building where there household is situated.



(b) Answer to Question (38): *My building has the following flood protection measurements...* The results show that the majority of the people who do have a form of flood protection particularity rely on a (permanent) concrete slab in the door opening that functions as a small dike and prevents water from the street to flow into the household.



(c) Answer to Question (39): *When it is flooded, I...* In case of a flood, a very large majority will not change its daily pattern/activities. Some people will actually modify their activities slightly but will continue to do their business.

Figure B.13: This figure show the results about the occurrence of blockages, the locations of such blockages (see Section B.6.3.4) and the results about peoples activity patterns (see Section B.6.3.5).

B.6.3.6. Flood Damage

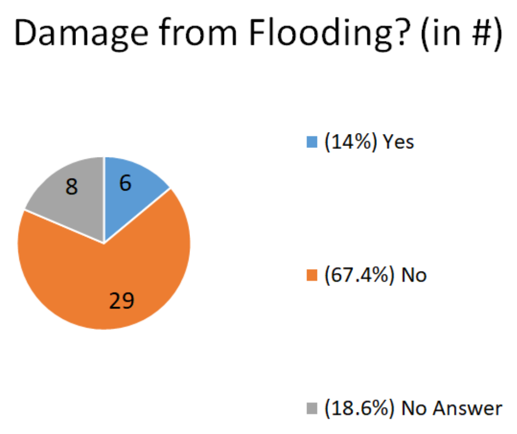
The large majority of respondents answered that they never had any damage from floods Figure B.14a), and people who did had any damage did not answer how much damage they had (Figure B.14b) and what type of damage it was (Figure B.14c). Field observations showed that quite a lot of households had some form of flood protection and at the same time the majority of Latha's citizens was living not on ground level. The little number of respondents who experienced any flood damage could be the result of these two factors. Unfortunately the respondents who did respond that they had any flood damage did not specify how much damage they had and what the damage consisted of. It is unclear why these respondents did not answer these questions, as testing this question did not show any problems and/or misinterpretations.

B.6.3.7. Drain Maintenance

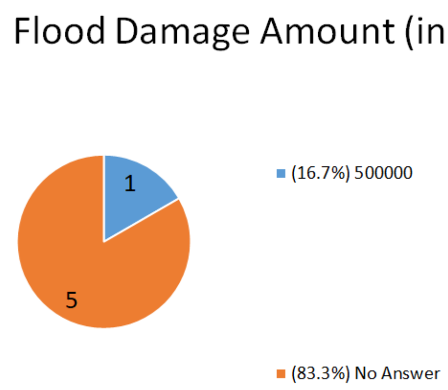
The majority of the respondents indicated that the drains were maintained once per year, followed by a group of 30% that answered that the drains were maintained 2 or 3 times per year (Figure B.15a) and the most likely reason for maintenance was because the rainy season was approaching (Figure B.15b). This was consistent with the results from the interviews with the YCDC EDRB (see Table D.2) and YCDC PCCD (Table D.1).

B.6.3.8. Flood Improvements

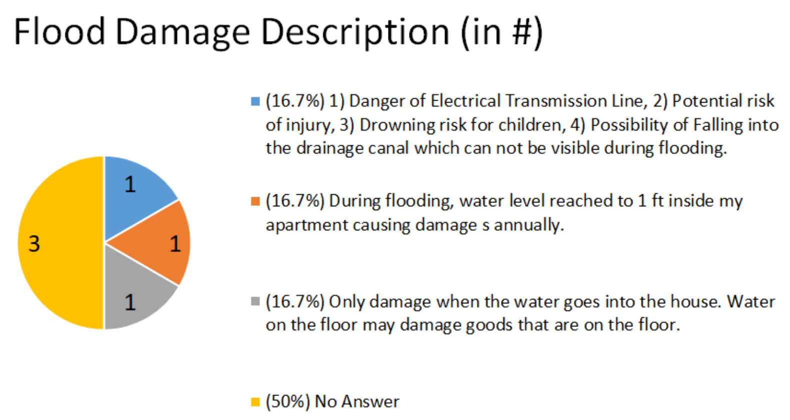
The questionnaire made clear that the YCDC implemented some improvement in the last 5 years to reduce (the consequences) of floods. Sixteen people responded that the sizes of drains had been increased and 14 people mentioned that the road was raised (Figure B.15c). Interviews with YCDC EDRB are in line with these responses (see Table D.2).



(a) Answer to Question (40): *Did you ever had any damage from flooding?* Only a small fraction of the respondents ever experienced damage from a flood.

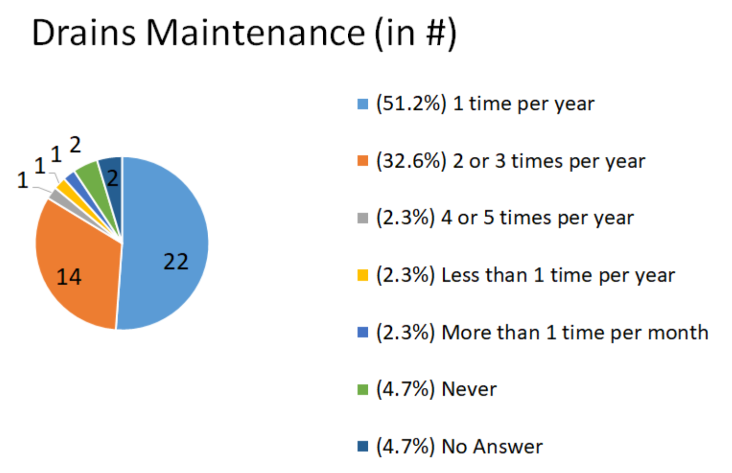


(b) Answer to Question (41): *What was the total damage for the most recent time you had damage caused by flooding? (answer in Kyat)* From the respondents who ever experienced damage from a flood (Figure B.14a) only one person answered the question. This makes the results from this question (almost) useless.

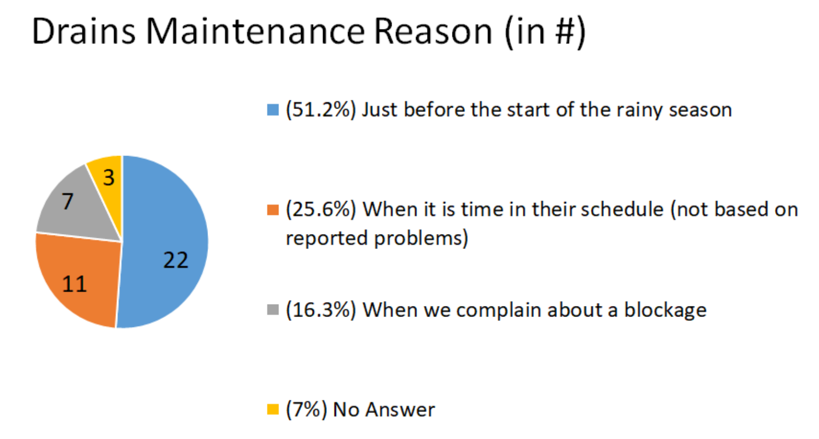


(c) Answer to Question (42): *Please describe what was damaged?* Most respondents who replied that they experienced a flood did not answer this question. From the respondents who did answer this question it could be observed that the most damage consisted of water on the floor, damaging property.

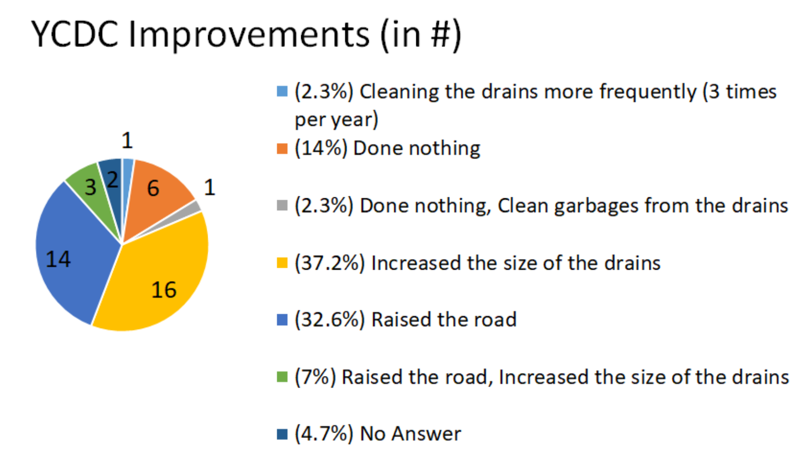
Figure B.14: This figure show the results about the flood damage, damage amount and flood damage description (see Section B.6.3.6).



(a) Answer to Question (43): *How often get the drains in your street get cleaned/maintained?* The questionnaire shows that the drains will most likely be cleaned only once a year or otherwise 2 or 3 times a year.



(b) Answer to Question (44): *They clean the drains...* Most of the times the moment that the drains get cleaned is just before the start of the rainy season, according to the respondents.



(c) Answer to Question (45): *In recent years (maximum of 5 years ago), YCDC has made the following improvements that reduced flooding:* From the questionnaire it seems likely that the YCDC has implemented some improvements in the past five years. Especially increasing the size of the drains and raising the road were improvements made by the YCDC.

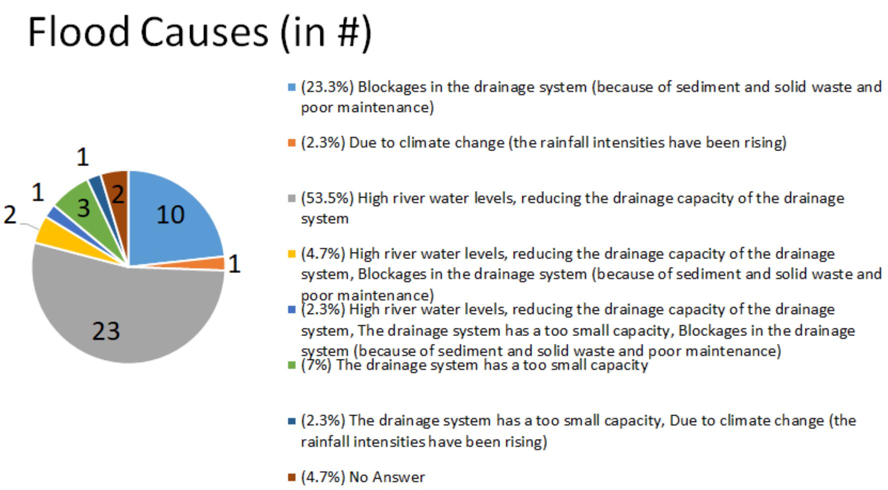
Figure B.15: This figure show the results about the maintenance frequency of the drains and the maintenance schedule of the drains (see Section B.6.3.7). Moreover it shows the results of the question about any improvements made by the YCDC (see Section B.6.3.8).

B.6.3.9. Flood Causes

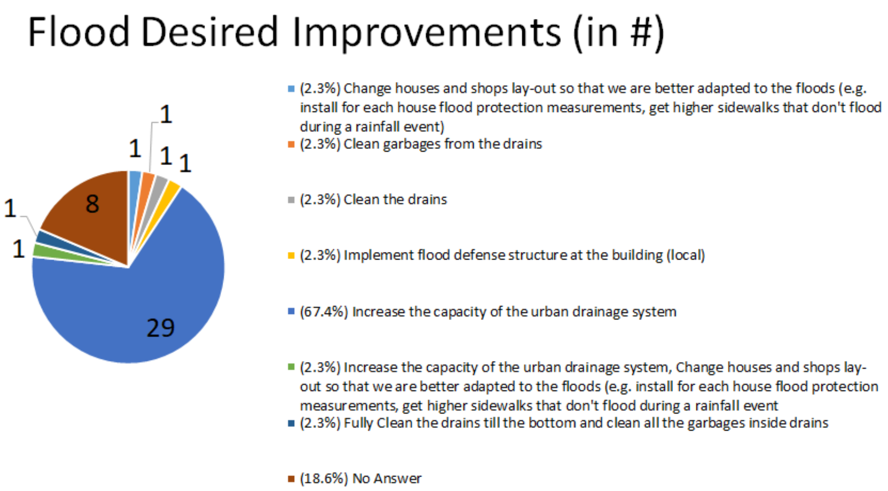
It seemed that the majority of the respondents had relative good knowledge/awareness about the flood causes (Figure B.16a). Interestingly a large group responded that the floods are caused by either blockages, but the majority of the respondents responded that the floods are caused by high river water levels, reducing the drainage system's outflow. The SOBEK results show that the Yangon River water levels play a dominant role in the manifestation of floods. The fact that such a large group replied that either blockages or high river water levels are causing floods, shows that the respondents had some form of flood awareness.

B.6.3.10. Desired Flood Improvements

Most respondents would have liked to see that the floods are resolved by increasing the capacity of the urban drainage system (Figure B.16b). Only a small group responded that they would have liked to see the floods being resolved by more frequent maintenance to the drains.



(a) Answer to Question (46): *What do you think causes the flooding?* The majority of the respondents thinks that the floods are the result of high river water levels, that reduce the drainage capacity of the drainage system and/or that the flood is caused by blockages in the drainage system.



(b) Answer to Question (47): *How should the flooding be solved?* Increasing the capacity of the urban drainage system is by far the most popular desired improvement to reduce the flood probability.

Figure B.16: This figure show the results about the flood causes (see Section B.6.3.9) and the desired improvements to reduce future floods (see Section B.6.3.10).

B.7. Discussion Results

The discussion of all results of the questionnaire is too elaborate and would be distracting too much from the main message of this section. Therefore, the result's anomalies were discussed straight after the presentation of the result itself in Section B.6.

The obtained sample size was too small to be sufficiently representative for the entire Latha Township population of about 25,000 people. The required minimum sample size was more than 380 respondents for a margin of error of 5% (p = 0.05) and a confidence interval of 95% (α = 0.95). Although the initially distributed 210 questionnaires (150 for HHs and 60 for shops) were too little, the low response rate reduced the reliability even more. The sample contained just 48 respondents. The questionnaire results for the shops were not even considered in this research as there only were 16 respondents and triangulation provided insufficient additional data.
Moreover, the questionnaires were distributed by the wards. This could have been the cause of the bias that was observed in the questionnaire data. For example, the sample consisted of too much old male respondents (see Figure 5.2). This also might have had the effect that respondents were giving socially expected (e.g. fearing that a negative answer or critique could lead them into trouble with the YCDC) or untrue (e.g. not reporting the right HH income, because you do not pay all required taxes for your actual income). Unfortunately there was no clear way to check this and YCDC permission was required for the distribution of the questionnaires.
Design errors, translation errors, interpretation errors also may have added to the uncertainty of the questionnaire results.
Finally, the questionnaires only provided a snapshot of the situation at that time. It may well be that the results of the questionnaires would have been completely different if the questionnaire was distributed right after a serious flood event.

The under-sampling may have resulted in observing results that were not there (type-I errors) or not being able to observe results that actually were there (type-II errors). For example, cross-tables (e.g.) were made to see if there were any relations between different behaviours and properties of HHs. In this case study there were no clear trends observed, whereas they might have been there but the sample size was just too small to detect this.
This uncertainty and the previously mentioned weaknesses resulted in errors and a dataset that was not a 100% reliable. However, the triangulation with the results of the field observations and interviews provided a method to still come up with truthful propositions about the results of the questionnaire. Moreover, one needs to remember that the objective of this study was to conduct an explorative study, acknowledging that the results would be not completely representative.

A possible improvement would be to do elaborate interviews with some of the respondents to ask additional questions that might provide more useful insights and allow for additional data that might be used for triangulation. A possible solution to get a larger sample size would be to distribute the questionnaire digitally. However, this does make it difficult to check if people actually live in the township.
Alternatively, different methods could have been applied that are less effected by a small sample size. A possible methodology could be the Q-Method (Stephenson, 1994).
For an improved statistical analysis of these larger samples other or additional tests may be required, for example a Chi-square test.
For a good example of an better designed research see for example Muñoz-Cadena et al. (2009, 2012).

B.8. Conclusions

In general the results from the questionnaires were in line with the fieldwork observations and interviews. All together the data provided useful insights. First of all, it may be concluded that the citizens had some flood awareness (Figure B.16a and Figure 4.12a) as was to be expected based upon the profiles of the respondents (Section 4.1.1.1) while recalling from Section 1.2 that: *It was concluded that "class is the most influential factor in predicting flood risk awareness, followed by flood experience and length of time in residence" (Burningham et al., 2008, p. 216). With class was meant social class.*
However, despite this awareness, their dissatisfactions (Figure B.8b, Figure B.9b) towards the current solid waste management policies and implementations and desires that YCDC reduces the floods (Figure B.16b),

only a small group responded that either flood management or improved solid waste management was their priority issue (Figure B.5d). One of the possible explanations could be that Latha's citizens are so used to the flooding, that they have become resilient to flooding. This could be supported by the fact that people hardly change their activities during a flood (Figure B.13c), do not experience any damage (Figure B.14a) and the fact that some respondents reported that they had flood protection measures (Figure B.13a) for their house/building

Important human activities are the disposal patterns and cleaning habits from citizens. Insufficient containers, insufficient container collection frequencies, missing containers and neighbours that threw their waste on the street all have an impact on how likely a citizen is to not properly dispose its waste. The maintenance state of the drains, cleaning actions by the YCDC are also important human activities that change the state/condition of the drains affecting the probability that waste get in the drain and gets stuck or propagates to the FGS.

C

Data Collection & Field Observations

C.1. Introduction

For this case study (the Latha Township) a lot of different datasets were collected, which were used in the various components of this mixed-method research. Although not all the collected data was explicitly used, it is still presented in this appendix as it provides background information and might be useful to others. This chapter provides an overview of the data collection methodology, the collected data (the results) and a discussion on some of the collected datasets followed by a conclusion. Appendix A might provide additional information about the mentioned locations used in the results of the datasets and field observations.

C.2. Methodology

In order to acquire all required data, a data collection was set-up. For this research different methods were used:

1. Literature studies
2. Data inquiries at relevant institutions and organisations
3. Interviews
4. Attending a conference
5. Field observations

Some of the data was successfully collected from previous studies and scientific literature. However until 2011, Myanmar was hard to access for foreigners, which limited the number of international (English) studies and datasets. Moreover, a lot of the data was not available in digital format.
Therefore data inquiries were made at relevant institutions and organisations. For this research the Yangon City Development Committee (YCDC) and National Engineering and Planning Service (NEPS) were contacted. The Yangon City Development Committee Engineering Department of Roads and Bridges (YCDC EDRB) and Yangon City Development Committee Pollution Control and Cleansing Department (YCDC PCCD) departments were contacted. Contact with the YCDC EDRB went through Kyaw Min Oo, Assistant Engineer. Contact with YCDC PCCD went through Aung Myint Maw (Assistant Chief Engineer) for the city wide department and through U Myot Soe Thein (Latha Engineer) for the Latha department. Contact with NEPS was with U Khin Lat.
In addition to the data inquiries, short (unstructured) interviews and conversations were held with various people with no clear notes. However, they sometimes did provide useful information. Some interviews had a more systematic approach with the results presented in a separate appendix, Appendix D.
The Dutch Embassy hosted a event about *solid waste management in Myanmar*. The mini conference was attended by several YCDC policy makers and solid waste management (SWM) experts.

Despite all previously mentioned efforts not all required datasets were obtained. Therefore, additional fieldwork was conducted within the Latha Township.

Most of the collected data was also analysed, or processed in order to be used in this research. Often more than one of the data collection methods contributed to the assimilation of a complete dataset. The assimilated results of the collected, analysed and processed data are shown in the next section.

C.3. Results

C.3.1. Land Use

Based on its land use characteristics (see Figure C.1), the township was split up into three areas: the hospital area, the residential area and Strand Road (night) Market (see Figure C.2. In the northern hospital area the building density was relatively lower and the area was more unpaved and *green* (Figure C.1b). Along the south side of Strand Road a recently (early 2017) opened new (night) market area (Figure C.1c) hosted a lot of food market stands. The residential area (Figure C.1a) with its smaller north-south oriented streets, was where the majority of Latha's citizens live (MIP - DP, 2015) and where a large number of shops, restaurants and street shops sold their products.

(a) Maha Bandula Road in the Latha Township during Chinese new year, seen from the junction with Maha Bandula Road and Shwedagon Pagoda Road looking to the west.

(b) Hospital area on the left and the residential area on the right. Seen from the junction between Lanmadaw Street and Anarwrahta Road, looking in north-east direction.

(c) Strand Road (night) market. In this area, a lot of salesmen sell their products.

Figure C.1: A clear difference should be observed between Latha's residential area (Figure C.1a) and Latha's hospital area (Figure C.1b). The hospital area had much less purvious areas, a lower building density and a lower population density. At Strand road, only market salesmen sell their products from stands.

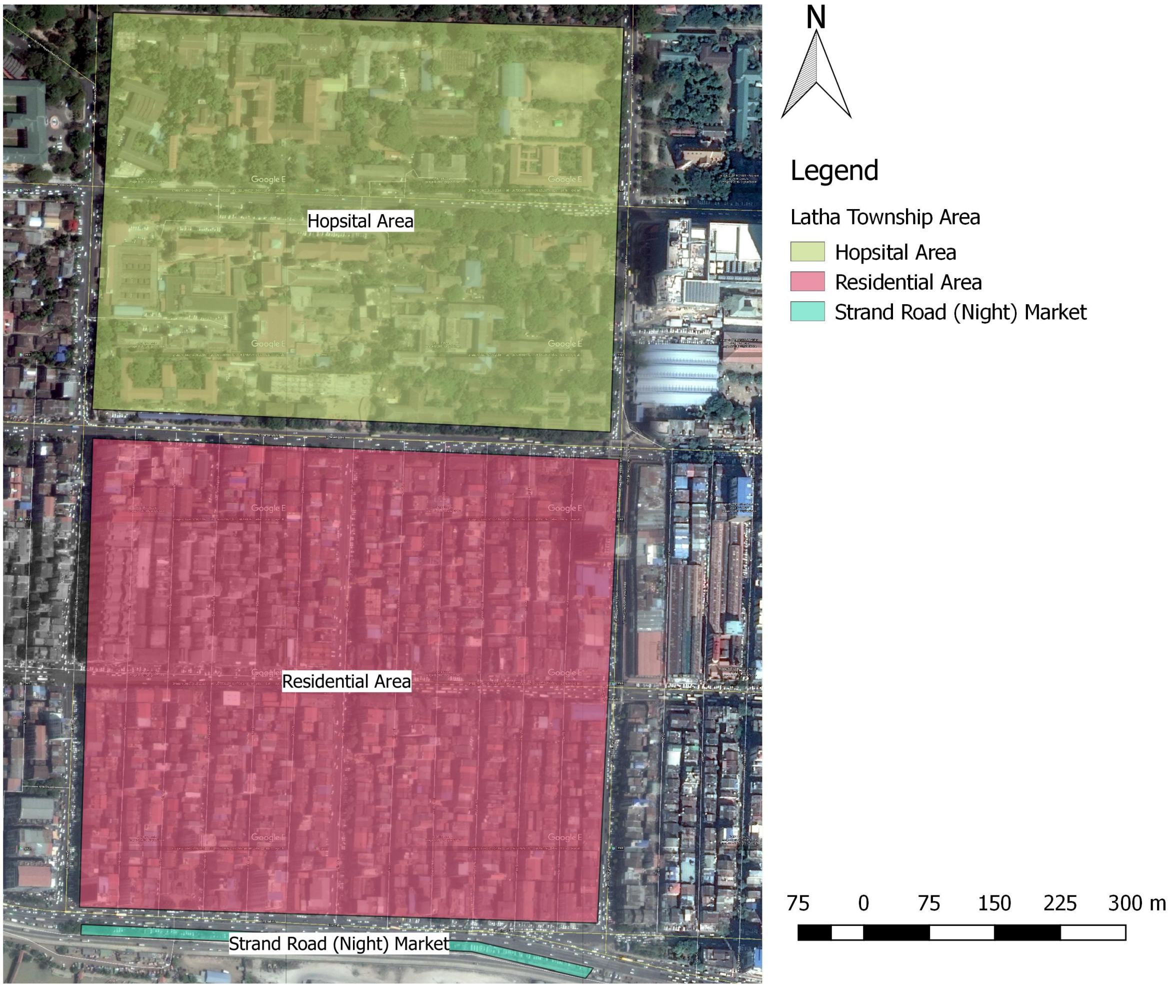


Figure C.2: The Latha township was divided into 3 parts with each an individual character. In the north there was the hospital area. This was a relatively green area with scattered hospital departments. There was a relative high proportion of unpaved areas. The middle part of the township consisted of a typical Yangon Central Business District residential area, with a north-south grid-like/block lay-out. This area will be referred to as the residential area. At the southern edge of Latha a (night) market area was permitted since January 2017.

C.3.2. Institutional Set-Up of Yangon & Latha Township

Yangon had a very hierarchical institutional set-up. For Yangon city there was the YCDC, which had a large number of departments working on different agendas YCDC (2017). The city was divided into multiple districts, consisting of several townships (see appendix, Figure A.7). Each township was divided into wards that make out the smallest institutional unit/administrative areas. Within the Latha Township there were ten wards (Figure C.3), numbers 1 to 8 were situated in the residential area and wards 9 and 10 were situated in the hospital area. Typically the wards had about 3 streets under their supervision. For some streets, the western part fell under a different ward then the eastern part of the street. The Strand Road (night) market did not fall under the responsibility of the township, but was managed by the YCDC Market Department (Tun Lin Aung, personal communication, April 4, 2017). All ten wards had their own administrative office and were responsible for implementing parts of the YCDC's activities. The wards were overseen by the General Latha Township Office, which was responsible for the Latha township as a whole. Weekly meetings with the General Township Officer and all ten Ward officers allowed for planning and coordination.

For this research the most important departments were the YCDC EDRB and the YCDC PCCD. The YCDC EDRB was responsible for the drainage system, cleaning and maintenance of the drainage system and operation of the flood gate structures (FGSs). The YCDC PCCD was responsible for the waste container collection and for cleaning the streets. Both departments had representatives at each institutional level till township level (thus not at ward level).

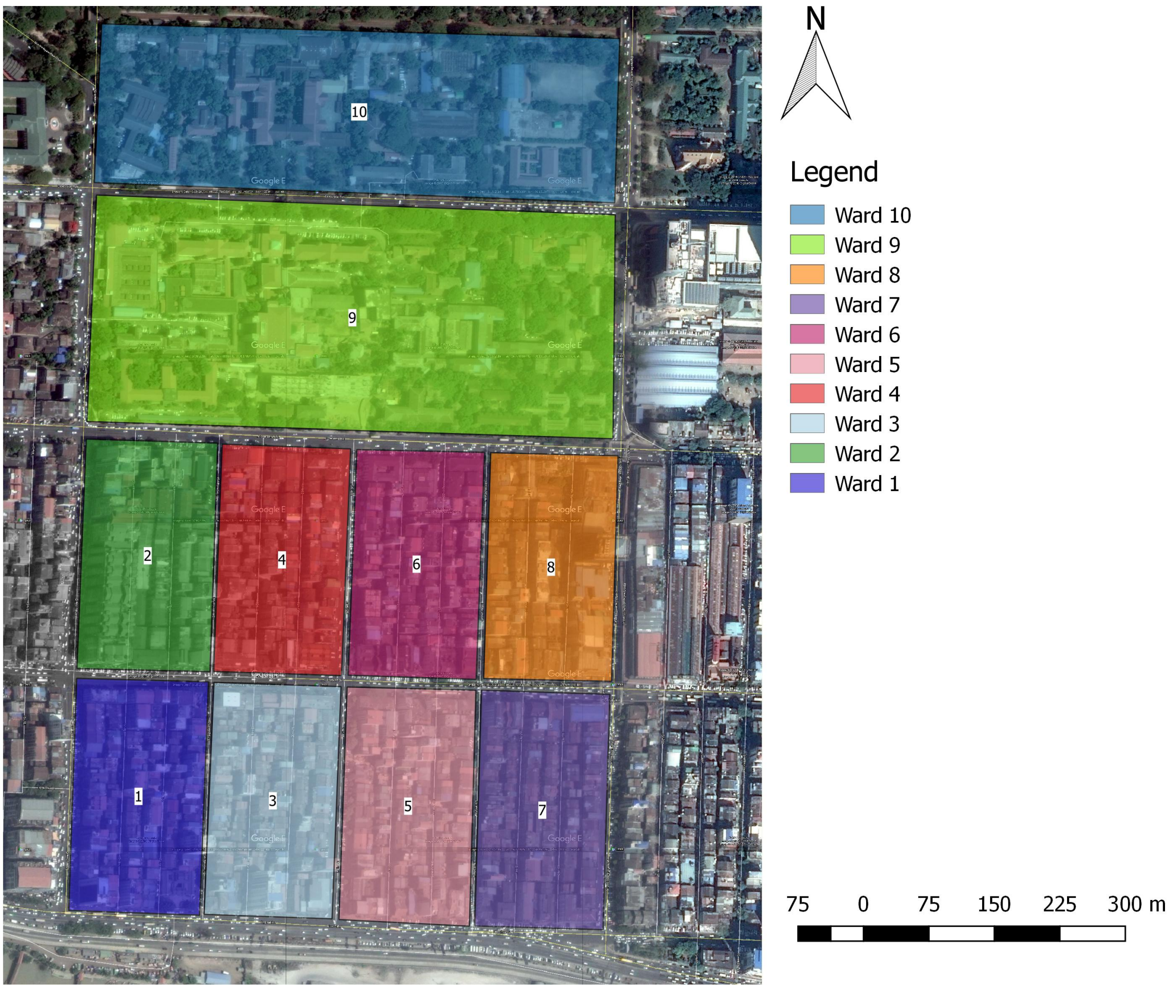


Figure C.3: The Latha Township consists of 10 wards. These ten wards all have their own administrative office and are responsible for implementing parts of the YCDC's activities. The wards are overseen by the General Latha Township Office, which is responsible for the Latha township as a whole.

