HANOI UNIVERSITY OF RESOURCES AND ENVIRONMENT
FACULTY OF WATER RESOURCES

DO THI THUY DUNG

BACHELOR THESIS

RESEARCH TO PROPOSE SOLUTIONS FOR URBAN FLOODING IN THE MY DINH AREA OF HANOI, VIETNAM

Ha Noi, 2020

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Thank you so much!

Do Thi Thuy Dung

Hanoi, June 2020

STATUTORY DECLARATION

I herewith formally declare that the submitted Bachelor's Thesis titled "***Research to propose solutions for urban flooding in the My Dinh area of Hanoi, Vietnam***" has been written by myself independently.

All of the figures and documents which I employed when producing this academic work in this thesis are true with high precision. I marked and separately listed all of the literature as well as the other sources clearly at the Bibliography. The thesis has not been used for any degree, I am aware that the violation of this regulation will lead to the failure of the thesis.

Hanoi, 20/06/2020

Student

Do Thi Thuy Dung

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ABBREVIATIONS

SuDs : Sustainable drainage systems

GIS: Geographic Information System

MSL: Mean Sea Level

DEM: Digital Evaluation Map

FEMA: Federal Emergency Management Agency

VACI: Vuon (Green) - Ao (Water) - Chuong (Biodiversity) - Initiative

IPCC: Intergovernmental Panel on Climate Change

TCVN 8317: 2010 : Vietnam national regulation on irrigation works - procedures for management, operation, and maintenance of electric pumping stations

INTRODUCTION

1. Problem statement

Nowadays, a large number of cities in Viet Nam are facing serious flooding issues. Hanoi has become the national center for economy, culture, and society, and hence the capital has encountered a rapid urbanization. Besides its benefits, these rapid transformations of the city also came with many drawbacks that have adverse impacts on the city's drainage systems. The study area is located in the Western part of Hanoi. Even though it was a new urban area, the area still deeply flooded and slowly drained after heavy rains. This not only causes a bundle of difficulties in the daily life of people but ruins the urban landscapes as well.

Since 1998, Phase I and phase II of the Hanoi Drainage Project have been conducted by the government. Subsequently, the stormwater drainage system in the urban area of To Lich, Lu, Set, and Kim Nguu rivers with an area of 77.5 km^2 (including Ba Dinh, Hoan Kiem, Dong Da, and Hai Ba Trung districts, Hoang Mai, Tay Ho and a part of Cau Giay and Thanh Xuan districts) has been completed. This system was designed to cope with storms with an average intensity of 300mm/2 days [1,2]. However, My Dinh was excluded from this project and still suffered from prolonged flooding without any improvement.

In addition, the inundation in My Dinh is mainly due to the rapid urbanization. Urban development makes drainage systems unable to keep up with that pace of growth. Urbanization has led to the massive increase of infrastructure, areas that used to be bare land of free-grown trees, now replaced by houses, tall buildings, or concrete streets. The population density in Hanoi is 2505 people per km^2, in some districts up to 35,341 people per km^2 [29]. The increase of impervious surfaces increases the amount of water discharge, exceeds the drainage capacity and leads to flooding.

Another factor that accounts for the flooding issues in the research area is climate change. Climate change causes a series of precipitation events increasing both in intensity and frequency, these erratic rain events are even unpredictable, making it hard to proactively prepare appropriate coping measures.

However, the research area locates in connection with other regions, so the problems also come from other external factors. The study area is a low-lying area, when downpours occur, the flows from surrounding areas are likely to flow into it and cause serious flooding.

Therefore, the topic " *Research to propose solutions for urban flooding in the My Dinh area of Hanoi, Vietnam*" will partly help find efficient solutions to reduce flood risks for My Dinh, Hanoi in particular, and other urban areas.

2. Objectives

This study will pursue the following objectives in order to propose solutions for urban flooding in My Dinh suburb in Hanoi.

1. Find out the causes of flooding in the study area
2. Provide solutions from the root cause

3. Research methods

1. Method of collecting materials and synthetic materials
2. Field work method
3. Method of mapping and GIS
4. Method of comparison, evaluation

4. Scope

The scope of this research is about 10km to the West of central Hanoi, Which includes four precincts: Mai Dich, My Dinh 1, My Dinh 2, Phu Do. The zone is surrounded by three routes (Ho Tung Mau, Le Duc Tho, Nguyen Co Thach) with an area of 155ha (1,55km^2).

5. Structure of thesis

- Chapter I: Literature review
- Chapter II: Flooding overview in the study area
- Chapter III: The proposal of solution

CHAPTER 1: LITERATURE REVIEW

1.1 Overview of the study area

1.1.1 Geographic location

The study area is in coordinates:

Latitude: 21º01’24”N

Longitude: 105º46’23”E

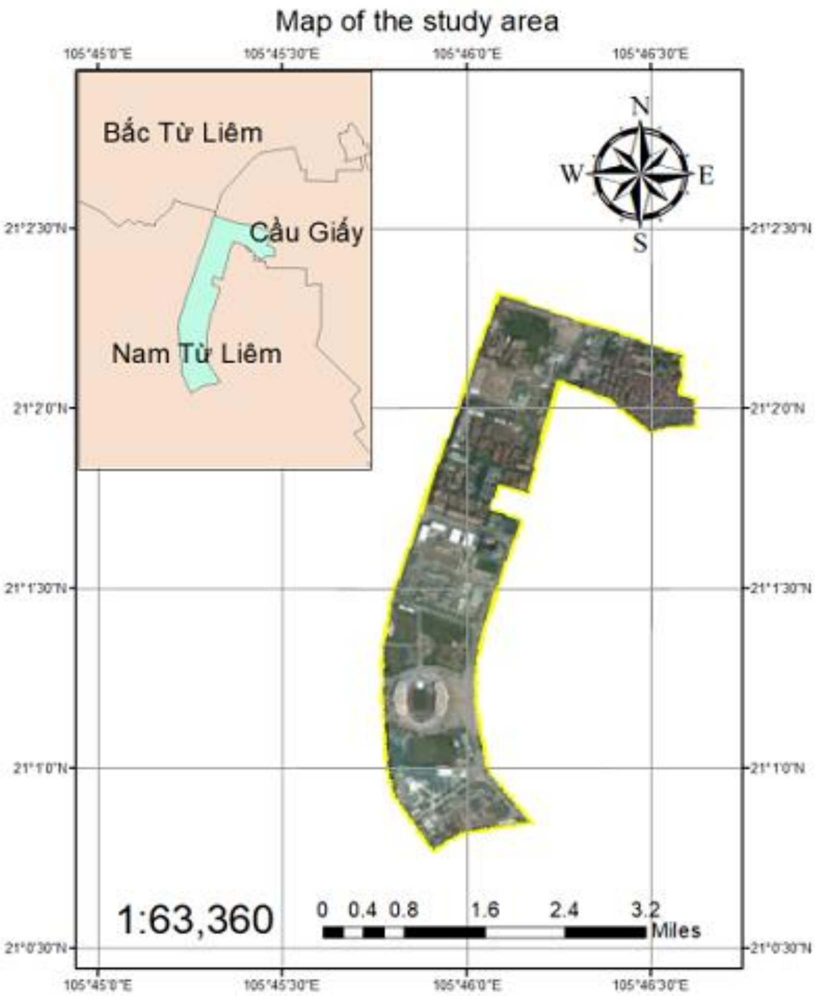


Figure 1.1 Location map of the research area

1.1.2 Geographical features

The topography of the region is mainly plain, relatively flat, the average height is 15-20m above the average sea level (MSL). Geological base is relatively stable. The main soils are metamorphic rocks, sediments, magma [4]. The terrain goes down from north to south and from west to east. So far, My Dinh has focused on exploiting industrial activities and urban development. My Dinh National Stadium is one of the outstanding architectures of the study area. Located in the southern part of the study area, it was officially opened in September 2003 to become the main venue for the 2004 Southeast Asian Games, holding the opening and closing ceremonies.

1.1.3 Climate features

Climate data (temperature, rainfall, humidity) is collected from Lang gauging station for the years 2010-2015 since the station has a location that is closest to the research area and puts hydro-meteorological data in storage for over 50 years.

The climate of the Northern Delta in general and the My Dinh area in particular is on the edge of the tropical climatic zone, which is a hot and humid climate with four distinct seasons (Spring, Summer, Autumn, and Winter). The rainy season coincides with the southwest monsoon and occurs from May to October. The dry season coincides with the northeast monsoon from October to April of the following year.

- **Temperature**

The average annual temperature (period 2011-2015) of My Dinh area is quite high, reaching 24^{o}C, the difference of average temperature in the hottest month (June) and the coldest month (January) is approximately 15^{o}C.

The coldest months of the year usually occur in December, January and February with an average temperature ranging from about 16 to 19^{o}C. The month with the lowest average temperature in 5 years is January with the average temperature being 16^{o}C. The hottest months of the year are May and June with an average temperature of about 28-31^{o}C. The month with the highest average temperature in 5 year period is June with the average monthly temperature of 30^{o}C. In recent years, My Dinh area has experienced many unexpected changes in climate and weather. In early January 2012, the winter was the coldest record in the last 5 years with average temperatures below 10°C. According to data from the *National Centre for Hydro-Meteorological Forecasting*, people also experienced a continuous and prolonged heatwave since the last 5 years. The highest temperature during the day outdoors is occasionally up to 40ºC. The lowest temperature at night is about 37-38ºC. Figure 1.3 shows the changes in temperature from 2011 to 2015 recorded at Lang gauging station (See Apendix A for more details) [6].

