Quantitative microbial risk assessment of water consumption in flood-prone communities, Nakhon Si Thammarat province, Thailand

Mr. Teeraphat Attavinijtrakarn

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การประเมินความเสี่ยงจากจุลินทรีย์ในน้ำอุปโภคบริโภคของชุมชนที่เสี่ยงต่อการเกิดอุทกภัย จังหวัดนครศรีธรรมราช ประเทศไทย

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By	Mr. Teeraphat Attavinijtrakarn
Field of Study	Public Health
Thesis Advisor	Wandee Sirichokchatchawan, Ph.D.
Thesis Co Advisor	JENYUK LOHWACHARIN, Ph.D.

Accepted by the COLLEGE OF PUBLIC HEALTH SCIENCES, Chulalongkorn University in Partial Fulfillment of the Requirement for the Master of Public Health

.... Dean of the COLLEGE OF PUBLIC HEALTH SCIENCES
(Professor SATHIRAKORN PONGPANICH)

THESIS COMMITTEE

.... Chairman
(Assistant Professor NUTTA TANEEPANICHSKUL, Ph.D.)

.... Thesis Advisor
(Wandee Sirichokchatchawan, Ph.D.)

.... Thesis Co-Advisor
(JENYUK LOHWACHARIN, Ph.D.)

.... External Examiner
(Assistant Professor Athit Phetrak)

ธีรภัทร อัตวินิจตระการ : การประเมินความเสี่ยงจากจุลินทรีย์ในน้ำอุปโภคบริโภคของชุมชนที่เสี่ยงต่อการเกิดอุทกภัย จังหวัดนครศรีธรรมราช ประเทศไทย. (Quantitative microbial risk assessment of water consumption in flood-prone communities, Nakhon Si Thammarat province, Thailand) อ.ที่ปรึกษาหลัก : ดร.วันดี ศิริโชคชัชวาล, อ.ที่ปรึกษาร่วม : ดร.เจนยุกต์ โล่ห์วัชรินทร์

งานวิจัยนี้เป็นการศึกษาภาคตัดขวางเพื่อสำรวจครัวเรือน โดยใช้แบบสอบถามสัมภาษณ์แบบตัวต่อตัวเพื่อกำหนดลักษณะทั่วไปและการใช้น้ำระหว่างการเกิดอุทกภัย ในชุมชนที่เสี่ยงต่อการเกิดน้ำท่วมในอำเภอปากพนังและอำเภอเชียรใหญ่ จังหวัดนครศรีธรรมราช ระหว่างเดือนกุมภาพันธ์ - กรกฎาคม 2563 จากการสำรวจ 425 ครัวเรือน พบว่า 69.5% เป็นเพศหญิง สองในสามของผู้เข้าร่วมอายุ 46 ปีขึ้นไปและมีรายได้เฉลี่ยต่อเดือนของครัวเรือน 7305.13 ± 7016.56 บาท ในช่วงที่เกิดน้ำท่วมชาวบ้านใช้น้ำจากน้ำขวดที่รัฐบาลแจกและน้ำที่เก็บไว้ในบ้านของตัวเองเป็นหลัก จากการสำรวจน้ำฝนที่เก็บไว้ซึ่งส่วนใหญ่จะไหลผ่านกระเบื้องหลังคาหรือท่อถูกนำมาใช้สำหรับการดื่มและการปรุงอาหารในช่วงน้ำท่วม ตัวอย่างน้ำที่เก็บในชุมชนดังกล่าวจำนวน 28 ตัวอย่างถูกนำมาตรวจสอบคุณภาพน้ำผ่านความขุ่น ตัวบ่งชี้ของจุลินทรีย์และประเมินความเสี่ยงต่อสุขภาพโดยใช้ QMRA เชื้อแบคทีเลีย E. coli ซึ่งเป็นตัวบ่งชี้การปนเปื้อนในอุจจาระ ถูกนำมาใช้ในเพื่อประเมินจำนวน Cryptosporidium oocysts ในตัวอย่างน้ำ ผลการศึกษาพบว่าตัวอย่างน้ำ 27 จาก 28 ตัวอย่าง ผ่านมาตรฐานความขุ่นสำหรับน้ำดื่ม ขององค์การอนามัยโลก (≤ 5NTU) ในขณะที่เชื้อแบคทีเรียโคลิฟอร์มทั้งหมดจาก 12 ตัวอย่างมีจำนวนตั้งแต่ 5 CFU / mL ถึง 235 CFU / mL มีตัวอย่างเพียงสองตัวอย่างเท่านั้นที่มีการปนเปื้อนของเชื้อ E. coli ที่ 1 และ 2 CFU / mL ในการศึกษานี้ได้ใช้ QMRA เพื่อตรวจสอบความน่าจะเป็นของการติดเชื้อ Cryptosporidium ต่อคนต่อปี โดยอัตราส่วนของเชื้อ E. coli: Cryptosporidium ถูกนำมาใช้เพื่อประเมินการปนเปื้อนของ Cryptosporidium oocysts จากตัวอย่าง แบบจำลองเลขชี้กำลังใช้สำหรับหาความสัมพันธ์ของปริมาณการตอบสนองต่อการติดเชื้อ Cryptosporidium ซึ่งการได้รับเชื้อดังกล่าวถูกสันนิษฐานว่าต้องดื่มน้ำประมาณ 2 ลิตร/คน/วันในผู้ใหญ่ และคาดว่าจะพบ oocyst จำนวน 0.02 ต่อปริมาณน้ำ 1 ลิตร ความน่าจะเป็นของการติดเชื้อ Cryptosporidium oocysts ในผู้ใหญ่คือ 0.000168 หลังจากทำการวิเคราะห์ลักษณะความเสี่ยงพบว่าความน่าจะเป็นของโรคต่อคนต่อปีเท่ากับ 7.858 x 10-3 จากผลการศึกษาดังกล่าวยังพบว่า ความเสี่ยงของโรคจำนวน 10-3 ต่อคนต่อปี บ่งชี้ว่า 0.1% ของคนในพื้นที่ที่ทำการศึกษานี้จะติดเชื้อโรคจากการดื่มน้ำที่เก็บไว้เป็นประจำทุกปี

สาขาวิชา	สาธารณสุขศาสตร์	ลายมือชื่อนิสิต	....
ปีการศึกษา	2562	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
		ลายมือชื่อ อ.ที่ปรึกษาร่วม	....

6274009853 : MAJOR PUBLIC HEALTH
KEYWORD: stored rainwater; drinking water quality; turbidity; microbial indicators; flood-prone communities; Nakhon Si Thammarat province

Teeraphat Attavinijtrakarn : Quantitative microbial risk assessment of water consumption in flood-prone communities, Nakhon Si Thammarat province, Thailand. Advisor: Wandee Sirichokchatchawan, Ph.D. Co-advisor: JENYUK LOHWACHARIN, Ph.D.

A cross-sectional study was performed for household survey using a questionnaire with a face-to-face interview to determine the general characteristics and water consumptions during flooding events in flood-prone communities, Pak Phanang and Chian Yai district, Nakhon Si Thammarat province, Thailand between February-July 2020. From a 425 household survey, 69.5% were female, two-thirds of the participants aged 46 years old and above, and had the average monthly household income at 7305.13 ± 7016.56 Baht. Free bottled water and stored water in their own houses were the two main sources of drinking water during floods. From the survey, stored rainwater typically collecting via roof tiles or pipes were used for drinking and cooking during floods in the study community. 28 stored water samples were collected to determine the water quality through turbidity and microbial indicator and to estimate the health risk from consumption of stored water using QMRA. *E. coli*, a fecal indicator, was used to estimate the presence of *Cryptosporidium* oocysts in the water samples. The results show that 27 out of 28 water samples passed the turbidity standard from WHO for drinking water (≤ 5NTU). Whereas, the total coliform bacteria found from 12 samples ranging from 5 CFU/mL to 235 CFU/mL. Only two samples had *E.coli* contamination at 1 and 2 CFU/mL. In this study, the QMRA was conducted to examine the probability of disease pppy of *Cryptosporidium* infection. A ratio of *E. coli*: *Cryptosporidium was applied* to estimate the contamination of *Cryptosporidium* oocysts from the samples. The exponential model was used for dose-response relations of *Cryptosporidium* infection. The route of exposure was the ingestion of drinking water, which assumed to be 2L/person/day in adults. It was estimated to have 0.02 oocyst /1L of stored water. The probability of infection with *Cryptosporidium* oocysts in a single exposure for adults was 0.000168. After performing risk characterization, the study found that the probability of disease per person per year was 7.858×10^{-3}. From the results, a disease risk of 10^{-3} per person per year indicated that 0.1% of the people in the study area would get infected with the disease annually from drinking the stored water.

Field of Study: Public Health		Student's Signature ....
Academic Year: 2019		Advisor's Signature ....
		Co-advisor's Signature ....