C.3.3. Solid Waste: Production, Management and Network

The amount of solid waste that was produced and the location, collection frequency and capacity of the containers and similar data was important in order to understand how waste potentially ends up in the drains and to properly model these processes in a socio-hydrological model.

The local department for the Latha Township of the Yangon City Development Committee Pollution Control and Cleansing Department (YCDC PCCD) provided a map with the location of all containers in the area, see Figure C.4. Each container had a volume of 660L and is depicted by a green rectangle in Figure C.4.

The Dutch Embassy hosted a event about *solid waste management in Myanmar*. Various experts and stakeholders were present. This event yielded 3 possible waste production rates (Table C.1, sources: 1,2 and 3). Based upon a few days of fieldwork a solid waste expert estimated the solid waste production for Yangon to be at least 0.8 kg/capita/day and noted that for the Latha Township this number was probably even higher (Herman Huisman (Rijkswaterstaat), personal communication, March 23, 2017).
According to data provided by the YCDC PCCD for the Latha Township the waste production per capita was much higher, Table C.1 source 4. The waste production should be around 1.44 kg/capita/day (U Myot Soe Thein, personal communication, March 28, 2017).

Table C.1: Based upon different sources there was quite a range of possible waste production rates for the Yangon Township, running from 0.33 kg/capita/day to 1.44 kg/capita/day.
Source 1: data obtained from slide titled "Profile" by YCDC PCCD on 23-03-2017. Source 2: Source 1: data obtained from slide titled "Profile" by YCDC PCCD on 23-03-2017. Source 3: data obtained from YCDC PCCD Latha Township (U Myot Soe Thein, personal communication, March 28, 2017). Source 4: data obtained from Dutch Waste Expert (Herman Huisman (Rijkswaterstaat), personal communication, March 23, 2017).

Source	Waste Production (kg/capita/day)
YCDC PCCD (source 1)	0.33
YCDC PCCD (source 2)	0.41
Dutch Waste Experts (source 3)	> 0.80
YCDC PCCD (Latha) (source 4)	1.44

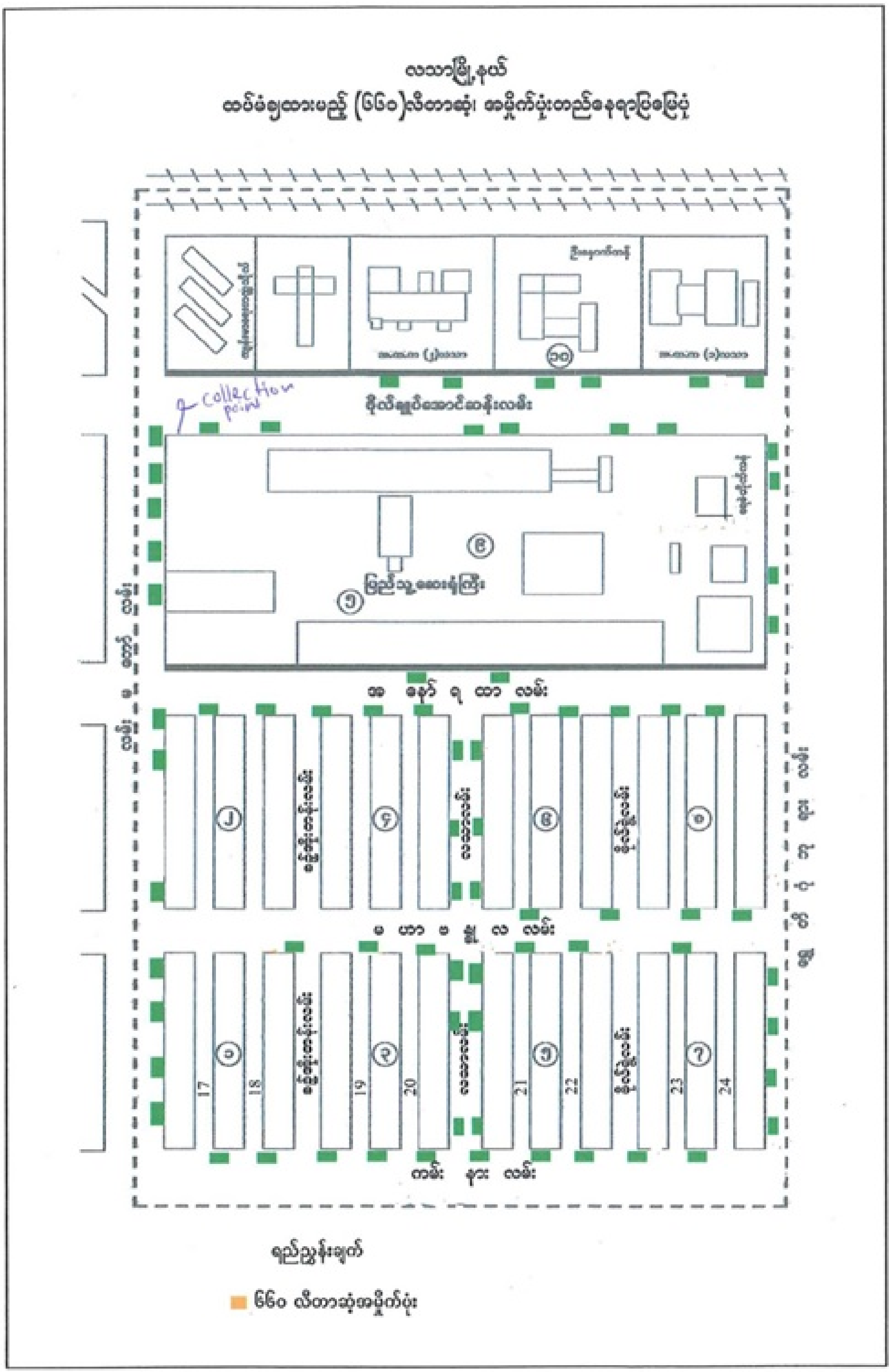


Figure C.4: Overview map of container locations in the Latha Township. The green squares represented a 660L container on that specific location. In the north-west corner there was a collection point. Obtained from YCDC PCCD (Latha Office) on 29-03-2017.

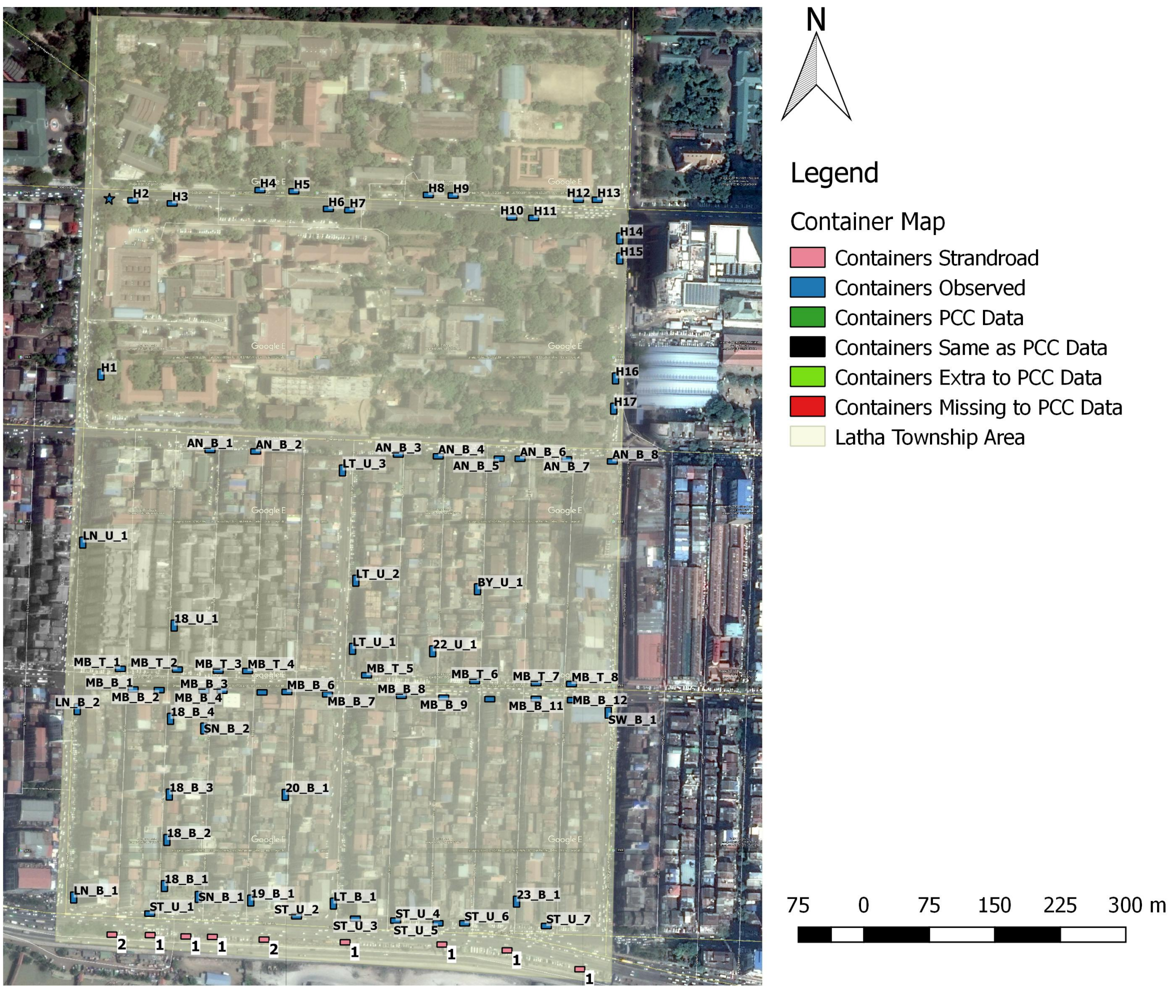


Figure C.5: Location description of the locations with containers. See Table C.2 and Figure C.6 for the number of containers per location.

Table C.2: Number of Containers per Location based upon fieldwork results. See Figure C.5 for the locations. Res refers to the residential area of Latha and Hos to the hospital area (Wards 9 and 10, see Section C.3.2). The *average street* indicates how much containers there were on average per location with containers, and the *average street* gives how much containers there were on average per street.

Area	Loaction	Containers (-)	Area	Loaction	Containers (-)
Res	18_B_1	1	Hos	H1	1
Res	18_B_2	1	Hos	H2	1
Res	18_B_3	1	Hos	H3	1
Res	18_B_4	1	Hos	H4	1
Res	18_U_1	3	Hos	H5	1
Res	19_B_1	1	Hos	H6	1
Res	20_B_1	1	Hos	H7	1
Res	22_U_1	1	Hos	H8	1
Res	23_B_1	1	Hos	H9	1
Res	AN_B_1	3	Hos	H10	1
Res	AN_B_2	3	Hos	H11	1
Res	AN_B_3	2	Hos	H12	1
Res	AN_B_4	2	Hos	H13	1
Res	AN_B_5	1	Hos	H14	1
Res	AN_B_6	2	Hos	H15	1
Res	AN_B_7	1	Hos	H16	1
Res	AN_B_8	1	Hos	H17	1
Res	BY_U_1	1			
Res	LN_B_1	1			
Res	LN_B_2	1			
Res	LN_U_1	12			
Res	LT_B_1	2			
Res	LT_U_1	1			
Res	LT_U_2	2			
Res	LT_U_3	1			
Res	MB_B_1	1			
Res	MB_B_2	2			
Res	MB_B_3	2			
Res	MB_B_4	1			
Res	MB_B_5	2			
Res	MB_B_6	3			
Res	MB_B_7	2			
Res	MB_B_8	1			
Res	MB_B_9	2			
Res	MB_B_10	2			
Res	MB_B_11	2			
Res	MB_B_12	2			
Res	MB_T_1	2			
Res	MB_T_2	2			
Res	MB_T_3	1			
Res	MB_T_4	2			
Res	MB_T_5	2			
Res	MB_T_6	1			
Res	MB_T_7	2			
Res	MB_T_8	1			
Res	SN_B_1	3			
Res	SN_B_2	1			
Res	ST_U_1	2			
Res	ST_U_2	2			
Res	ST_U_3	1			
Res	ST_U_4	2			
Res	ST_U_5	1			
Res	ST_U_6	2			
Res	ST_U_7	2			
Res	SW_B_1	2			
Total Containers Residential Area		100	Total Hospital Area		17
Average Containers per Residential Location		1.8	Average Containers per Hospital Location		1
Streets in Residential Area		16	Streets in Hospital Area		3
Average Residential Street		6.3	Average Hospital Street		5.7
Total Containers		117			
Average Containers per Location		1.625			
Average Containers per Street		6.2			

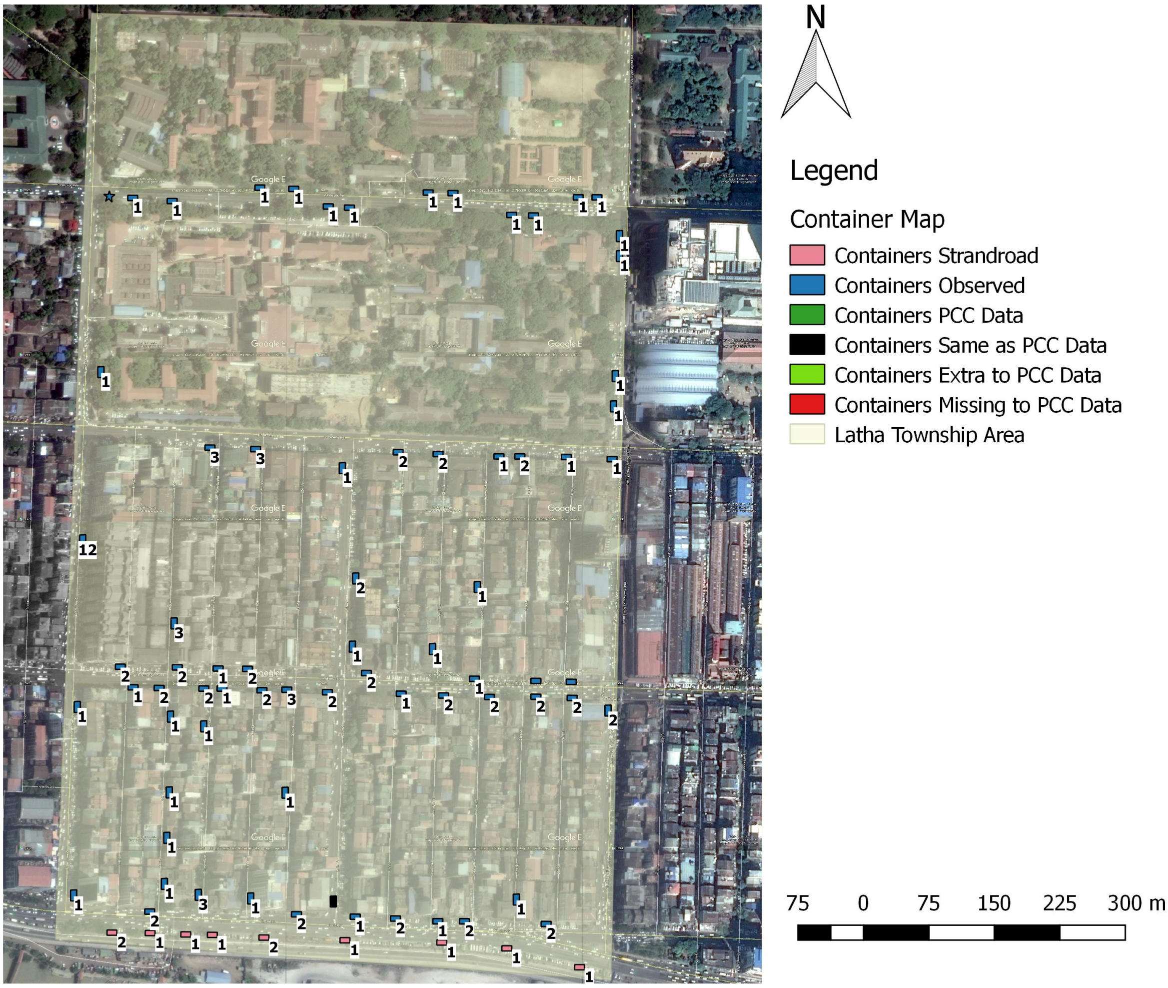


Figure C.6: The actual observed positions of the containers in the area. The numbered labels show the observed number of containers on that spot. The pink containers represent the recent extra placed containers on Strand Road (for the night markets).

C.3.4. Commercial Activities

Data about commercial activities was required in order to model the waste production by shops, restaurants and market salesmen in a socio-hydrological model. For example, commercial activities might have a large contribution to the solid waste production. The Latha Township is one of the six townships in the downtown central business district and had a high level of commercial activity. Moreover, in case of a flood it could be expected that businesses make less profits because of less customers and/or damage to properties and goods. A process that could be included in the socio-hydrological model (SHM).
For this study a distinction was made between different types of commercial activities. There were shops and restaurants deploying their activities in a physical building (shops), markets where salesmen sell goods from a stand on the street or market building (markets) and restaurants that are being runned from the streets (street restaurants). This difference was made since shops were better regulated whereas markets and street shops were sometimes also operated illegally. This had consequences for the collection of solid waste and the taxation on waste production that was only installed on officially registered commercial activities. Another reason for this differentiation was that most shops need higher water levels on the street before water may threat to damage their properties. However if there is a flood, it may well be that the damage to the shops is higher than to markets and street restaurants that are able to (temporarily) move their commercial activities.

Shops and restaurants were primarily situated along the larger streets: Lanmadaw Street, Sinn O Dan Street, Latha Street, Bo Ywe Road, Shwedagon Pagoda Road, Anawratha Road, Maha Bandula Road and Strand Road. The 24th street upper block was an exception and also had a high degree of commercial activities and there was even a multiple stories shopping mall along Maha Bandula Road between 24th street and Shwedagon Pagoda Road. There was a daily (morning) market in the 17th and 18th street (upper block). In the northern part of the 17th street upper block there also was a large market building in a basement. Along Strand road there was a (night) market that becomes active from around Noon and runs till around 10 to 11 pm. From the late afternoon, the night market also hosted a lot of street restaurants. Apart from the streets restaurants along Strand Road, most street restaurants were at the beginning of the smaller streets close to Maha Bandula Road. Maha Bandula Road had probably the most people passing by and thus provides ample opportunities to seduce a hungry passerby. The 19th street's upper block was an exception, since it hosted a lot of restaurants that served barbecue food on the street. Figure C.7 provides an overview of the different commercial activities in Latha, with estimations of the length of commercial activity stretches.

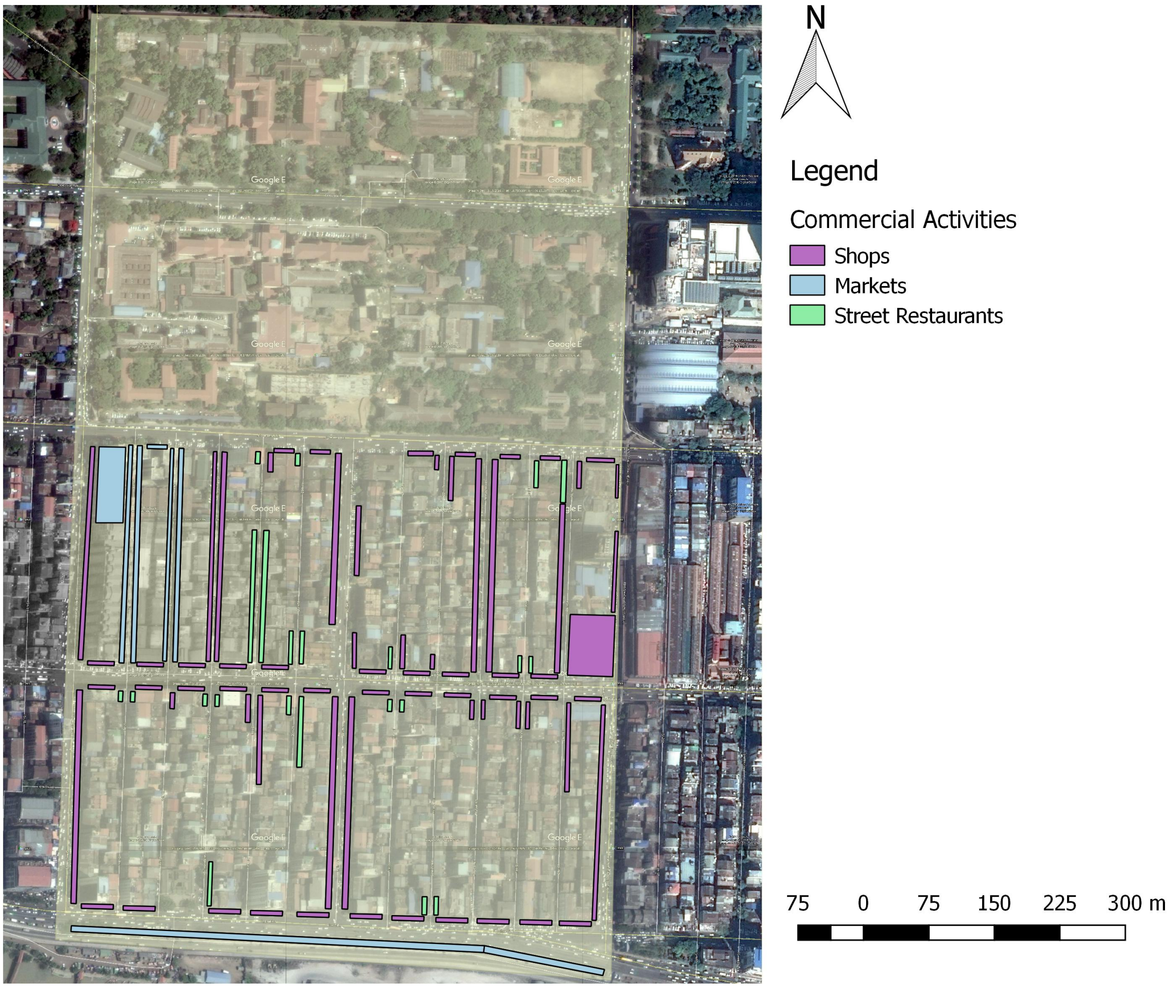


Figure C.7: Commercial activity map with indicative (estimated) running meters of activity. Three differentiations were made between the different commercial activities. Firstly, shops: physical building, including restaurants. Secondly, markets: stands or people selling non-food (half) products, raw materials or raw, unprocessed or half processed food products. Third and finally, street restaurants: small businesses that serve food and/or drinks on streets. Data obtained by field observations between 01-03-2017 and 30-03-2017.

C.3.5. Census Data

For this study, socio-economic data was collected in order to model socio-economic processes. This data was collected through questionnaires, interviews and observations. Census data provides a reference that was used to cross-check the results from the questionnaires. Moreover, it served as an additional data source for modelling socio-economic processes. The census data can be found in Section B.4.

C.3.6. Interview Data

For this study additional data was acquired through interviews. This data served also as a verification of some of the other datasets. The interview results are presented in a separate appendix, Appendix D.

C.3.7. Urban Drainage Network

The layout of the urban drainage network and dimensions of the drains were obtained from a map (Figure C.8). The map also indicates the directions of flow, location of FGSs and underground drains (not considered for this research).

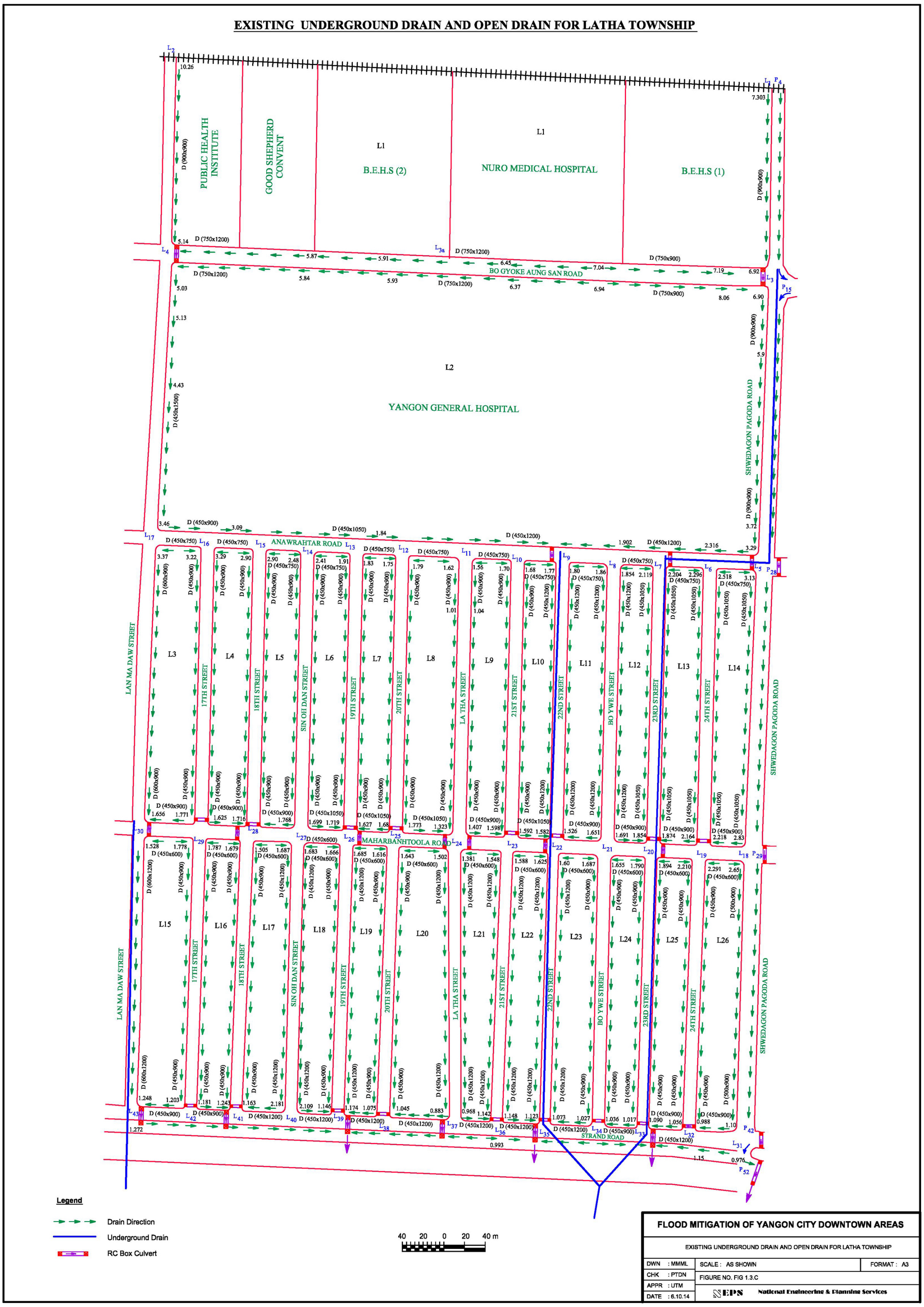


Figure C.8: Overview map of the existing urban drainage system of the Latha Township, for more details see Figure C.13. The map shows the location and dimensions of the drains, shows locations of culverts and provides ground elevation levels. It also indicates the directions of flow, location of FGSs and underground drains (not considered for this research). The map is titled: “Existing Underground Drain and Open Drain for Latha Township” and was created by the National Engineering & Planning Services (NEPS) on 06-10-2014. Obtained from Yangon City Development Council Engineering Department Roads & Bridges (YCDC EDRB) on 04-04-2017.

The urban drainage network layout map of Figure C.8 presents the data for the dimensions of the drains. There were no units specified, although it seemed reasonable that the used units for the dimensions of the drains were millimetres. The drainage network map also did not specify the types of inlets. For each different type of inlets, there might be different blockage probabilities. An explorative field observation study showed that there was a great variety in inlets for the Latha Township as the examples of Figure C.9 show.
As mentioned the obtained drainage map did not specify if drains were pressurized or not. Fieldwork (see Figure C.9 and Figure C.10) concluded that most drains should be characterized as open canals, apart from the culverts and a small section along Strand Road. Figure C.11 provides an overview of the pressurized and canal drains. The canal-type drains were typically covered with concrete slabs, although the sizes of these slabs varied (Figure C.10, top left and right). Some of the canal-type drains were not covered (Anawratha Road and Strand Road, Figure C.10 bottom right). The drains were made from a combination of concrete and bricks (Kyaw Mein Oo, personal communication, April 6, 2017), see Figure C.10 bottom left for an impression (picture taken on 39th Street). The maintenance state of the drains varied throughout the entire township, also see Figure C.10.
Based on the elevation data (see Section C.3.8) and the (overland) flow directions of the urban drainage map (Figure C.8) an indicative analysis was made which areas drained to which outflow FGS under low flow conditions, see Figure C.12. Gate 5 was expected to drain the western half of the residential area of the Latha Township. This area was expected to have the fastest response to rainfall as the more urban character result in higher runoff coefficients. Moreover, the longest flow paths in this area were shorter than the longest flow paths in the other areas. Gate 6 had by far the largest connected area (see Table C.6) and also the biggest lag between the peak in rainfall and discharge through the gate, since the flow paths were the longest. The area draining to gate 7 was the smallest, but it had long flow paths since it drained a part of the hospital area.
Under high flow conditions the areas might drain to different gates as all gates were connected trough a drain at the south side of Strand Road. Moreover, the hospital area parts might also drain through other gates, since there was a drain at the north side of Anarwrahta Road connecting the hospital area that drained to gate 6 and gate 7 (see Figure C.11). Furthermore, the analysis showed that the system is highly looped and thus alternative flood paths were possible. The results of the actual flood model should provide more insights in the dynamics.