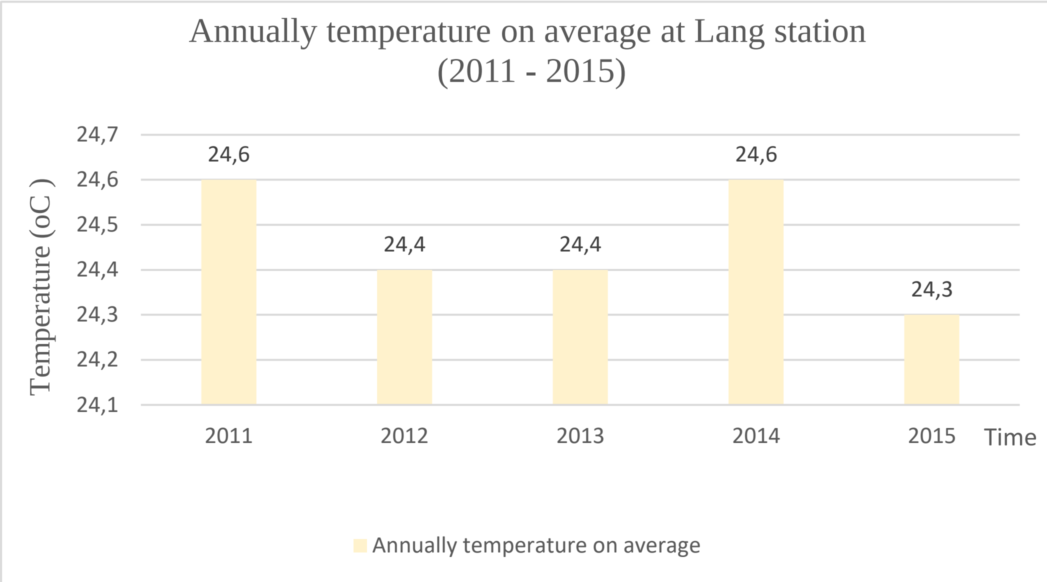


Figure 1.2 Annual temperature on average at Lang station (2011-2015)

- **Humidity**

The annual average humidity of My Dinh area is lower than other regions, reaching an average of 79%. The humidity also changes monthly, varying from 78% to 88%.

The humidity in the air varies seasonally and depends on two distinct seasons (the dry season and the wet season). The dry season starts from November to March of the following year, with the average monthly humidity ranging from 79- 88%. The driest month usually occurs in December with the average humidity ranging from 67 to 70%, of which in December 2014 the humidity dropped to a low level of about 67%.

The wet season coinciding with the rainy season starts from April to October. In this period, the average monthly humidity ranges from 73-85%. The wettest month in the last 5 years was April with an average humidity of 84%, of which April 2014 had a very high average humidity of 88%. Figure 1.4 shows the change in humidity from 2011 to 2015 recorded at Lang gauging station (See Apendix B for more details) [6].

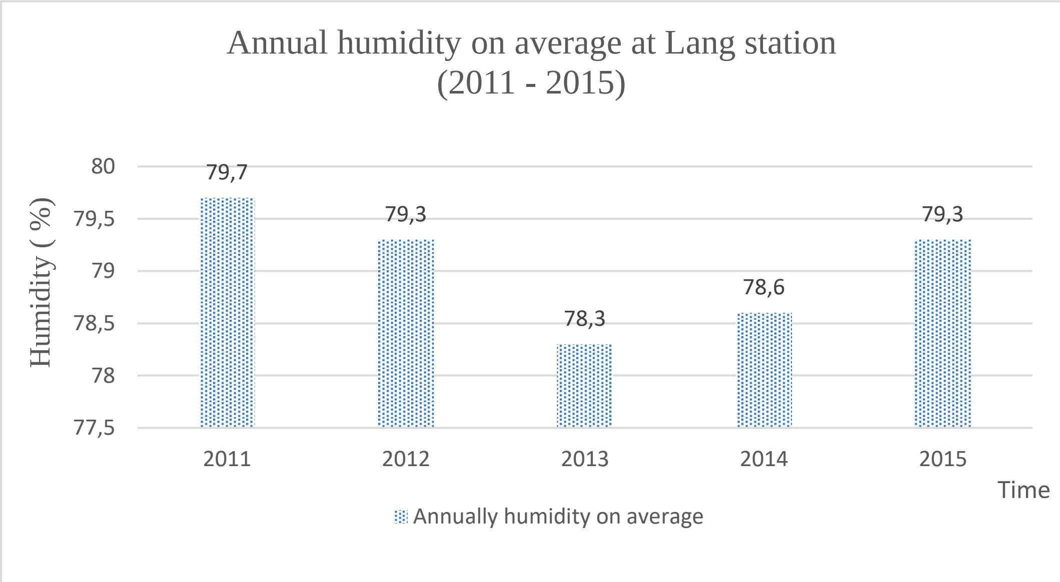


Figure 1.3 Annual humidity on average at Lang station (2011 - 2015)

- **Rainfall:**

The average annual rainfall in My Dinh area is in the order of 1600-1900 mm. The rain regime divides into two distinct seasons. The rainy season occurs from May to October and the dry season lasts from November to April of the year after.

The annual rainfall is concentrated mostly in the rainy season, accounting for 80-85% of the total annual rainfall. The wettest month was in August with an average rainfall of about 400-450 mm. In August 2013 the average rainfall peaked at 541.4 mm. In the early months of winter, there is little rain, but in the second half of winter, there usually is some drizzle. In the winter, the area is also subject to the northeast monsoon keeping the average rainfall in these months very low, ranging from 11.8-126.2 mm.The number of rainy days in My Dinh area is 160 days on average. During the rainy season, there are many rainy days, about 15 days per month. In the dry periods, by contrast, have fewer rainy days, generally 10-12 days per month [6].

1.1.4 Hydro-Meteorological and Water resources features

The Nhue River is a large river located along the study area. The main task of the Nhue river is drain the stormwater of Hanoi and Ha Dong before flowing to Day river (Phu Ly, Ha Nam). It has a flow rate of about 30 m^3/s. The flow regime of the Nhue River depends entirely on the process of Lien Mac sewer (taking water from the Red River), Thanh Liet Dam (collecting water from To Lich River) and some other large sewers along the Nhue River [4]. Besides, Mai Dich-Phu Do channel and Dong Bong I channel (5-6 meters in width and about 3 meters in depth) are in charge of draining stormwater and wastewater in the area.There are 4 gauging stations: Lang, Dong Anh, Lien Mac and Ha Dong located close to the research area. Lang station began monitoring rainfall from 1886 to 1928 before starting to monitor other factors. Dong Anh and Lien Mac station started operating in the 1960s [4].

Table 1.1 A network of hydro-meteorological stations in and around the area [4]

Station	Type of station	Factor	Coordinate	
			Longitude	Latitude
Lang	Level III	X, t^0	105°48’	21°01’
Dong Anh	Level IV	X, t^0	105°52'	21°08'
Lien Mac	Level IV	X, t^0	105°45'	21°05'
Ha Dong	Level II	X, t^0	105°45’	20°58’

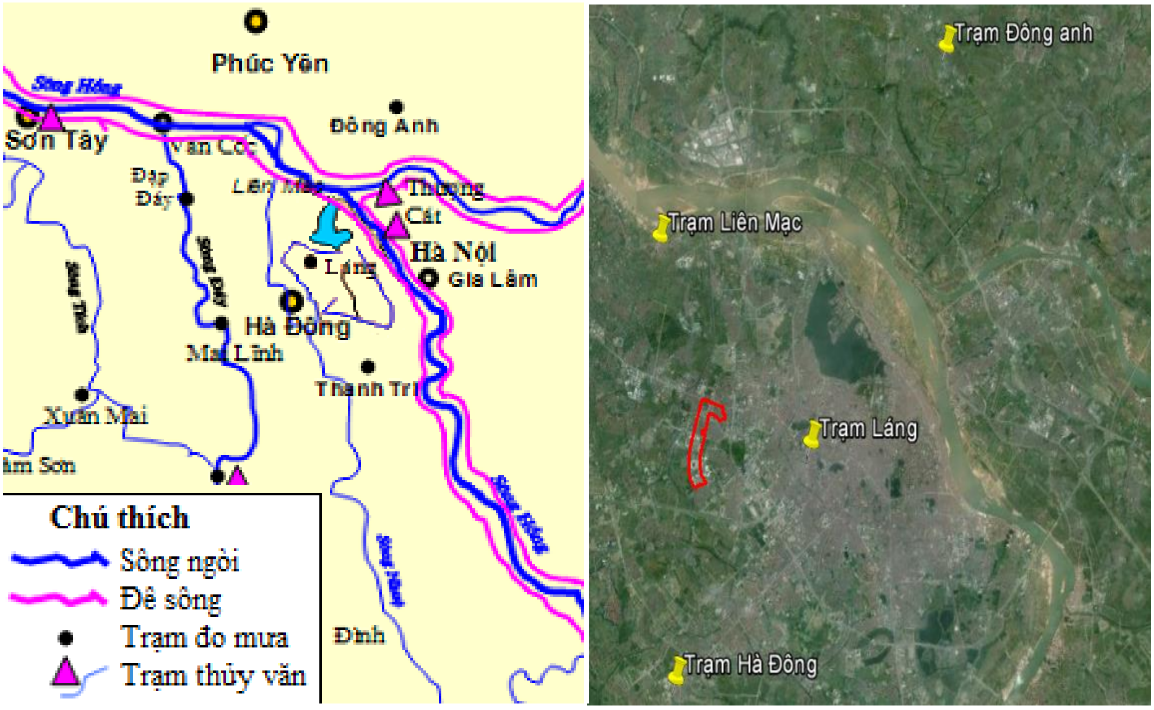


Figure 1.4 A network of rivers, streams and hydro-meteorological stations in the study area[5]

1.2 Literature study

1.2.1 Literature review

Urban floods have remained as key challenges to various socio-economic activities of the cities, threatening sustainability of urban areas in many countries around the world. There is a growing movement of using nature based solutions in minimizing the hydrological impacts of urban development on the surrounding environment, such as low-impact-development (United States), water sensitive urban design (Australia), and Vuon (Green) – Ao (Water) – Chuong (Biodiversity) Initiative – VACI (Vietnam) [20]. This study aims to find out the solutions to address urban flooding in My Dinh area in Hanoi. However, There are a large number of solutions, making it difficult to decide on what is the most suitable.