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Teeraphat Attavinijtrakarn

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CHAPTER I:

INTRODUCTION

Background & Rationale

Global warming and climate changes are presumed to intensify and increase frequency of many extreme weather events, which adversely impact on human health globally. It is estimated that these events will cost nearly three-hundred thousand lives and more than two billion US dollars between 2030 and 2050 (1). Since 1960, three times of weather-related natural disasters have been reported worldwide, with the vast majority occurred in developing countries. Amongst the natural disasters, floods have the tendency to increase in both frequency and severity, as worse as rainfall patterns. The consequences can include lacking safe water, contamination of freshwater supplies, and increasing the risk of water-borne diseases. The most affected population are those in poorer resources especially on health facilities and infrastructure. It is nearly impossible to overcome flooding without prompted assistance and response from all stakeholders (2).

According to the UN Office for Disaster Risk Reduction (UNISDR) and the Belgian-based Centre for Research on the Epidemiology of Disasters (CRED), billions of people were affected by floods in the last three decades, which also account for more than half of all weather-related disasters. In South America, especially countries such as Brazil, Uruguay and Argentina, around 560,000 people were affected by floods each year from 1995 to 2004 (3). While in Europe, specifically in 2010, there were more than 300 flooding events occurred across 27 countries. Nevertheless, they cannot be compared to Asia and Africa, which have constantly been struck by floods (4). For instance, South Asia was hit by torrential seasonal monsoons in 2017 between June and September. The event caused widespread flooding in Bangladesh, India, India, Nepal and Pakistan. It took about 2,000 lives and affected more than 41 million people (5).

In Thailand, severe flooding occurred during monsoon season starting from July 2011 and continued in some areas until the middle of January 2012. The flooding spread along the Mekong and Chao Phraya river across northern, northeastern, central, and southern parts of Thailand. The most affected provinces include Ayutthaya, Nakhon Sawan and Nakhon Si Thammarat. Not only it caused millions of dollars in damages, but also affected as many as It has been described as the worst flooding in history of Thailand (6).

The impacts of floods are not only in your asset but also health and quality of life. Many researches indicate that either physical (infection, illness and injuries) or mental health (insomnia, anxiety, depression and post-traumatic disorder) or both may be getting bad consequences during and after flood. The stress can decrease your quality of life and wellbeing concurrently. There are many risks and causes of illness throughout the period of flooding. When you directly contact with contaminated floodwater which consists of bacteria, pollutants, and sewages, then you will get some skin or gastrointestinal infection. In a similar case, you should avoid utilization from tap water because it is not safe and often contaminated with bacteria when flood occurs (7). The essential point is that the contamination of organic and inorganic pathogen will fold in the water system during the flood. Thus, using microbial indicators to estimate the hygiene of water is based on achieving *E. coli* concentration to achieve a 99.9% reduction, present a containing less than 3x 103 spores of *Clostridium perfringens* per gram and absence of *Salmonella. Spp* in 50 gram. The pathogens can carry through flood flow to source of waters, and infection will occur via ingestion or utilization of contaminated water (8). *E. coli* are common bacteria living in the gastrointestinal organ of humans, animals, and their feces. They are also found in soil and plant material. Since these bacteria are familiar with the environment; they are commonly used as an indicator for water quality assessment (9).

Therefore, the objective of this study was to assess human health risk through a quantitative microbial risk assessment (QMRA) from consumption of water during floods in flood-prone communities of Nakhon Si Thammarat province, Thailand. The concentration of *E. coli* was measured as the fecal indicator for estimating the pathogen of interest in this study.

Research question

1. What is a human health risks from water consumption in flood-prone communities of Nakhon Si Thammarat province, Thailand?
2. What is a hazard identification (pathogens) from water consumption in flood-prone communities of Nakhon Si Thammarat province, Thailand?
3. What is the characteristics of exposure with the hazard from water consumption in flood-prone communities of in Nakhon Si Thammarat province, Thailand?
4. What is a dose-response from water consumption in flood-prone communities of Nakhon Si Thammarat province, Thailand?

General Objective:

To assess human health risks from water consumption in flood-prone communities of Nakhon Si Thammarat province, Thailand.

Specific Objectives:

1. To identify the pathogen of interest from water consumption in flood-prone communities of in Nakhon Si Thammarat province, Thailand.
2. To assess the characteristics of exposure from water consumption in flood-prone communities of Nakhon Si Thammarat province, Thailand.
3. To determine the dose-response from water consumption in flood-prone communities of Nakhon Si Thammarat province, Thailand

Conceptual framework

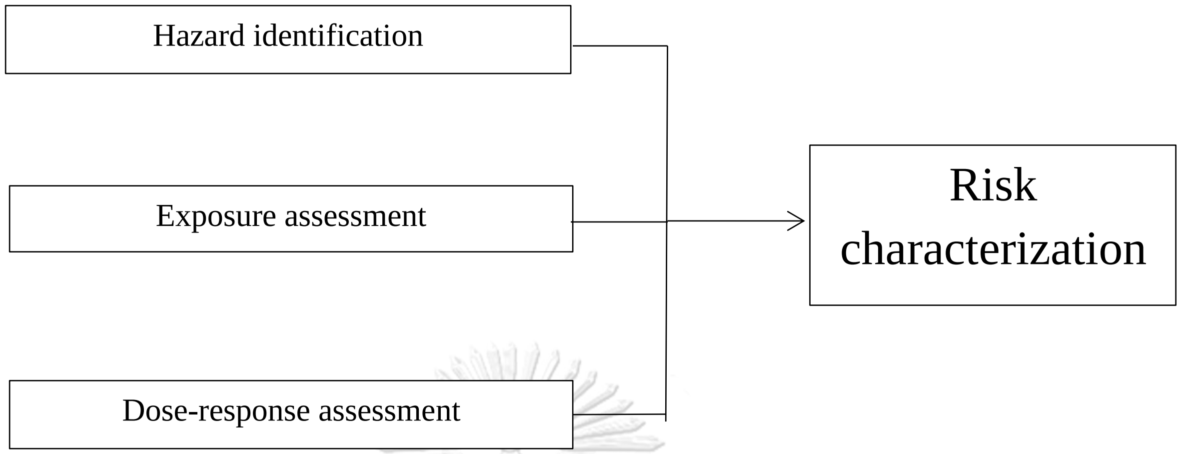


Figure 1 conceptual framework

Operational definitions

1. General characteristics consist of gender, age, educational level, occupation, householder, underlying disease, living area, and access to drinking water during flood.

a. Gender refers to the self-reported sex or observed sex of the study participant and categorized as male and female.
b. Age refers to the self-reported age in years, which is age of the study participant at the time of last birthday.
c. Educational level refers to the highest formal education which an individual has attained and successfully graduated.
d. Occupation refers to the profession of the study participant classified as employee, self-employed, labor, student, retired and unemployed.
e. Householder refers to a person who is the head of household.
f. Underlying disease refers to a chronic comorbidity or condition of the study participant.
g. Living area refers to the area belong exclusively to the accommodation unit of the study participant.
h. Access to drinking water during flood refers to the study participant can approach to drinking water during flood or not.

2. Characteristic of exposure refers to an intended ingestion of drinking water during flood in the study participant.

3. Source of drinking water refers to a place or thing, from which water can be obtained and used by the study participant, for example, tap water, ground water, and bottled water.

4. Patterns of flood refer to a type of flood that occurs in Thailand. There two types consist of flash floods and frequent floods.

i. Flash flood refers to acute, intense, and high-velocity overflow of water caused by torrential rain falling. We describe this flood type in Nakhon Si Thammarat and Nakhon Sawan provinces.

j. Frequent flood refers to river flood or surface water flood. We describe this flood type in Ayutthaya and Nakhon Sawan provinces.

5. *E. coli* concentration refers to the amount of *E. coli* bacteria in the collection of drinking water during flood after calculation. We commonly used as an indication of drinking water safety.

6. Human health risks refer to probability of getting sick of the study participant who intended ingestion the drinking water during flood.

CHAPTER II:
LITERATURE REVIEW

2.1 Flooding: Types and Causes

Flood can be classified into five major common types according to some characters of hydrology, cause, geography, or severity (10).

2.1.1 **Flash flood** is a rapid pattern of low-slope areas. It differs from other floods type by using a timescale. This flood type usually takes time less than six hours between rainfall and the onset of flooding.

Flash floods have various types of causes. Most of them occur when it heavily rains from tropical storms or hurricanes and rapidly flows on saturated and dry soil which is poor absorption capacity. The area covered by water in this flood type is relatively smaller than other types. In some areas, flash floods occur after eruptions of the volcanoes. In some places near glaciers, flash flood directly affects by the melting of snow or iceberg (11).

Flash floods are extremely dangerous because of the sudden onset and high moving speed of the water. It can transport and destroy large objects easily such as vehicles and trees. Many people have underestimated the dangers of this situation so, one of the recommendations is to get out rather than try to cross that area.

2.1.2 **Coastal flood** occurs when the water from the sea overflows to the ground. It is one of the magnificent natural events. Three common pathways of this flood type consist of direct flooding, overtopping, and breaching of a barrier (12).

Coastal flood can take place by three common causes including storms and storm surges, rising sea levels, and tsunamis.