C.3.8. Ground Level Elevation

Ground level elevation data was obtained from a map titled “Existing Underground Drain and Open Drain for Latha Township”, see Figure C.8. The map showed ground level elevations for each corner of the streets and some other points, see Figure C.13).
Based on the map, the minimum known ground level elevation within the residential area was +0.883 m with respect to an unknown reference system (north west corner of the Latha Street and Strand Road intersection). The maximum ground level elevation and the maximum elevation was +3.46 m with respect to an unknown reference system (north east corner of the Lanmadaw Street and Anarwrahta Road intersection). For more information on the reference system, see Section C.3.10.

Figure C.9: Example of four different drain inlets. Top left: small pipe like holes on 18th Street upper block. Top right: grated inlet on 18th Street lower block. Bottom left: large rectangular inlet on Latha Street. Bottom right: square inlet on Strand Road. The drain could be seen as canal from concrete or brick and mortar walls, covered by concrete slabs. The type of inlets, state of maintenance is varying from location to location. All pictures taken between 28-02-2017 and 05-03-2017.

Figure C.10: The drains canal drains had different types of concrete slabs that cover them off (top left, top right). The smaller slabs were more often partially broken or missing, as opposed to the larger slabs. The drains and culvert were made from a combination of concrete and bricks (bottom left, picture taken on 39th Street). Some of the drains were even without a cover, as for example the drains along the south side of strand road (bottom right). Data obtained by field observations between 01-03-2017 and 30-03-2017.

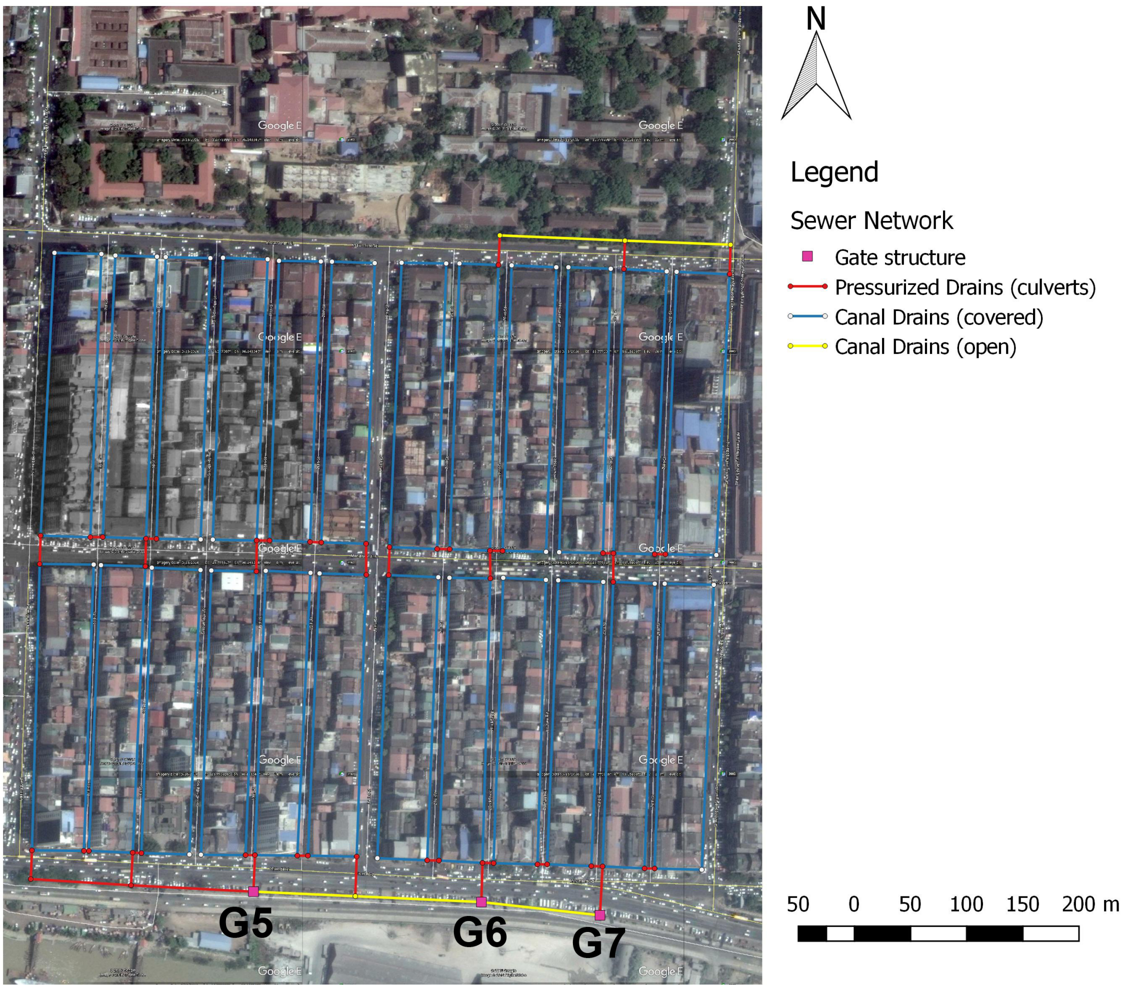


Figure C.11: Overview of type of drains. The drains that were classified as a covered canal are indicated in blue while open canals are displayed with yellow. Culverts and pressurized drains are depicted with red. The 3 gate outlet structures are indicated by the magenta squares (gate 5, 6 and 7). Data obtained by field observations between 01-03-2017 and 30-03-2017.

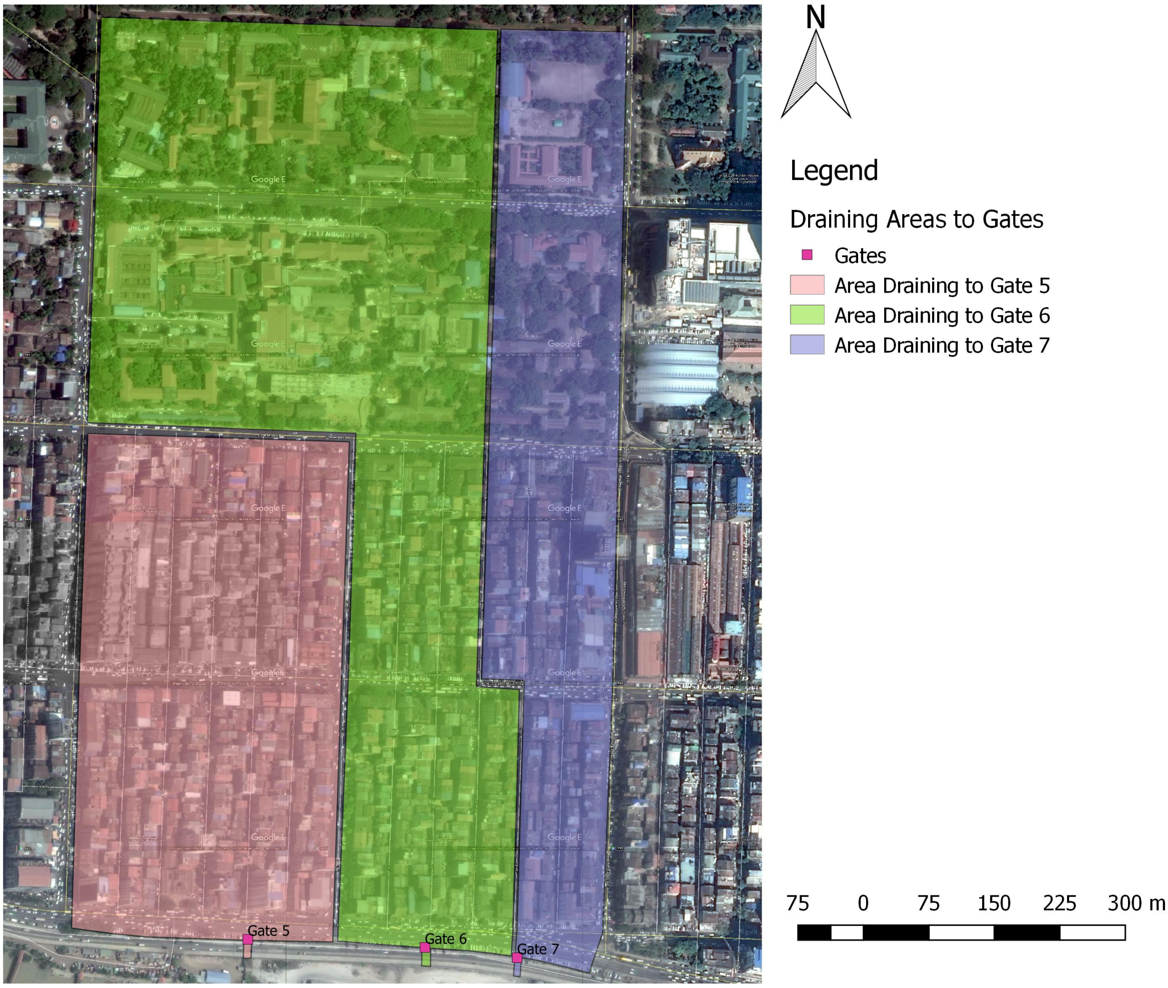


Figure C.12: Overview of which areas drained to which gate. Note that gate 6 (~317,000 m^2) had the largest draining area especially because the majority of the hospital compound eventually drained to this gate. Gate 5 (~179,000 m^2) and gate 7 (~149,000 m^2) were somewhat smaller. Gate 6 should have had a slightly longer lag between the peak of a rainfall event and the maximum out flowing discharge as a result of the long distance between the hospital compound and the gate. Data obtained by field observations between 01-03-2017 and 30-03-2017 and from Figure C.8.

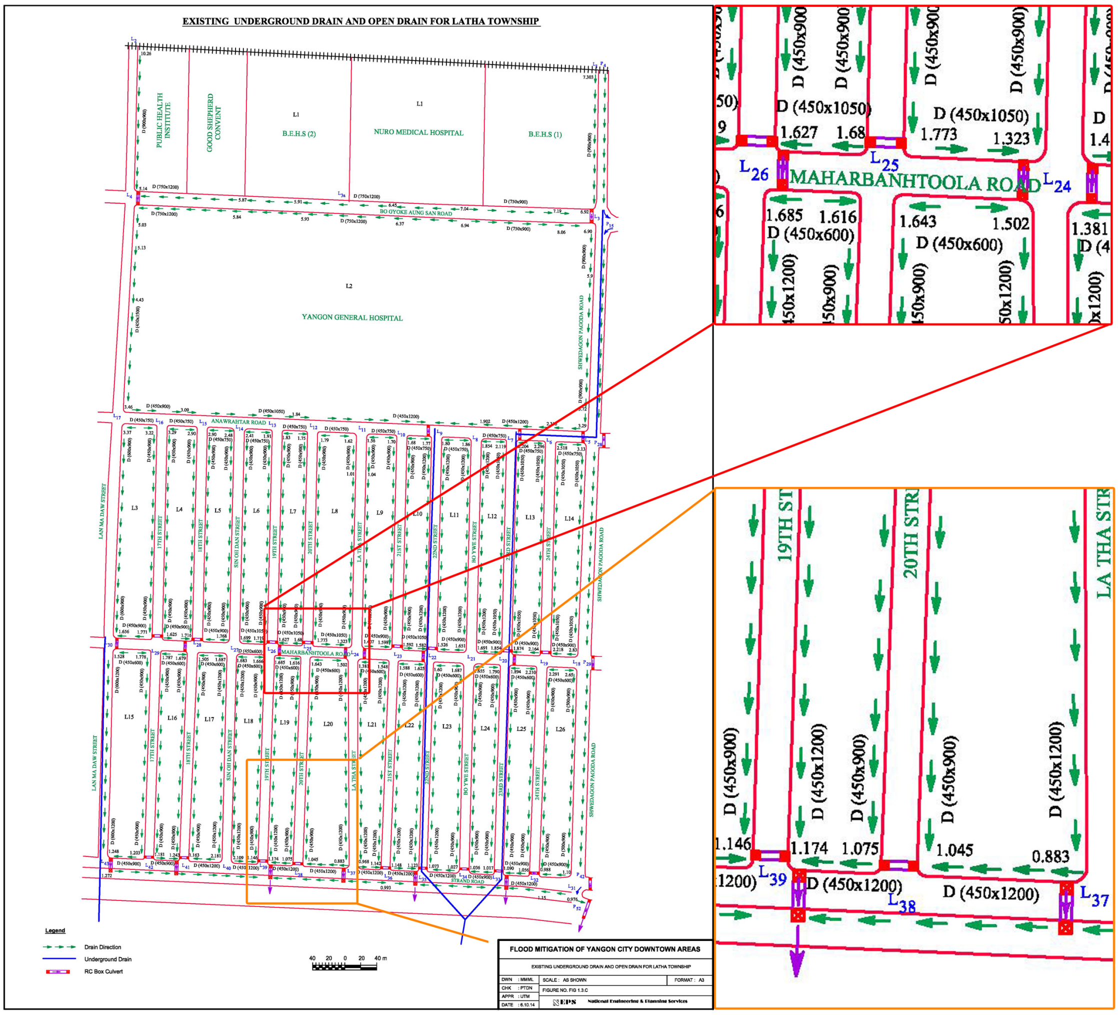


Figure C.13: Ground level elevation data was obtained from a map of the existing drainage system for the Latha Township. For example, in the top right detail you can read a ground level elevation of 1.323 m. Moreover, the detail also shows that the map provided the dimensions and positions of the drains e.g. 450x1050mm and the direction of flow through the drains (green arrows). Finally, culverts were also indicated by the magenta-red shapes. The fat blue lines were not relevant for this study. Modified from Figure C.8, "Existing Underground Drain and Open Drain for Latha Township", created by NEPS on October 6 2014 and obtained from YCDC EDRB on April 4 2017.

The ground level elevation point data was post-processed with Matlab, in order to estimate ground level elevations for the entire research area (the residential area), so that it could be used in the 2D overland flow module of the SOBEK model in a later stage. The research area was divided into square cells of 5x5 meter. With the known data points a 3rd order inverse distance weighting interpolation (see Equation C.1) was used to estimate ground level elevations.

$$\hat{z} = \frac{\sum_{i=1}^{n}\left(\frac{z_i}{d_i{}^3}\right)}{\sum_{i=1}^{n}\left(\frac{1}{d_i{}^3}\right)} \tag{C.1}$$

Inverse distance weighting gives a higher weight to known data point close to the point that is interpolated than for points that are far away. A first or second order inverse distance resulted in to big elevation jumps over the cells, whereas a 3rd or higher order resulted in a smooth enough surface. From these smooth enough surfaces the lowest order interpolation was selected. The result of the interpolation is shown in Figure C.14. Note that for usage in SOBEK some points (locations of buildings and outskirts of the raster) were replaced by NaN values (displayed as grey cells in Figure E.2). This was done to reduce the computation time in SOBEK.

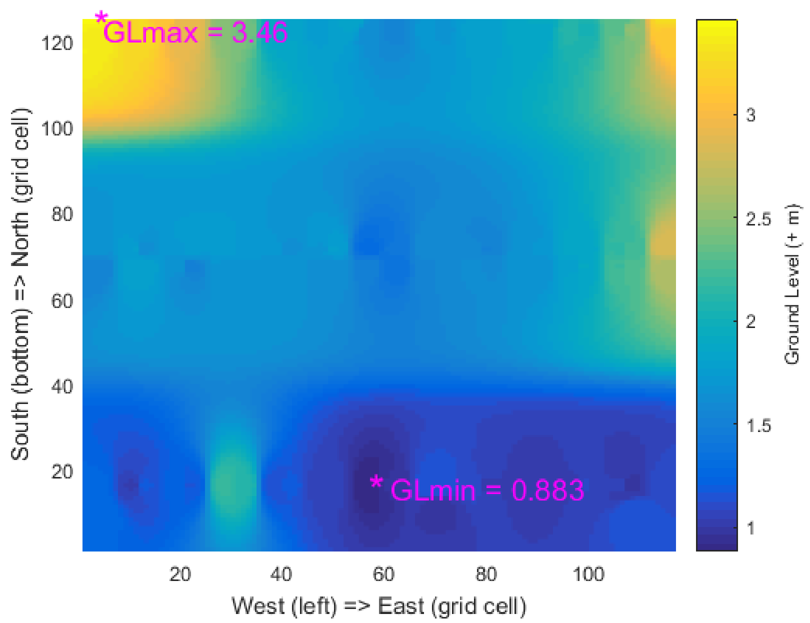


Figure C.14: Ground level elevations for the Latha Township. The township was divided into 5x5 meter cells. The ground level elevations were estimated by a 3rd order inverse distance interpolation based on known elevations in the Latha Township.

C.3.9. Flood Records

In order to validate the flood model results, flood records from past historic flood events were collected. These past historic flood events were documented by employees of the YCDC EDRB, see Figure C.15. This was done by scratching a line on the inside of FGS 7 (see Figure C.12 for the location of gate 7). For each severe flood event the water level was registered with the date of this event. For the water level YCDC EDRB used (Kyaw Mein Oo, personal communication, April 6, 2017) the reference of mean sea level (MSL) at Kyaikkami (formerly known as Amherst, Figure A.2).
The height between ground level outside of the FGS and the top of the FGS inside was measured with a roll-up tape and estimated at 1.85 meter, see Figure C.16. The distance from the top of the wall with the scratch marks to the actual scratch marks was also measured. The results are shown in Figure C.16 and Table C.3.
However, there seems to be an inconsistency in the data. For example the record of 14 July 2014 had a recorded water level of +6.81m MSL and a 47 cm measurement from the top of the structure. The record of 13 July 2014 had a recorded water level of +6.72m MSL and a measurement of 50 cm from the top of the structure. Thus the recorded data reported a difference of 9 cm, whereas the measurements resulted in a 3 cm difference.

Figure C.15: Scratch marks made by employees of YCDC EDRB for flood records. The scratch marks were on the inside of the FGS, downstream of the gate (for the normal drainage direction). Left you see the inside of the FGS. The top right provides an overview. Details of one of the flood mark records are shown bottom right, with own measurements to relate the measurements from YCDC to ground levels. All photos were taken on 06-04-2017.

Table C.3: Flood record scratch marks measurements, for different flood events. The forth column was obtained by subtracting column 3 from 1.40 m: the difference between GL and the top of the structure (see Figure C.16). Data collected on 06-04-2017.

Date of Record	Recorded Water Level (m MSL)	Distance from top inside (m)	WL above GL outside of gate (m)
04-08-2016	+6.28	0.74	0.66
22-08-2015	+7.22	0.45	0.95
14-07-2014	+6.81	0.47	0.93
13-07-2014	+6.72	0.50	0.90

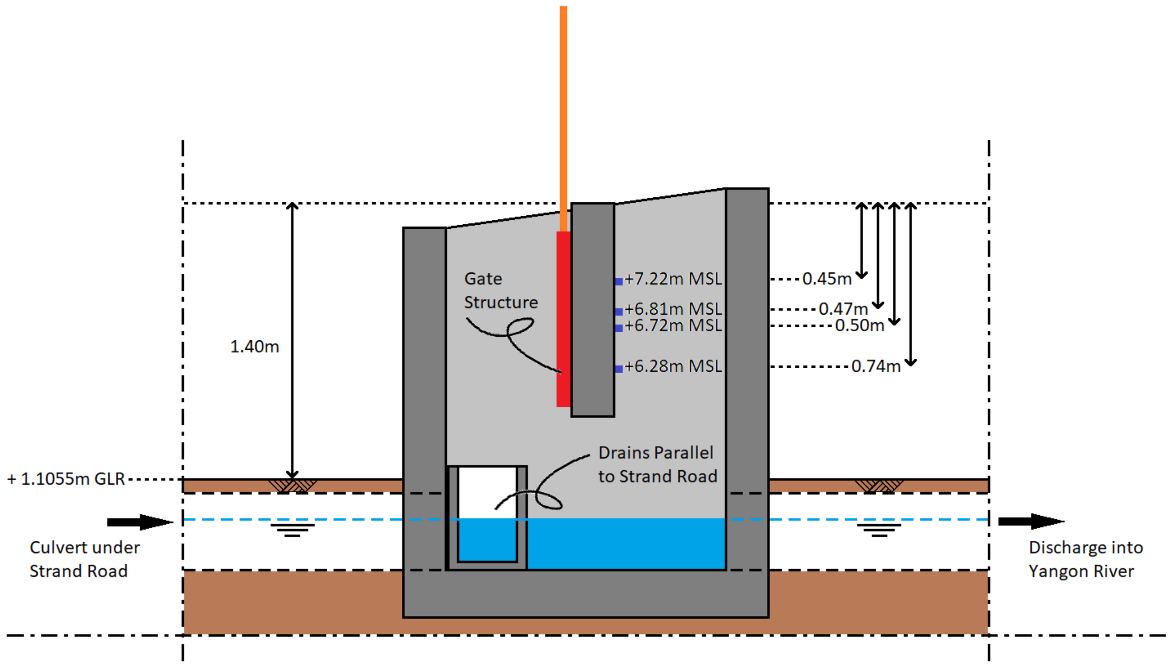


Figure C.16: A schematic cross-section of the FGS, not to scale. Ground level elevation at the FGS was +1.055 m GLR. In the structure 4 scratch marks were present (blue squares). The top of the wall with the scratch marks was 1.40 m above ground level. Data collected on 06-04-2017.

C.3.10. Ground Level Reference

As mentioned in Section C.3.8 the used reference system for ground levels was not specified on the map (Figure C.8), nor were the units for ground level elevations.
Employees from NEPS stated that NEPS used ground level elevations with respect to meters MSL at Kyaikkami (see Figure 2.3) (Nyein Thandar Ko, personal communication, June 14, 2017). The scratch marks (see Section C.3.9) provided a possibility to make a crude assumption about the ground level elevations related to mean sea level (MSL). However, it was questionable that this was the correct reference system.
The linear interpolation of Section C.3.8 resulted in a ground level elevation of 1.015 meters at the location of gate 7 and thus this corresponded to 1.015 m MSL according to NEPS. The collected scratch marks had much higher values, for example the flood record of 14 July 2014 had a recorded water level of +6.81m MSL (see Section C.3.9). This resulted in a water depth of about 5.8 m (6.81 – 1.01 = 5.80) during that historic flood event. However, the field measurements found that the scratch mark was made 0.93 m above ground level (see Table C.3).
Alternatively, the used ground level elevation reference system could be with respect to mean water level (MWL), since “ground level is usually indicated from main water level” (JICA and YCDC, 2013, p.5), which is +3.121 m (JICA and YCDC, 2013). It was assumed that: MWL is referenced to mean sea level (MSL), the units were meters and thus MWL = +3.121 m MSL.
However, this assumption is highly questionable as it also resulted in conflicting results. If ground level was

with respect to MWL = +3.121m MSL, than ground level at gate 7's location was +4.136m MSL. This meant that for the event of 22-08-2015 the water depth on the street at the FGS was about 3 meter (7.22 – 4.14 = 3.08). This was contradictory with the field observations too (Table C.3).

Since both approached did not provide an accurate reference system, an artificial reference system was introduced: ground level reference (GLR), which related ground level elevations to meter MSL. GLR used the field measurements with the flood record scratch marks. However, as was pointed out in Section C.3.9, the flood records also showed some inconsistencies. Therefore, three GLRs were set (Table C.4). The effects of the different GLRs were tested in different cases of the flood model (see cases 1,2,3 in Table E.1).

Table C.4: Data conversion that links ground level values from the drainage map (Figure C.8) to MSL, by means of the scratch marks.

GL Reference	Scratch Mark (Date)	Scratch Mark (m MSL)	GL (m GLR)	GL (m MSL)
GLR 1	22-08-2015	+7.22	0.00	+5.22
GLR 2	14-07-2014	+6.81	0.00	+4.83
GLR 3	13-07-2014	+6.72	0.00	+4.77

C.3.11. Yangon River Water Levels

The water level in the Yangon River was of importance as it served as the downstream boundary condition of the urban drainage system. The drains discharged into the river if the water level was sufficiently low and did not discharge when the 3 FGSs were closed because of too high water levels in the Yangon River.
Figure C.17 shows water levels for the Yangon River for the month of July in 2014. The data was acquired from the study of De Koning and Janssen (2015) on 05-06-2017. It was comprised of a discrete dataset from the Myanmar Port Authority with water levels for the year 2014. It remains unknown if these water levels were actual measurements or if they were modelled results of a tidal model. Contact with the authors from De Koning and Janssen (2015), the YCDC EDRB, local experts from Royal HaskoningDHV and experts from Arcadis has not resulted in any clarification on this. Attempts were made to contact the Yangon Porth Authority, but they did not reply.
In the dataset itself high water levels and low water levels were recorded together with the day and time. The location for these water levels was to be believed (M. Janssen, personal communication, 20-06-2017) at Monkey Point (see Figure A.5), however this also remains unclear. Monkey point is situated roughly 5 km downstream of outlet structures for the Latha Township, which were just to the left of the Yangon Port (see Figure A.5).

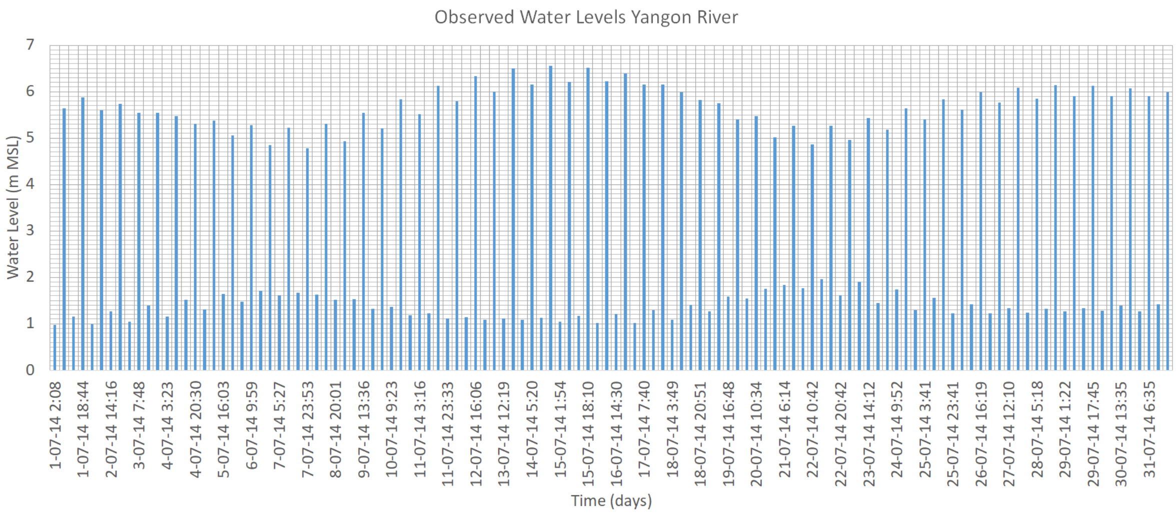


Figure C.17: Water Levels for the Yangon River with respect to meters MSL. Obtained from the research by De Koning and Janssen (2015), through personal contact with M. Janssen on 05-06-2017.

In Figure C.18a the blue points are the plotted discrete water levels from Figure C.17. The blue line is a fitted line through the points. It can be clearly seen that the water levels in the data set followed a sinusoidal pattern with a fast tidal influence (of about 12 hours) and a slow tidal influence (of about 15 days). A note has to be made that this could be an artefact, if the data set is not from actual measurements but from a tidal model (see Section C.3.11). The green line was the average water level based upon the discrete data of high water levels and low water levels. The average water level for July was + 3.52m MSL, which is higher than Means Water Level (MWL) as MWL = + 3.12m MSL (see Section C.3.10).
Since the rainfall data contained hourly rainfall volumes (see Section C.3.13), the smallest used model time step was also hourly. The only problem was that the water level dataset did not contain hourly values, but a discrete dataset that only contained the day and time of a high water level or low water level. A hourly time series for the water level in the Yangon River was estimated based on the time series.
Due to the fact that there was only data for the peaks available (high water levels and low water levels) and that the discrete time steps intervals were not constant, applying a Fourier fit proofed to perform poor (e.g. 8^{th} order Fourier fit, only has a R^2 of 0.0121). However, based upon the observations it was clearly observed that the behaviour could be described by a combination of sinuses. Therefore Equation C.2 was used in order to approximate and simulate hourly water levels for the Yangon River. The used parameters are shown in Table C.5 and the result is shown in Figure C.18a by the red line.

$$WL_{sim} = \Big(\big(A_{slow} - A_{fast}\big) \cdot sin\big(\omega_{slow} \cdot (t + t_0) + \varphi_{slow}\big) + A_{fast}\Big) \cdot sin\big(\omega_{fast} \cdot (t + t_0) + \varphi_{fast}\big) + WL_{mean} \quad \text{(C.2)}$$

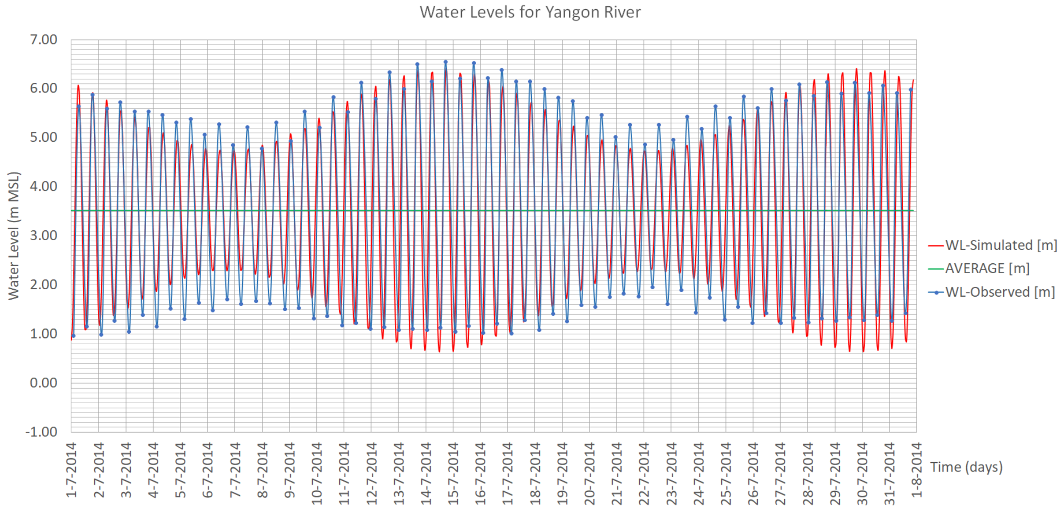
Table C.5: Used parameters for Equation C.2.