The research of Huan et al. (2016) uses Model for Urban Stormwater Improvement Conceptualization (MUSIC) to quantify stormwater bypass of its two different solutions including rainwater tank and vegetation area increment. The paper simulated drainage capacity of My Dinh urban area for floods in 2003 and 2008 as well as evaluating the effectiveness of measures such as rainwater tanks and buffer strips to reduce flooding based on the flooding in 2008 for the study area. MUSIC model results showed that the flood peak flow reduced 10.2% and 19.4% corresponding to rainwater tanks and buffered area measure. The results clearly show the effectiveness of urban water sensitive systems design. Additionally, these solutions are eco-friendly therefore they should be applied widely. This is a preliminary result of the pilot study and it should continuously improve. This software can apply to many areas in Vietnam for other aspects as the control of water quality, applying for rural area.

However, besides the effectiveness in reducing the peak flow, to assess whether or not this solution is feasible, it is necessary to consider other factors such as the cost of construction, the life span of the structure, the environmental impacts, etc. Therefore, this research is going to compare all aspects of solutions in order to find out the most suitable one.

1.2.2 Urban flooding and urban drainage system

a. Urban drainage

According to David Butler and John W. Davies (2004), Drainage is indispensable in developed urban areas because every human activities are closely related to the natural water cycle. This interaction includes two main forms: the abstraction of water from the natural circle to meet the water needs of humans in daily life, and the cover of impervious surfaces that help to transfer rainwater out of the local natural drainage system. Hence, two sorts of water that require drainage be apparent [11].

The first is wastewater, water that is discharged after has been used to support human life, to meet the requirements of the industry and is no longer directly valid for those purposes. The improper treatment may lead to environmental pollution, create health risks. Wastewater consists of many components such as dissolved materials, fine solids, and larger solids, deriving from WC, from the washing of various kinds, from industry and other sources of water use [11].

The second type of water that demands drainage is the rainwater (water created from the precipitation) that falls on the surface of a residential area. Without the proper drainage, it would cause inconvenience, damage, overflows and health risks.

It contains several contaminants, stemming from precipitation, air or catchment surfaces [11].

These two types of water are treated by urban drainage systems to lessen the impact on human life and the environment. Urban drainage has two main interfaces: the public and the environment (See Figure 1.5). The public often tends to flush only and not pay any attention to consequences in the future, and this may partly explain the lack of public awareness and the importance of urban services [11].

Figure 1.5 Interfaces with the public and the environment [11]

In many urban areas, the artificial system of sewers is completely in charge of the drainage. This system includes pipes, construction of collection and dispose of this water. Meanwhile, in underdeveloped and low-income populations, there is no main drainage. Wastewater is treated sketchy and green cover becomes a natural drainage system of stormwater [11].

There are two types of sewer systems: combined sewer system and separated sewer system. In a combined sewer system, rainwater and sewage are drained in one pipe. While in a separated sewer system, in which it drains rainwater and wastewater in two distinct pipes. For both sewerage systems, the underground drainage system is linked to the impermeable surfaces. A separated stormwater drainage system is intended to carry this runoff straight to receiving water bodies, with limited or no treatment [12].

The urban drainage system is a system that is both social and technical in nature, located in a large-scale urban environment combining many other subsystems to create a complete system [13]. These subsystems (e.g. roads, buildings, pipe, surface water) all intimately associate in different ways [14]. However, each subsystem has its own ways of operation, functions, and interactions with factors, can therefore lead to conflicts in the relationships. These relationships and association cause the system complexity, making it complicated to understand and predict the interactions between subsystems and factors [15].

b. Urban flooding

Although the devastation caused by frequent typhoons and frequent urban floods to the riverine and coastal areas should be considered, the total costs of urban flooding have not been accurately recorded. These are reasons: such floods occur frequently: they are scattered in every street of neighborhoods; they do not impact seriously on the total economic costs compared to other major events, and they are not recorded regularly. However, these events have resulted in drastic economic and social damage to vulnerable communities, communities that are nearly unable to cope with them. Mobile vehicles and household appliances, in the absence of liquid assets, are often their most valuable property [17].

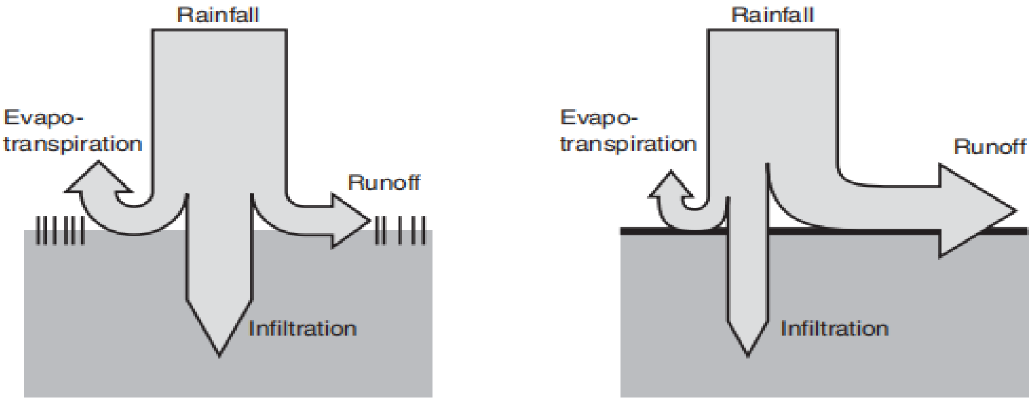
The Federal Emergency Management Agency (FEMA) defined that urban flooding as "*the inundation of property in a built environment, particularly in more densely populated areas, caused by rain falling on increased amounts of impervious surfaces and overwhelming the capacity of drainage systems*." [19] The definition can be split into three separate components: heavy precipitation (which is expected to become more frequent due to climate change), increased urbanization, and insufficient or outdated stormwater infrastructure presents a challenge in and of itself. It is worth noting that FEMA's definition does not refer to floodplains, rivers, or coastlines. Because of the fact that urban flooding hardly related to water bodies. In urban areas, the faster the pace of urbanization and the increase in impervious surfaces, the greater the likelihood of flooding. In urban environments, permeable surfaces such as agricultural land, vegetation and bare soil have been converted into residential areas. As a result, it forms the runoff on the concrete surfaces, which is known as alluvial flood or urban flood. In heavy rain, if the capacity of the existing drainage system does not meet the demand for excess water drainage the water will overflow and flood the urban infrastructure [16].

In Asia, urban flooding occurs frequently. Almost every city is at high risk of flooding, and this has negative impacts on urban citizens. However, very few cities have implemented flood management or urban flood-proofing plans, and the government needs to work harder to address these issues. In developing countries the main causes attributed to urban flooding are human influences on flood channels, the lack of knowledge in flood management, the shortage of early flood warning systems, and the limitation of solid waste in drainage systems [16].

c. Effect of urbanization on drainage

Urban drainage replaces one part of the natural water cycle and, as with any artificial system that takes the place of a natural one, it is important that the full effects are understood.

When stormwater falls on a natural or permeable surface, some water returns to the atmosphere through evaporation, or evaporation of plants; others drain into the surface and become groundwater; and some overflow on the surface (See Figure 1.6 (a)). The relative proportion is determined by the sort of the surface and changes over time during a storm. (The surface runoff will increase when the surface is no longer permeable) [11]. In contrast, urban areas with typical buildings and concrete structures have a very poor capacity to store rainfall and snowmelt. Constructing roads and buildings means reducing the area of vegetation, soil and depressions from the land surface. Permeable surfaces are replaced by impermeable surfaces such as roads, roofs, parking lots and footpaths that contain less water, reducing the invasion of water into the ground, speeding up the flow of water to channels and streams.(See Figure 1.6(b)) [13].



(a) Pre-urbanisation (b) Post-urbanisation

Surface runoff moves swifter over hard surfaces and through sewers than it does over natural surfaces and along natural streams. This suggests that the flow will both arrive and die away faster, and therefore the peak flow will be greater (See Figure 1.7) [11].