Storms can affect flooding during storm surges especially tropical cyclones and hurricanes. This makes the waves extremely larger than normal. Wind blows directly from the sea to the land causing the water to accumulate against the coast. This is known as wind setup. Low atmospheric pressure with storm systems leads to increase the surface sea level. This is known as a barometric setup. Finally, raised wave breaking height becomes a higher sea level in the surf zone. This is known as a wave set up. Three processes interact with each other to form a great wave that can overtop natural and engineered coastal protection (13).

According to climate change, the estimated mean of sea level is rising around eighty-eight centimeters globally. It can predict the frequency and severity of storm events like a hurricane. Rising of sea-level impacts on flooding and persistent torrents of low-slope area. The conclusion of this situation will change more significant into the next century especially the people who live nearby the coastal zone (14).

2.1.3 **Urban flood** is known as flooding in urban areas. It is characterized by the impacts on the population in their communities. This flood type usually torrent on land or infrastructure in a building area and take the damage to local water drainage system, for example, sewer pipes, toilets, and sinks. The water increases approximately slow and the water level usually does not reach harmful heights. In urban areas, the effect of flooding can be increased by covering streets and roads. It progresses the speed of moving water.

Flooding in urban areas can be caused by flash floods, or coastal floods, or river floods. High-intensity rainfall also cause flooding when the capacity of water drainage and local sewage system is not sufficient. The impact of this situation is the disturbance of regular living in the city. People cannot go to work or school because of blocking their roads (15).

2.1.4 **Fluvial flood**, or river flood, occurs when heavy rainfall or excessive snowmelt into the nearby river. This becomes to exceed its capacity. The effect can cause overflow from downstream to break their banks or dams. The damage can be extensive and torrent several areas. The severity of a river flood is defined as the amount of impact in each area. For example, how long it takes for accumulation, earlier saturation of local soils, and the ground surrounding the river system. In low-slope areas, flood rise slowly and take time for a day compare to high areas.

There are two main common types of river flood. The first is overbank flooding. It happens when the water flow higher than the edges of a river. This is the most common flood type which can be found in any size of water stream. The second is a flash flood which is characterized by an acute, intense, and high-velocity overflow of water caused by rain falling within a short time. Because of the force and high speed of the water, flash flood is highly dangerous and can destroy surrounding buildings (16).

2.1.5 **Pluvial flood**, or surface water flood, is caused when massive rainfall produces an overflowing water. It often occurs in combination with river and coastal flood. It also happens when an urban drainage system decreases, and water flows out into streets and nearby structures. The level of water occurs continuously and slowly that people have more time to move to safe locations. This flood pattern has no immediate effect on life, but it may cause significant economic damage (17).

2.2 Flood Record:

2.2.1Global record

2.2.1.1 Flood disaster

The report by UN reveals that between 1995 and 2015, floods affected 2.3 billion people worldwide, which estimates for 56% of all those affected by weather-related disasters. And around 157,000 people died from flooding in the last 20 years. Between 1995 and 2015, there are more than three thousand flood disasters, which estimated 43% of all-natural disasters, reported and analyzed by the UN Office for Disaster Risk Reduction (UNISDR) (18).

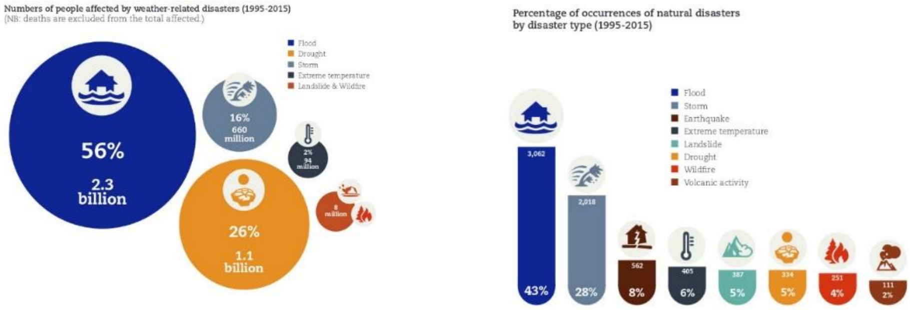


Figure 2 Number of people affected by weather-related disasters (1995-2015) [18]

Figure 3 Percentage of occurrences of natural disasters by disaster type (1995-2015) [18]

According to the report, floods hit in Asia and Africa more than other continents. Between 2005 and 2014, the number had risen to 2.2 million people, approximately a four-fold increase. The trend of flooding increases both frequency and severity around the world. 37 European countries have recorded 3,563 floods in total between 1980 and 2010. The highest number of floods are reported in 2010 and associated with the Central European floods (19).

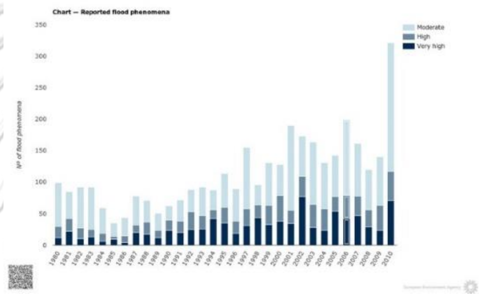


Figure 4 Chart of reported flood phenomena [19]

2.2.1.2 The effect of flooding

The Aqueduct Global Flood Analyzer is a web-based interactive platform. It can measure the impact of river flood by urban damage, affected GDP and population in the state or country. The purpose is to promote the awareness about flood risks and the outcome by free accessible global data. The analysis shows that around 21 million people around the world are impacted by floods every year. This number may increase to 54 million in 2030 due to climate change. The Analyzer evaluates the current and future potential situation of GDP and the affected population and urban damage from river floods globally (20).

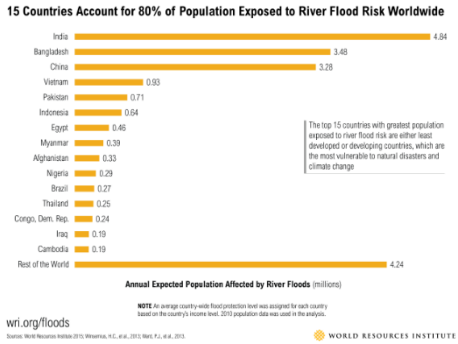


Figure 5 15 Countries account for 80% of population exposed to river flood risk worldwide
[20]

Ranking by the number of people hit by flooding into 164 countries, they mentioned that the top 15 countries estimate as 80 percent of the total population affected every year. Most of them are less developed or developing countries. The data, analyzed by World Resources Institutes, reveals that flooding also has an impact on the percentage of GDP every year. India becomes the most GDP exposed around $14.3 billion. Bangladesh is a second, at $5.4 million. China and Brazil are the first and fifth country which affect respectively by gross GDP.

Moreover, the analysis describes a clear trend across the world. Especially in lower and middle-income countries, socio-economic development is supposed to concentrate more vulnerable people, buildings, and infrastructure. So, the developing world is expected to observe more GDP about flood risks in 2030 (21).

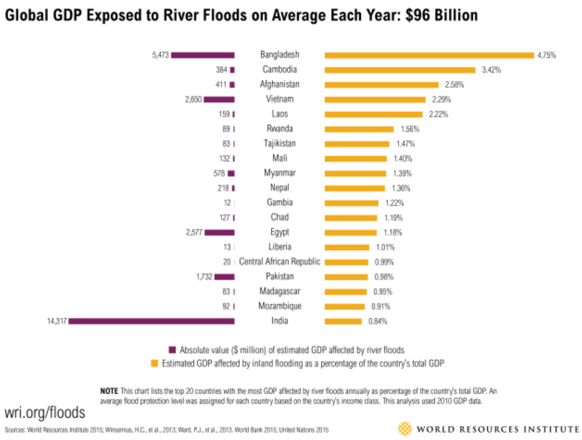


Figure 6 Global GDP exposed to river flood on average each year: $96 billion [21]

2.2.2 Thailand record

2.2.2.1 Pattern of Flood in Thailand

There are three patterns of flood in Thailand depended on the landscape and environment of each area that results in varies severities (22).

1 Flash flood is characterized by an acute, intense, and high-velocity overflow of water caused by rain falling within a short time. Most of this flood type often occurs in areas with steep slopes or less ability to store water. Because of the force and high speed of the water, flash flood is highly dangerous and can destroy surrounding buildings.

2 River flood or fluvial flood occurs when the water level in a river, lake or stream rises and overflows over the surrounding banks, shores, and neighboring land. The rising water level comes from heavy rain. This damage can be widespread as the overflow, which affect to dams and barriers breaking down.

3 Surface water flood or pluvial flood occurs when an urban drainage system decreases, and water flows out into streets and nearby structures. The level of water occurs continuously and slowly that people have more time to move to safe locations. This flood pattern has no immediate effect on life, but it may cause significant economic damage (17).

2.2.2.2 Flood disaster in Thailand

Flooding is one of the common natural disasters in Thailand which occurs almost every year during the monsoon season. The seasonal effect is different in each region. For example, in the southern region of Thailand, monsoon frequently begins in October and ends in March. From the past until now, Thailand has several flooding with high severity, for example, big floods in Bangkok in 1995, flash flood in Thailand in 2010, the worst flooding in Thailand in 2011, Eastern Thailand flood in 2013, and Southern Thailand flood in 2017.