Parameter	Value	Units
A_{slow}	2.900	m
A_{fast}	2.065	m
T_{slow}	15.500	days
T_{fast}	0.518	days
ω_{slow}	0.405	1/day
ω_{fast}	12.12	1/day
φ_{slow}	0.5π	(-)
φ_{fast}	-0.1π	(-)
WL_{mean}	3.525	m MSL
t_0 (01-07-2014 00:00)	84821	days
t	Input	days
WL_{sim}	Output	m MSL

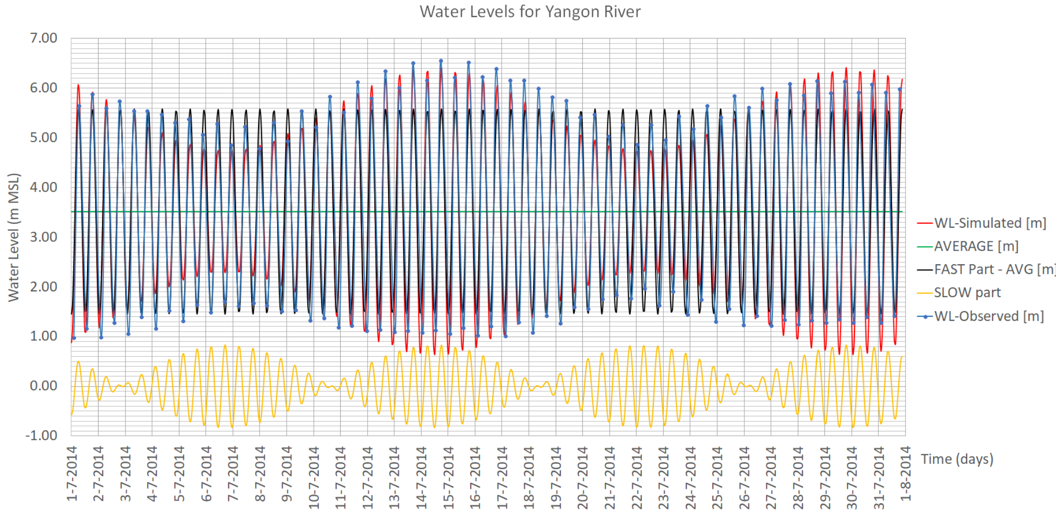
The fit was manually made by estimating the different parameters and tweaking them. The fit was optimised for the high water levels during the period from 11-07-2014 till 18-07-2014. Equation C.3 was used in order to plot the fast part of the water level: black line in Figure C.18b and Figure C.18c, and Equation C.4 was used in order to plot the slow part of the water level: yellow line in Figure C.18b and Figure C.18c.

$$WL_{fast} = A_{fast} \cdot sin\big(\omega_{fast} \cdot (t + t_0) + \varphi_{fast}\big) + WL_{mean} \quad \text{(C.3)}$$

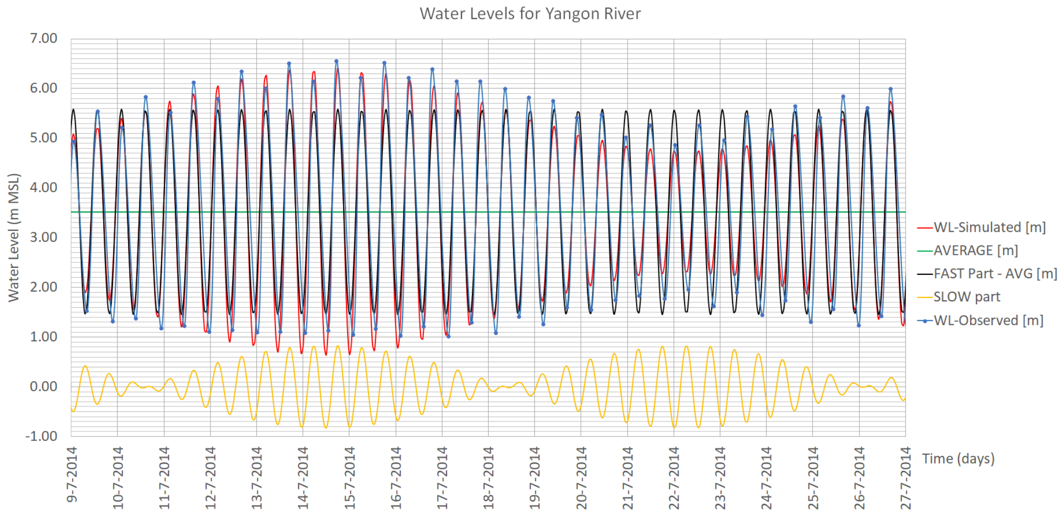
$$WL_{slow} = \big(A_{slow} - A_{fast}\big) \cdot sin\big(\omega_{slow} \cdot (t + t_0) + \varphi_{slow}\big) \cdot sin\big(\omega_{fast} \cdot (t + t_0) + \varphi_{fast}\big) \quad \text{(C.4)}$$



(a) Water Levels for the month of July 2014. The blue point was the actual discrete data from the original dataset. The blue line was sketched through the points but had no mathematical representation. Based on the blue line it was observed that there was a fast tidal influence with a period of about 12 hours and that there was a slow tidal influence of about 15 days. The red line was a simulated water level which was a combination of sinuses as in Equation C.2. The green line was the average water level of the observations.



(b) Water levels (observed and simulated) for July 2014 including the 2 part of the approximation. The fast part in black (Equation C.3), the slow part in yellow (Equation C.4).



(c) Detail of water levels (observed and simulated) for July 2014 including the 2 part of the approximation. The fast part in black (Equation C.3), the slow part in yellow (Equation C.4). If you combine the fast part (black line) and slow part (yellow line) you will get to the simulated series (red line

Figure C.18: The simulated Yangon River water levels.

C.3.12. Operation Rules Outflow Flood Gate Structures

Latha's drainage system drained through 3 outflow flood gate structure (OFGS) (e.g. Figure C.19, the purple arrow in the orange detail of Figure C.13 and Figure C.15) that were closed during high water levels in the Yangon River. They were an integral part of the urban drainage system and thus had to be modelled in the flood model model. These gates were manually operated by YCDC EDRB employees (Kyaw Mein Oo, personal communication, April 6, 2017). However, there were no clear operation rules for when the gates were closed. Most of the times the gates were closed about 2 to 4 hours before high water (Kyaw Mein Oo, personal communication, April 6, 2017).

Figure C.19: Flood gate structure along Strand Road.

C.3.13. Rainfall Data

The main input for the flood model was rainfall. Figure C.20 shows the hourly rainfall volumes for Yangon in July 2014. This data was extracted from a dataset containing the hourly rainfall volumes for May 1st 2014 till November 30th 2014 and May 1st 2015 till November 30th 2015. Figure C.21 shows an intensity duration frequency curve (IDF-curve), that was made by NEPS based on the rainfall records of the Kaba Aye Rainfall station (See Figure A.5) between 1980 and 2011.

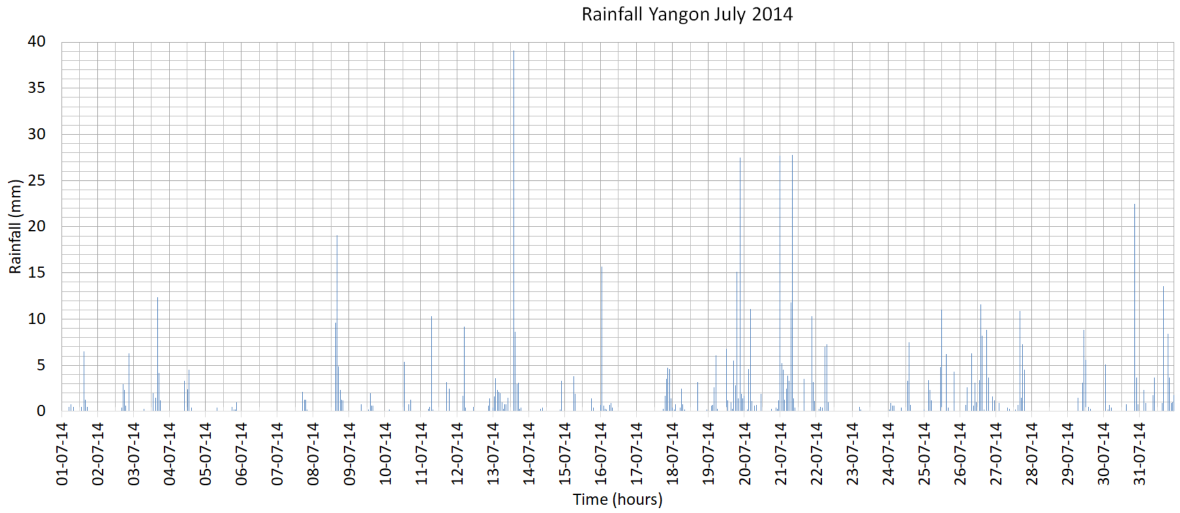


Figure C.20: Hourly precipitation from Kaba Aye Station (See Figure A.5) for the month of July 2014. It could be observed that the total hourly precipitation did not exceed 40mm per hour, which is relatively low. Also, there were no extreme cases of events with long durations and with a relatively high (average) intensity (Also see Figure C.21). Obtained from Dorien Honingh on 15 September, 2016.

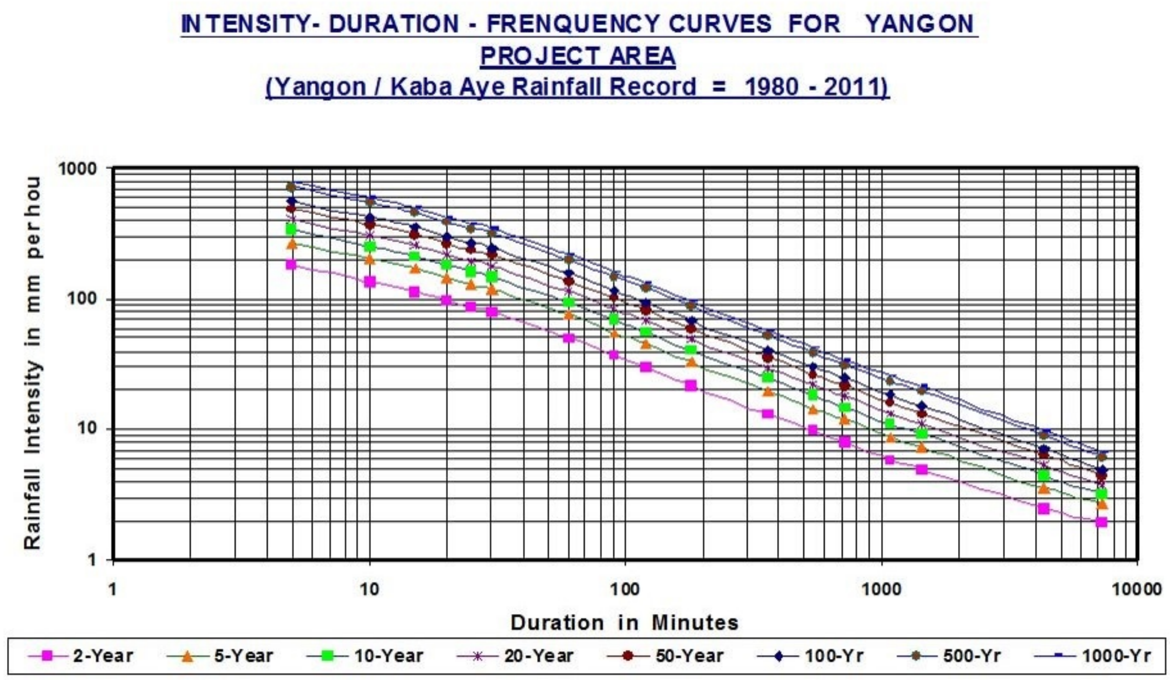


Figure C.21: Intensity Duration Frequency Curve for Yangon. Made by NEPS from data of 1980 till 2011, obtained from YCDC EDRB on 04-04-2017.

To get a better understanding of how extreme the rainfall was that caused the 2014 floods (see Section C.3.9) the rainfall dataset was analysed for the month of July 2014. For durations between 1 hour and 24 hours (with increments of 1 hour), the average intensities were calculated and plotted in Figure C.22. The analysis showed that the average one hourly intensity did not exceed 40mm in July 2014. For a duration of 9 hours the ID-curve made a jump. This was the result of the temporal distribution of the rain. In a certain period of 9 hours, the first and ninth hour had significant more rain than the hours in between, see Figure C.23.

Based on Figure C.24 there seemed to be an (almost) exponential relation for 1 till 8 hours, a different exponential relation for 9 hours till 22 hours and again a small jump from 22 hours to 23 hours. Something similar as in Figure C.23 may explain this second jump.
When the rainfall of July 2014 was compared to the long term statistics of Yangon (Figure C.22), it was concluded that there was hardly any extreme rainfall in that period. The average intensities did not exceed a return period of once in two years.
Since the rainfall in July 2014 was not extreme, this was good time frame to research urban pluvial flooding as there are no likely extreme events that caused the actual floods. Moreover, it may be expected that the drainage system was designed in such a way that it should be able to sufficiently drain under ordinary (not extreme) conditions.
Any flooding under such conditions might be an indication that either the model (input data) is wrong or that the assumption of a sufficiently designed drainage system is false. If there is no flooding under ideal conditions: no blockages, no leaking gates and no increased friction because of solid waste in the drains, we could experiment if such inclusion of processes actually do result in flooding. If it does flood under conditions with blockages, leaking gates or increased friction, this might be a strong indicator that social processes such as maintenance and solid waste management play a role in the flood problem.

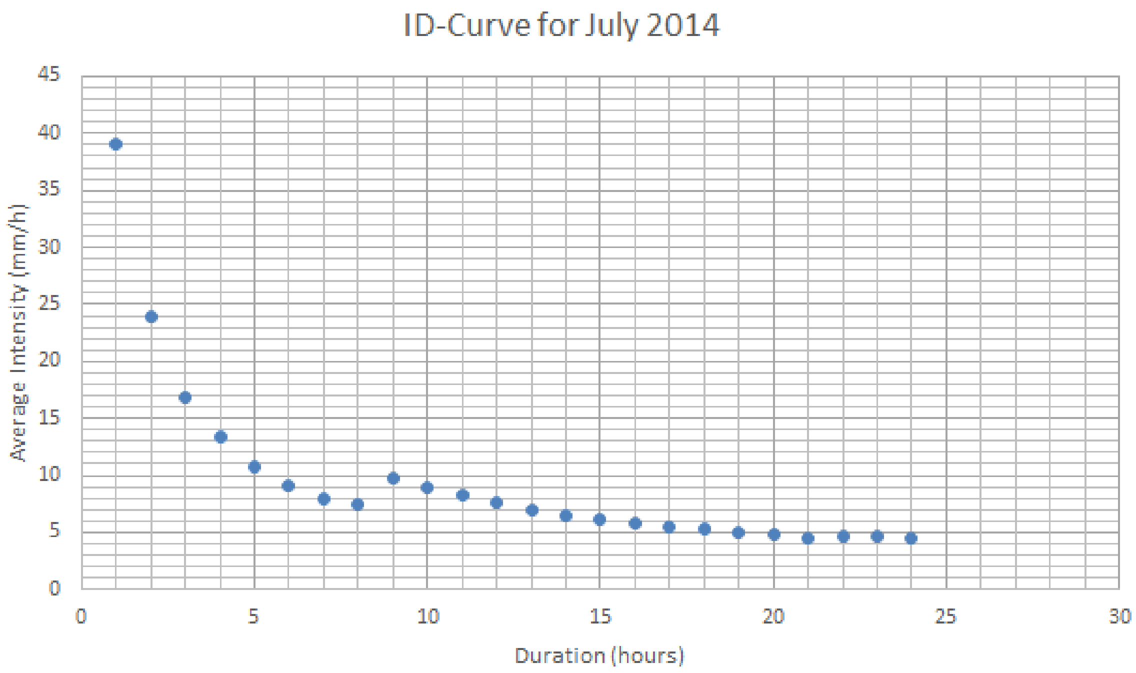


Figure C.22: ID-curve based on hourly rainfall data at Kaba Aye Station for the month of July 2014.

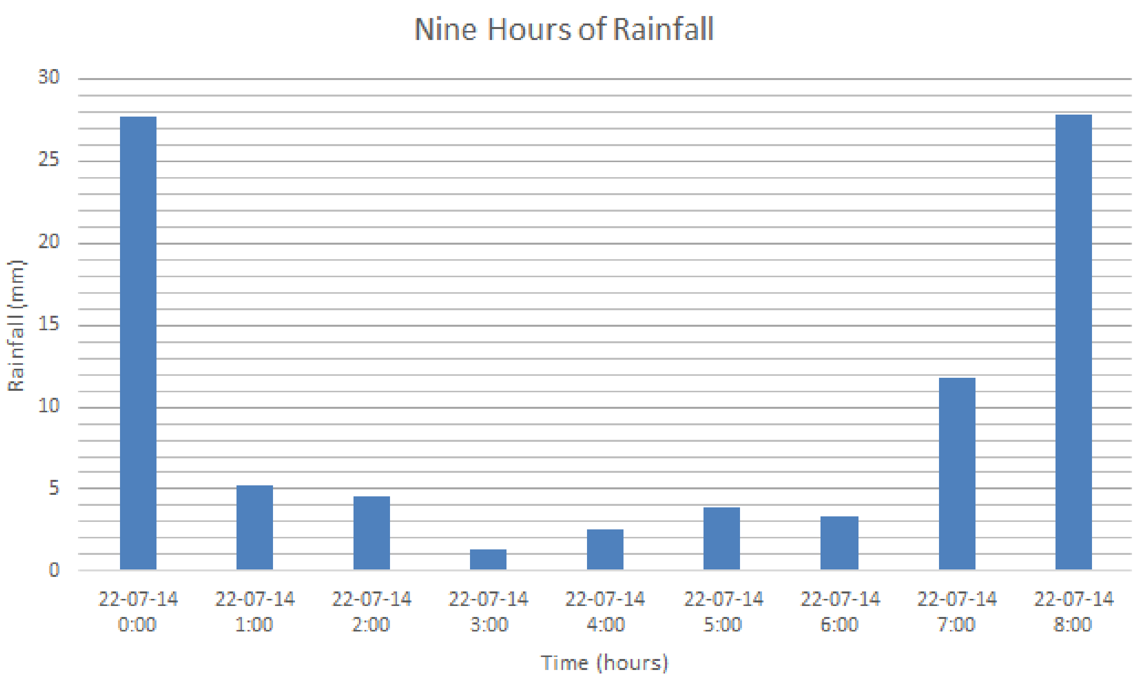


Figure C.23: Nine hours of rainfall with a high rainfall volume in the beginning and at the end of the duration. This clarifies the jump in the ID-curve from 8 hours to 9 hours in Figure C.22

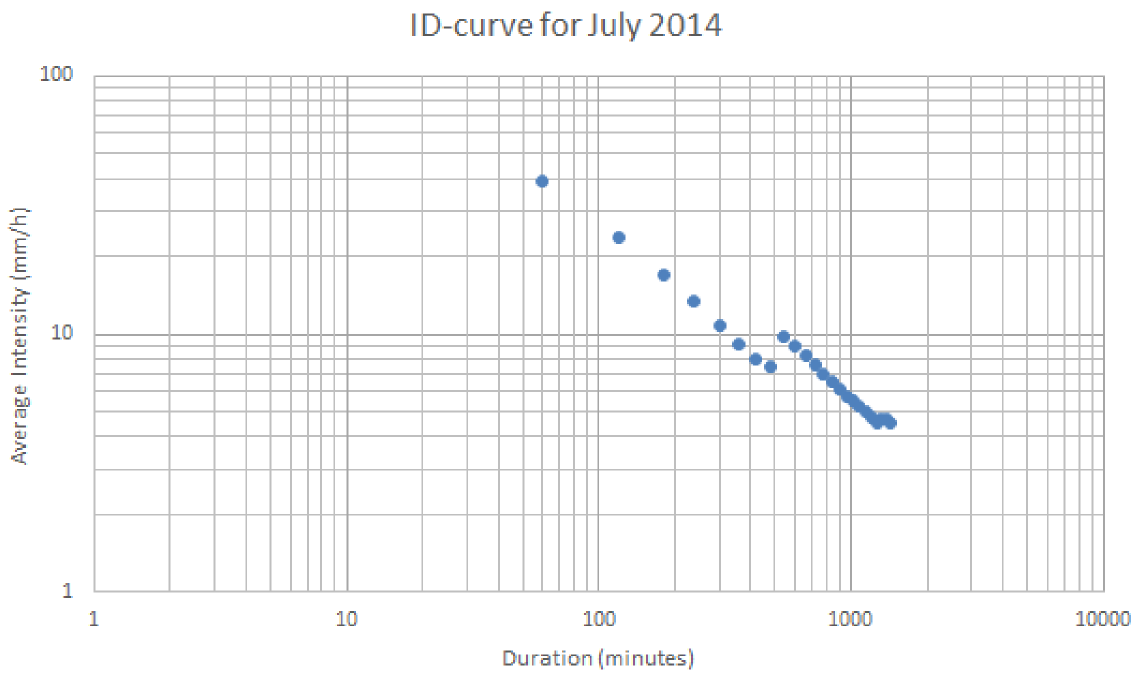


Figure C.24: ID-curve on log-log scale. We see 2 jumps, indicating a period of rainfall with a relative high precipitation in the first and last hour. Also there seemed to be two (quasi) exponential behaviours for 1 till 8 hours and 9 till 22 hours, because of the (almost) linear trend on log-log scale (see Figure C.25).

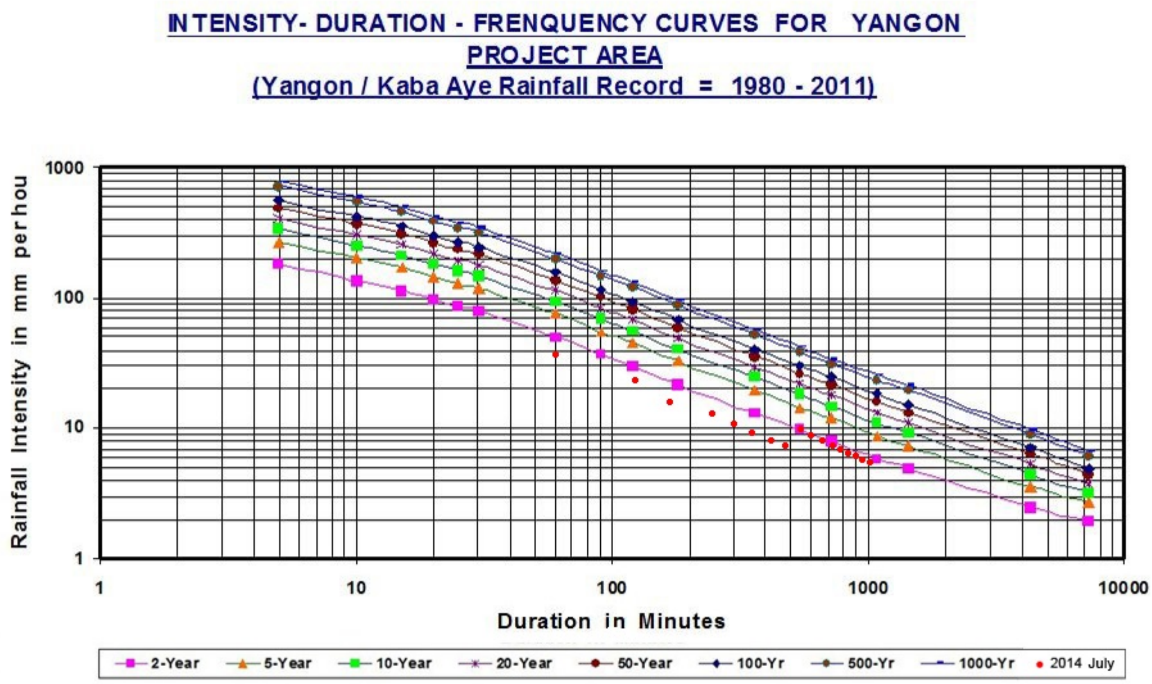


Figure C.25: Average Intensities for July 2014 with respect to the long term statistics for Yangon. We may conclude that the rainfall in July 2014 is not extreme, especially for the durations of 1 till 8 hours.
IDF-curve made by NEPS from data of 1980 till 2011, obtained from YCDC EDRB on 04-04-2017 (see Section C.3.13).

C.3.14. Total Water Flow

Rainfall is not the only water that had to be drained by the drains. In Latha there was a combined sewer system. This waste water, the so called dry weather flow (DWF) together with the runoff from the rainfall storm weather flow (SWF) is the total weather flow (TWF). In order to model the SWF and DWF, the contributing runoff areas were estimated. Figure C.26 shows the different areas that drain to a specific drain.

C.3.14.1. Storm Water Flow

From all the rainfall that falls on the Latha Township not every drip ends up in the drainage system. Processes like interception, transpiration and infiltration reduced the total runoff. Since there was insufficient data to correctly model all these processes, rainfall runoff coefficients were used to estimate the percentage of rainfall that actually ends up in the drainage system. For design plans by NEPS, values of around C = 0.8 were used for the residential area (for the areas See Figure A.14) and around C = 0.4 for the hospital area (U Khin Lat (NEPS), personal communication, 09-03-2017).

C.3.14.2. Dry Weather Flow

The contributed areas from Figure C.26 were used for the allocation of the inhabitants of the Latha Township. The total number of inhabitants (25.000, see Table B.2) were distributed over the Latha Township, according

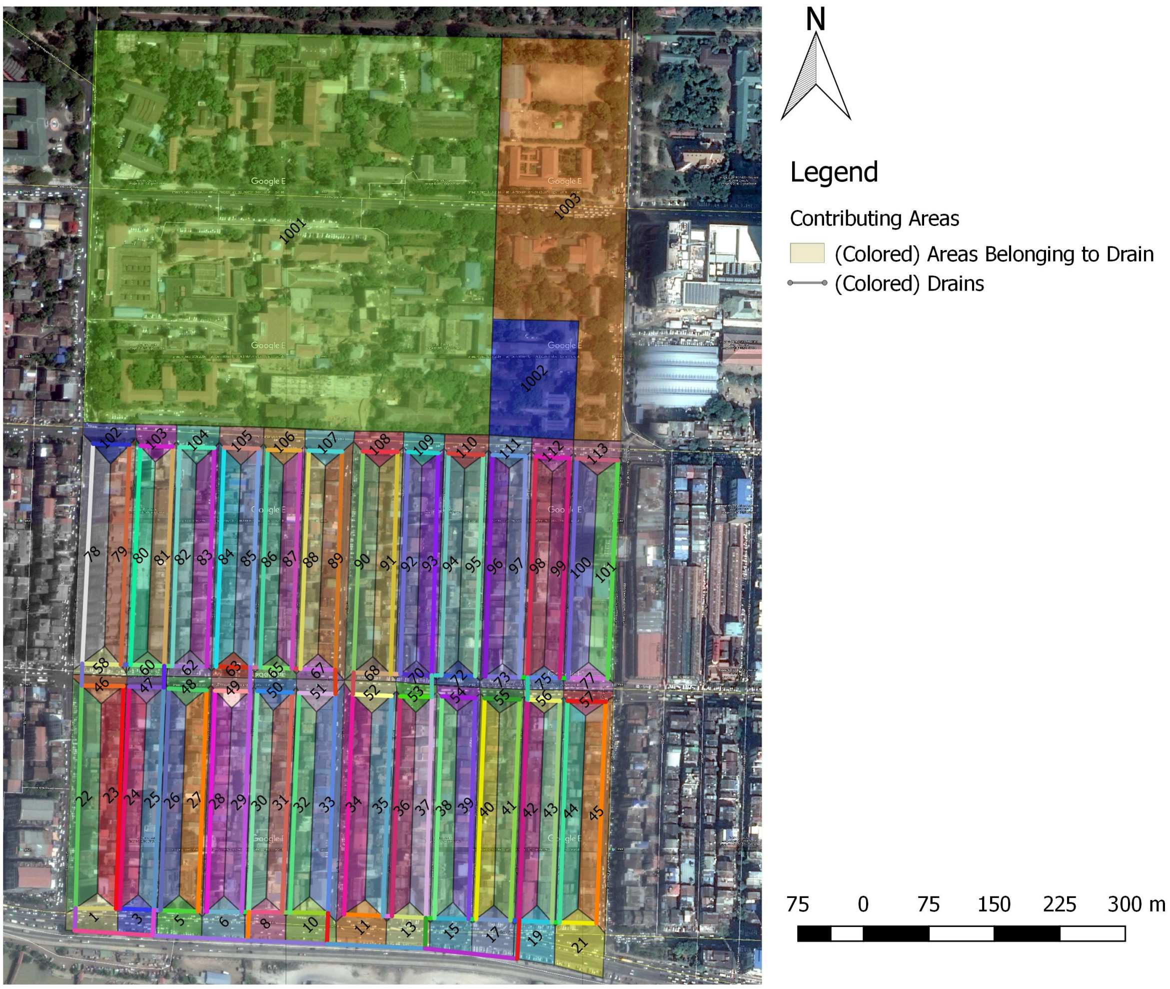


Figure C.26: Contributing areas per drain. There were a total of 104 individual areas that contributed to the total area of roughly 645,000 m^2. The areas 1001, 1002 and 1003 were modelled as upstream boundary conditions. They drained to the top 3 (pressurized) drains that are connected by an open drain along the north side of Anarwrahta Road, see Figure C.11. The surface area of the different sections is shown in Table C.6. Data obtained by field observations between 01-03-2017 and 30-03-2017 and from Figure C.8.