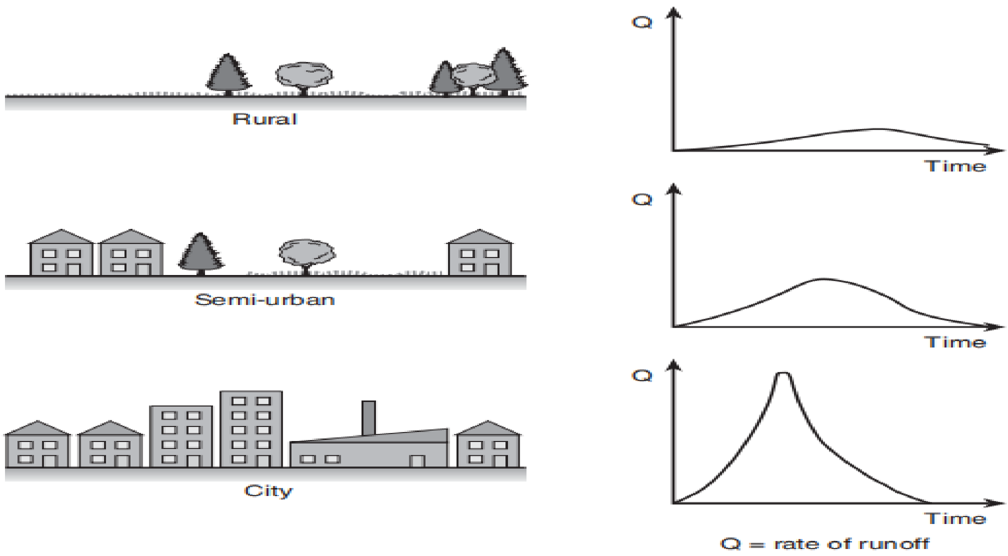


Figure 1.7 Effect of urbanization on peak rate of runoff [11]

At many places such as Le Duc Tho Road, Nguyen Co Thach Road, and Do Xuan Hop Road, the drainage system is encroached by constructions or filled by solid waste (See Figure 1.8). While in many other roads, the drainage system fails to meet the technical requirements, leading to limited capacity to collect waste-water or rainwater. The un-collected rainwater and gray water from sewer surcharges run over streets.

Figure 1.8 The drainage system is encroached by construction and filled by solid wastes on Do Xuan Hop street.

This obviously increases the danger of sudden flooding of the river. It also has strong implications for water quality. In an artificial environment, there are likely to be more pollutants on the catchment surface and in the air than there would be in a natural environment. The rapid runoff of stormwater is likely to cause pollutants and sediments to be washed off the surface or scoured by the river [11]. Combined sewer systems, which allow both wastewater and stormwater to drain in the same pipe, are likely to allow pollutants to flow into the river [11]. Also for separated sewer systems, the stormwater is transported directly to the surface water without further treatment.

The existence of a considerable amount of wastewater is an outcome of the urbanization. Water is used as a means to dispose of body waste and other bathroom wastes, via WCs. In a developed system, before being returned to the urban water supply system, wastewater will be removed from pollutants and toxins when they are treated in the sewage treatment plant. In nature, water itself has a mechanism of self-cleaning by removing some material, body waste, but not in the amount created by urbanization [11].

1.3 Solution for urban flooding reduction caused by heavy rain

To reduce urban flooding in the study area, this study focus on applying the Sustainable Drainage system (SuDs).

Systems that drain rainwater in a way more sustainable than conventional drainage systems are known as SuDs [42]. It provides a range of approaches to manage surface water concerning the amount of water (floods), water quality (pollution), biodiversity (fauna and flora), and amenity [30].

SuDs mimic the natural drainage process and often manage rainwater close to where it falls. SuDs is intended to transport surface water, slowing down the flow before it joins the water basin, they provide natural cover to store rainwater and can be used to infiltrate water into the soil or evaporate from transpiration of vegetation or surface water [30].

Compared to natural drainage systems, faster flow accumulation, and higher flood peaks are the principal characteristics of many urban drainage systems, which increase the risk of flooding. Natural drainage methods are likely to help the catchment responses return to a more natural state. By using the invasive and storage features of semi-natural devices such as trenches, swamps, or ponds, the catchment response is slowed down, peak flow decreases and thereby reducing flood risks [41].

Originally, SuDs are designed to improve rainwater quality, receiving water bodies, and reduce peak flows. However, SuDs today also show significant effectiveness in draining design storms, thus they are considered as a reliable alternative to conventional pipe drainage systems [42]. If SuDs are well designed, they are cheaper for construction and maintenance than conventional urban drainage systems [43]. Therefore, SuDs are regarded as a cost-effective replacement to conventional drainage systems.

Rainwater harvesting and Greenroof

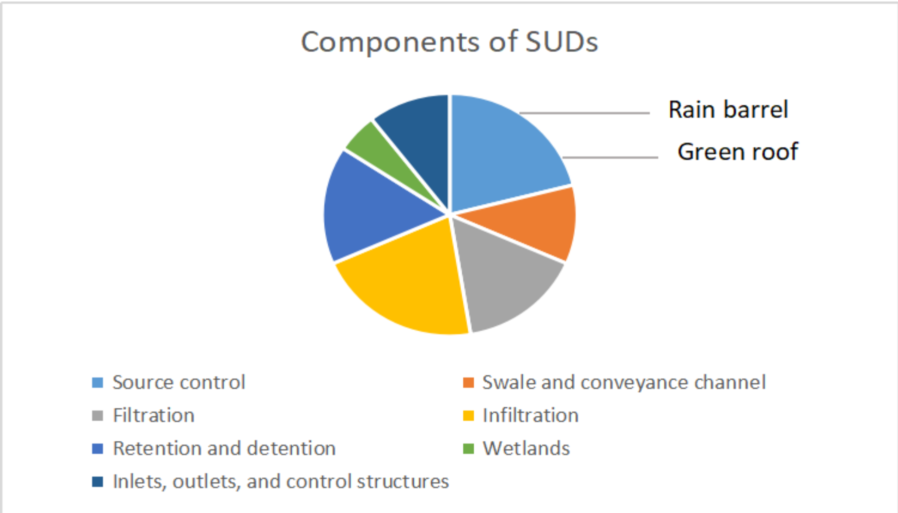


Figure 1.9 Overview of SuDs components and the component that contains Green roof and the Rainwater harvesting (Rain barrel) approach.

Rainwater harvesting and Green roof are components of source control section. Most source control components will be located within the private properties or highway areas. Their purpose is to manage rainfall close to where it falls, not allowing it to become a problem elsewhere [30]. Source controls look to maximize permeability within a site to promote attenuation, treatment and infiltration reducing the need for off-site conveyance [30].

a. Rainwater harvesting

The importance of rain water harvesting

Stormwater overload is one of the fundamental causes of inundation in the study area, so stormwater harvesting is required to help the existing drainage system runs by its practical capacity. In a combined drainage system, rainwater and wastewater in a sewer may lead to the waste of rainwater sources. It is necessary to construct rainwater collection works to both improve the inundation situation in the research area and possibly save an extensive amount of water that will serve for many purposes in the future. Also, because the study area is located in the region of monsoon tropical climate with the typical characters of high humidity and extensive rainfall, it is perfectly appropriate to collect rainwater.

When rainwater is collected and retained, it could be an abundant source of water to support the main water supply, especially in the dry season. Importantly, it is not only used for individual families but also the whole community [32]. Also, rainwater has a high risk of pollution as it flows over the land surface and picks up potential pollutants that may include sediment, nutrients, bacteria from animal and human waste, and petroleum by-products (from leaking vehicles). Therefor, rainwater harvesting is necessary and the application of rain barrel and green roof have strong abilities to address these issues. Harvested rainwater can be used for irrigation, washing the streets of the city, or replacing the flush water in the toilets. It also contributes to creating a sense of social responsibility and environmental awareness. Moreover, the importance of rainwater harvesting lies in the fact that it can be stored for the supplement of groundwater and to improve its quality. This also helps replenish the groundwater level, which can then be easily exploited and counteracts subsidence [32].

Methods of rainwater harvesting

There are two common method of rainwater harvesting: Rooftop rainwater harvesting and Surface runoff harvesting.

Rooftop rainwater harvesting

The method that collecting rainwater runoff from roof surfaces such as tiles, metal sheets, plastics, but not grass or palm leaf. The rainwater can be directly collected by keeping a bucket or container beneath the roof [32]. Rainwater harvesting is suitable for individual homes and schools.

Figure 1.10 Stormwater collected and retained in a barrel [35]

Surface runoff harvesting

Is the harvesting of rainwater that runs over the roads after a rainstorm or into lakes, streams, rivers, or reservoirs for storage that are on the surface or underground. Surface water harvesting is most appropriate in urban areas. Here rainwater flows as surface runoff and can be stored for future use. During storage of rainwater, it is important to incorporate efficient and effective water conservation methods i.e. by reducing evaporation [33].

Figure 1.11 Construction of underground storage tank in Ho Chi Minh [34]

Figure 1.12 Detention basin [35]

Advantages and disadvantages of Rain Barrels

The advantages and disadvantages of using a rainwater barrel for rainwater harvesting include [38].

Advantages

- The barrels are the easiest ways of collecting rainwater. Because the components to install a barrel rainwater collection system are very simple and are much cheaper than other forms of rainwater collection.
- They are cheap, especially if they are being reused after having a previous life.
- Since they are being reused, it becomes a great way to reduce the amount of waste going to the landfills.
- The barrels are lightweight and easy to move around even by one person.
- They are easily installed, thus reducing the cost of installation.