Figure 7 The worst flooding in Thailand [23]

The worst flooding in Thailand occurs during 2011 by monsoon seasonal. Flooding starts in July which is initiated by the landfall of tropical storm. It spreads through many provinces of northern, northeastern, and central region along the Mekong and Chao Phraya river basins. This situation persists in some provinces until mid-January 2012. The impact causes a total of 815 deaths and 13.6 million people affected. Sixty-five of Thailand's are announced flood disaster zones (23). The estimation of economic damages is approximately 1,425 trillion baht (US$46.5 billion) by the World Bank. The losses are including infrastructure property, major industrial estates, agricultural sector, and tourism.

2.2.2.3 Flooding in study area [Ayutthaya, Nakhon Sawan, and Nakhon Si Thammarat]

In the last decade, Ayutthaya has flooded several times. In 2017, the flood occurs for four times because of an increase in the flow rate from the Chao Phraya Dam. This affects several districts and causes a lot of damage in agricultural areas, temples, historical park, and residential structure. Many houses, especially in low-lying areas, inundate for 50 cm deep. Boats are the only way of transport in their communities (24).

Figure 8 Flooding in Ayutthaya (2017) [24]

Nearly 500 families in Phak Hai district have sustained flooding for more than four months. The requirement of necessary support, especially portable toilets and utilizing water, is very important. Many families have to move to a temporary shelter at Wat Tha Din Daeng, where the sub-district office administrative organization provides food (25).

The flooding also happens in Nakhon Sawan province. In 2018, approximately 900 residents are inundated after flooding due to heavy tropical storm. This affects many areas in Phichit and Nakhon Sawan. The breaking sandbag barrier results in a rapid overflow of flooding into the city. Around hundreds of patients have to move out of the Regional Hospitals by boat because the power supplies and basic life support systems are obstructed (26).

Nakhon Si Thammarat is the one that frequently occurs flooding. Flash flood, triggered by mountain runoff, hits several districts in 2018 and results in widespread damage more than hundreds of businesses, including banks and grocery stores. Almost the household along the main street is under 30 to 70 centimeters of water. More than 35 schools are closed due to the torrent of transportation (27).

Figure 9 Flooding in Nakhon Si Thammarat (2018) [27]

The worst flooding in 2011 directly affects these three provinces. The UNESCO, participating in the world-class expertise and facilitating international collaboration, supports the Ministry of Culture's Fine Arts Department in Thailand. A multidisciplinary team works hard together to ensure that the historical place and its natural setting will be sustainably managed in the future (25).

2.3 Structure of water supply and sewer systems in Thailand (including study area)

2.3.1 Thailand's Water Supply

Adequate freshwater availability is an important factor for Thailand's future development. Water is one of the basic necessities and need for several sectors including agriculture, industry, and tourism. These different demands depend on the available water resources. Nowadays, working between each sector increase more incomes but this will increase the consumption of water usage. The estimation of demand is up to 20 percent a year.

National, drinking water supplies are usually provided by two agencies: The Provincial Waterworks Authority (PWA) and the Metropolitan Waterworks Authority (MWA). The responsibility of MWA is to produce and distribute drinking water in the Bangkok metropolitan region, while the PWA is responsible for water source improvement, treatment, storage, and delivery to all the urban and rural areas in the provinces.

The goal of Thailand's development strategy is to improve the water drainage system and water supply infrastructure service in our country. Increasing and developing the existing natural water reservoirs are one of the basic methods for every region. Moreover, Thailand attempts to decrease the non-profit volume of the water operation system. The impact will achieve all villages in the Bangkok Region with water supply services and more than 80% of provincial villages before 2021 (28).

2.3.2 Water supply and treatment process (structure and production process of tap water, pumping station and service area)

Clean and safe water is necessary for our health, hygiene, and the productivity of our community's everyday life. The larger water supply serves for many resources of houses, business, or industrial sector. It is important to treat before being provided or distributed for utilization and consumption. The smaller water supply, especially for individual properties, also has to be clean and safe for drinking and using. So the design of the water system structure is essential for investigation, evaluation, analysis, and treatment. The purpose is to increase the efficiency of all processes. Monitoring of water quality can indicate that the water is safe enough from toxic substances and pathogen contamination (29).

That's why water treatment process is extremely important. Some process can vary depending on different areas and the technology of the treatment plant, but the basic principles are mainly the same. This picture describes commonly standard of water treatment processes.

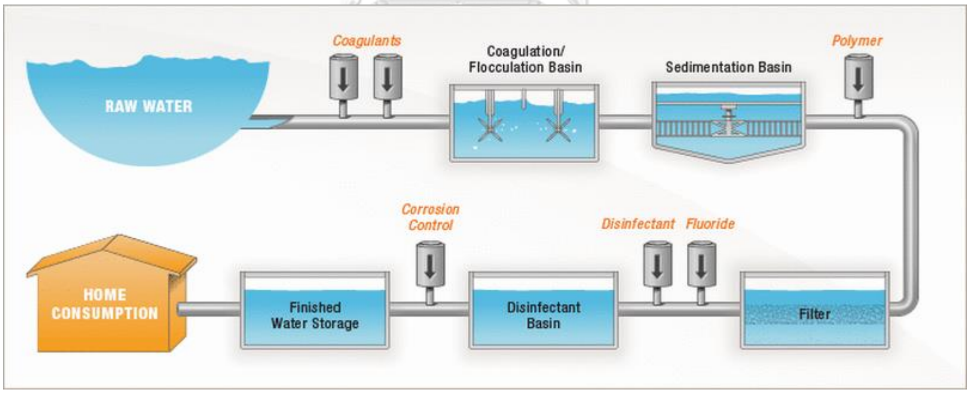


Figure 10 Water supply and treatment process [29]

1. Coagulation and Flocculation process

The first step of the water treatment process is coagulation and flocculation. The process aims to remove color, turbidity, algae and other pathogens from surface waters. Adding a chemical coagulant to the water makes the formation of a sediment or precipitate catching those contaminations. The groups of dirty particles attach to form larger, heavier particles called flocs which are easier to remove. Then it is isolated from the treated water by sedimentation and filtration.

Aluminum sulfate and ferric sulfate are the most commonly used coagulants but other kinds can also apply. The dose of coagulants has a rate limited by raw water quality near the inlet of a mixing tank or flocculator. The coagulant is rapidly separated with high turbulence. The water is flocculated and then passes into the sedimentation tank. This sludge has to regularly remove.

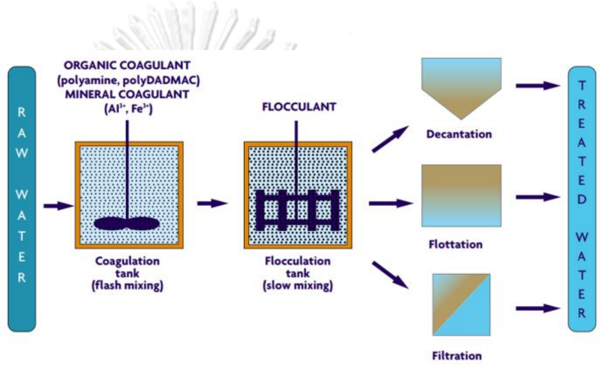


Figure 11 Coagulation and Flocculation process [30]

The advantage of this step is to decrease time-consuming and high effectively remove fine particles and pathogens such as bacteria and protozoa. The major disadvantages of treatment for small particles are the expense and the requirement for accurate dose monitoring. The dose and efficiency process depend on raw water quality, the coagulation consuming, and operational factors including temperature, coagulant dose rate, and pH value (30).

2. Sedimentation process

The water and the floc particles move slowly toward sedimentation basins. Then the heavy particles fall to the bottom that is called sludge. Simple sedimentation applies for reducing turbidity and solids particles in suspension. These tanks are produced to decrease the velocity of the flow of water so as to allow suspended solids to fall under gravity. There are various designs of sedimentation tanks. The selection depends on simple settlement tests existing tanks treating similar waters. Without the coagulation process, these will only remove large or heavy particles.

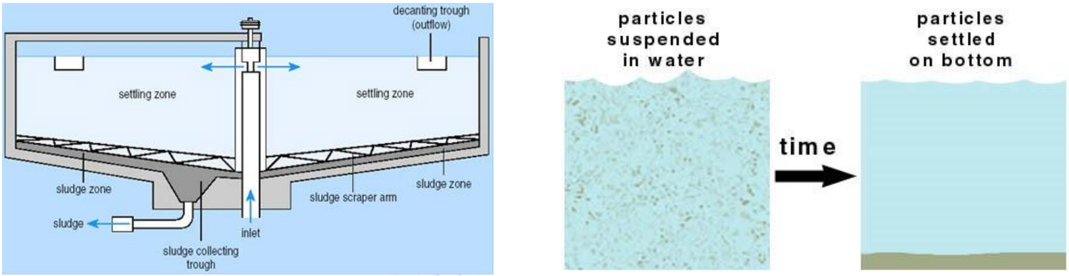


Figure 12 Sedimentation process [30]

Sedimentation tanks are commonly rectangular with length to width ratios between 2:1 and 5:1. The tank is deep between 1.5 and 2.0 m. The tank should be covered to prevent contamination. It normally requires cleaning not frequent more than once per year (30).