Table C.6: This table shows the areas of the contributing areas shown in Figure C.26. It also provides an overview of the population distribution that was used for the DWF.

Area ID	Area (m^2)	People (-)	Area ID	Area (m^2)	People (-)	Area ID	Area (m^2)	People (-)
1	1959	115	43	5237	308	84	5973	351
3	1612	95	44	6209	365	85	5912	348
5	1870	110	45	7676	451	86	5729	337
6	1880	111	46	1180	69	87	5568	327
8	1823	107	47	912	54	88	5824	342
10	2342	138	48	1129	66	89	7646	450
11	2339	137	49	1114	65	90	7671	452
13	2037	120	50	1130	66	91	6354	374
15	2151	126	51	1237	73	92	5522	325
17	2314	136	52	1311	77	93	6008	354
19	2481	146	53	985	58	94	5820	342
21	3431	202	54	881	52	95	6416	377
22	8360	491	55	885	52	96	5973	351
23	6197	364	56	800	47	97	5978	351
24	5551	326	57	1023	60	98	5773	339
25	5433	319	58	1160	68	99	5632	331
26	5761	339	60	862	51	100	6657	391
27	6685	393	62	941	55	101	6581	387
28	5815	342	63	910	53	102	1797	106
29	5942	349	65	816	48	103	1466	86
30	5439	320	67	926	54	104	1581	93
31	5850	344	68	875	51	105	1588	93
32	5944	349	70	739	43	106	1477	87
33	7608	448	72	910	53	107	1607	94
34	7822	461	73	947	56	108	1599	94
35	6345	373	75	871	51	109	1312	77
36	5746	338	77	1199	70	110	1477	87
37	5720	336	78	8172	481	111	1337	79
38	5991	352	79	6350	373	112	1328	78
39	5917	348	80	5609	330	113	1607	94
40	5620	330	81	5748	338	1001	211479	2646
41	6232	366	82	5782	340	1002	13076	164
42	5794	341	83	6001	353	1003	55142	690

Residential Area Total Area (m^2):	365751	**Residential Area Total Population (#):**	21500
Hospital Area Total Area (m^2):	279697	**Hospital Area Total Population (#):**	3500
Total Area (m^2):	645448	**Total Population (#):**	25000

to the area. However, although there were people living in the hospital area (wards 9 and 10, see Figure A.14, Section C.3.2 and Figure A.20), areas 1001, 1002 and 1003 in Figure C.26), the exact number remains unclear. From the census data (Table B.2) it was know that there were about 7000 people living in institutions (this included hospitals) in the Latha Township. A part of this population had to be living on the hospital terrain. For this research it was assumed that this was 50% and thus 3500 people. The 3500 people were assumed to be distributed relative to the contributing areas of the hospital terrain (areas 1001, 1002 and 1003). The remaining 21500 people were distributed according to the relative areas of the areas 1 till 113. The DWF was modelled (for simplicity) to flow in the drain from the upstream side of the drain for the entire area at once.
The DWF was estimated based upon the water consumption in the township. The reported water consumption for Yangon was 94 L/capita/day in 2011 (JICA and YCDC, 2013, p.95). This number would probably be somewhat higher for 2014, because of increased wealth. Moreover, the average income of people living in the Latha Township was higher than the whole of Yangon and thus the water consumption might be expected to be higher. However, not all of the consumed water will end up in the drains and a small loss of consumed water is reasonable.
For the total DWF it was also likely that in the Latha Township the dry weather flow was higher than for other parts of Yangon, because of the relative higher degree of commercial activities.
Since exact numbers for the Latha Township were missing, the dry weather flow is estimated on 120 L/capita/day (on the high side), as this results in a scenario which was more critical when looking into flooding. This is below the expected water consumption of 173 L/capita/day in 2040 (JICA and YCDC, 2013, p.95). It may be expected that water consumption was not constant over the day. Moreover, there may have been extraordinary days where during a period the actual water consumption was a lot higher than the average daily water consumption. Usually this results in the usage of peak factors. In this study peak factors were used for some cases, see Section C.3.14.2.

C.4. Discussion

In general the discussion on the datasets will be in the relevant chapters and appendices where the data was actually used.

C.4.1. Urban Drainage Network

Although the drainage map only showed drains that run along the streets, field observations showed that there were also drains in between the houses. These drains, drained the DWF and runoff from the back of the buildings to the main road, see Figure C.27. However, these canals were not modelled in order to simplify the flood model and since there was no data available about the dimensions.
Interviews with the YCDC EDRB, field observations and the questionnaires provide data that from 2015 onwards, improvements were made to the drainage system and street's ground elevation levels.
The impact of ignoring the back canals and improvements to the drainage system was limited. The back canals eventually drain to the main drains and change the distribution of the runoff and DWF slightly. However, since the runoff and DWF were modelled to enter the drain at the beginning, this is a worst case scenario. In reality a part of the flow will enter the drain more downstream, which has a positive effect on the drainage speed.
The improvements to the drainage system were also expected to have a positive effect on reducing the flood vulnerability, since the larger drains result in less friction losses, more storage and a lower blocking/clogging probability. Moreover, the modifications were made after 2014, while the flood model was used to model 2014. To even further reduce the impacts additional data and measurements could help. Cooperation with the YCDC EDRB is most likely required.

C.4.2. Ground Level Elevations

One of the problems faced while interpolating the ground level elevations was the limited number of known points and the spatial distribution of these points. The elevation data was only available on street corners. The street pattern was a grid-like layout with most streets running from north to south which were connected by three main road running from west to east. This resulted in the situation that the distances between street corners in west-east direction were short and long distances between street corners in north-south direction.

Figure C.27: Example of a canal between (behind) the houses that drains back of houses in case of runoff and transports the DWF to the main drains.
Picture taken on 11-01-2017

As a consequence it was more likely that the interpolation was a better approximation for the main west-east oriented roads (especially Maha Bandula Road and to a lesser extent Anarwrahta Road and Strand Road) than for the streets that are oriented north-south (Lanmadaw till Shwedagon Pagoda Road).
The limited number of points in the north-south direction introduced another weakness. For this model all known points were used to interpolate an unknown point. This meant that for example points from the south-east corner also effect edthe interpolation of points all the way in the north-east corner, albeit really small. The interpolation results might be improved by implementing restrictions on e.g. the number of closest points used for interpolation or a maximum distance between the point being interpolated and the known points that are used for the interpolation.
Furthermore, one of the weaknesses of inverse weighting interpolation was that the interpolated values can never be outside of the known maximum (upper bound) and minimum (lower bound) values. However, in reality there might have been points in the Latha Township that were actually higher or lower than maximum or minimum known ground level elevations. Another point of discussion was the used order of inverse distance weighting interpolation. The judgement of the most suitable order was in this case based upon subjective criteria.
As a final weakness, there was the missing ground level reference. It remained unknown what the actual ground level was compared to the Yangon River water levels.

The uncertainties in the ground level elevation data as a result of interpolation had an impact on the reliability of the flood model. Water depths, flood frequencies and flood durations for example may be overestimated if the ground level is too low or under estimated if the elevation is too high.
The uncertainty in the ground level elevation data had a bigger impact on the lower blocks of the Latha townships, since these were more low-laying than the upper block and thus were more flood prone than the upper block.

Extra measurements in especially the lower block streets (north-south oriented) could help to improve the accuracy of the results. By also measuring the elevation at some of the known points it is possible to correlate the other known data points to a known reference level.
Furthermore the resolution of the used grid (5x5 meter cells) could be increased to get better (interpolation) results. Such a modification will result in longer computation times whereas the observed improvements on accuracy may be limited, and thus therefore the acquisition of additional elevations points with a known reference level should get priority.
Another option would be to find a point (e.g. Maha Bandula Park) and obtain the elevation data in the same (unknown) reference system NEPS used for the Latha Township ground level elevation dataset. Such a point could then be correlated to a datum using STRM-DEM (1-arcsecond) data. Unfortunately there is not a suitable point in the NEPS dataset for Latha that allows for such a strategy. The problem is that there is not a sufficient large enough area with a known NEPS elevation.

C.4.3. Flood Records

There seemed to be an inconsistency as was mentioned in the results section. This had an effect on the reliability of the data for verification of the flood model results. YCDC EDRB did not seem to have clear or strict guidelines and procedures for when a flood was recorded. Therefore, it might be that in reality the number of floods is higher when shorter durations or lower water depths were also considered and recorded as a flood.

C.4.4. Yangon River Water Levels

For a drainage system that discharged into a tidal river (the downstream boundary condition), with outflow structures that were operated based on the downstream water level it was really important to have good data on the downstream water levels. As was mentioned in Section C.3.11 there was a high uncertainty on the reliability and quality of the data. It was even unknown if the water levels from the dataset were actually measured or if they come from a tidal model. Furthermore, the data was measured/modelled for Monkey Point and not for the Yangon River at the location of the gate outlet structures.
In order to work with the collected data, the discrete data had to be approximated using Equation C.2 and the parameters from Table C.5. The approximation of the simulated water levels were done by hand on subjective criteria, which is a clear weakness.

That the data was actually for Monkey Point and not for the Yangon River adjacent to the Latha Township was the least crucial weakness. The water level at Monkey Point might be different for example due to backwater curves because of the confluence of Yangon River with the Bago River and Panzundaung Creek. However, the Latha Township drainage outflow structures were relatively close to Monkey Point that such effects may be limited. Moreover, reliable data for the Yangon River, Bago River and Panzundaung Creek such as discharges, cross-section profiles, riverbed slopes and other required data might be scarce. Therefore it will be hard to study the precise effect into great detail.
More troublesome seemed to be the fact that the water levels were probably derived from a tidal model. This meant that was impossible to assess the quality of the data, as the model and model's assumptions were unknown. For example, did this model update its predictions based upon the actual discharge in the Yangon River, Panzundaung Creek and Bago River? This is of importance as the river discharge effects the tidal progression. Once again, reliable data for the three rivers may be scarce, making it hard to improve the model output.
The biggest impact seemed to be that the river water levels effected the discharge capacity of the drainage system and the operation of the gated outflow structures. Too high river water levels will result in too low discharges (shorter durations of free flow and smaller discharges under submerged flow conditions) and too frequent closures of the gates which might result in completely filled storages in the drains and eventually flooding. For too low river water levels the opposite applies.

One of the things that could be done is to try and investigate if the data is indeed modelled in a tidal model and if so what does the model look like and what assumptions are made. This might allow for a better judgement on the reliability of the data.
However, what seems to be a better improvement is to obtain a reliable dataset with actual measured water levels with a known reference datum and run the model with that data.
As obtaining a reliable old dataset might turn out to be difficult the best solution would be to do water level measurements in cooperation with the Myanmar and run the model with rainfall data, ground level elevation data, drainage network layout data, etc. that is recorded on the same time. Such a dataset may be of great value to other researchers, YCDC, ministries and other organizations such as the Yangon Port Authority. The same applies to e.g. discharges, cross-section profiles, riverbed slopes data.

C.4.5. Rainfall Data

The rainfall data was measured at an unknown location in Yangon, probably around Kaba Aye Road which is 13km away from the Latha Township.
At the location of the Kaba Aye Station the rainfall volume was measured per hour. An analysis of the drainage system showed that a completely empty system had a lag time of about 30 minutes between the peak of the rainfall and the peak of the total discharge in case of a rainfall event with a duration of about 35 minutes and a total volume of 55mm. This meant that under such conditions the system might be considered to responds faster than the rainfall data interval. Based on the fast hydraulic response of the system it might be concluded that rainfall data with a higher temporal resolution is desired.

The fact that the rainfall measurements were 13km away from Latha did have some impact on the reliability of the data. During Myanmar's rain season large rainfall weather fronts hit the coastal areas. The temporal and spatial resolutions of rainfall events may be expected to not that different from the Latha Township to the location of the Kaba Aye station. The limited temporal resolution might result in too low average intensities that underestimate or overestimate the speed of the hydraulic response. Moreover, the distribution of the rainfall in the one hour time step also has an effect that cannot be modelled by this data. If a majority of the hourly precipitation falls in the beginning of that hour and the system is almost empty the system's response is different than when the system starts to slowly fill up and the majority of the rainfall volume falls at the end of the 1 hour time step.

One of the things that could be done to improve future data is to install a (automatic) rain gauge or distrometer in the Latha Township that records the average rainfall per every 1 or 5 minutes.
Another thing that could be done is to create a synthetic dataset based on the actual data where the volumes are distributed skewed over smaller time steps to research the effects of the temporal distribution.

C.5. Conclusion

For this case, quite a lot of data was collected. In general it should be concluded that most of the data had a large degree of uncertainty. One of the most frequent occurring issues was the lack of clear reference systems or inconsistencies in the data set. However, since this research is an explorative study the impacts were often limited. Using various cases will allow for the study of the impacts of the uncertainties.

Field work provided a crucial source of additional datasets and allowed for the verification of some of the data. However, with more support from local authorities even more data could be acquired, which should be attempted if desired.

D

Interviews

Different meetings were set-up with the two relevant Yangon City Development Committee (YCDC) departments (see Section 2.2.5) when it comes to solid waste management and the drainage system. The Yangon City Development Committee Pollution Control and Cleansing Department (YCDC PCCD) is responsible for the waste collection in Latha, Table D.1 shows the most important results from the semi-structured interview. The Yangon City Development Committee Engineering Department of Roads and Bridges (YCDC EDRB) is responsible for the drainage system, the most notable results from two meeting (e.g. like the meeting of Figure D.2) with semi-structured interviews can be found in Table D.2. Table D.3 shows the most important results from the unstructured interviews with Latha's citizens (for example like Figure D.1).

Table D.1: Summary of the transcript from the semi-structured interview with the YCDC PCCD Latha Office

Date:	*28-03-2017*
Organisation:	*YCDC PCCD Latha Office*
Name:	*U Myot Soe Thein*
Q:	*How much household waste is collected per day for Latha?*
A:	For Latha the waste production was 36,000 kg per day. Waste from the hospital area was collected separately and that was about 4,000 kg/day.
Q:	*How often is the waste collected per day for Latha?*
A:	One time per day at 6 AM a truck collected all the waste from the containers and brings it to the transfer collection point. Moreover, twice a day YCDC PCCD employees collected small garbage with a cart. They collect especially recyclable waste. Eventually all the waste goes to the Htein Bin Final Disposal Site.
Q:	*How many containers are there in Latha and what are their locations?*
A:	In total there were 120 containers in the area and a map was provided with the locations of the containers. Each container could contain 660 Liters.
Q:	*How much is the waste production variation from day to day?*
A:	The waste production was relatively stable. Almost every day the YCDC PCCD collected about the same amount of waste, even Sundays did not show a large deviation compared to the other days of the week (Myanmar is thought to have a six day economy).
Q:	*How many households are there according to your data in Latha?*
A:	There were 2998 households in Latha.
Q:	*How much tax or fees does a households have to pay for the collection of waste?*
A:	A household had to pay 1800 Kyat per three months.

Q: *How much tax or fees does a shop have to pay for the collection of waste?*
A: A shop had to pay 300 Kyat/day, however some market salesmen and shop owners did not do this.

Q: *How often do the streets get cleaned?*
A: The streets were cleaned every day by YCDC PCCD employees that went around with a cart. The streets were broomed and the collected waste was disposed in the cart.

Q: *How often do the drains get cleaned?*
A: Open (uncovered) drains got cleaned every day. Covered drains got cleaned one or two times per year just before the start of the rainy season. If the YCDC PCCD received complaints about a blockage, incidental maintenance was executed. The drains of 17th and 18th Street got cleaned three or four times, as they got blocked more often. This was probably related to the market at 17th and 18th Street.

Q: *What was recently updated on the drainage system?*
A: In 2015 some drains were upgraded, resulting in no floods for 2016.

Table D.2: Summary of the transcripts from from the two semi-structured interviews with the YCDC EDRB General Office

Date: *30-03-2017 & 06-04-2017*
Organisation: *YCDC EDRB General Office*
Name: *Kyaw Mein Oo*

Q: *Why does the Latha Township flood?*
A: The Latha Township was one of the lowest areas in the central business district and was most flood prone. Lanmadaw sometimes also experienced floods. However the other 4 townships of the central business district had higher ground level elevations and hardly had floods.
The floods themselves were caused by heavy rainfall events. In some cases drains were blocked, causing floods. Another issue was that sometimes the flood gates could not be fully closed because of blockages. Finally, high water levels in the Yangon River often resulted in having to close the flood gate structures (FGSs). If it rained the drains would become full since the could not drain to the river, eventually resulting in floods.

Q: *How long does a flood typically last?*
A: Floods because of blockages often lasted for 20 to 30 minutes. After this time frame, often a YCDC EDRB employee arrived on the scene to clear the blockage by using long bamboo sticks. However, really heavy floods could last up to 3 to 4 hours or so.

Q: *What is the water depth during a typical flood?*
A: The water depth is typically somewhere between a few centimetres to about 20 centimetres. However, during a sever flood the water depths might be over half a meter at Strand Road.

Q: *How frequent are there floods during a typical year?*
A: There are about 4 floods during the rainy season, although the severity differs from time to time.

Q: *Which areas can be flooded during a flood in the Latha Township?*
A: Often Strand Road and the lower blocks were flooded first. Especially around Latha Street, 22nd and 23rd Street. The floods never extended further than the south side of the Hospital terrain.

Q: *Who is responsible for cleaning the inlets, drains and structures in the drainage system?*

A:	The YCDC EDRB was responsible for all the waste in the drainage system, waste in the inlets and waste in the flood gate structures. Cleaning the streets and containers was the responsibility of the YCDC PCCD . Scheduled maintenance to the inlets by YCDC PCCD was not possible as this is a different **YCDC !** (**YCDC !**)department with different responsibilities. "Cleaning the drains and inlets was our responsibility".
Q:	*How often are the drains cleaned and when?*
A:	The drains were cleaned once per year, just before the start of the rainy season.
Q:	*What causes blockages in the drains?*
A:	Citizens who disposed their waste in the drains or on the street. Eventually this waste got stuck in some of the culverts and sometimes prevented the FGSs to not be fully closed by a YCDC EDRB employee. Waste might also got stuck behind water pipelines, electrical wires and telecommunication lines that runned through the drains. This was a problem that could not be prevented by the YCDC EDRB . The pipelines, electrical wires and telecommunication lines were under the responsibillity of other YCDC departments. There used to be a lack of communication and coordination between the different YCDC departments. However, recently the coordination improved and new connections are now made as much as possible outside of the drains, aside of the road.
Q:	*At which location do the floods start most of the times?*
A:	The gate at 22nd and 23rd street (this is gate 7) often had the worst blockages. Also the culverts close to this drain got blocked relatively frequent. The junction of Latha Street and Strand Road was also a problem area, which often was one of the first places to be flooded.
Q:	*How often do the gates get blocked?*
A:	In the past the gates used to be leaky along the side walls. Therefore the gates were upgraded in 2013. However, sometime waste still gets stuck in the gate not allowing them to be fully closed. The same applied to the high water valves that were at the other end of the drain that connected the gate with the Yangon River.
Q:	*Does Latha experience subsidence?*
A:	In the last few years Latha did not experience any significant subsidence.

Table D.3: Transcript summary of the unstructured mini-interviews with Latha citizens.

Date:	*28-02-2017 till 08-04-2017*
Organisation:	*Latha Township*
Name:	*Latha Township Citizens*
Q:	*How much waste do you produce per day?*
A:	Most of the people said that they produced about one plastic bag of waste per day.
Q:	*How often do you dispose your waste and where do you dispose it?*
A:	The majority of the interviews mentioned that they disposed their waste once a day in a container of the YCDC. However, a small number of people also mentioned that there were small companies who offered services of waste collection at the door.
Q:	*What should be improved on Latha's solid waste management?*
A:	An often heard answer was that one of the problems was that the YCDC PCCD did not have sufficient employees cleaning the streets. As a result, not all the waste that lied around on the streets got cleaned. Moreover, some of the street cleaners were reported to be too focussed on recyclable materials like plastic bottles and cans, but did not clean other types of waste. The collection of waste close to containers was better than waste on the streets (especially in the smaller streets).

Q: *What do you think about the number of containers?*
A: There were insufficient containers. Some interviewees also mentioned that there was a problem with the location of the containers. Most containers were almost everywhere positioned at the beginning and end of a street. This was done so that the YCDC PCCD was able to collect the containers fast. However, some people felt that this distance was too far. They asked to the YCDC if additional containers could be placed halfway of the street, but the YCDC did not want to cooperate, because it would be disruptive to their collection procedure.
Also most respondents complained that they felt they paid enough tax, but that the containers were always full. They said that more containers were required or collection should be more frequent.
However, when asked how the interviewee would feel about additional containers in front of their house, most people answered negative. There seemed to be some kind of not in my backyard opinion.

Q: *How often does it happen that the containers in your street are missing?*
A: People said that it did happen, but not too often. In most cases a container was placed back a few days later.

Q: *What do you do if a container is full or if the container(s) in your street are missing?*
A: Most of the people said that they would still go to the container and just make a pile next to the container or on the spot of the missing container. However, some people also said that they made piles in front of their houses. But since this waste was not always collected the next day, some citizens mentioned that it was best to still go to the location of the container, since there the collection was better.

Q: *What do you think is the biggest problem in solid waste management (SWM) from the side of citizens?*
A: Not all shops pay waste taxes and do not throw away their waste in the containers. Most shops are often cleaned with water, flushing all the garbage and dirt in the drain.
Another problem is that sometimes households on the higher floors just throw their waste out of the window, especially in the back alley drains. Therefore security cameras were placed in some streets and back alleys behind the buildings to prevent illegal waste dumps. However, there were still too little cameras (especially in the back alleys) and some cameras got deliberately obstructed and destroyed.

Q: *How often does it flood in Latha?*
A: According to most respondents short floods that lasted about 30 minutes occurred a few times per year. During these floods, the water depth was to about ankle height and most people said they would continue their daily business as usual. Long floods only happen once or twice a year with durations of a few hours and water depths of about half way the calves to knee height.

Q: *Where do these floods occur?*
A: Most of the times it flooded especially around Strand Road and the south end of Latha street, because these were the low laying areas.

Q: *Why do you think floods occur in the Latha Township?*
A: Most interviewees said that they thought that the floods were the results of blockages in the drains. The blockages were the results of people disposing waste outside of containers and the streets and drains were cleaned insufficient.
Another often heard reason was that the drainage system was too small for heavy rainfall events. But there were some recent improvements made to the drainage system and some streets were slightly raised.

Q: *Does your property you have flood protection measures and if so what?*
A: A lot of people who lived on ground level had a concrete slab in the (door) opening of their building. However, this concrete slab was multi-functional. It also served as a measure to prevent rats from entering the property.

Q: *How often do the drains get cleaned and when do they get cleaned?*
A: The large majority indicated that the drains only got cleaned once a year, just before the start of the rainy season. Most of these people also complained that they would like to see that the drains would be cleaned more often during the entire year.
Around the market of 17th and 18th street (see Figure) people complained more often about blocked drains and reported that drains were cleaned more often, sometimes even 4 times per year and not only just before the start of the rainy season.
Multiple times, interviewees also complained about the maintenance state of the drains. At a lot of locations the concrete drain covers were partially broken. This was a dangerous situation as people could hurt themselves. Moreover, they said that sometimes people also dispose waste through these openings into the drains.

Q: *How do you think the flood problems should be resolved?*
A: Almost all respondents mentioned increasing the size of the drains as the main solution. In addition a large group suggested more frequent cleaning of the drains before and during the rainy season.

Figure D.1: Picture of an unstructured mini-interview with citizens of the upper block of 20_{th} Street. Picture taken on March 19, 2017.

Figure D.2: Picture of an interview with the YCDC EDRB. Picture taken on March 30, 2017.

E

Flood Model

E.1. Introduction

For this study the floods in the Latha Township (see Chapter 2) were modelled using a flood model. Different cases were used to research the area and flood dynamics in order to identify the most important hydrological and hydraulic processes. The model and hydrodynamic calculations were made with SOBEK and required a large amount of different data input types that had to be collected, analysed and processed/prepared for usage. This appendix elaborates on the used software, cases and input data, followed by the results that show that the floods are primarily caused by the downstream boundary conditions (the Yangon River). The used model (concept), the used data with its uncertainties and the results are discussed, followed by the conclusions and recommendations. Figure E.1 shows what different materials and methods were used for the flood model and will be explained in Section E.2 and Section E.3.

E.2. Materials & Methods

Figure E.1 shows what different materials were used as input for the flood model and will be explained in the next subsections. The month July 2014 has yielded the largest reliable/most complete physics datasets (urban drainage network layout, ground level elevation, flood records, river water levels and rainfall data) for the Latha Township. Therefore, most of the collected data is presented in such a way that especially the data for the month July 2014 is shown. However, in reality datasets might be bigger and more data from other periods is also available but committed for clarity. The month July 2014 has two other benefits, which are: that it is within the rainy season and that there actually are flood records of that period. Thus using this month makes sense from an urban flooding perspective.

E.2.1. SOBEK

In this research SOBEK 2.13 Rural (Deltares, 2013) was used to do the hydrodynamic calculations on the drainage network. SOBEK uses the complete Saint-Venant (S-V) Equations and a self-created numerical computation grid called Delft-scheme that is numerical stable and ensures a closed water balance. For this model the following modules were used: 1DFLOW (Rural), 1DFLOW (Urban), Overland Flow (2D) and RR. Other versions than SOBEK 2.13 Rural should treat the model with care, as it turned out that SOBEK 2.15 Rural runs with a bug for the real time controller of the gates (orifice structures). This bug does not occur in SOBEK 2.13 Rural, but other versions than SOBEK 2.13 Rural have not been tested on this bug.

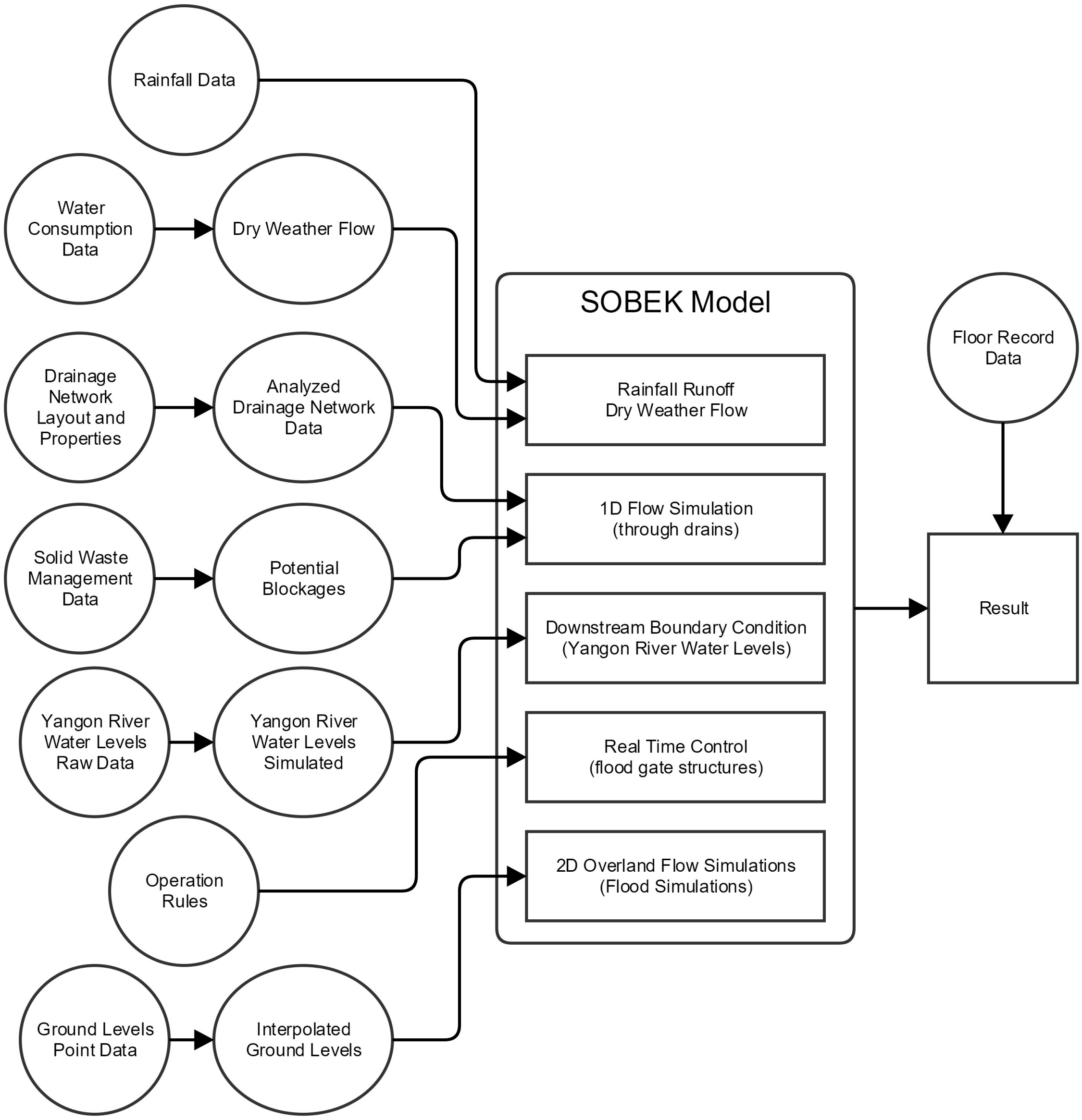


Figure E.1: The SOBEK model requires a lot of different inputs from the materials and methods of this chapter, to properly model the Latha Township.