Disadvantages

- They are small in size and therefore can't store large volumes of water. For this reason, if you need more water, you must connect several barrels that will be able to serve your water needs.
- By joining several water barrels, it increases the chances of leakages due to the multiple joints, especially with pipes.
- If not well-sealed, the stormwater is at risk of being polluted, people using polluted water will have digestive problems, and this is also a condition for dengue outbreaks to appear, which pose a serious threat to public health.

b. Green Roof

A green roof is a roof with a flat or descent structure covered by a multi-layered system. These layers may consist of a waterproof layer, a growing habitat layer, and a drainage layer (optional) [30]. Green roofs aim to catch and keep hold of rainfall, reduce the amount of flow, and diminish the peak flow [31]. Furthermore, because green roofs store water in the growing media and plants, latent heat loss is accomplished via transpiration from plants and evaporation of moisture from the growing medium – collectively referred to as evapo-transpiration

[39], that is why the temperature in the houses stay cooler in summer and warmer in winter.

There are three main types: extensive, intensive, and semi-intensive. They are classified by the following characteristics [31]:

- The extensive green roof has a relatively thin growing medium- generally less than 6 inches, a limited roof load, simple plant diversity, rarely irrigation requirement [31].
- Intensive green roofs have more soil, deeper growing environments - may be up to several feet away, which allows the development of a greater variety of plants even miniature trees. They also have a larger roof load and require more frequent maintenance and watering [31].
- Semi- intensive green roofs inherit the features of both types. In particular, the roof structure, type of plants, annual rainfall, rainwater efficiency requirements are the factors that determine the depth of a green roof [31].

❖ Components of Green roof

Figure 1.13 Basic components of typical Green roof [40]

Where

- Vegetation or the living component provide runoff mitigation by removing water from the growing medium and releasing it back to the atmosphere;

- Growing medium that provides water, nutrients, and anchorage to the plants;

- A filter/retention layer that works to prevent small particles from clogging the drainage and also serves to store water;

- A drainage layer that will channel excess water away;

- A root barrier that prevents plant roots from damaging the root membrane.

❖ Advantage and disadvantage of Green roof [30]

Table 1.2 Advantage and disadvantage of Green roof

Advantage	Disadvantage
Mimic predevelopment state of hydraulics and hydrology	It costs more than conventional roof (see next section for details)
Good removal capability of atmospherically deposited urban pollutants	Not appropriate for steep roofs
Can be applied in high density developments	Opportunities for retrofitting may be limited by roof structure (strength, pitch etc)
Can be retrofitted (reliant on site specifics)	Any subsequent damage to waterproof membrane likely to be more critical since water is encouraged to remain on the roof
Ecological, aesthetic and amenity benefits	Maintenance of roof vegetation (depending on the type of green roof) requires a lot of effort and time
No additional land take	
Improve air quality	
Help manage urban heat island impacts	
Regulate the temperature in the houses	

CHAPTER 2: FLOODING OVERVIEW IN THE STUDY AREA

In this chapter, the current situation of the drainage system, the current flood condition, and the causes of flooding in the study area are presented.

2.1 Overview of the existing drainage system

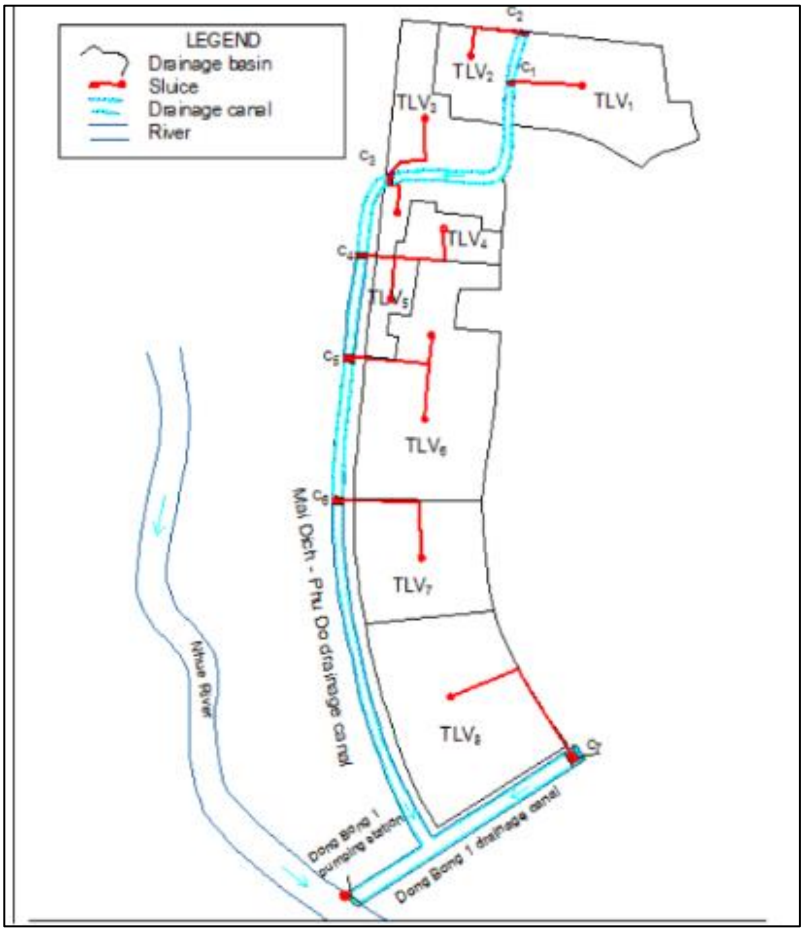


Figure 2.1 Map of regional drainage system along Mai Dich - Phu Do drainage ditch to Dong Bong 1 Pumping Station [24]

The drainage system in My Dinh area is a combined sewer system for both rainwater and wastewater. As can be seen in Figure 3.1, the water is gathered into underground sewers installed proactively along the streets, alleys, and hamlets (sewer network level 2, level 3), then collected into ditches (sewer network level 1) and then drains into rivers.

The drainage system includes sewers, ditches, and drainage pumping stations. Specifically, along the left of the study area is the open ditch Mai Dich - Phu Do located on Nguyen Co Thach street. The length of the ditch is L = 3,410m, originating from the outlet of sluice B x H = (1.5x1.2) m, passing Ho Tung Mau street and heading to Dong Bong 1 ditch and then through Dong Bong 1 pumping station with a capacity of 8 m^3/s and flows into Nhue River [24].

The system covers draining rain- and waste-water for communes of Mai Dich, My Dinh 1, My Dinh 2, Phu Do and is bordered by streets of Ho Tung Mau, Le Duc Tho, Nguyen Co Thach. This ditch is under the management of Hanoi Drainage Company. The sewer segment on Nguyen Co Thach street, which travels through My Dinh Stadium to Dong Bong 1 ditch is used to be an open ditch segment that has been improved with two side handrails, sidewalks, and synchronous roads. There are also collector sewers on the ditch system, which are responsible for each sub-basin drainage. Here are some pictures of the drainage system roadmap in My Dinh area :

Figure 2.2 T-junction from Mai Dich-Phu Do ditch to Dong Bong I drainage ditch [6]

Figure 2.3 Dong Bong I pumping station

2.2 Overview of the flooding in My Dinh area

Inundation after just a few showers of rain has become an unaddressed problem

in Hanoi for many years. The Government has made every effort to obtain solutions to flooding, but so far, Hanoi still flooded after every prolonged, extensive rain. Dangerously, these downpours have increased in frequency and intensity. For example, the residents of Hanoi witnessed showers on Lunar New Year's Eve 2020 for the first time in many years. Even in many places, hail appeared. Precipitation measured in 3 hours in some places such as Lang 35mm, Hoan Kiem 67mm, Tay Ho 55mm, Ba Dinh 66mm, Dong Da 90mm, etc. and caused flooding in many streets with inundation heights from 0.2m to 0, 5m. Although, the study area is a new urban area but it is regularly flooded when heavy rains occur.

Figure 2.4 Inundation in front of Huyndai My Dinh on July 17, 2014 [6]

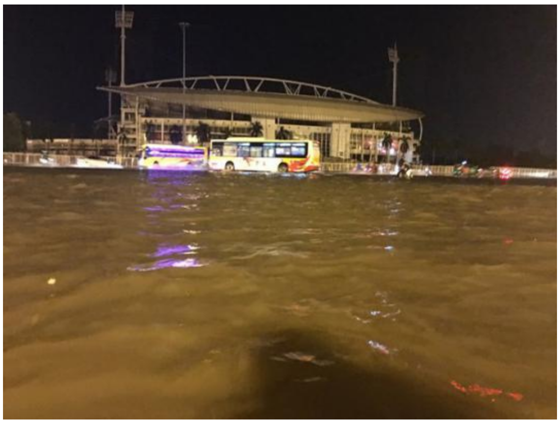


Figure 2.5 Inundation in front of My Dinh National Stadium on July 07, 2017 [33]

2.3 The causes of urban flooding in My Dinh area

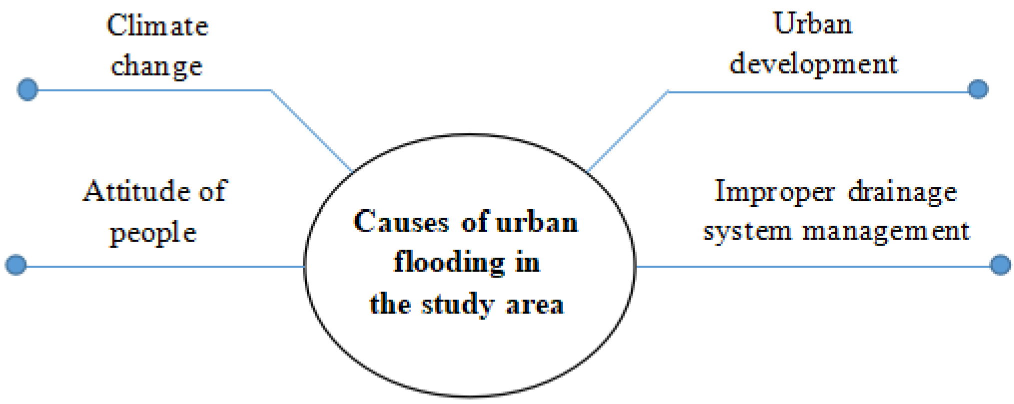


Figure 2.6 The classification of causes

2.3.1 Climate change

The impact of climate change on flooding is something that has not been clearly defined. Not only do variable weather- and human-related factors play into whether or not a flood occurs, but limited data on the floods from the past make it difficult to measure them against the climate-driven trends of floods today. However, as the IPCC (Intergovernmental Panel on Climate Change) noted in its special report on extremes, it is increasingly clear that climate change "has detectably influenced" several of the water-related variables that contribute to floods, such as rainfall and snowmelt [25].