3. Filtration process

This step designs to remove particles when water flows into a filter. It is made of layers of sand, gravel, and small anthracite. Filtration accumulates the suspended contaminants in water and increases the effectiveness of disinfection. Screens are sufficient for the removal of particles and debris from raw water. It implements a preliminary treatment stage. The coarse screens use to remove large particles while the band screens or micro-strainers will remove smaller particles and algae. Microstrainers utilize as a pre-treatment to decrease solids loading before coagulation or filtration. It consists of very fine mesh panels. The mesh will assure that suspension and algae are retained.

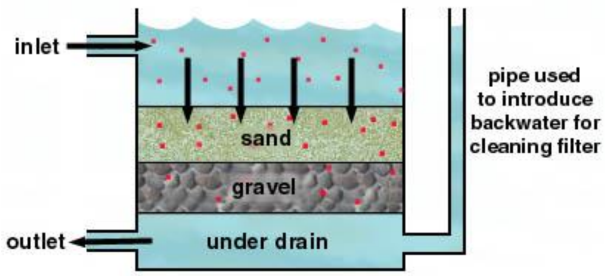


Figure 13 Filtration process

Turbidity and algae are removed from raw waters by, sand and gravel filters. Slow sand filtration is a biological process whereas rapid sand filtration is a physical treatment process. Many small waters supply in a household usually consist of a spun filter within a standard housing.

4. Aeration process

Aeration process is designed to achieve adequate mass transfer of oxygen into water and removal of gases and volatile compounds by air stripping. This process is applied for the removal of volatile organics, carbon dioxide, some taste and odor-causing compounds, and radon. It is one of the specialist techniques and has not generally seen in private and household water supplies. Oxygen transfer can use a simple cascade or diffusion of air into water, without the requirement for complicated equipment.

For oxygen transfer, the steps of aerators are planned for flowing water into a thin film. The requirements of the design are between 1.0 and 3.0m which provide for loading about 10 to 30m3 /m2.h. These types of aerators can use for oxidation and precipitation of iron and manganese. There are many techniques of air stripping including counter-current cascade aeration in packed towers, diffused aeration in basins and spray aeration. Packed tower aerators are mostly utilized because they produce high energy efficiency.

5. Chemical treatment process

5.1 Control of pH value

The pH in water should modify during treatment and before conveying. There are many reasons as following:

- to guarantee that the pH value achieves the water quality standards
- to measure corrosion in the transporting system to consumers
- to improve the capacity and effectiveness of disinfection
- to promote the elimination of iron and manganese, color and turbidity by chemical coagulation, and other contaminants in water

5.2 Iron and manganese removal

Iron is normally present as ferrous compounds in groundwater. It is important to oxidize ferrous iron by aeration for removing iron to the insoluble ferric hydroxide. If the iron exists in an organic complex, a potential oxidant such as chlorine or potassium permanganate is required following by filtration or coagulation.

5.3 Taste and odor removal

These two things can be eliminated by several methods, including aeration, ozonation, and absorption on activated carbon. The method depends on the source of the taste and odor. Absorption on activated carbon is the most effective method for the removal of natural or taste and odor. The granular activated carbon (GAC) is the selected solution and applied as a filter medium replacing sand in existing filters when usual treatment is needed. This makes contamination and impurities to wash out.

6. Membrane process

The major importance of membrane processes in water treatment is reverse osmosis, nanofiltration, ultrafiltration, and microfiltration. These methods apply to the production of water for the industrial sector, pharmaceutical utilization, and treatment of drinking water. The characteristics are explained in the picture below (31).

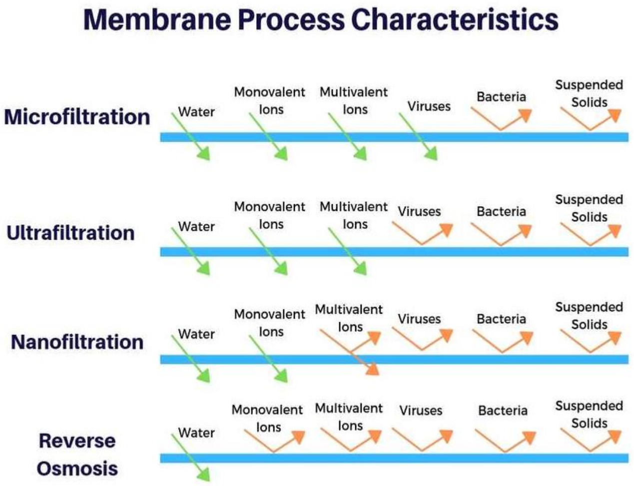


Figure 14 Membrane process [31]

Two solutions are divided by a semipermeable membrane. Only solvent can pass through this membrane, from the lower to higher concentration, but not for the solute. This process is called osmosis. In contrast, the solvent moves from the higher to lower concentration with the required osmotic pressure. This process is called reverse osmosis.

The pressure in reverse osmosis is regularly around 15 to 50 bar. Membrane pore is less than 0.002µm. The common utilization of reverse osmosis is the desalination of seawater.

- Microfiltration: This is a direct addition of conventional filtration. It can remove almost particles greater than 0.05µm, bacteria, and amoeboid cysts. It also applies to combination with coagulation or powder activated carbon (PAC) to remove viruses and dissolved organic carbon in water treatment. These membranes have pore sizes between 0.01 to 12µm. So it helps to reject colloidal and suspended material at operating pressures of 1 to 2 bar.

- Ultrafiltration: The principle is similar to reverse osmosis, but the membranes have larger pore sizes (generally 0.002 to 0.03µm) and operate at lower pressures. These membranes do not allow organic molecules which weight more than 800 pass.
- Nanofiltration: The characteristic is between reverse osmosis and ultrafiltration membranes which has pore sizes around 0.001 to 0.01µm. Monovalent ions such as sodium or potassium can pass but not for divalent ions such as calcium and magnesium and organic molecules with a weight higher than 200. Operating pressures are commonly about 5 bar.

7. Disinfection process

Contamination by sewage and animal feces is an important hazard associated with drinking water. Because these carry the causative organisms of infectious diseases. The disinfection process can eliminate or inactivate pathogenic microorganisms in the raw water. Various surface waters may carry E. coli between tens to many thousands per 100ml. Groundwater has lower microbial concentrations than other sources because of geological features.

Many disinfection methods apply in the water treatment process. For example, adding chlorine use generally for large water supply, but ultraviolet irradiation commonly uses in private supply. Different microorganisms have different sensitivities to disinfect. The effectiveness of disinfection depends on disinfectant concentration and contact time, pH, and temperature. The outcome of disinfectant concentration (C in mg/l, measured at the end of the contact period) and time (t in minutes) is called Ct (in mg/l.min). $Ct = C \times t$

7.1. Ultraviolet (UV) irradiation is the favored method for disinfection in small water supplies with small distribution systems. This is especially affected by water quality and flow rate. When the water passes through this process, it becomes a good quality, less color, and turbidity for utilizing and drinking. The general measure for the appropriate treatment by UV disinfection is UV254 absorbance that monitors and analysis by laboratory. However, pre-filtration is always required before the UV disinfection process, especially if Cryptosporidium is expected to be present (32).

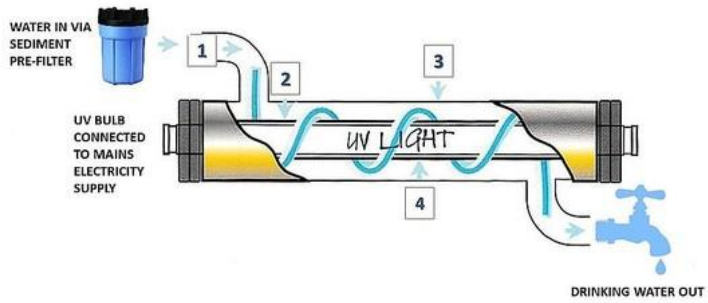


Figure 15 Ultraviolet (UV) irradiation [32]

The dose of UV radiation is shown as an energy flux, in units of mW.s/cm2 (milliwatt seconds per square centimeter) or more usually as millijoules per centimeter squared (mJ/cm2). The minimum dose for disinfection depends on several factors, such as the susceptibility of microorganisms. In general, it should be around 40mJ/cm2. UV intensity will be decreased by the aging of the lamp and the absorption of UV radiation by water contamination. So the recommendation is to change the lamps in periods and clean the quartz sleeve. Color and turbidity can affect radiation intensity. The treated water has to test for estimation of the transmission or absorption (UV254) by the supplier.