E.3. SOBEK Model

Figure E.2 shows a snapshot of the SOBEK model. In the legend the various model components are named. The *cross-section nodes* define the profile of the canals. The *manholes* connect the different canals (blue arrowed lines) where there was no runoff or DWF coming into the system. With the *manholes with runoff* the runoff and dry weather flow into the system was modelled. The *manholes with measurements*, measure water levels and discharges that were used for real time control of the flood gate structures (FGSs). In order to make correct calculations, additional points for computation were specified by *calculation points*. The *boundary nodes* were used to model the downstream boundary condition. The *2D grid point* defined the 5x5 meter 2D raster with elevation data and the *2D history points* recorded data from the overland flow calculations. The elevation was colour mapped by a brown gradient scale. Some locations had no elevation data, the grey cells (because of buildings on that location and not defining these cells improves the computation time). Some drains were pressurized (see Figure C.11), which are the black arrowed lines. The gates that can be controlled by data from the manholes with measurements are modelled as orifices, the green arrowed lines.
There were quite some uncertainties in the data. Modelling different cases allowed for researching how these uncertainties affect flooding and the model's results for the different variable settings. In total 42 cases were runned in the model to evaluate the drainage system's behaviour. Table E.1 shows an overview of all the different 42 cases. The cases will be explained in the next section. Figure E.1 showed what different inputs were used in the SOBEK model. However, for each case some settings were kept constant. The used time step was 30 seconds for computations (to ensure numerical stability and efficient computation speeds) and 5 minutes for output generation (to ensure for not too big data sets but allow for sufficient detail). The initial water level was set at 0.1 meter water depth in all drains, this ensured that the model does not run into numerical stability issues at the start.

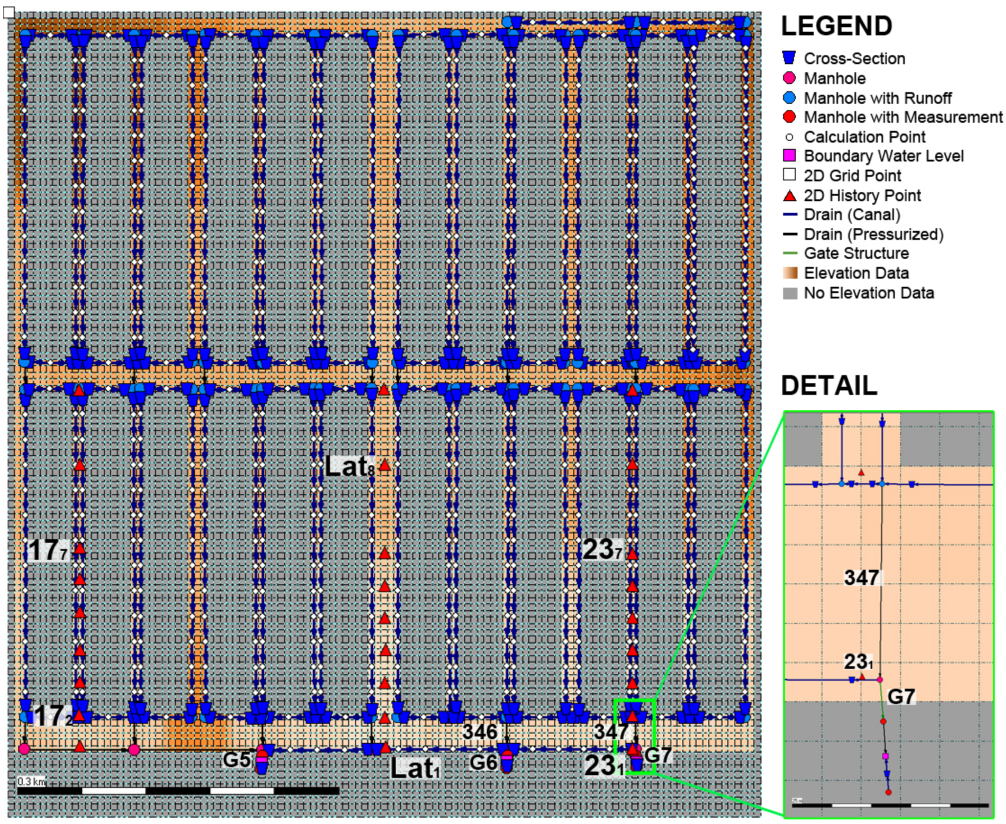


Figure E.2: SOBEK Model Schematization. In the legend the various model components are named. There are different type of connection nodes, connecting canals and pipes. Eventually the system drains to the river, the downstream boundary nodes. In order to model the flood a 5x5 meter 2D raster and other modelling components are defined.See Section E.3 for an explanation. The six 2D History Points (17_2, 17_7, Lat_1, Lat_8, 23_1 and 23_7) will be used to evaluate the results (see Section 4.2), 346 and 347 are the culverts that will be (partially) blocked for some cases and G5, G6 and G7 are Gates 5, 6 and 7.

E.3.1. Scenario Based Flood Modelling

In order to deal with uncertainty in the hydrological and hydraulic data, different cases were modelled in the flood model. In total 42 cases of the flood model were runned to evaluate the drainage system's behaviour. Table 3.8 shows an overview of all the different 42 cases.

E.3.1.1. Ground Level Reference Cases

Since the ground level reference was unknown (see Section 3.1.3 and appendix Section C.3.8 and Section C.3.10) different cases were set-up with for the various ground level references (cases: 1, 2, 3).

E.3.1.2. Wall Roughness

Recall from Section 3.1.3 that the SOBEK model used a Manning's roughness m = $0.015\,s/m^{1/3}$ for the brick with concrete drains. However, the build up of waste in the drains and the maintenance state of the drains had an impact on the hydraulic resistance of the drains. Different cases were ran to observe the effects of higher and lower Manning's roughness values on the flood frequency and water depths (cases 4, 5, 6, 7, 8). Case 8 used a Manning's roughness value (m = $0.060\,s/m^{1/3}$) that approximated a really poor maintained canal (Oregon State University, 2006).

E.3.1.3. Flood Gate Structure Operational Settings Cases

Generally, the gates were closed a few hours before high water and opened a few hours after the peak water level. However SOBEK only allowed for real time control based on water levels. Different Yangon River water level (YRWL) targets were used to change the gate setting to either be fully open or fully closed (cases: 9, 10, 11, 12, 13, 31, 32).

E.3.1.4. Runoff Coefficients Cases

To investigate the effects of the uncertainty in the runoff processes, different settings for runoff coefficients were used (cases: 14, 15, 16, 17, 18, 19). A distinction was made between the much more purvious hospital area and the residential area (see Figure 2.9). In the first few cases either the runoff coefficient from the residential area was raised or lowered or the runoff coefficient from the hospital area was altered. Later combinations of a raised/lowered runoff coefficient for the residential area and different runoff coefficients for the hospital area were modelled.

E.3.1.5. Blockages Cases

In order to research how a blockage at a critical location (or multiple locations) affected Latha's flood dynamics, different scenarios were set-up (cases: 20, 21, 22, 23, 24). The locations were selected based upon the drainage system lay-out and information about blockages from the Yangon City Development Committee Engineering Department of Roads and Bridges (YCDC EDRB) (Table D.2). The blockages were simulated by reducing the cross-sectional area from the top (keeping the invert level constant). Different blockage percentages (25%, 50%, 75% and 100%) were used and one case with a blockage of 50% at two locations.

E.3.1.6. Dry Weather Flow Cases

In the dry weather flow cases (cases: 25, 26, 27) different temporal patterns and dry weather flow quantities were used to study the uncertainties as mentioned in Section C.3.14.2. In Case 25 the DWF was increased by 50% and in Case 26 by 100%, resulting in 180 L/capita/day and 240 L/capita/day respectively. In Case 27 the temporal variation was addressed, resulting in a high dry weather flow between 07:00 and 19:00 and a lower DWF during the night time.

E.3.1.7. Leakage Gate Structure Cases

Interviews with the YCDC EDRB learned that at some times the FGSs were partially blocked by waste and that in the past the gates were thought to be leaky (Kyaw Mein Oo, personal communication, April 6, 2017). To research the impacts of a small gap (not full closure of the gate) resulting in a leaky gate, different small opening sizes were modelled (cases: 28, 29, 30).
In addition case 42 was created to study the effects of a gate that did not close at all.

E.3.1.8. Time Shift Yangon River Water Levels Cases

To find out how the timing of the YRWLs (the downstream boundary condition) affected flooding, 3 cases were modelled where the YRWL series was shifted relative to the rainfall series (cases: 33, 34, 35). Simply put, the rain (timing) was kept the same, whereas the moments of high water (and all other water levels) were shifted such that they occurred three, six or nine hours later than they actually occurred. The river's fast tidal period is about 12 hours (see Section C.3.11). This implicates that for a 3 hour shift: high water occurred when the water level in the original series was mean water level and falling, that for a 6 hour shift: high water occurred when the water level in the original series was at low water and for a 9 hour shift: high water occurred when the water level in the original series was at mean water level and rising.

E.3.1.9. Combined Settings Cases

To see some of the combined affects of different settings, 3 cases were runned (cases: 36, 37, 38). In these cases the water level were shifted, together with lower runoff coefficients and gate settings that resulted in short periods of closure of the FGSs.

E.3.1.10. Improved Storage, Infiltration, Evaporation and Runoff Cases

For all cases until now (cases: 1–38), the rainfall runoff process was modelled crude. A fixed runoff coefficient was assigned to the hospital area and the residential area. For simplicity no distinction was made between, roofs, roads and pervious areas. Also, infiltration, interception and evaporation were simplified. Additional cases were runned to analyse the impact of these simplifications (cases: 39, 40). Case 41 not only included these improvements, but also a change in the operational control of the FGSs and a shift of the YRWL. Table E.3 in Appendix E shows the used values.

Table E.1: An overview of all the different cases that will be modelled. Different: ground level references (GLR), roughness (Manning), real time control (RTC) of the FGSs, runoff coefficients, (partial) blockages of drains, dry weather flow (DWF), Leakage of the FGSs, timing of tide in the Yangon River (shift WL), more detailed storage, infiltration, evaporation and runoff (improved S, I, E, C) and combined cases. See Table 3.9 for an explanation of the headers.
* Culvert running under Strand Road at the 22nd Street, ** Culvert running under Strand Road at the 23rd Street, *** 90 L/capita/day (19:00-07:00) and 240 L/capita/day (07:00-19:00), **** See Table E.3 for used values. NA means not available, as this setting/variable might not apply to this case.

	Case	Cr	Ch	RTC open	RTC closed	Leakage gap	Gap loc.	GLR	YRWL dt	DWF	m	Blckg. loc. 1	Blckg %	Loc. Descript.	Blckg. loc. 2	Blckg %	Loc. Descript.
GLR	1	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.015	NA	NA	NA	NA	NA	NA
	2	0.8	0.4	-0.1	0.0	0	NA	4.83	0	120	0.015	NA	NA	NA	NA	NA	NA
	3	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
Roughness	4	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.005	NA	NA	NA	NA	NA	NA
	5	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.010	NA	NA	NA	NA	NA	NA
	6	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.020	NA	NA	NA	NA	NA	NA
	7	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.025	NA	NA	NA	NA	NA	NA
	8	0.8	0.4	-0.1	0.0	0	NA	5.22	0	120	0.060	NA	NA	NA	NA	NA	NA
RTC	9	0.8	0.4	0.1	0.2	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	10	0.8	0.4	0.0	0.1	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	11	0.8	0.4	-0.2	-0.1	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	12	0.8	0.4	-0.3	-0.2	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	13	0.8	0.4	-0.5	-0.4	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
Runoff	14	0.9	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	15	0.7	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	16	0.8	0.5	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	17	0.8	0.3	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	18	0.9	0.5	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	19	0.7	0.3	-0.1	0.0	0	NA	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
Blockages	20	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	346	25	*	NA	NA	NA
	21	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	346	50	*	NA	NA	NA
	22	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	346	75	*	NA	NA	NA
	23	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	346	100	*	NA	NA	NA
	24	0.8	0.4	-0.1	0.0	0	NA	4.77	0	120	0.015	346	50	*	347	50	**
DWF	25	0.8	0.4	-0.1	0.0	0	NA	4.77	0	180	0.015	NA	NA	NA	NA	NA	NA
	26	0.8	0.4	-0.1	0.0	0	NA	4.77	0	240	0.015	NA	NA	NA	NA	NA	NA
	27	0.8	0.4	-0.1	0.0	0	NA	4.77	0	***	0.015	NA	NA	NA	NA	NA	NA
Leakage	28	0.8	0.4	-0.1	0.0	0.05	Gate 7	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	29	0.8	0.4	-0.1	0.0	0.10	Gate 7	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
	30	0.8	0.4	-0.1	0.0	0.20	Gate 7	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA
RTC 2	31	0.8	0.4	0.2	0.3	0	NA	5.22	0	120	0.015	NA	NA	NA	NA	NA	NA
	32	0.8	0.4	0.9	1.0	0	NA	5.22	0	120	0.015	NA	NA	NA	NA	NA	NA
Shift WL	33	0.8	0.4	-0.1	0.0	0	NA	5.22	3	120	0.015	NA	NA	NA	NA	NA	NA
	34	0.8	0.4	-0.1	0.0	0	NA	5.22	6	120	0.015	NA	NA	NA	NA	NA	NA
	35	0.8	0.4	-0.1	0.0	0	NA	5.22	9	120	0.015	NA	NA	NA	NA	NA	NA
Shift WL	36	0.7	0.3	0.9	1.0	0	NA	5.22	3	120	0.015	NA	NA	NA	NA	NA	NA
& RTC	37	0.7	0.3	0.9	1.0	0	NA	5.22	6	120	0.015	NA	NA	NA	NA	NA	NA
& Crunoff	38	0.7	0.3	0.9	1.0	0	NA	5.22	9	120	0.015	NA	NA	NA	NA	NA	NA
Improved	39	****	****	-0.1	0.0	0	NA	5.22	0	120	0.015	NA	NA	NA	NA	NA	NA
S, I, E, C	40	****	****	-0.1	0.0	0	NA	5.22	0	120	0.015	NA	NA	NA	NA	NA	NA
RTC, Shift WL, S, I, E, C	41	****	****	0.9	1.0	0	NA	5.22	6	120	0.015	NA	NA	NA	NA	NA	NA
Open Gate	42	0.8	0.4	NA	NA	1.20	Gate 7	4.77	0	120	0.015	NA	NA	NA	NA	NA	NA

Table E.2: The headers of Table 3.8 are explained in this table.

Description	Explenation	Units
Case	Case number	NA
Cr	Runoff Coefficient Residential Area	(-)
Ch	Runoff Coefficient Hospital Area	(-)
RTC open	Water Level at datum for which the gate is 100% open	m GLR
RTC closed	Water Level at datum for which the gate is 100% closed	m GLR
Leakage gap	Opening size gate gap from the bottom	m
GLR	Ground Level Reference , 0.00 m GLR in m MSL	m MSL
WL dt	Water Level boundary condition time shift	hours
DWF	Dry Weather Flow	L/capita/day
m	Manning friction value	$s/m^{1/3}$
Blckg. loc. 1	Location of blockage 1	NA
Blckg %	Part of the drain blocked	(%)
Loc. Descript.	Description of the location	NA
Blckg. loc. 2	Location of blockage 2	NA

Table E.3: Used values for the cases with improved storage, infiltration, evaporation and runoff.

	Residential Area			Hospital Area		
Case	Area Type	Value	Units	Area Type	Value	Units
39& 41	Roads	50	%	Roads	20	%
	Unpaved	20	%	Unpaved	60	%
	Roofs	30	%	Roofs	20	%
Case	Area Type	Value	Units	Area Type	Value	Units
40	Roads	30	%	Roads	10	%
	Unpaved	40	%	Unpaved	70	%
	Roofs	30	%	Roofs	20	%
Case	Storage on	Value	Units	Storage on	Value	Units
39& 40& 41	Roads	0.5	mm	Roads	0.5	mm
	Unpaved	4	mm	Unpaved	4	mm
	Roofs	2	mm	Roofs	2	mm
	Infiltration for	Value	Units	Infiltration for	Value	Units
	Roads	0	mm/h	Roads	0	mm/h
	Unpaved	0.5 to 2	mm/h	Unpaved	0.5 to 2	mm/h
	Roofs	0	mm/h	Roofs	0	mm/h
	Runoff from	Value	Units	Runoff from	Value	Units
	Roads	0.8	(-)	Roads	0.8	(-)
	Unpaved	0.4	(-)	Unpaved	0.4	(-)
	Roofs	0.8	(-)	Roofs	0.8	(-)

E.4. SOBEK Results

Group	Case	Point 17_2									Point 17_7									Point Lat_1								
		Num of Floods	TotDuration	min Duration	Avg. Duration	Max Duration	Tot.max. Depth	min max depth	avg.max.depth	max.max.depth	Num of Floods	TotDuration	min Duration	Avg. Duration	Max Duration	Tot.max. Depth	min max depth	avg.max.depth	max.max.depth	Num of Floods	TotDuration	min Duration	Avg. Duration	Max Duration	Tot.max. Depth	min max depth	avg.max.depth	max.max.depth
GLR	2	14	2611.5	25.0	186.54	492.0	3.86	0.09	0.28	0.68	2	436.0	107.5	218.00	328.5	0.25	0.06	0.13	0.19	19	2938.5	17.5	154.66	428.5	5.29	0.04	0.28	0.79
	1	14	2170.5	25.0	155.04	459.5	3.33	0.06	0.24	0.63	1	270.5	270.5	270.50	270.5	0.14	0.14	0.14	0.14	16	2245.0	17.5	140.31	400.0	4.33	0.07	0.27	0.74
	2	14	2611.5	25.0	186.54	492.0	3.86	0.09	0.28	0.68	2	436.0	107.5	218.00	328.5	0.25	0.06	0.13	0.19	19	2938.5	17.5	154.66	428.5	5.29	0.04	0.28	0.79
	3	14	2722.5	25.0	194.46	498.5	3.96	0.09	0.28	0.69	2	481.5	142.0	240.75	339.5	0.28	0.08	0.14	0.20	19	3400.0	17.5	178.95	435.0	5.57	0.07	0.29	0.80
Roughness	1	14	2170.5	25.0	155.04	459.5	3.33	0.06	0.24	0.63	1	270.5	270.5	270.50	270.5	0.14	0.14	0.14	0.14	16	2245.0	17.5	140.31	400.0	4.33	0.07	0.27	0.74
	4	11	1660.0	29.5	150.91	387.0	2.73	0.09	0.25	0.60	1	228.0	228.0	228.00	228.0	0.12	0.12	0.12	0.12	16	2205.5	3.5	137.84	391.0	4.22	0.03	0.26	0.71
	5	14	1900.5	2.0	135.75	429.0	3.06	0.03	0.22	0.62	1	254.0	254.0	254.00	254.0	0.13	0.13	0.13	0.13	16	2221.5	5.0	138.84	403.0	4.26	0.04	0.27	0.73
	6	14	2413.0	30.5	172.36	491.0	3.53	0.08	0.25	0.64	1	289.5	289.5	289.50	289.5	0.15	0.15	0.15	0.15	16	2276.0	22.5	142.25	398.0	4.38	0.07	0.27	0.75
	7	16	2733.5	18.0	170.84	528.5	3.83	0.06	0.24	0.65	1	312.0	312.0	312.00	312.0	0.16	0.16	0.16	0.16	16	2354.5	30.0	147.16	405.0	4.46	0.08	0.28	0.76
	8	15	5700.5	51.0	380.03	1025.0	4.25	0.08	0.28	0.69	3	880.0	159.0	293.33	477.0	0.41	0.10	0.14	0.20	16	3551.0	45.0	221.94	536.5	4.96	0.07	0.31	0.80
RTC	3	14	2722.5	25.0	194.46	498.5	3.96	0.09	0.28	0.69	2	481.5	142.0	240.75	339.5	0.28	0.08	0.14	0.20	19	3400.0	17.5	178.95	435.0	5.57	0.07	0.29	0.80
	9	14	2506.0	25.0	179.00	484.0	3.75	0.09	0.27	0.67	2	364.5	50.0	182.25	314.5	0.22	0.04	0.11	0.18	17	2632.5	17.5	154.85	421.0	5.01	0.07	0.29	0.78
	10	14	2604.5	25.0	186.04	491.5	3.85	0.09	0.28	0.68	2	430.5	103.5	215.25	327.0	0.25	0.06	0.12	0.19	18	2874.5	17.5	159.69	428.0	5.24	0.07	0.29	0.79
	11	15	3265.5	25.0	217.70	506.0	4.13	0.07	0.28	0.70	2	528.0	177.0	264.00	351.0	0.31	0.10	0.15	0.21	17	3615.5	18.0	212.68	441.5	5.53	0.07	0.33	0.81
	12	14	3565.5	25.0	254.68	512.5	4.19	0.09	0.30	0.70	2	572.5	210.0	286.25	362.5	0.34	0.12	0.17	0.22	17	3782.0	18.0	222.47	448.0	5.68	0.07	0.33	0.82
	13	14	3881.0	25.0	277.21	525.0	4.40	0.09	0.31	0.71	2	636.5	256.0	318.25	380.5	0.39	0.16	0.19	0.23	17	4073.0	17.5	239.59	462.5	5.99	0.07	0.35	0.83
Runoff	3	14	2722.5	25.0	194.46	498.5	3.96	0.09	0.28	0.69	2	481.5	142.0	240.75	339.5	0.28	0.08	0.14	0.20	19	3400.0	17.5	178.95	435.0	5.57	0.07	0.29	0.80
	14	14	2722.5	24.5	194.46	498.5	3.96	0.09	0.28	0.69	2	481.5	142.0	240.75	339.5	0.28	0.08	0.14	0.20	19	3400.5	17.5	178.97	435.0	5.56	0.07	0.29	0.80
	15	14	2722.0	24.5	194.43	498.5	3.96	0.09	0.28	0.69	2	482.5	142.5	241.25	340.0	0.28	0.08	0.14	0.20	19	3400.0	18.0	178.95	435.0	5.57	0.07	0.29	0.80
	16	14	2723.0	25.0	194.50	498.5	3.96	0.09	0.28	0.69	2	481.5	141.5	240.75	340.0	0.28	0.08	0.14	0.20	19	3399.5	17.5	178.92	435.0	5.57	0.07	0.29	0.80
	17	14	2721.5	24.5	194.39	499.0	3.95	0.09	0.28	0.69	2	481.0	142.0	240.50	339.0	0.28	0.08	0.14	0.20	19	3400.0	17.5	178.95	434.5	5.56	0.06	0.29	0.80
	18	14	2724.0	25.0	194.57	498.5	3.96	0.09	0.28	0.69	2	481.0	141.5	240.50	339.5	0.28	0.08	0.14	0.20	19	3400.5	18.0	178.97	434.5	5.57	0.07	0.29	0.80
	19	14	2722.0	24.5	194.43	498.5	3.95	0.09	0.28	0.69	2	481.5	142.5	240.75	339.0	0.28	0.08	0.14	0.20	19	3398.5	17.5	178.87	434.5	5.56	0.06	0.29	0.80
Blockages	3	14	2722.5	25.0	194.46	498.5	3.96	0.09	0.28	0.69	2	481.5	142.0	240.75	339.5	0.28	0.08	0.14	0.20	19	3400.0	17.5	178.95	435.0	5.57	0.07	0.29	0.80
	20	14	2726.0	24.5	194.71	499.0	3.96	0.09	0.28	0.69	2	483.5	143.5	241.75	340.0	0.28	0.08	0.14	0.20	19	3406.5	19.0	179.29	435.0	5.58	0.07	0.29	0.80
	21	14	2735.0	25.5	195.36	499.0	3.98	0.09	0.28	0.69	2	486.5	146.5	243.25	340.0	0.28	0.08	0.14	0.20	19	3433.0	23.0	180.68	435.0	5.63	0.08	0.30	0.80
	22	16	2888.5	27.5	180.53	499.5	4.08	0.04	0.26	0.69	2	492.5	151.5	246.25	341.0	0.29	0.08	0.14	0.20	19	3481.0	29.5	183.21	436.0	5.70	0.10	0.30	0.80
	23	17	3072.5	4.0	180.74	499.5	4.19	0.03	0.25	0.69	2	499.0	157.0	249.50	342.0	0.29	0.09	0.15	0.20	17	3571.5	35.5	210.09	437.5	5.54	0.11	0.33	0.80
	24	16	2864.5	25.5	179.03	499.5	4.06	0.03	0.25	0.69	2	492.5	151.5	246.25	341.0	0.29	0.08	0.14	0.20	19	3462.5	26.0	182.24	435.5	5.68	0.09	0.30	0.80
DWF	3	14	2722.5	25.0	194.46	498.5	3.96	0.09	0.28	0.69	2	481.5	142.0	240.75	339.5	0.28	0.08	0.14	0.20	19	3400.0	17.5	178.95	435.0	5.57	0.07	0.29	0.80
	25	16	2888.5	26.0	180.53	501.0	4.13	0.04	0.26	0.69	2	491.5	149.0	245.75	342.5	0.29	0.08	0.14	0.21	19	3483.5	19.0	183.34	436.5	5.76	0.07	0.30	0.80
	26	18	3108.0	9.0	172.67	504.0	4.33	0.03	0.24	0.70	2	500.0	155.0	250.00	345.0	0.30	0.09	0.15	0.21	19	3562.0	20.5	187.47	438.0	5.93	0.07	0.31	0.81
	27	16	2889.5	9.0	180.59	501.0	4.11	0.03	0.26	0.69	2	482.0	138.5	241.00	343.5	0.28	0.07	0.14	0.21	19	3428.0	17.0	180.42	436.5	5.69	0.06	0.30	0.81
Leakage	3	14	2722.5	25.0	194.46	498.5	3.96	0.09	0.28	0.69	2	481.5	142.0	240.75	339.5	0.28	0.08	0.14	0.20	19	3400.0	17.5	178.95	435.0	5.57	0.07	0.29	0.80
	28	15	2850.5	25.0	190.03	496.5	4.02	0.06	0.27	0.68	2	449.0	113.0	224.50	336.0	0.25	0.05	0.12	0.20	19	3486.5	17.5	183.50	433.5	5.57	0.07	0.29	0.80
	29	16	2981.0	25.0	186.31	495.0	4.10	0.04	0.26	0.68	1	333.0	333.0	333.00	333.0	0.20	0.20	0.20	0.20	26	3725.5	8.5	143.29	432.0	6.04	0.04	0.23	0.79
	30	22	3755.5	24.5	170.70	491.5	4.60	0.03	0.21	0.68	1	327.0	327.0	327.00	327.0	0.20	0.20	0.20	0.20	29	4962.5	17.5	171.12	429.0	7.25	0.07	0.25	0.79
RTC 2	1	14	2170.5	25.0	155.04	459.5	3.33	0.06	0.24	0.63	1	270.5	270.5	270.50	270.5	0.14	0.14	0.14	0.14	16	2245.0	17.5	140.31	400.0	4.33	0.07	0.27	0.74
	31	12	1695.5	9.5	141.29	432.0	2.70	0.03	0.23	0.58	1	192.0	192.0	192.00	192.0	0.09	0.09	0.09	0.09	16	1802.0	6.0	112.63	376.5	3.58	0.05	0.22	0.69
	32	12	1695.5	9.5	141.29	432.0	2.70	0.03	0.23	0.58	1	192.0	192.0	192.00	192.0	0.09	0.09	0.09	0.09	16	1802.0	6.0	112.63	376.5	3.58	0.05	0.22	0.69
Shift WL	1	14	2170.5	25.0	155.04	459.5	3.33	0.06	0.24	0.63	1	270.5	270.5	270.50	270.5	0.14	0.14	0.14	0.14	16	2245.0	17.5	140.31	400.0	4.33	0.07	0.27	0.74
	33	10	1531.5	14.5	153.15	309.5	2.72	0.04	0.27	0.68	1	164.5	164.5	164.50	164.5	0.19	0.19	0.19	0.19	10	1598.0	67.0	159.80	288.5	3.33	0.13	0.33	0.79
	34	11	1498.0	27.5	136.18	229.5	2.46	0.09	0.22	0.42	0	0.0	0.0	0.00	0.0	0.00	0.00	0.00	0.00	12	1438.5	7.0	119.88	242.5	2.87	0.05	0.24	0.38
	35	14	1818.0	25.0	129.86	248.0	2.72	0.05	0.19	0.43	0	0.0	0.0	0.00	0.0	0.00	0.00	0.00	0.00	16	1874.0	7.5	117.13	264.5	3.56	0.04	0.22	0.57
Shift WL & RTC & Crunoff	1	14	2170.5	25.0	155.04	459.5	3.33	0.06	0.24	0.63	1	270.5	270.5	270.50	270.5	0.14	0.14	0.14	0.14	16	2245.0	17.5	140.31	400.0	4.33	0.07	0.27	0.74
	36	9	854.5	24.5	94.94	270.0	2.1	0	0.2	0.6	1	113.0	113.0	113	113.0	0.2	0.2	0.2	0.2	12	742.0	2.5	61.83	207.5	2.2	0	0.2	0.8
	37	7	815.0	27.0	116.4	185.5	1.9	0.1	0.3	0.4	0	0.0	0.0	0	0.0	0	0	0	0	15	1042.0	2.5	69.47	134.5	2.3	0	0.2	0.4
	38	10	1023.5	24.5	102.4	185.0	2	0.1	0.2	0.4	0	0.0	0.0	0	0.0	0	0	0	0	16	1158.0	2.5	72.38	157.0	2.4	0	0.2	0.4
Improved S, I, E, C	1	14	2170.5	25.0	155	459.5	3.3	0.1	0.2	0.6	1	270.5	270.5	270.5	270.5	0.1	0.1	0.1	0.1	16	2245.0	17.5	140.3	400.0	4.3	0.1	0.3	0.7
	39	14	2027.0	13.5	144.8	458.0	3.1	0	0.2	0.6	1	268.5	268.5	268.5	268.5	0.1	0.1	0.1	0.1	14	1935.5	7.5	138.3	398.5	4	0	0.3	0.7
	40	13	1890.0	4.5	145.4	456.5	2.9	0	0.2	0.6	1	264.5	264.5	264.5	264.5	0.1	0.1	0.1	0.1	13	1818.0	11.5	139.9	395.5	3.7	0.1	0.3	0.7
RTC, WL shift S, I, E, C	1	14	2170.5	25.0	155	459.5	3.3	0.1	0.2	0.6	1	270.5	270.5	270.5	270.5	0.1	0.1	0.1	0.1	16	2245.0	17.5	140.3	400.0	4.3	0.1	0.3	0.7
	41	7	793.5	27.0	113.4	183.5	1.9	0.1	0.3	0.4	0	0.0	0.0	0	0.0	0	0	0	0	14	853.0	0.5	60.93	133.5	2.1	0	0.2	0.4