The increased frequency of occurrence of flood events in the world is partially attributed to climate change-driven increase of extreme precipitation [20]. Climate change is making weather less predictable, rains more uncertain and heavy storm rainfalls more likely. Heavy thunderstorms appear to have increased in frequency [22]. As Nguyen Van Thang et al. pointed out that if the recent period is from 1986 to 2009 and the previous period is from 1960 to 1985, the frequency of tropical cyclones in Vietnam in the recent period (7.88 storms) is much higher than the previous period (7.35 storms) [44]. Extreme rainfall events have led to dramatic damage to human life and property, most seriously by contributing to urban flooding [21].

Due to global warming, the global water cycle is likely to be accelerated, resulting in many regions with increased flood magnitude, as well as flood frequency [22]. According to Nguyen Van Thang et al., The average temperature of the lowest half-decade occurred in one of three half decades before 1975: 1961 - 1965, 1966 - 1970, 1971 - 1975, most of 1961 - 1965, and the highest were in the last three half decades. here: 1991 - 1995, 1996 - 2000 and 2001 - 2005, most in 2001-2005. Yearly temperatures in recent half decades are higher than in previous half. Regarding the increasing trend of temperature, the temperature increase in the last five decades is 0.6 - 0.9^0C [44].

The historical flood in Hanoi in November 2008 was caused by unusually heavy and prolonged rainfall event. By the time of the afternoon on November 1st, 2008, the total rainfall in Hanoi area ranged from 350 to 550mm. According to observed data series during the rain, the rainfall in the first two days was considered as a record. In former Hanoi area, it has been the biggest rainfall since the historical rain on November 1984. The elevation of flooding surface ranges from 5.5-7m [21]. This historical flood flooded the whole My Dinh area, causing much damage.

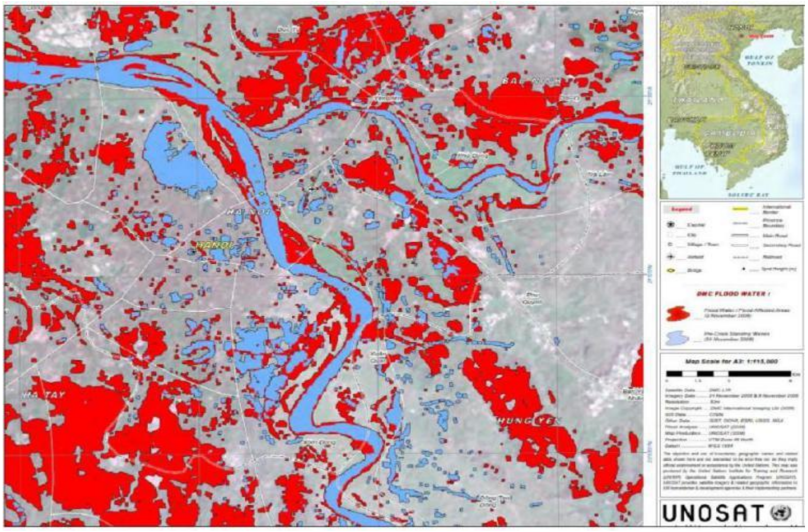


Figure 2.7 Map of Hanoi inundation from 9 to 21 November 2008 [6]

Figure 2.8 Flooded underground parking at C6 apartment in My Dinh 1 urban area - historical precipitation in November 2008 [6]

2.3.2 Urban development

In 2008, the urban population accounted for more than half of the world's population. By 2030, it is expected that the residents living in urban areas will reach 5 billion - 60% of the world's population [26][27]. Population growth in urban areas is more common in developing countries than in developed countries. For the massive migration from rural areas to cities and the transformation of rural settlements into cities, many cities in developing countries witness rapid population growth leading to uncontrolled urban development with industrial growth, infrastructure development, and human settlement [26][27].

Historical statistics show that Hanoi's population increased rapidly in the second half of the 20th century. After the most recent boundary expansion in August 2008,Hanoi had 6,233 million people and became one of the 17 largest capitals in the world [7][29]. According to the results of a survey on April 1, the total population of Hanoi was 6,451,909, [8][29] the average population in 2010 was 6,561,900 [9][29]. As of December 31, 2015, the population of Hanoi was 7,558,956. As of 2018, the population of Hanoi was 8,215,000, 55% of the population (4.5 million) lived in urban areas, 3.7 million lived in rural areas (45%). And the average population density of Hanoi is 2505 people / km^2 [29].

The extension in artificial surfaces due to urbanization contributes to an increase in flooding regularity due to the lack of permeable surface and reduction of flow resistance (due to faster concentration times). The hydro-meteorological changes driven by urbanization, and resulting impacts on excessive showers, are also being established: a strong relationship between urban areas and local microclimate has been shown after a significant amount of study over the last twenty years [27]. My Dinh suburb has been undergoing rapid urbanization during the past decades. Most of ground covered of industrial zone, concrete surfaces. The changes in land use associated with urban development have an adverse impact on the urban hydrological processes, which may result in the increase of urban flood risk.

Besides, a significant amount of waste heat derived from human activities and the increase in energy consumption are resulting in environmental problems, including the rise in temperature in the urban atmosphere [28][27]. When the area of vegetation cover is lessened, the evapotranspiration decreases contribute to the latent temperature flux. Also, the radioactive properties of the urban environment differ significantly and can absorb more radiation for the urban canopy characteristics. These changes have certain effects on the circulation of the area, meteorological parameters, and their interaction with precipitation [28][27].

2.3.3 Improper drainage system management

When it rains most of the rainwater is dumped directly into the sewer, causing the drainage system to become overloaded. Also, part of the sewer entryways will also get blocked by leaves, dirt and trash, so water cannot enter the drainage system (See Figure 3.9). Twenty years ago, Hanoi had many areas of greenery and ponds. In these areas, every time it rains, part of the rainwater will seep into the ground and supplement groundwater for the soil, part of the rainwater will flow into lakes and ponds, and the rest will be drained into water drains and discharged into rivers.

Figure 2.9 The sewer entryways are destroyed and blocked by rubbish on Nguyen Co Thach Street

On the Nhue River system, for the lack of regular dredging and the encroachment of houses and buildings, these drainage axes are clogged. In early 2005, the Nhue river section from Lien Mac I to Lien Mac II sluice gate was dredged according to the design section, but after two seasons of water intake, the sediment layer was 1m thick. In addition, the area's drainage system is also inadequate, degraded, and untreated wastewater causes a decrease in drainage capacity, leading to inundation in the case of heavy rain and an unsanitary environment.

2.3.4 Attitude Of People

One of the most important factors causing urban flooding is the attitude of people. Many people living and working in areas affected by urban floods do not seem to realize that it is their daily habits that contribute to getting this flooding worse. And they do not understand that they can take action to significantly reduce their property damage (See Apendix C for more field work images) .

Most of the current drainage systems in Hanoi in general and My Dinh in particular is the combined sewer system. Since both rainwater and wastewater are drained together into such a sewer line, it is easy to cause plaque on the wall of the sewer, which requires special attention from the early stages. These residues stem from both rainwater and wastewater. In moving to the sewer, the dirt will easily be swept away by the stormwater runoff into the sewer. If domestic waste such as cooking oil or fragments of leftovers is not carefully getting rid of, they will drain directly into the drainage system. After accumulating gradually, these wastes clogging the drainage system, therefore preventing rainwater from drainage when heavy rains occur resulting in flooding.

CHAPTER 3 : THE PROPOSAL OF SOLUTION

This chapter explores the solutions to reduce urban flooding in the study area. There are two types of solution, non - constructive method and constructive method. In the non-constructive section, solutions that are not related to construction materials, the installation of equipment will be presented. In the constructive section, solutions to increase the area of permeability and water storage for the area via the application of sustainable urban drainage systems (SuDs) will be shown.

3.1 Non - constructive method

3.1.1 Raising local people’s awareness

Raising people’s awareness has a vital role to play in reducing urban flood risk and its damage. The individuals settling in affected areas, who directly suffer from the devastation caused by floods, their actions will be more proactive and bring an impressive effect on their communities.

However, many people are not fully aware of their contribution to flood disasters and rarely understand the actual risks (sort of risks, consequences, and possibility of occurrence) that they have to handle. The citizens assume that the responsibility belongs to the government and entrust the problems completely to the officials. It is necessary to pay more attention to promotional campaign so that the basic knowledge about urban flooding issues can approach the citizens in urban flood-prone areas. The initiative from the beginning leads to the highest efficiency later.