2.3.3 Sewer systems

2.3.3.1 Sewerage System Division in Thailand

The Department of Drainage and Sewerage (DDS) was found in October 1967 under the Royal Decree. They are responsible for planning, maintaining, and controlling on sewers, for example, pumping manholes, sewerage system, and water drainage system. They also prevent and solve flooding problems in Central and Rural areas (33).

There are four Subdivision as following:

1. Administration Section has general responsibility including broad executive management, secretarial works, meeting administration, financial and budgetary, control and supplies, services and facilitate the office accommodation and vehicles.
2. Maintenance 1 Sub-Division has responsibility for managing and maintaining on drainage sewerage system, protection and implementation of inundation water, reducing water level on pumping manholes, establishing sandbag wall, and investigation of public utility on water drainage system.
3. Maintenance 2 Sub-Division has the same responsibilities as Maintenance 1 Sub-Division but covers in other areas.
4. Sewer Engineering Sub-Division has responsibility for planning and implementing flood protection's way and water system drainage in flooding areas which distributed into fifteen polders.

2.3.3.2 Type of sewerage system in Thailand

Sewerage is an important infrastructure that carries sewage or water drainage via sewers. It contains several parts including manholes, pumping, chambers of the combined sewer, or sanitary sewer. The ends of the sewerage system almost deliver at the target environment or wastewater treatment plant area. In American, the term sewer system is used more regularly to the large infrastructure of sewers. But the term sewerage system is often used in British English.

The main component of each sewer system is produced from large pipelines and pumping station. It conveys the sewage and surface runoff from the beginning of production to the endpoint of treatment. There are three common types of gravity sewers including combined sewer, simplified sewer, and storm drain. For another essential type does not rely on gravity which means sanitary sewer commonly including vacuum sewer and effluent sewer.

1. A **combined sewer** is a collection system of pipes and tunnels. It is planned for simultaneously collecting sewage water and surface runoff in our system. This is one of the gravity sewer type which does not use worldwide nowadays when building a new sewer system. This sewer type almost separate from sanitary type but existing in older communities and towns (34).

   Combined sewers system can produce serious problems about water pollution through combined sewer overflow (CSO). Because the discharges of sewage will exceed the capacity of the treatment plant, or reach the maximum flow rate of the sewer system. In some situations when unusually high surface runoff occurs, like heavy rainstorms, the pressure on individual branches of this system may cause overflows out of input resources. The impact becomes flooding with toxic sewage contamination of utilizing and drinking water. It also burdens economic system to clean up and restore the environment (35).

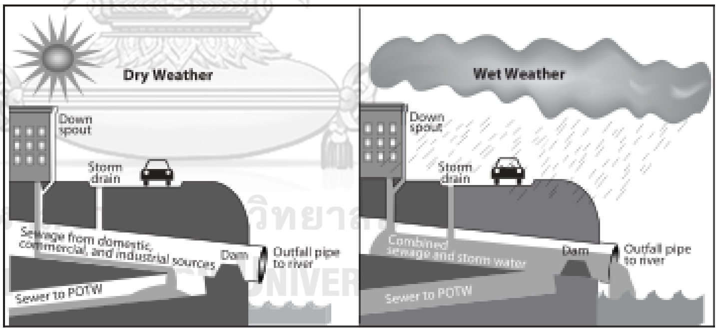


Figure 16 Combined sewers system [35]

This picture explains the combined sewer system. In a normal situation, such as dry weather and tiny storms, all sewage water is controlled by the publicly owned treatment works (POTW). To the contrast in unusual situations, such as massive storms, the assistance structure releases some of the mixed storm-water and sewage to nearby water bodies. This causes both negative environmental and bad consequences of unsafe water consumption.

1. **Simplified sewer**, also called small-bore sewer, is a collecting system from every household wastewater including blackwater and greywater. This system always set in the front yard or under the sidewalk more than in the center of the street. It consists of small-diameter pipes that appropriates for low-income areas. Additionally, it provides a more adjustable design with the new regular housing plan. The advantage of this type is estimated to reduce investment capital up to 50% compared to a conventional sewer system (36).

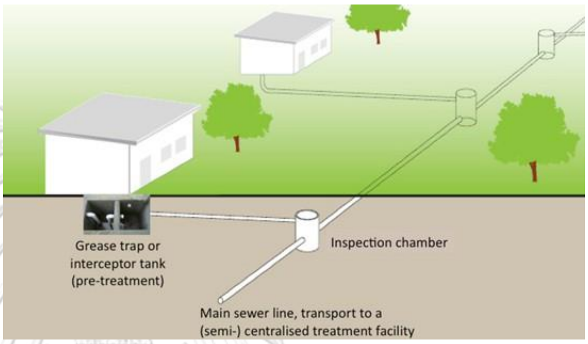


Figure 17 Simplified sewer system [36]

This picture displays a diagram of a simplified sewer. It consists of smaller diameter pipes, grease trap or interceptor tank for pre-treatment plan, inspection chamber for maintenance, and a main sewer line for conveying sewerage to a centralized treatment facility. This system is more technical and feasible than conventional sewer.

1. A **storm drain**, also known as storm sewer in the United States and Canada, surface water drain/sewer in the United Kingdom, or storm water drain in Australia and New Zealand is infrastructure designed to reduce excess groundwater from the surface areas such as pavement, street, and parking.

Figure 18 Strom drain system [37]

Pipes takes water from motorways, street gutters, and cities when it becomes flooding after heavy rainfall. Most of this sewer system is gravity sewers that drain untreated water into streams or rivers. The problem is the contamination of dangerous and toxic substances in the water (37).

1. A **sanitary sewer** or foul sewer is an underground pipe or tunnel system for conveying sewage from houses and industrial buildings, not including stormwater, to manage and treat disposal before release to surface water. This type of sewer is part of an overall system which is named sewage system. It differs from a storm sewer that accumulates snowmelt and rainwater from pavement and street nearby surface water. Sanitary sewers are more complex than a chain of pipelines. They have a total transportation system including pump stations, power mains, manholes, storage facilities, and other components. The common two types of sanitary sewer explain below (38).

4.1 A **vacuum sewer** is a method of transporting sewage to a treatment plant. It consists of two parts. The first part is a partial vacuum pipe system that keeps air pressure inside below comparing to atmospheric pressure. The second part is the vacuum collecting station. When the system is utilized, valves can open automatically because of different pressure. A single central vacuum station can receive the sewage and wastewater from several thousand homes, depending on the local situation (39).

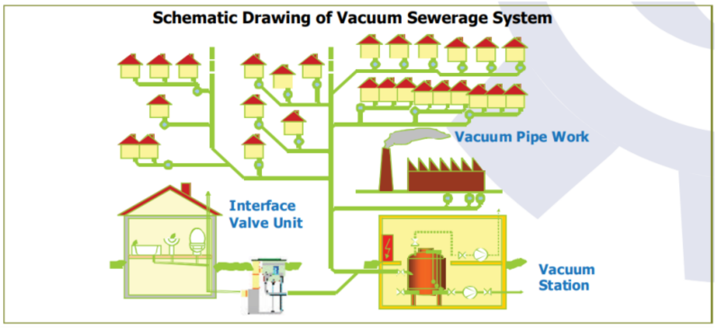


Figure 19 Vacuum sewer system [39]

4.2 **Effluent sewer**, also called septic tank effluent drainage (STED) or solids-free sewer systems (SFS), have septic tanks that receive wastewater from houses and construction. Then it transports the discharge from the tank to the centralized sewage treatment plant.

2.4 Effects of Flooding

2.4.1 Water supply and water utilization

In general, domestic water supply has to treat and clean before distribution to the household for using and consuming. Every country has several methods to measure and qualify the safety of water. The water supply system is a main process to accumulate the raw water, treat and purify, and distribution to the household. The purpose of utilizing treated water are various reasons such as agricultural, residential, industrial, and public. The quality of water supply has to evaluate and test in term of clean and safe before conveying to the consumers.

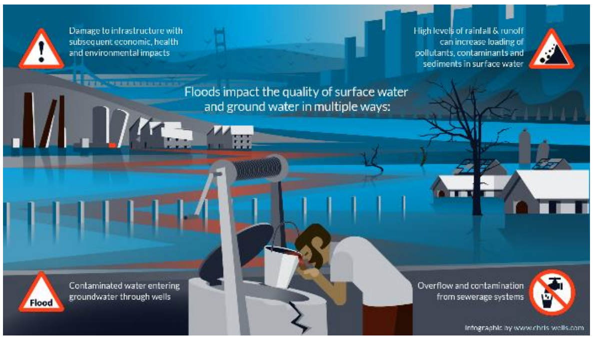


Figure 20 Floods impact the quality of surface water and ground water in multiple ways. [40]

The clean water supply during or after flooding is difficult, especially against insufficient systematic water management. This condition affects water consumption, utilization, and sanitation in every household. There are five common major impact of floods on water supply system which consists of 1. destruction of water intake, 2. damage to the water pumping station, 3. blocking due to sediment deposition, 4. inadequate of water intake area, and 5. pollute availability of groundwater.