Group	Case	Point Lat_8									Point 23_1									Point 23_7								
		Num of Floods	TotDuration	min Duration	Avg. Duration	Max Duration	Tot.max. Depth	min max depth	avg.max.depth	max.max.depth	Num of Floods	TotDuration	min Duration	Avg. Duration	Max Duration	Tot.max. Depth	min max depth	avg.max.depth	max.max.depth	Num of Floods	TotDuration	min Duration	Avg. Duration	Max Duration	Tot.max. Depth	min max depth	avg.max.depth	max.max.depth
GLR	2	3	546.0	28.5	182.00	339.5	0.43	0.07	0.14	0.24	14	1863.0	0.5	133.07	394.0	3.20	0.03	0.23	0.66	1	259.5	259.5	259.50	259.5	0.13	0.13	0.13	0.13
	1	4	409.5	6.5	102.38	311.0	0.34	0.03	0.09	0.20	13	1404.5	0.5	108.04	362.0	2.37	0.03	0.18	0.61	1	168.5	168.5	168.50	168.5	0.08	0.08	0.08	0.08
	2	3	546.0	28.5	182.00	339.5	0.43	0.07	0.14	0.24	14	1863.0	0.5	133.07	394.0	3.20	0.03	0.23	0.66	1	259.5	259.5	259.50	259.5	0.13	0.13	0.13	0.13
	3	3	572.0	35.5	190.67	345.5	0.45	0.07	0.15	0.25	12	1954.0	0.5	162.83	403.0	3.24	0.05	0.27	0.67	1	274.0	274.0	274.00	274.0	0.14	0.14	0.14	0.14
Roughness	1	4	409.5	6.5	102.38	311.0	0.34	0.03	0.09	0.20	13	1404.5	0.5	108.04	362.0	2.37	0.03	0.18	0.61	1	168.5	168.5	168.50	168.5	0.08	0.08	0.08	0.08
	4	3	252.5	2.5	84.17	245.5	0.23	0.03	0.08	0.17	27	1441.5	0.5	53.39	365.5	2.96	0.03	0.11	0.58	1	110.5	110.5	110.50	110.5	0.05	0.05	0.05	0.05
	5	2	316.0	28.5	158.00	287.5	0.22	0.04	0.11	0.18	12	1396.5	0.5	116.38	369.0	2.38	0.04	0.20	0.60	1	141.0	141.0	141.00	141.0	0.07	0.07	0.07	0.07
	6	4	517.5	26.0	129.38	321.0	0.47	0.07	0.12	0.21	13	1374.0	0.5	105.69	357.0	2.35	0.03	0.18	0.62	1	195.5	195.5	195.50	195.5	0.09	0.09	0.09	0.09
	7	4	570.5	42.0	142.63	331.0	0.58	0.11	0.15	0.22	10	1381.0	6.5	138.10	360.5	2.31	0.03	0.23	0.63	1	210.0	210.0	210.00	210.0	0.10	0.10	0.10	0.10
	8	10	1191.5	15.5	119.15	404.5	1.30	0.04	0.13	0.26	13	2025.0	0.5	155.77	477.0	3.04	0.03	0.23	0.67	2	292.0	23.5	146.00	268.5	0.17	0.03	0.09	0.14
RTC	3	3	572.0	35.5	190.67	345.5	0.45	0.07	0.15	0.25	12	1954.0	0.5	162.83	403.0	3.24	0.05	0.27	0.67	1	274.0	274.0	274.00	274.0	0.14	0.14	0.14	0.14
	9	3	518.5	23.0	172.83	332.0	0.39	0.07	0.13	0.23	13	1764.0	0.5	135.69	383.5	2.99	0.03	0.23	0.65	1	242.0	242.0	242.00	242.0	0.12	0.12	0.12	0.12
	10	3	543.5	28.0	181.17	338.5	0.42	0.07	0.14	0.24	11	1855.0	29.5	168.64	393.0	3.08	0.10	0.28	0.66	1	258.5	258.5	258.50	258.5	0.13	0.13	0.13	0.13
	11	3	606.5	48.0	202.17	352.5	0.48	0.07	0.16	0.26	17	2425.0	0.5	142.65	413.0	3.56	0.03	0.21	0.68	2	296.0	7.5	148.00	288.5	0.18	0.03	0.09	0.15
	12	4	653.0	11.0	163.25	359.5	0.55	0.04	0.14	0.27	13	2795.5	44.0	215.04	421.5	3.61	0.09	0.28	0.69	2	398.5	99.0	199.25	299.5	0.21	0.05	0.10	0.15
	13	4	732.5	26.5	183.13	372.0	0.63	0.06	0.16	0.28	14	3114.5	0.5	222.46	435.5	3.89	0.03	0.28	0.70	2	512.5	197.0	256.25	315.5	0.26	0.09	0.13	0.16
Runoff	3	3	572.0	35.5	190.67	345.5	0.45	0.07	0.15	0.25	12	1954.0	0.5	162.83	403.0	3.24	0.05	0.27	0.67	1	274.0	274.0	274.00	274.0	0.14	0.14	0.14	0.14
	14	3	572.5	35.5	190.83	345.5	0.45	0.07	0.15	0.25	13	1954.5	0.5	150.35	403.0	3.27	0.04	0.25	0.67	1	274.0	274.0	274.00	274.0	0.14	0.14	0.14	0.14
	15	3	572.5	35.5	190.83	346.0	0.45	0.07	0.15	0.25	11	1952.5	34.0	177.50	403.0	3.20	0.11	0.29	0.67	1	274.0	274.0	274.00	274.0	0.14	0.14	0.14	0.14
	16	3	573.0	35.5	191.00	346.0	0.45	0.07	0.15	0.25	13	1955.0	0.5	150.38	403.0	3.28	0.04	0.25	0.67	1	274.0	274.0	274.00	274.0	0.14	0.14	0.14	0.14
	17	3	571.5	35.0	190.50	345.5	0.45	0.07	0.15	0.25	13	1952.0	0.5	150.15	403.0	3.27	0.03	0.25	0.67	1	274.5	274.5	274.50	274.5	0.14	0.14	0.14	0.14
	18	3	573.5	36.0	191.17	346.0	0.45	0.07	0.15	0.25	14	1956.5	0.5	139.75	403.0	3.29	0.03	0.24	0.67	1	273.5	273.5	273.50	273.5	0.14	0.14	0.14	0.14
	19	3	571.5	35.0	190.50	345.5	0.45	0.07	0.15	0.25	13	1951.0	0.5	150.08	402.5	3.27	0.03	0.25	0.67	1	274.5	274.5	274.50	274.5	0.14	0.14	0.14	0.14
Blockages	3	3	572.0	35.5	190.67	345.5	0.45	0.07	0.15	0.25	12	1954.0	0.5	162.83	403.0	3.24	0.05	0.27	0.67	1	274.0	274.0	274.00	274.0	0.14	0.14	0.14	0.14
	20	3	573.0	35.5	191.00	346.0	0.45	0.07	0.15	0.25	12	1956.5	0.5	163.04	403.0	3.23	0.03	0.27	0.67	1	274.5	274.5	274.50	274.5	0.14	0.14	0.14	0.14
	21	3	573.5	35.5	191.17	346.0	0.46	0.07	0.15	0.25	15	1963.0	0.5	130.87	403.5	3.34	0.03	0.22	0.67	1	275.0	275.0	275.00	275.0	0.14	0.14	0.14	0.14
	22	3	575.0	35.5	191.67	346.0	0.46	0.07	0.15	0.25	12	1970.0	0.5	164.17	403.5	3.26	0.03	0.27	0.67	1	276.5	276.5	276.50	276.5	0.14	0.14	0.14	0.14
	23	3	578.0	36.5	192.67	347.0	0.47	0.08	0.16	0.26	15	2000.0	0.5	133.33	404.5	3.40	0.03	0.23	0.67	1	277.5	277.5	277.50	277.5	0.14	0.14	0.14	0.14
	24	3	575.0	35.5	191.67	346.0	0.46	0.07	0.15	0.25	16	1956.0	0.5	122.25	402.0	3.41	0.03	0.21	0.67	1	276.5	276.5	276.50	276.5	0.14	0.14	0.14	0.14
DWF	3	3	572.0	35.5	190.67	345.5	0.45	0.07	0.15	0.25	12	1954.0	0.5	162.83	403.0	3.24	0.05	0.27	0.67	1	274.0	274.0	274.00	274.0	0.14	0.14	0.14	0.14
	25	3	577.5	38.0	192.50	347.0	0.47	0.08	0.16	0.26	13	1994.5	0.5	153.42	404.5	3.36	0.03	0.26	0.67	1	276.0	276.0	276.00	276.0	0.14	0.14	0.14	0.14
	26	3	582.5	40.0	194.17	348.5	0.48	0.08	0.16	0.26	19	2069.5	0.5	108.92	406.0	3.64	0.03	0.19	0.68	1	278.0	278.0	278.00	278.0	0.15	0.15	0.15	0.15
	27	3	572.5	34.0	190.83	348.0	0.46	0.07	0.15	0.26	15	1998.0	0.5	133.20	404.5	3.40	0.03	0.23	0.68	1	277.5	277.5	277.50	277.5	0.14	0.14	0.14	0.14
Leakage	3	3	572.0	35.5	190.67	345.5	0.45	0.07	0.15	0.25	12	1954.0	0.5	162.83	403.0	3.24	0.05	0.27	0.67	1	274.0	274.0	274.00	274.0	0.14	0.14	0.14	0.14
	28	3	564.5	34.5	188.17	344.5	0.42	0.07	0.14	0.25	14	2060.0	0.5	147.14	401.5	3.31	0.04	0.24	0.67	1	268.0	268.0	268.00	268.0	0.13	0.13	0.13	0.13
	29	3	556.5	33.0	185.50	343.0	0.41	0.07	0.14	0.25	14	2128.5	0.5	152.04	400.0	3.34	0.03	0.24	0.66	1	263.0	263.0	263.00	263.0	0.13	0.13	0.13	0.13
	30	3	474.5	28.5	158.17	340.5	0.40	0.07	0.13	0.25	19	2709.5	0.5	142.61	397.5	3.70	0.03	0.19	0.66	1	251.0	251.0	251.00	251.0	0.13	0.13	0.13	0.13
RTC 2	1	4	409.5	6.5	102.38	311.0	0.34	0.03	0.09	0.20	13	1404.5	0.5	108.04	362.0	2.37	0.03	0.18	0.61	1	168.5	168.5	168.50	168.5	0.08	0.08	0.08	0.08
	31	2	263.0	45.5	131.50	217.5	0.26	0.12	0.13	0.14	8	995.0	26.5	124.38	339.0	1.63	0.06	0.20	0.56	0	0.0	0.0	0.00	0.0	0.00	0.00	0.00	0.00
	32	2	263.0	45.5	131.50	217.5	0.26	0.12	0.13	0.14	8	995.0	26.5	124.38	339.0	1.63	0.06	0.20	0.56	0	0.0	0.0	0.00	0.0	0.00	0.00	0.00	0.00
Shift WL	1	4	409.5	6.5	102.38	311.0	0.34	0.03	0.09	0.20	13	1404.5	0.5	108.04	362.0	2.37	0.03	0.18	0.61	1	168.5	168.5	168.50	168.5	0.08	0.08	0.08	0.08
	33	3	181.5	14.0	60.50	148.5	0.34	0.04	0.11	0.24	10	869.5	0.5	86.95	219.0	1.99	0.03	0.20	0.66	1	89.5	89.5	89.50	89.5	0.13	0.13	0.13	0.13
	34	1	41.5	41.5	41.50	41.5	0.12	0.12	0.12	0.12	10	859.0	0.5	85.90	210.0	1.25	0.03	0.12	0.24	0	0.0	0.0	0.00	0.0	0.00	0.00	0.00	0.00
	35	2	51.5	10.5	25.75	41.0	0.15	0.04	0.08	0.12	15	1131.0	0.5	75.40	222.0	1.67	0.03	0.11	0.44	0	0.0	0.0	0.00	0.0	0.00	0.00	0.00	0.00
Shift WL & RTC & Crunoff	1	4	409.5	6.5	102.38	311.0	0.34	0.03	0.09	0.20	13	1404.5	0.5	108.04	362.0	2.37	0.03	0.18	0.61	1	168.5	168.5	168.50	168.5	0.08	0.08	0.08	0.08
	36	1	101.0	101.0	101	101.0	0.2	0.2	0.2	0.2	5	269.5	4.0	53.9	173.0	0.9	0	0.2	0.6	1	38.0	38.0	38	38.0	0.1	0.1	0.1	0.1
	37	1	41.5	41.5	41.5	41.5	0.1	0.1	0.1	0.1	6	279.5	0.5	46.58	95.5	0.8	0	0.1	0.3	0	0.0	0.0	0	0.0	0	0	0	0
	38	1	41.5	41.5	41.5	41.5	0.1	0.1	0.1	0.1	6	334.5	23.0	55.75	90.5	0.6	0	0.1	0.2	0	0.0	0.0	0	0.0	0	0	0	0
Improved S, I, E, C	1	4	409.5	6.5	102.4	311.0	0.3	0	0.1	0.2	13	1404.5	0.5	108	362.0	2.4	0	0.2	0.6	1	168.5	168.5	168.5	168.5	0.1	0.1	0.1	0.1
	39	3	414.5	26.0	138.2	310.0	0.3	0.1	0.1	0.2	11	1286.0	0.5	116.9	361.5	2.2	0	0.2	0.6	1	164.0	164.0	164	164.0	0.1	0.1	0.1	0.1
	40	2	355.0	63.5	177.5	291.5	0.2	0.1	0.1	0.2	12	1225.0	0.5	102.1	364.0	2.2	0	0.2	0.6	1	157.5	157.5	157.5	157.5	0.1	0.1	0.1	0.1
RTC, WL shift S, I, E, C	1	4	409.5	6.5	102.4	311.0	0.3	0	0.1	0.2	13	1404.5	0.5	108	362.0	2.4	0	0.2	0.6	1	168.5	168.5	168.5	168.5	0.1	0.1	0.1	0.1
	41	1	40.5	40.5	40.5	40.5	0.1	0.1	0.1	0.1	6	267.0	0.5	44.5	90.0	0.8	0	0.1	0.3	0	0.0	0.0	0	0.0	0	0	0	0

Table E.4: A plot of the data for Case 3 at the point Lat_1 (see Figure E.2), for the entire model simulation time. On the left y-axis water depth in meters for the red line, and the Yangon River water levels in meters Ground Level Reference (GLR) for the black line. On the right y-axis the rainfall in millimetres for the blue line. Most flood events coincide with a high water level in the Yangon River and if there is rainfall simultaneously.

E.5. Discussion

The discussion is divided into two parts. In the first part the used methods and materials are discussed, while in the second part there is a discussion about the results.

E.5.1. Data and Model Discussion

Uncertainties in the data from the materials section (Section 3.1.3) and assumptions for the methodology section (Section 3.2.5) introduced quite a number of points open to discussion. In this section these discussion points will be stipulated, evaluated on their impact and a proposed improvement will be suggested.

E.5.1.1. Urban Drainage Network

Although the drainage map only shows drains that run along the streets, field observations showed that there are also drains in between the houses, that drain the DWF and runoff from the back of the buildings to the main road, see Figure C.27. However, these canals have not been modelled in order to simplify the modelling and since there was no data available about the dimensions.
Another weakness is that based on field observations, the questionnaires and interviews with YCDC EDRB it is known that from 2015 onwards there have been improvements made to the drainage system and street elevation levels.

E.5.1.2. Ground Level Elevations

One of the problems faced while interpolating the ground level elevations is the limited number of known points and the spatial distribution of these points. The elevation data is only available on street corners. The street pattern is grid-like layout with most streets running from north to south which are connected by three main road running from west to east. This results in the situation that the distances between street corners in west-east direction are short and long distances between street corners in north-south direction. As a consequence it is more likely that the interpolation is a better approximation for the main west-east oriented roads (especially Maha Bandula Road and to a lesser extent Anarwrahta Road and Strand Road) than for the streets that are oriented north-south (Lanmadaw till Shwedagon Pagoda Road).
The limited number of points in the north-south direction introduces another weakness. For this model all known points were used to interpolate an unknown point. This means that for example points from the south-east corner also effect the interpolation of points all the way in the north-east corner albeit really small. The interpolation results may be improved by implementing restrictions on e.g. the number of closest points used for interpolation or a maximum distance between the point being interpolated and the known points that are used for the interpolation.
Furthermore, one of the weaknesses of inverse weighting interpolation is that the interpolated values can never be outside of the known maximum (upper bound) and minimum (lower bound) values. However, in reality there may be points in the Latha Township that are actually higher or lower than maximum or minimum known ground level elevations. Another point of discussion is the used order of inverse distance weighting interpolation. The judgement of the most suitable order was in this case based upon subjective criteria.

The uncertainties in the ground level elevation data as a result of interpolation have an impact on the reliability of the results of the model. Water depths, flood frequencies and flood durations for example may be overestimated if the ground level is too low or under estimated if the elevation is too high.
The uncertainty in the ground level elevation data has a bigger impact on the lower blocks of the Latha townships, since these are more low-laying than the upper block and thus are more flood prone that the upper block.

Extra measurements in especially the lower block streets (north-south oriented) could help to improve the accuracy of the results. By also measuring the elevation at some of the known points it is possible to correlate the other known data points to a known reference level.
Furthermore the resolution of the used grid (5x5 meter cells) could be increased to get better (interpolation) results. Such a modification will result in longer computation times whereas the observed improvements on

accuracy may be limited, and thus therefore the acquisition of additional elevations points with a known reference level should get priority.
Another option would be to find a point (e.g. Maha Bandula Park) and obtain the elevation data in the same (unknown) reference system NEPS used for the Latha Township ground level elevation dataset. Such a point could then be correlated to a datum using STRM-DEM (1-arcsecond) data. Unfortunately there is not a suitable point in the NEPS dataset for Latha that allows for such a strategy. The problem is that there is not a sufficient large enough area with a known NEPS elevation.

E.5.1.3. Flood Records

There seems to be an inconsistency.

A remark has to be made that the frequency of flooding based upon the scratch marks does not match with the reported flood frequency based upon the questionnaires and interviews. Based on interviews with YCDC EDRB, a potential cause may be identified. YCDC does not have clear or strict guidelines and procedures for when a flood is recorded.

E.5.1.4. Yangon River Water Levels

For a drainage system that is discharging into a tidal river (the downstream boundary condition), with outflow structures that are operated based on the downstream water level it is really important to have good data on the downstream water levels. As is mentioned in Section C.3.11 there is a high uncertainty on the reliability and quality of the data. It is even unknown if the water levels from the dataset are actually measured or if they come from a tidal model. Furthermore, the data is measured/modelled for Monkey Point and not for the Yangon River at the location of the gate outlet structures.
In order to work with what we have got, the discrete data had to be approximated using Equation C.2 and the parameters from Table C.5. The approximation of the simulated water levels have been done by hand on subjective criteria, which is a clear weakness.

That the data is actually for Monkey Point and not for the Yangon River adjacent to the Latha Township is the least crucial. The water level at Monkey Point may be different for example due to backwater curves because of the confluence of Yangon River with the Bago River and Panzundaung Creek. However, the Latha Township drainage outflow structures are relatively close to Monkey Point that such effects may be limited. Moreover, reliable data for the Yangon River, Bago River and Panzundaung Creek such as discharges, cross-section profiles, riverbed slopes and other required data may be scarce. Therefore it will be hard to study the precise effect into great detail.
More troublesome seems to be the fact that the water levels are probably derived from a tidal model. This means that is impossible to assess the quality of the data, as the model and model's assumptions are unknown. For example, does this model update its predictions based upon the actual discharge in the Yangon River, Panzundaung Creek and Bago River? This is of importance as the river discharge effects the tidal progression. Once again, reliable data for the three rivers may be scarce, making it hard to improve the model output.
The biggest impact seems to be that the river water levels effect the discharge capacity of the drainage system and the operation of the gated outflow structures. Too high river water levels will result in too low discharges (shorter durations of free flow and smaller discharges under submerged flow conditions) and too frequent closures of the gates which may result in completely filled storages in the drains and eventually flooding. For too low river water levels the opposite applies.

One of the things that could be done is to try and investigate if the data is indeed modelled in a tidal model and if so what does the model look like and what assumptions are made. This might allow for a better judgement on the reliability of the data.
However, what seems to be a better improvement is to obtain a reliable dataset with actual measured water levels with a known reference datum and run the model with that data.
As obtaining a reliable old dataset might turn out to be difficult the best solution would be to do water level measurements in cooperation with the Myanmar and run the model with rainfall data, ground level elevation data, drainage network layout data, etc. that is recorded on the same time. Such a dataset may be of great value to other researchers, YCDC, ministries and other organizations such as the Yangon Port Authority. The same applies to e.g. discharges, cross-section profiles, riverbed slopes data.

E.5.1.5. Rainfall Data

The rainfall data is measured at an unknown location in Yangon, probably around Kaba Aye Road which is 13km away from the Latha Township.
At the location of the Kaba Aye Station the rainfall volume is measured per hour. An analysis of the drainage system shows that a completely empty system has a lag time of about 30 minutes between the peak of the rainfall and the peak of the total discharge incase of a rainfall event with a duration of about 35 minutes and a total volume of 55mm. This means that under such conditions the system may be considered to responds faster than the rainfall data interval. Based on the fast hydraulic response of the system we may conclude that rainfall data with a higher temporal resolution is desired.

The fact that the rainfall measurements are 4.5km away from Latha does not have a big impact on the reliability of the data. During Myanmar's rain season large rainfall weather fronts hit the coastal areas. The temporal and spatial resolutions of rainfall events may be expected to not that different from the Latha Township to the location of the Kaba Aye station. Furthermore, the rainfall does not seem to be that extreme and thus we may expect less localized extremes that deviate significantly between the two locations. The limited temporal resolution may result in too low average intensities that underestimate or overestimate the speed of the hydraulic response. Moreover, the distribution of the rainfall in the one hour time step also has an effect that cannot be modelled by this data. If a majority of the hourly precipitation falls in the beginning of that hour and the system is almost empty the system's response is different than when the system starts to slowly fill up and the majority of the rainfall volume falls at the end of the 1 hour time step.

One of the things that could be done to improve future data is to install a (automatic) rain guage or distrometer in the Latha Township that records the average rainfall per every 1 or 5 minutes.
Another thing that could be done is to create a synthetic dataset based on the actual data where the volumes are distributed skewed over smaller time steps to research the effects of the temporal distribution.

E.5.1.6. Total Weather Flow

The dry weater flow (DWF) and rainfall runoff (storm water flow, SWF) is modelled to enter the drains aggregated for an entire area a the start of the drain (the upstream part of the drain) in order to simplify the modelling and since there is insufficient data available to correctly allocate the DWF and SWF inflows.

The consequence of this simplification is that there will be a delay in the drainage, since a part of the flow will now have to go through a longer stretch of the drain than it actually was supposed to flow through (water close to the downstream part of the drain would be drained already to the next stretch). This results in a situation that overestimates the flow through the drains and thus results in a higher flood risk.

The model results may be improved by building a SOBEK model with more nodes with runoff, to simulate inflow closer to the source. Based on such model the impact of an more distributed inflow may be researched. Since the scale of the system is relatively small (especially for the shorter drain sections running from west to east) it may be expected that this only has a limited impact.
In order to make such a model, more data is required about the population (density) at specific locations. An extra census survey could be implemented to acquire this data. Moreover, a survey should be done to record all the locations of the inlets that allow for SWF inflow.

E.5.1.7. Dry Weather FLow

For this study an assumption was made about the total DWF. The DWF is partially estimated based upon a number of water consumption per capita per day for the entire Yangon region. This actual number is most likely too low, since the level of economic wealth is higher in the Latha Township as compared to the whole of Yangon. Moreover the data is already from a few years ago and due to economic growth this number may have increased. Another contribution to the dry weather flow is based upon commercial activities such as shops, restaurants, hotels/hostels and other forms of hospitality which shows higher signs of activity in the Latha Township when compared to the whole of Yangon. Therefore the DWF is estimated to be 120 L/capita/day.

However, the impact of the accuracy of the dry weather flow might be limited since the total DWF is only a very small fraction of the total weather flow (TWF) compared to the SWF. In case of a minor rainfall event of 20 mm/h for a duration of 1 hour the average $Q_{SWF} = C \cdot A \cdot I = 0.7 \cdot 645{,}000 \cdot 20/1000 = 9063\,m^3/h$ and when compared to the DWF of one hour: $Q = q_{consump} \cdot N_{inhab} = 120/1000/24 \cdot 25{,}000 = 125\,\mathrm{m}^3/\mathrm{h}$ we may conclude that this is indeed limited (DWF/TWF = 1.36%), let alone for more heavy rainfall events. A different runoff coefficient also hardly has an effect on the relative share of the DWF compared to the TWF.

As a possible improvement it would be possible to measure the dry weather flow during the dry season at the 3 gate locations. This could be done by implementing weirs with a known discharge formula and measure water levels at and around the weirs (upstream and downstream), in order to make a good estimation of the total DWF. This might give the most reliable results as it will be hard to get reliable data based upon questionnaires or surveys in order to better estimate the dry weather flow condition. However since to the limited impact for this study, it should not get priority.

Another problem is that the exact population distribution is unknown for the Latha township. A part of the population living in institutions is allocated to the hospital area, this was estimated to be 50%. for the residential area of the township (wards 1 till 8) the remaining population is distributed over the area according to contributing areas that are connected to a drain. However, field observations have shown that an evenly distributed population is most likely unrealistic. Some locations have hardly any (residential) buildings whereas other areas are full of high rise buildings, housing more people.

As explained in the earlier paragraphs of this section, the impact of errors in the DWF have a limited effect compared to the SWF. The unknown population for the hospital area has an effect that the DWF inflow from the hospital is wrong. However, the 50% estimation is on the high side and thus is more likely to over estimate the flow.

Digital elevation model (DEM) data could be used to make a better distribution of the population density. Assuming that there is a (causal) correlation between building heights (derived from DEM data) and people living in that area. For the hospital area it would be best to do a survey to better estimate the number of people living in this area.

F

Socio-Hydrological Model

F.1. Original Hypothesis

Figure F.1 shows a possible conceptual socio-hydrological model of the urban pluvial flooding human-water system for Yangon. More detailed overviews are shown in Figure F.2, Figure F.3a, Figure F.3b) and Figure F.4.