Achieving the purpose of spreading awareness through a promotional campaign requires the participation of all citizens and local officials. The first step that should be taken is to increase governmental advertisement using different types of media. As an example, messages through installed speakers have a very positive effect, information is accessible to all sort of citizens from young children who cannot read to the elderly have poor health. However, this mode of communication is only suitable for rural areas, but for urban areas it is uncommon to see the appearance of loudspeakers. Among the development of social networks such as Facebook, Instagram, Twitter, the government of each precinct can set up groups, fan-pages which include residents as members to specialize in posting general knowledge, warnings about urban flooding. This is not only a one-way knowledge impartment but also citizens can exchange and express their own opinions via comments. This method has the benefit of saving travel time while residents can update news at any time and place [34].

When it comes to promotional campaigns, women are the factor that requires special attention. They consume a colossal amount of water in taking care of cooking, washing, cleaning the house. Therefore, their every behavior has a certain impact on wastewater, and wastewater has a significant influence on urban flood risk. In Vietnam, each locality has its own Local Women's Union, the Local Women's Union can contribute to flood control by regularly organizing workshops, meetings to help women perceive their important part in preventing and resolving the consequences of inundation. Also, the presidents of these unions could pay a visit to each household, inspire the woman to take action to change the current situation, and encourage them to share the challenges they encounter while doing this. In some areas, the model "The road is self-managed by women" is highly appreciated. The model carries out several activities such as clean up the roads, planting trees along sidewalks that attract the participation of many homemakers. These activities are much practical in reducing the waste invading into the sewer entrance and enhancing vegetation cover on the roads [37].

Moreover, leaflets and handbooks are also an effective means of communication. Civil groups should actively distribute leaflets that contain essential information to the people, which should be concise but complete and easy to understand. Besides, hanging banners and slogans should also be considered. The content of these modes of advertisement should focus on inspiring people to change their living habits to mitigate urban flooding issues, for instance: collecting rubbish at prescribed places, creating a habit of sorting garbage, not directly pouring solid wastes from daily activities such as oil, leftovers, plant remains into sewerage.

3.1.2 Proper maintenance

A smoothly operated sewer system requires careful and regular maintenance. Besides being maintained regularly to avoid clogging and leakage, attention should be paid to the maintenance of pumping stations. Dong Bong I pumping station pumps collected wastewater into Nhue River, just a minor mistake in the pumping system can lead to the breakdown of the entire process, the maintenance procedure is followed the standard TCVN 8317:2010 about irrigation works-procedures for management, operation, and maintenance of electric pumping stations. During prolonged heavy rains, the drainage capacity is overloaded, the portable pumps are to support the transport of rainwater to the water bodies. If these machines are not routinely tested for functions to promptly address failures, the support task will fail resulting in high damages and therefore repair costs.

Some maintenance requirements can be reduced with the involvement of local people in maintenance activities, such as debris removal or reporting problems as they occur. Community participation informs citizens about their responsibilities and how their actions profit the entire community [17].

3.1.3 Comprehensive development plan

For the efforts to reduce urban floods in My Dinh area and achieve the highest efficiency therein, it is indispensable to develop a detailed plan. The plan should be implemented based on the cooperation and coordination between the governments who are in charge of urban flood management, city planning and the improvement of comprehensive plans for the watershed.

The negative consequences associated with floods are due to urbanization and increased surface impermeability. If the natural landscape is destroyed to make way for the development of urban and suburban areas, the function of the hydrological system will be impaired, soil permeability will decrease and peak discharge rises. However, the amount of impermeable surface is not the only factor responsible for flood impacts, but also the characteristics and intensity of the flood events over a given area. It is important to begin the construction of any urban development project that investors and local authorities have comprehensive plans compatible with the conditions of the project area. When a project is under construction, the government should strictly control the construction work under the approved planning, strictly punish cases of violating the regulation. Besides, contractors should not for personal profit but ruin the sustainable development of society. As so many contractors cheated by replacing good quality, high-cost construction materials into low-quality, low-cost materials to take advantage of for their credit. As a result, a range of buildings and roads were seriously degraded shortly after the construction.

3.2 Constructive method

The current drainage systems are no longer suitable for urban development conditions and changes in frequency and intensity of rainfall events, the scale and scope of future rain events are likely to increase significantly, making high-capacity systems also seem to be at high risk of being overloaded [27]. Hence upgrading the capacity of the drainage system is quite reasonable. However, the drainage system of an area is a combined system comprising complex sewers, the dismantling and re-installing of an alternative system may take time and also affect daily life. Besides, the expense is an important consideration in this case, to advance a sewerage system, a large sum of money is required. Consequently, this thesis applies methods from Sustainable drainage systems (SuDs) known as rain barrel and green roof for reasons following. Firstly, these methods have a negligible impact on the existing drainage system while ensuring flood mitigation for the area. Secondly, both of these methods only need to base on the available platform to install without looking up for new locations or smashing to build. Thus, for the green roof method, roofs are available, so the system only need soil layers and plants to complete, for the rain barrels pipes and water tanks are needed while detention basins, channels, and grills require digging, dredging.

3.2.1 Calculate the efficiency of each method

a. The efficiency of Rain water harvesting - Rain barrel

To evaluate the effectiveness of the rain barrel approach, comparison of the design discharge before and after the application of the method is carried out. The rational method, developed by Kuichling in 1889, estimates design discharges from urban watersheds. It is based on a simple formula that relates runoff producing potential of the area, the average critical intensity of rainfall for a particular time period (referred to as the time of concentration), and the contributing drainage area [37]. Below is the formula:

$$Q = C \times i\_crit \times A \qquad (1)$$

Where

Q : Design discharge (m^3/s)

C : Runoff coefficient (-)

i_crit : Critical design rainfall intensity (m/s)

A : Contributing drainage area (m^2)

<u>The calculation for each parameter is shown as follows:</u>

1. C = Runoff coefficient

Applying formula:

$$C_{SubcatchmentX} = \sum_{i=1}^{n} Ai \times Ci \qquad (2)$$

Where *i* represents a certain land use within sub-catchment *X* (I.e. buildings, parks), *Ai* is the total surface area within the sub-catchment that is made up of that land use, and *Ci* is the runoff coefficient for that land use types.

Types of land use within the study area and their areas shown in the Table 3.1 are collected from Google Earth:

Table 3.1 Land use types and their areas in the study area

Unit	Gardens & Parks	Unimproved areas	Street	Roofs of buildings	Water
m^2	369856	301903	216548	656984	596
% (compare to total area)	23,94	19,57	14	42,5	0

And the runoff coefficients per land use [11]:

Table 3.2 Runoff coefficient corresponds to each land use

Type of surface	Gardens and parks	Unimproved areas	Streets (brick)	Roofs of buildings	Water
Runoff Coefficient	0.2	0.2	0.775	0.85	0

==> According to formula (2), the average Runoff Coefficient is:

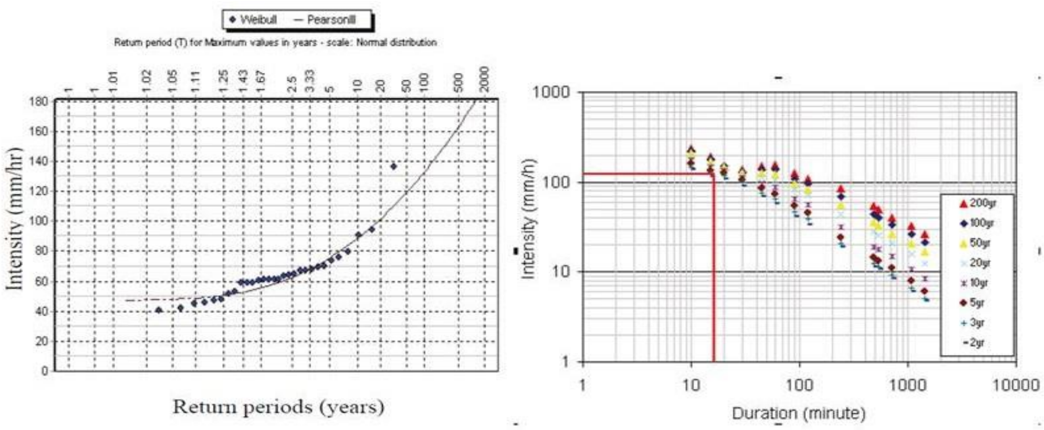
C = (0,2 * 23,94 %) + (0,2 * 19,57%) + (0,775 * 14%) + (0,85 * 42,5%) + (0 * 0%) = 0,56 (#1)

2. A : Contributing drainage area

A = 1550000 (m^2) (#2)

3. i-crit : Critical design rainfall intensity

According to the Establishment of Intensity-Duration-Frequency curves for Precipitation in the Monsoon Area in Vietnam of Nhat Le Minh and Kaoru Treasure Takara, we can see that the intensity of the research area related to rainfall duration and return period shown in the Figure 4.1a,b:



a) b)

Figure 3.1 a, Distribution rainfall intensity analysis at Hanoi station; b, Maximum rainfall intensities for difference time intervals and return periods [44]

- For rainfall duration, 15 minutes was chosen as it for flat urban areas.
- For return period, once every 2 years was chosen

Therefor, i_crit is about 120 mm/hr = $3,33.10^{-5}$ m/s, shown by the red line in the graph (See Figure 4.1b) (#3)

According to (#1), (#2), and (#3) and formula (1) we have the design discharge as below:

$Q_{design\ discharge}$ = 0,56 * 1550000 * $3,33.10^{-5}$ = 28,90 (m^3/s)

The fact that all houses can install a rain barrel system is not feasible. If we were to assume that all half of the roofs in the entire study area could harvest water, there can already be a large impact on the runoff. So I assume that after the rainwater harvesting method is applied, half of the roof (50% Roofs of buildings) will be converted into water bodies areas. And the option assumes that each family has land area approximately 30 m^2, will set up a rainwater tank with capacity storage of $1m^3$.