Figure 21 Contamination of water supply during flood

Contamination of water supplies is a main problem during floods. It can affect both surface water and groundwater. For the surface water resources, flooding causes the rivers dirty due to the increase of sediment and precipitate solid. Groundwater also decrease the quality due to contamination of pathogens and heavy materials.

Many studies of water quality assessment during flood reveals that most of the contamination is toxic substances and heavy metals such as chromium, copper, and zinc. In general, there are several impacts on water supply and utilization including inundation of water resources, interruption of the cleaning and treatment process, declining water quality due to the high level of bacteria and other pathogens (40).

2.4.2 Sewer systems

When there is an excessive amount of rainfall, the soil may lose the capacity to absorb water that becomes a saturated ground. Then it can occur a surface flooding. If the river levels reach full capability and break their banks, this condition will be increased further events.

Flooding can damage a septic tank or sewage treatment system in three main ways. The first is through the cover of the tank. The second is through underground pipeline joints, riser pieces, and manhole. The third is through the outlet pipeline which conveys the effluent to the drainage field or surface water.

The flooding increases the risk of contaminated sewage into the groundwater and water supply. Human sewage contains high levels of hazardous pathogens, bacteria, and viruses. It is dangerous to humans, animals and the environment. The common problems are including dirty drinking or utilizing water, contamination in the water system, getting infections and disease from the sewage and toxic materials (41).

2.4.3 Human health

The increased probability of flooding event worldwide supports the issue of how floods affect human health for both physical and mental problems. Besides the damaging effects on infrastructure and property. We can classify the health effects by using the term of occurrences into direct and indirect health outcomes. The impact immediately happens during or after the flooding. The bad situation develops in a day or early weeks following the flooding. The long-term effects can appear after months or years by itself.

There are several direct health outcomes including risk behavior, drowning, injuries, wound infection and dermatitis from contact with dirty water, hypothermia, gastrointestinal infection from drinking contaminated water, and other serious waterborne diseases. It also impacts on mental, emotional, and stress problems.

The Indirect health effects frequently occurs due to the damaging to the water supply system, sewer and sewage disposal systems. The lacking of adequate drinking water supply leads to waterborne infections, especially pathogenic *E.coli*, *Shigella* toxin, and other hazardous pathogens. Utilizing of contaminated water causes gastroenteritis and other serious illness. The destruction of underground pipelines and storage tanks results in releasing of toxic waste and vector-borne into the water system. Destruction of primary food products may become a food shortage and inadequate food supplier. Contamination of water utilization can disrupt some health service activities and insufficient medical care (42).

2.4.4 Microbial contamination and variation in:

2.4.4.1 Floodwaters

Flooding can disrupt water supply and sewage disposal systems. It may cause the overflowing of toxic substances and chemical materials. In general, most of flooding do not lead to dangerous outbreaks of infectious disease or chemical poisonings. Floodwater usually carries a lot of infectious organisms such as *E. coli, Salmonella, Shigella*, hepatitis A virus, agents of typhoid, and tetanus. The signs and symptoms of waterborne disease are similar, for example, nausea, vomiting, abdominal pain, diarrhea, and fever. Almost illness cases are associated with ingestion of contaminated water during floods. On the other hand, floodwaters can be contaminated by chemical waste from the agricultural or industrial sector (43).

Figure 22 Microbial contamination in floodwaters [43]

Three common types of pathogenic bacteria found in floodwater consist of *Shigella flexneri*, *Salmonella typhimurium*, and *Escherichia coli.* Generally, it uses 2–3 months to reduce the enteric bacteria in soil after flooding. There are many natural variabilities in environmental factors including soil components, pH, temperature, and microbial susceptibility. *Shigella* can persist in soil at room temperature for 9–12 days. Cryptosporidium oocysts can survive in a moist environment for 60–180 days.

Some fungus with spore-forming or anthrax spores can endure in soil for many years. Because of various microbial responses to the floodwater, implementing universal guidance is difficult.

Personal hygiene is one of the important ways to prevent the exposure risk of microbial contamination in floodwaters. Public health education has to include personal hygiene prevention and guidance such as adequate hand washing after contact the floodwaters. Moreover, education efforts should announce to avoid utilizing floodwaters for sanitation and consumption (44).

2.4.4.2 Ground water

Surface water flows downward into unsaturated zones which generally consists of small pores and cracks in the soil, sand, or rock. Then it reaches a stable water-saturated layer called the water table. The groundwater is below the water table. Groundwater produces about 0.6 percent of the total water in the world and around 20 percent of the available freshwater resources. Microbial organisms perform an essential part in the groundwater ecosystem and affect drinking water quality.

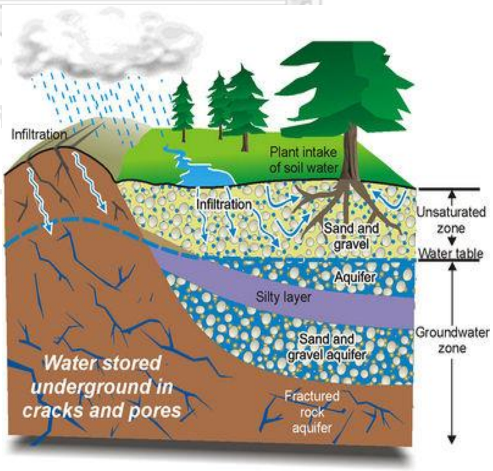


Figure 23 Ground water in ecosystem [45]

Gram-negative bacteria such as *Pseudomonas, Acinetobacter*, *Neisseria*, and *Moraxella* are found broadly in the groundwater system. Several studies reveal that around 95% of the platable colonies from groundwater contained non-streptomycete bacteria and more than 80% are gram-negative rods. For gram-positive bacteria such as *Staphylococcus* and *Streptococcus*, there are not plenty of groundwater systems (45).

Inadequate construction of wells, septic tanks, and offal holes results in microbial contamination of groundwater. In some small villages, the septic tanks are unsafe from microbial contamination for their drinking and utilizing water (46).

Figure 24 Inadequate management of offal hole can cause groundwater contamination. [46]

2.4.4.3 Surface water

Typically, surface water, such as ponds, lakes, and rivers, is the main source of rural water supply. The contamination of bacteria and microorganisms in surface water is more than groundwater. There are three common types of bacteria including coliform bacteria, *Escherichia coli*, and *Enterococci.* Coliform bacteria are an extensive assembly of various species of bacteria. They come from both fecal and non-fecal coliform bacterial sources. Fecal coliforms bacteria can be found naturally in the gastrointestinal tract of warm-blooded animals. Some type are pathogenic species that causes disease to human health. The presence of fecal coliform bacteria uses to indicate contamination in the water system.

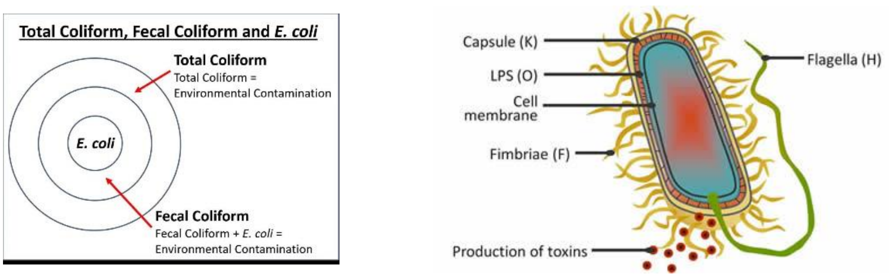


Figure 25 Total coliform and E.coli [47]

Escherichia coli, generally called *E. coli*, is one of the most common species of fecal coliform bacteria. It is a natural bacterium that extensively lives in the large intestines in human and warm-blooded animals. *E. coli* is used as an indicator organism to detect fecal contamination in the water supply. We can assume that if sewage is found in water, some pathogenic bacteria may also present.

Enterococci are another type of fecal bacteria. They are a subgroup of fecal streptococcus group. Enterococci can survive in salt water, so they use to indicate some organism for coastal beaches and shellfish harvesting areas (47).

2.4.4.4 Reservoir and catchment areas

Water-borne pathogen and bacterial contamination in water resources and reservoirs are significant quality concerns of water supply. There is many extensive implementing for perceptions of bacterial contamination in freshwater worldwide including lakes, rivers, groundwater, and reservoirs. Microbiological investigations of water reservoirs are regularly not taken during heavy rainfall and flooding events. Because this situation increases turbidity which frequently interrupts the interpretation of microbial contamination.

There are several types of bacteria in the natural reservoirs and catchment areas including *Escherichia coli*, coliform, fecal streptococcal, and *Clostridium perfringens.* It may increase the number of colonies during rainfall and runoff events. If the relevant parasite persists in some catchment areas, we can imply the increases in concentrations of *Giardia* and *Cryptosporidium.* Total microbial concentration in the water reservoir can cause the disease in drinking and utilizing water (48).

2.5 Risk assessment approach to flooding

Risk assessment is an essential tool of the conceptual framework and utilize in water-related WHO guidelines, for example, water safety management and sanitary investigation. These risk assessment approaches give the main information, requirement, benefit, and limitation of each method.