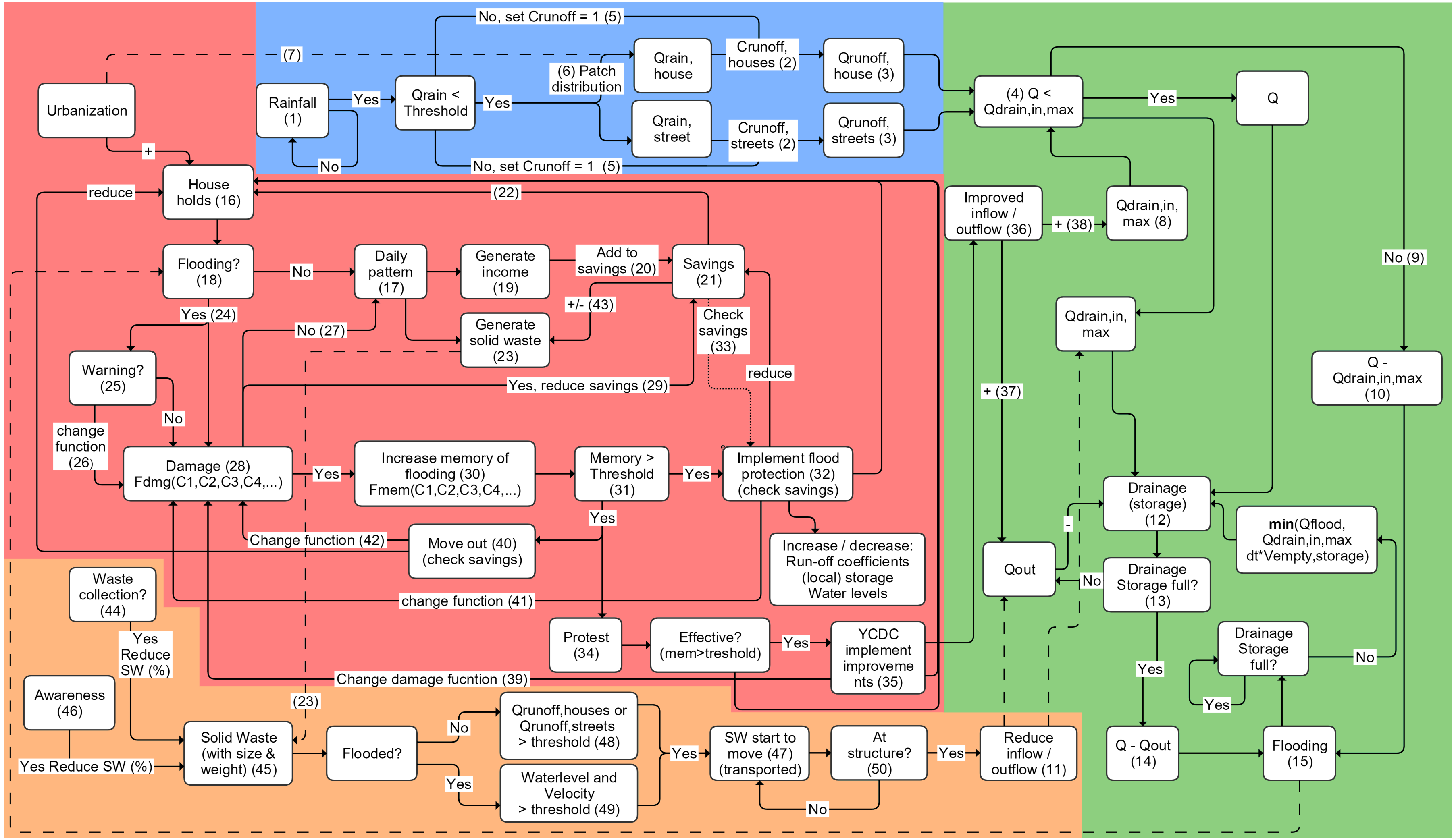


Figure F.1: Hypothesis of the human-flood interaction. The red section represents the citizens' daily activity patterns (Detail in Figure F.2), responses to a flood and other related processes while the orange section is focussed on solid waste production, solid waste management and solid waste in the drains (Detail in Figure F.3a). Together these two parts represent the human activities. The right side represents the hydrological and hydraulic processes: with the blue section for the rainfall (runoff) (Detail in Figure F.3b) and the green section for the urban drainage system's (flood) processes (Detail in Figure F.4).

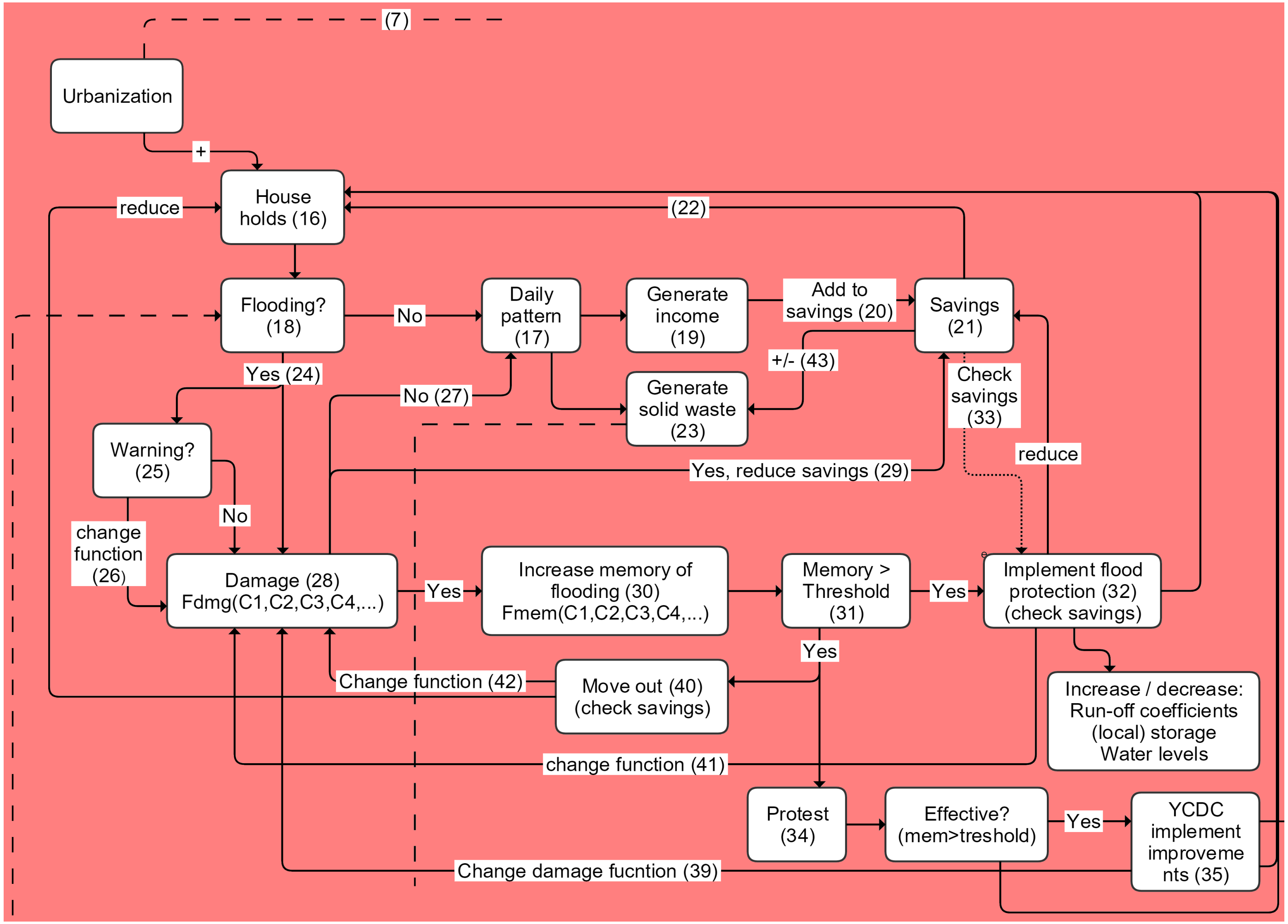
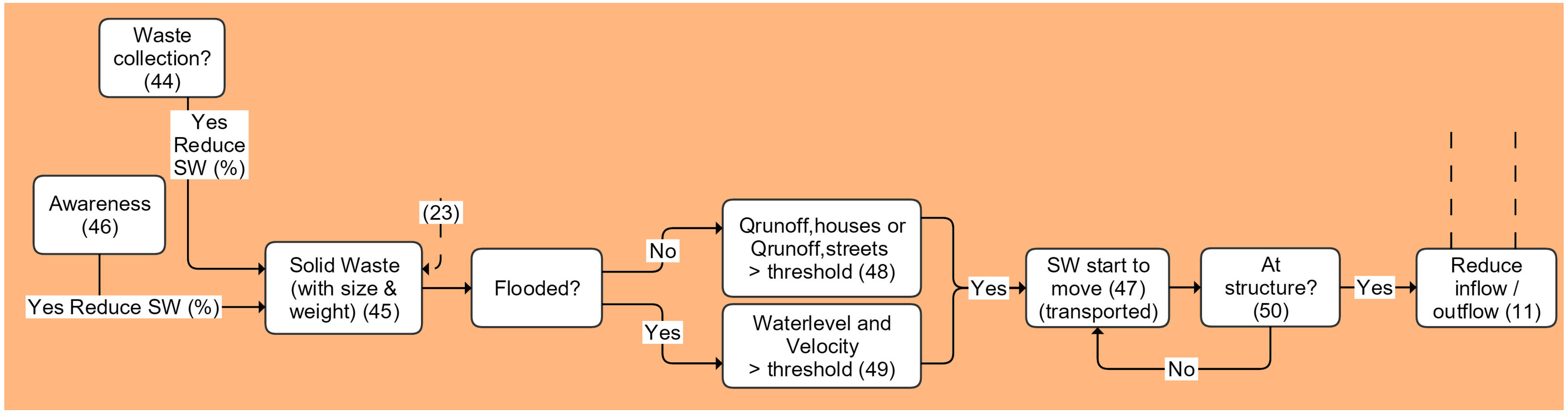
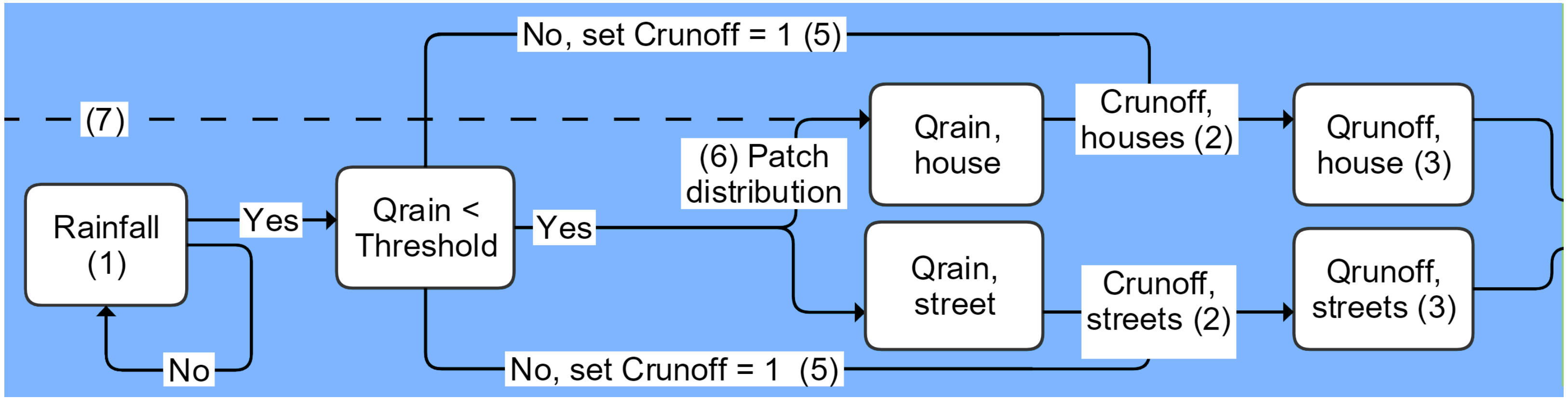


Figure F.2: Hypothesis of the human activities with their daily live patterns, responses to a flood and other related processes. Processes are represented by the rectangles with rounded corners. The lines show how properties, states and parameters are related. Solid lines represent processes, relations, states and parameters that have a small uncertainty. The long dashed lines represent processes, relations, states and parameters that have a larger uncertainty.



(a) Hypothesis of the (human) waste activities. Processes are represented by the rectangles with rounded corners. The lines show how properties, states and parameters are related. Solid lines represent processes, relations, states and parameters that have a small uncertainty. The long dashed lines represent processes, relations, states and parameters that have a larger uncertainty.



(b) Hypothesis of the rainfall processes. Processes are represented by the rectangles with rounded corners. The lines show how properties, states and parameters are related. Solid lines represent processes, relations, states and parameters that have a small uncertainty. The long dashed lines represent processes, relations, states and parameters that have a larger uncertainty.

Figure F.3: Hypothesis of the (human) waste activities and rainfall.

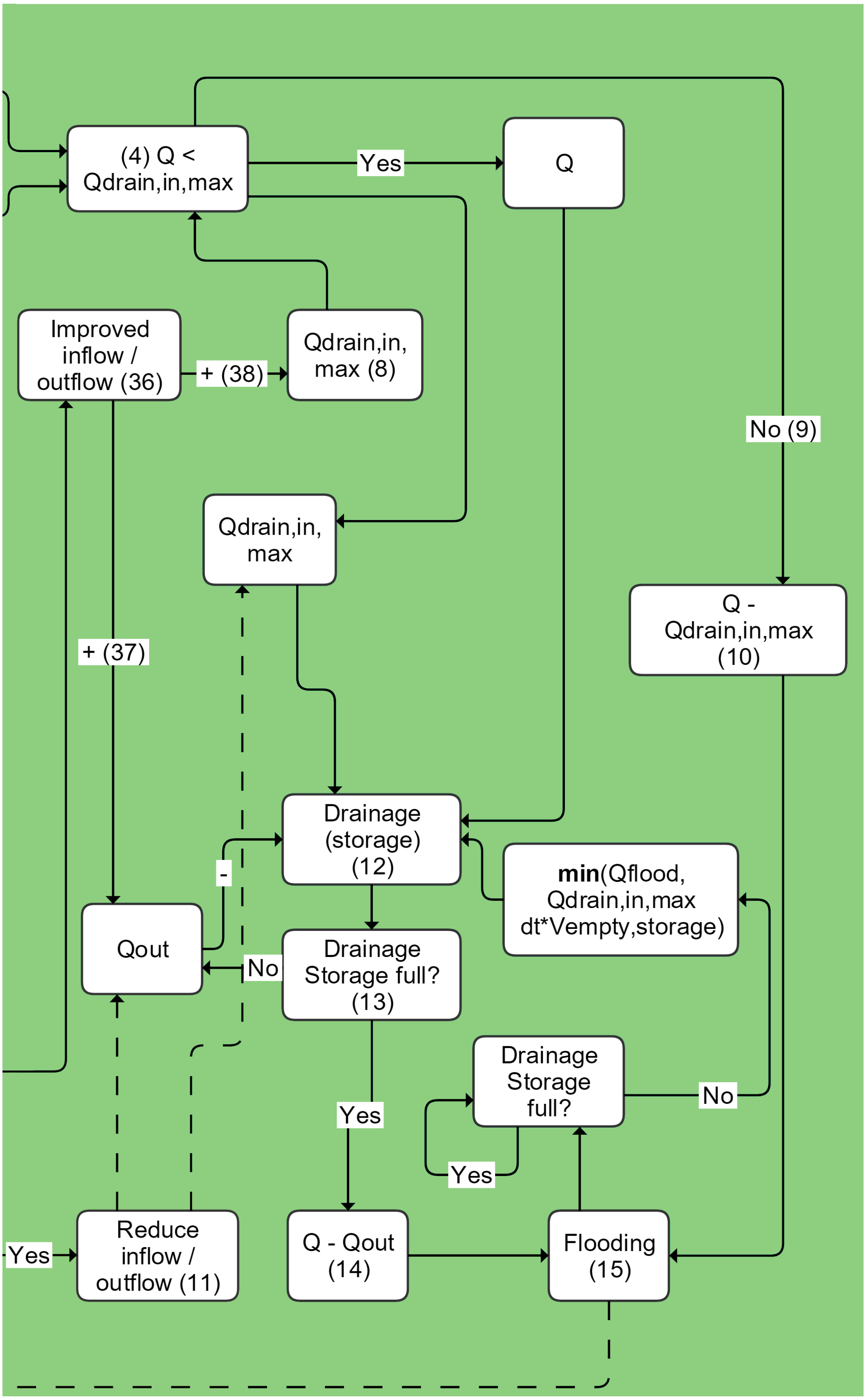


Figure F.4: Hypothesis of hydrological and hydraulic processes of the urban drainage system. Processes are represented by the rectangles with rounded corners. The lines show how properties, states and parameters are related. Solid lines represent processes, relations, states and parameters that have a small uncertainty. The long dashed lines represent processes, relations, states and parameters that have a larger uncertainty.

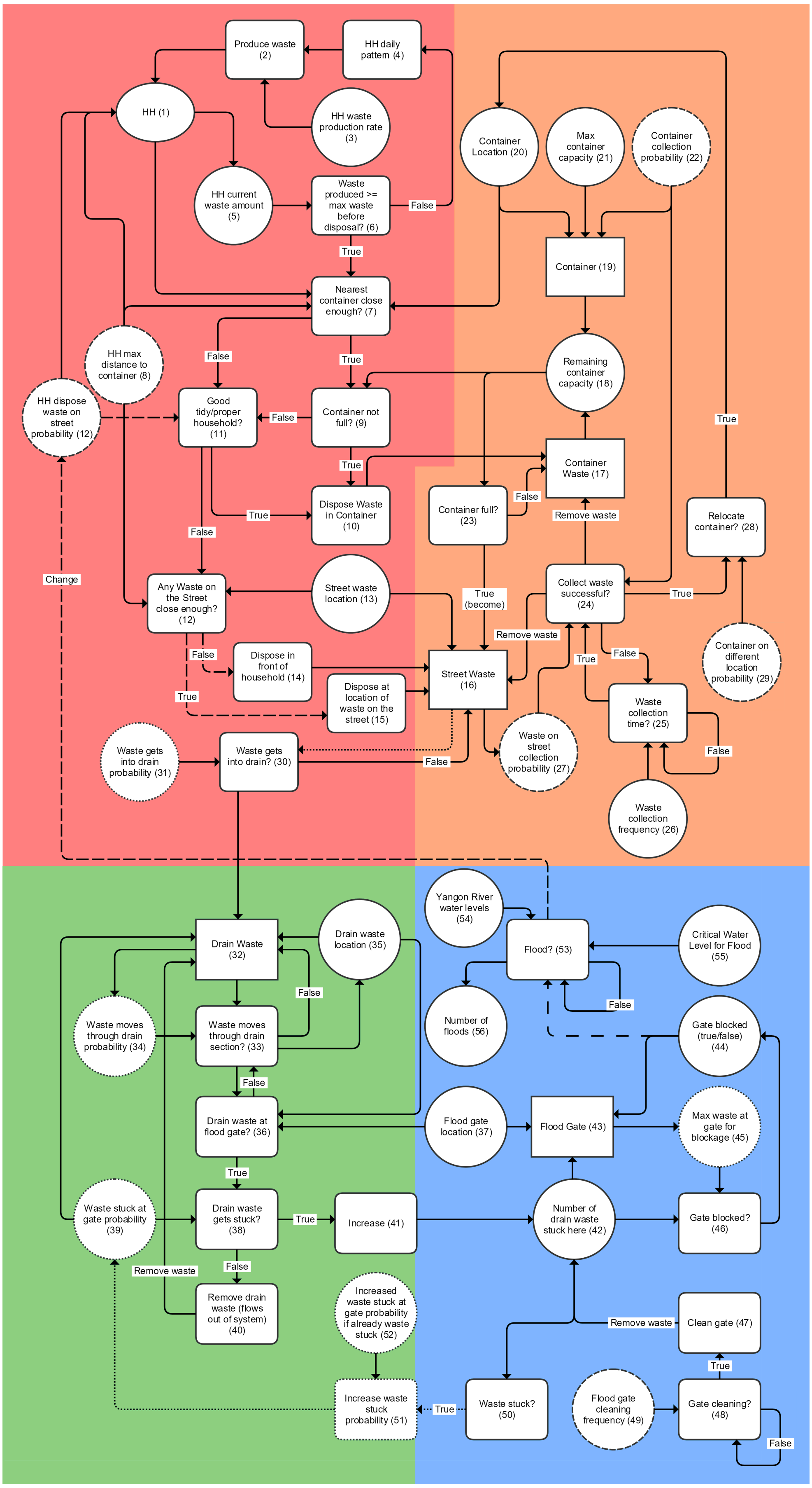


Figure F.5: Renewed hypothesis of the human-flood interaction. The red section represents the citizens' daily activity patterns producing waste and making decisions about their waste disposal practices. The orange section models the waste in and around the waste containers and waste on the streets with its collection and cleaning (by the YCDC). For a detail of the red and orange section see Figure F.6. The green section represents waste that *found its way into the drains* and moves through the drains to the FGSs. The blue section conceptualizes the FGS and potential blocking of the FGS that results in a flood. For a detail of the blue and green section see Figure F.7.

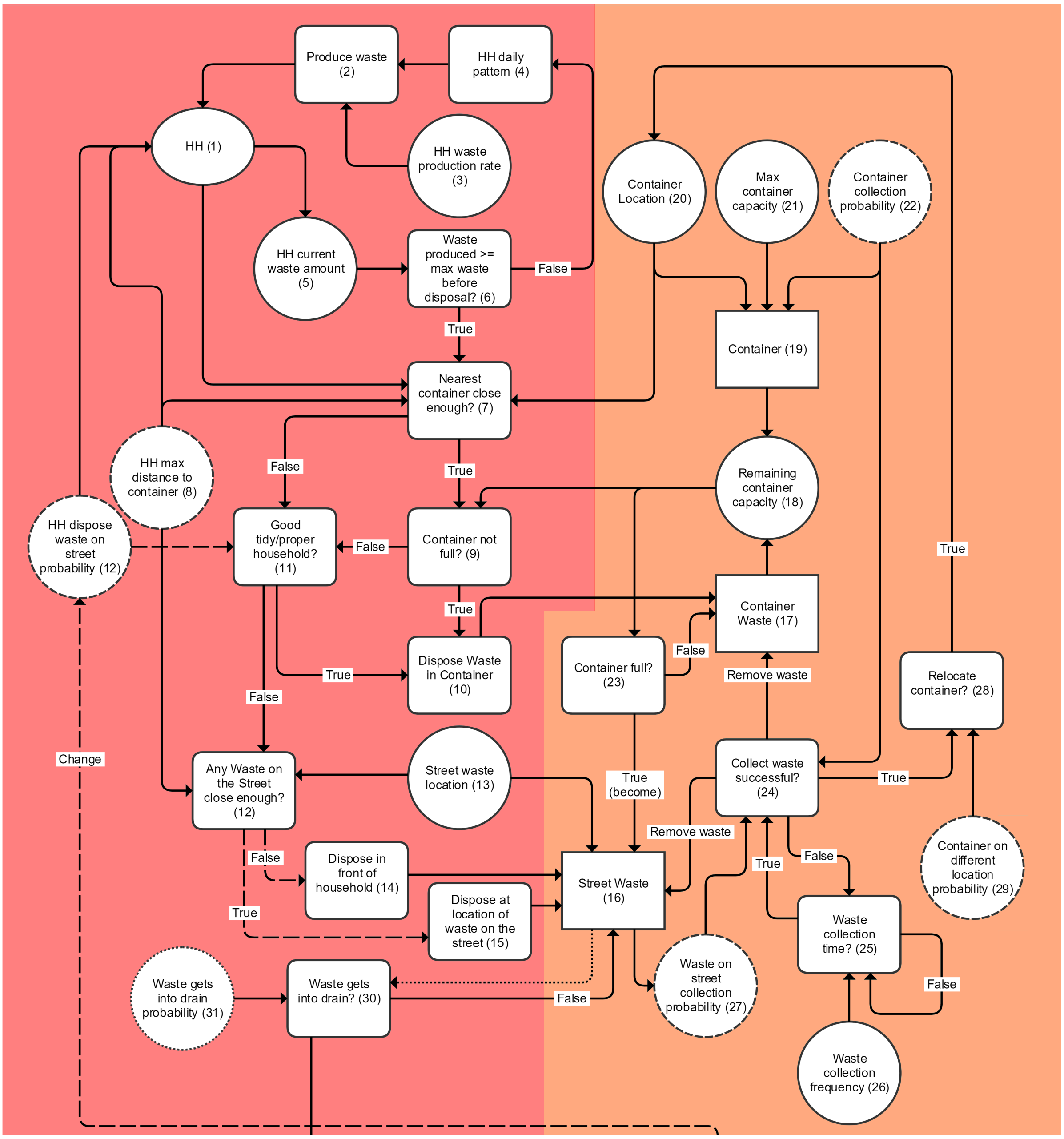


Figure F.6: Hypothesis of the human activities (red) and solid waste (management) related processes (orange). The circular shapes represent properties or states of agents or parameters of processes. Human agents are represented by an oval shape and non human agents are represented by rectangular shapes. Processes are represented by the rectangles with rounded corners. The lines show how properties, states and parameters are related. Solid lines represent processes, relations, states and parameters that have a small uncertainty. The long dashed lines represent processes, relations, states and parameters that have a medium uncertainty. The short dashed lines represent processes, relations, states and parameters that have a high uncertainty.

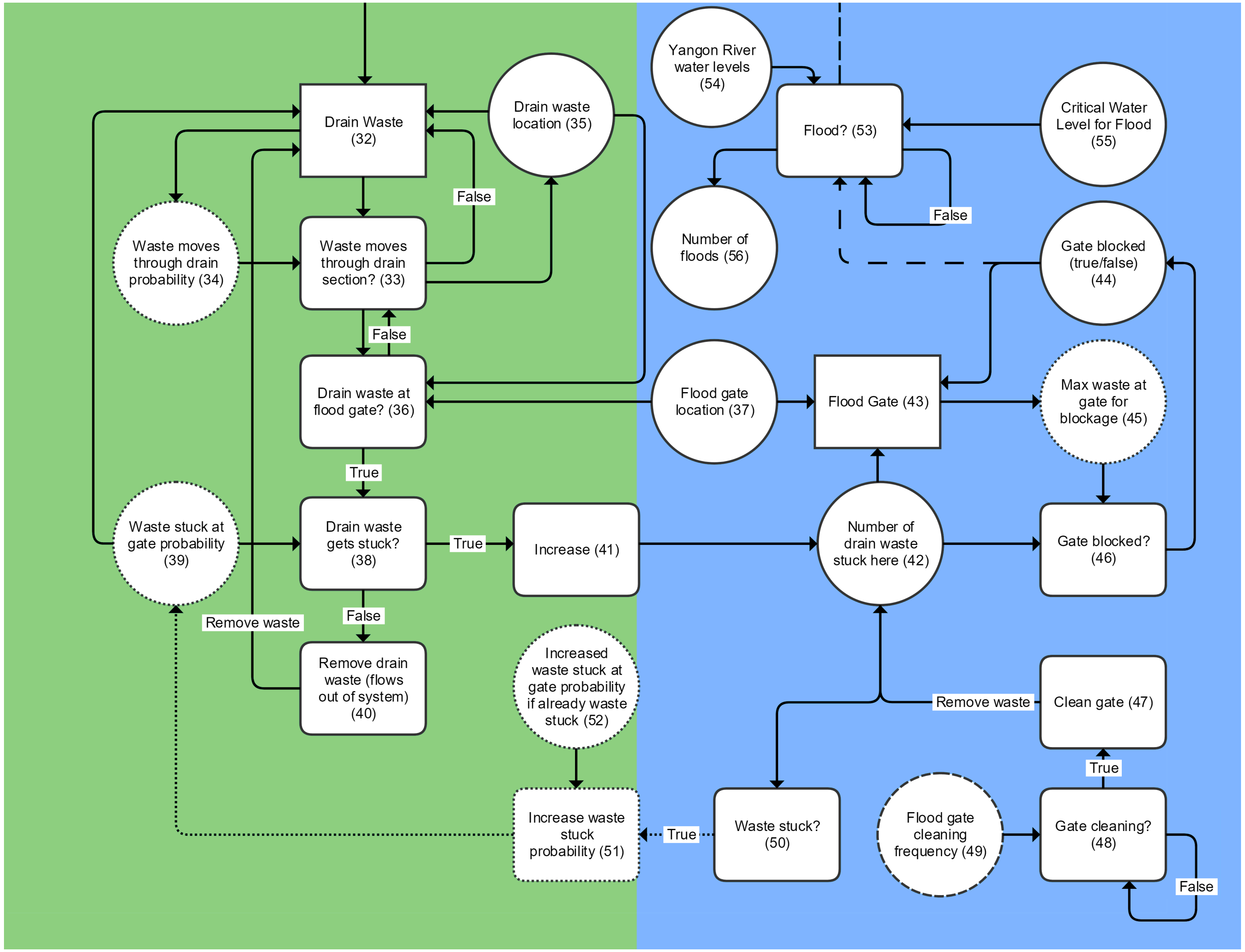


Figure F.7: Hypothesis of the processes of solid waste in the drains (green) and flood related processes (blue). The circular shapes represent properties or states of agents or parameters of processes. Human agents are represented by an oval shape and non human agents are represented by rectangular shapes. Processes are represented by the rectangles with rounded corners. The lines show how properties, states and parameters are related. Solid lines represent processes, relations, states and parameters that have a small uncertainty. The long dashed lines represent processes, relations, states and parameters that have a medium uncertainty. The short dashed lines represent processes, relations, states and parameters that have a high uncertainty.