Area of each land-use types after applying the rainwater harvesting method knowing that the initial areas are in Table 3.1:

Table 3.3 The area of each land-use types after applying the rainwater harvesting method

Unit	Gardens & Parks	Unimproved areas	Street	Roofs of buildings	Water
m^2	369856	301903	216548	328492	329088
% (compare to total area)	23,94	19,57	14	21,25	21,25

==> The average Runoff Coefficient after applying the rainwater harvesting method would be:

C = (0,2*23,94 %) + (0,2*19,57%) + (0,775*14%) + (0,85*21,25%) + (0*21,25%) = 0.38

==> According to the formula (1), the design discharge after applying the rainwater harvesting method would be:

$Q_{Rainwater\ harvesting}$ = 0,38 * 1550000 * $3,33.10^{-5}$ = 19,61 (m^3/s)

b. The efficiency of Green roof

To evaluate the effectiveness of this method, the Kuichling formula in 1889 is also used similar to the above rainwater harvesting method :

$$Q = C \times i\_crit \times A \qquad (1)$$

After applying the green roof method, I assume that the half of all the roof will be replaced by green roofs and become the area of Gardens & Parks. Area of each land-use types after applying the green roof method knowing that the initial areas are in Table 4.1:

Table 3.4 The area of each land-use types after applying the green roof method

Unit	Gardens & Parks	Unimproved areas	Street	Roofs of buidlings	Water
m^2	698348	301903	216548	328492	596
% (compare to total area)	45,19	19,57	14	21,25	0

==>The average Runoff Coefficient after applying the rainwater harvesting method would be:

C = (0,2*45,19%) + (0,2*19,57%) + (0,77*14%) + (0,85*21,25%) + (0*0%)

= 0,42

==> According to the formula (1), the design discharge after applying the green roofs method would be:

$Q_{Green\ roof} = 0{,}42 * 1550000 * 3{,}33.10^{-5} = 21{,}68\ (m^3/s)$

3.2.2 Result evaluation

Table 3.5 The hydraulic performance of measures

Design discharge (Q) of the area (m^3/s)	$Q_{Rain\ barrel}$ (m^3/s)	% Improvement	$Q_{Green\ roof}$ (m^3/s)	% Improvement
28,90	19,61	32,14	21,68	24,98

After using the rain barrel and the green roof, the initial design discharge was 28,90 m^3/s decreased by 19.61 m^3/s and 21.68 m^3/s, respectively. The percentage of flood reduction of rainwater tanks and green roof are 32,14% and 24,98% respectively.

CONCLUSION AND RECOMMENDATION

1 CONCLUSION

Flooding in My Dinh has existed for many years and there are many factors responsible for this problem. The prolonged flooding after every heavy precipitation has caused significant difficulties in the daily life and the production process of local people. With a view to contributing to alleviating this problem, the objective of this study is to propose effective and appropriate solutions for the research area.

a. To come up with solutions, this study firstly aims to explore the causes of flooding in the area. And four causes has been identified, they are *Climate change, Urbanization, Improper drainage system management,* and *People's attitude*:

For *climate change,* the data collected from gauging stations and previous studies show that climate change is the direct factor causing flooding in My Dinh suburb. Climate change leads to an increase in rainfall and the frequency of storms. The rainfall of the following years is higher than the previous years and the occurrence of historic storms tends to increase. The change is also reflected in the increase in the Earth's temperature, as the temperature increases, it speeds up the water cycle, thereby increasing the frequency of rainfall.

The second causing urban flood in the study area is *urbanization*. Rapid urban development contributes significantly to the decrease in the permeability area and rainwater catchments. As an enormous amount of storm-water can not seep into the soil or store in water-bodies will have to drain into the urban drainage system. However, the drainage system has not been upgraded to meet that enormous drainage demand. As a result, flooding occurs.

The site visit revealed that one of the significant impact factors is the *inadequacies in the management* of urban drainage systems. Field works showed that some sewer entryways on the roads were severely damaged, or that the Lien Mac I & II sewers were clogged up to 1m thick or the sewer entryways were covered with garbage. These issues are within the responsibility of the local authorities and they should be dealt with promptly. However, this situation still exists without any improvement.

Besides, the site visit also shows that *people's awareness* is a factor contribute to flooding in My Dinh suburb. People's habit of throwing garbage in the disorder place or not classifying garbage inadvertently causes the drainage system to be clogged, reducing the drainage capacity of the system. Most local people believe that waste sorting and collection is the responsibility of environmental workers, so it is necessary to have clear communication between actors.

b. Secondly, according to the nature of the problem, the solution is divided into two types, *constructive* and *non-constructive approach.*

- With the constructive approach, *Green roof* and *Rain barrel* were offered. These two approaches are recommended with the desire to address urbanization and climate change issues because they both recover the natural permeability area while limiting temperature increase or rapid evaporation.The Rational method of Kuichling in 1889 was used to calculate the effectiveness of these two approaches.

By comparing the design discharge before and after applying the two approaches, the effectiveness of rainwater control of Green roof and Rain barrel was determined with the percentage improvement of 24.98% and 32.14%, respectively.

- For non-constructive approach, *Raising local people's awareness*, *Proper maintenance,* and *Comprehensive development plan* are presented.

The site visit revealed that most of local people believe that they do not have to be responsible for reducing flood risks, therefor raising local people's awareness is proposed to provide people a better understanding of their role. This approach is achieved through the enhancement of social media such as leaflets, handbooks, banners, and social networks.

The site visit also revealed that the drainage system of the study area is facing many damage such as destroyed sewer entryways, clogged sewer up to 1m thick, seriously degraded pervious pavement, so this study proposes proper maintenance for the system. Regular maintenance will help prevent failures from occurring, and quickly repair new ones as they form.

This study shows that each construction plan needs doing in a comprehensive way that suits the conditions of the area. These conditions include hydrological, geological, and social conditions. Also, strict punishment of cases against the approved plan is required.

2 RECOMMENDATION

1. This study identifies the causes of flooding in the My Dinh suburb, this knowledge could serve as recommendation for future projects to research solutions other than the application of SuDs solutions..

2. These solutions are eco friendly and compatible with high-density residential areas. Therefore, the recommendation is made that they should be widely applied to other urban areas.

3. This study shows that women play a significant role in limiting flooding in the study area because they are most involved in water and waste in the family. This leads to the recommendation to focus on raising awareness and listening to their thoughts. It is essential to make them feel their vital role in this matter.

4. For the application of the methods to be realistic, it is necessary to have cost standards for these methods. Therefore the recommendation is that there should be cost norms for construction and installation if these methods are put into application.

5. Due to the lack of reference resources, the area of each land use using Google Earth to calculate would have errors. This leads to the recommendation to collect actual data about the area of the study area so that the calculation can achieve the most accurate results.

6. The fact that 50% of the roof of buildings becomes the Garden & Park and Water area when applying the Green roof and Rain barrel methods, respectively, is just a hypothesis. Therefore, it would be recommended for further research to study the people's approval to install these two systems, from which the percentage of the area to be converted will be determined.

8. This study only focused on two types of SuDs (the Green roof, and the Rain barrel). For further research, it is recommended that more types of SuDs (e.g., Detention basins) are added to the application, to create more chances in reducing urban flooding in the research area.

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APENDIX

A. The monthly temperature (^{O}C) on average at Lang station(2011-2015) [6]

Time	***2011***	***2012***	***2013***	***2014***	***2015***
Average	**24.6**	**24.4**	**24.4**	**24.6**	**24.3**
Jan	16.2	14.6	15.3	17.7	18.1
Feb	17.8	16.2	19.9	17.2	19.2
Mar	19.2	20.2	24.0	19.9	21.6
Apr	24.3	26.2	25.0	25.3	25.4
May	29.2	28.9	28.9	29.3	30.6
Jun	31.3	30.3	30.0	30.1	30.9
Jul	32.7	29.6	28.9	29.5	
Aug	28.8	29.3	29.1	29.0	
Sept	28.7	28.0	27.0	29.2	
Oct	26.3	26.8	25.6	27.0	
Nov	22.7	23.4	22.8	22.9	
Dec	17.4	18.7	16.3	17.6	

B. The monthly humidity (%) on average at Lang gauging station (2011-2015) [6]

Time	***2011***	***2012***	***2013***	***2014***	***2015***
Average	**79.7**	**79.3**	**78.3**	**78.6**	**79.3**
Jan	79	83	82	72	78
Feb	86	83	86	79	82
Mar	84	83	80	87	88
Apr	85	80	81	88	78
May	79	79	78	77	75
Jun	78	75	74	80	75
Jul	79	79	82	81	
Aug	84	79	81	82	
Sept	78	77	82	78	
Oct	76	76	73	73	
Nov	79	79	73	79	
Dec	69	79	68	67	

C. Images of field works

1. under constructed field at My Dinh street

2. Improper constructed sewer entryway on Nguyen Co Thach street

3. Solid waste are scattered on the street of Phu Do village