Especially in a drinking-water system, risk assessment is an important part of water safety plans. With the intentional objective of these principles, we would like to identify and evaluate the association between risk and water supply. Moreover, we can find the best step to improve the water system. In order to evaluate the process of systematic risk assessment, we have to explain and identify clearly about health hazards, hazardous events and the adequacy of the controls to prevent contamination.

1. Hazards are pathogens (or microorganisms) or agents (biological, chemical, radiological) that can cause a dangerous impact on people's health who drink or use the water.
2. Hazardous event is an event that causes a hazard to the drinking water or cannot remove it. This can appear in every procedure of the water supply system.
3. The adequacy of the controls to prevent contamination is a measure to prevent these hazards from happening or eliminate these pathogens out of the water system.

2.5.1 The concept of quantitative microbial risk assessment (QMRA)

QMRA (Quantitative Microbial Risk Assessment)

This is a method that uses the best measurements about microbial behavior to identify where they can become a hazard and evaluate the risk that they affect human health. It can be used to estimate the association between health risk and water safety management by applying scientific information with a systematic approach. QMRA is an important framework that uses for quantitative systematic data to explain and predict health outcomes in support of water safety management.

The four-step approach of QMRA as following:

1. Problem formulation is the first step to define the scope and purpose of the risk assessment in order to target each specific risk management question. Within this process can distribute within three topics.

1.1 Hazard identification

Concerning reference pathogens are determined, but not all of the associated human pathogens in a QMRA. We should be selected the important conditions such as related to the exposure pathway, source of drinking water, and the scope and severity of the disease. The results of hazard identification are determined what microorganisms, developed diagnostic tools, know possible transmission routes, and identify the data sources (clinical data, outbreak investigations, experimental and epidemiological studies).

1.2 Identify exposure pathway

Identification of the hazards pathway that transmits to humans. We scope the risk and determine what does the inclusion and exclusion. Specific hazardous events are identified as the situation that can affect the appearance of the hazard include in the assessment to explain risk management objectives.

1.3 Identify health outcome

It depends on the purpose of the assessment which includes infection or measurable outcome of the disease.

2. Exposure assessment:

This step aims to estimate the frequency and magnitude of exposure to pathogens via the pathways and hazardous events defined during the problem formulation. Quantitative information is required, for example, the bacterial concentrations in drinking water supply during normal and incident situations. We need data about the exposure of humans, such as the size and the nature of the exposed population, and how often they are exposed. Exposure assessment consists of these following steps:

2.1 Define the exposure pathways

2.2 Quantify each component of the exposure pathway

2.3 Characterize the exposure

3. Health effects assessment: This step combines the data between identified hazards and the specific study population. Health outcome, the severity of disease, and duration of illness after transmission of the pathogen are included. Moreover, we also access information on the relationship between ingested dose and the probability outcome that affects human's health immediately. We can explain this topic into three components:

3.1 Host characterization (Age, immune status, nutritional status, pregnancy etc.) and Human health effects (duration, severity of illness, secondary transmission)

3.2 Host pathogen profile: This component can separate into two parts. The first is variability (barrier and concentration of pathogens) and the second is sensitivity analysis (identify the important source of variability and uncertainty).

3.3 Dose response assessment: Dose-response is a relationship between exposure and the probability of infection. This can identify and evaluate for the reference hazards. Utilization of this assessment is important because we can find the association between the exposure and evaluated health outcomes. Dose-response consists of two following parts:

3.3.1 The overall probability of illness depends on the occurrence of three conditional probabilities:

- The probability that the organism is ingested. (This is an output from the exposure assessment)
- The probability that the organism can survive and infect human health.
- The probability of the host becoming ill once infected.

3.3.2 The microbial disease process that the dose-response analysis attempts to characterize is dependent on:

- The characteristics of the organism itself
- The susceptibility of the host, such as immunocompromise host
- The characteristics of the food in which the pathogen is carried

4. Risk characterization:

In this step, we combine the information from the exposure assessment and the health effects assessment to generate a quantitative measure of risk (the probability of occurrence and severity of adverse health effects in the exposed population). It is essential to consider consistency when combining the information (same hazards for exposure and health outcome, same population, and same time frame). We should recognize that QMRA does not calculate real disease outcomes, but implements a probability that disease may occur through the water system.

QMRA framework

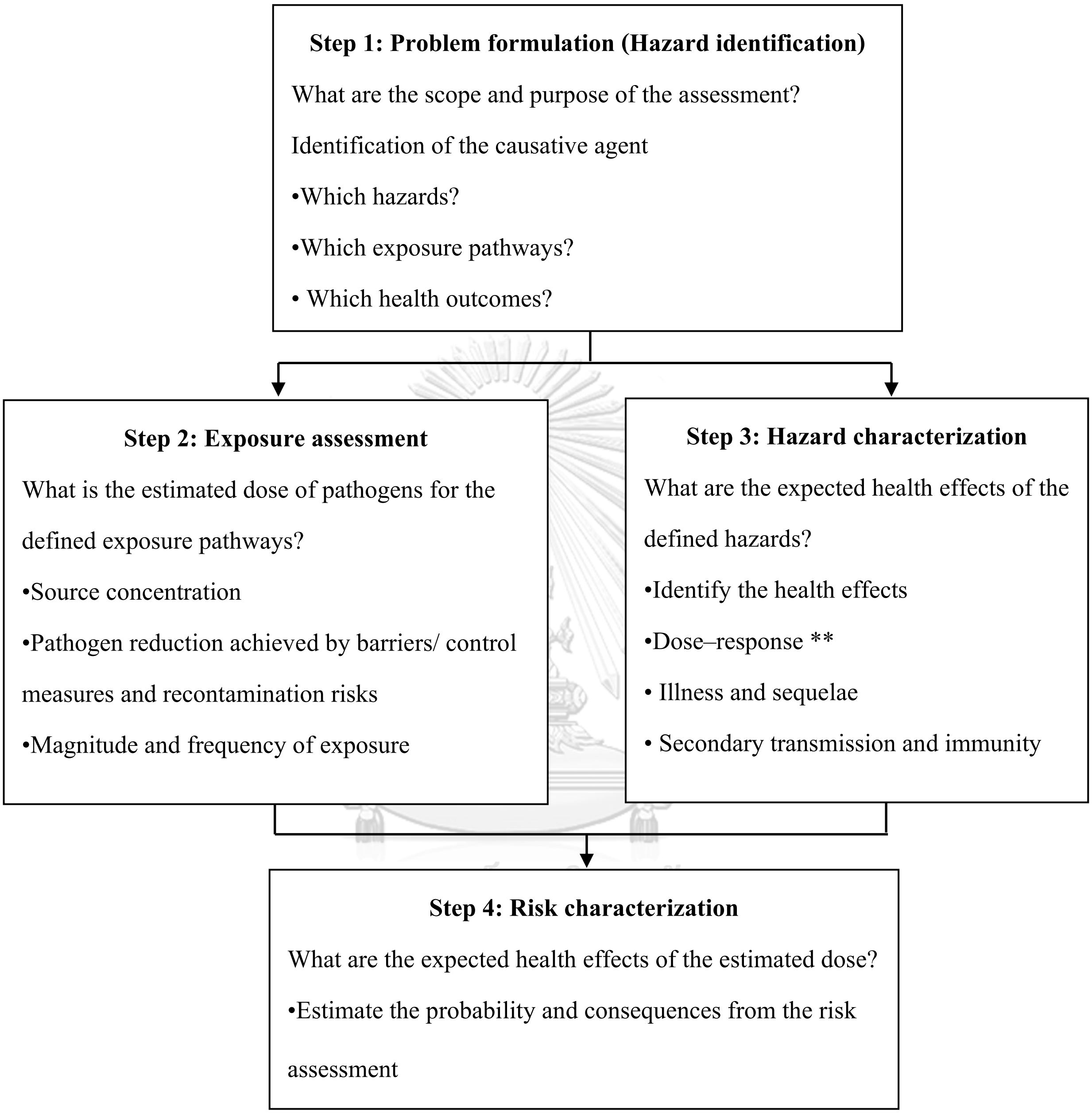


Figure 26 QMRA framework

2.5.2. Escherichia coli

Escherichia coli (E. coli) is a gram-negative bacterium, normally resides in the intestinal tract of people and animals. It is one of the natural important bacteria. However, some kind of *E. coli* are pathogenic and they cause infection in human health through contaminated water or food, for example, acute gastroenteritis. *E. coli* consists of a diverse group of bacteria which have six pathotypes associated with diarrhea and refer to diarrheagenic *E. coli* (49).

Escherichia coli O157: H7 is one serotype of the Shiga toxin-producing types of *E. coli*. It is an important cause of disease, typically foodborne illness, through consumption of contaminated water and raw food. Infection with this type directly causes acute hemorrhagic diarrhea and abdominal cramps. Symptoms of intestinal infection include watery diarrhea, abdominal pain, nausea, vomiting, and fever. More severe cases can lead to bloody diarrhea, dehydration, and turn to renal failure. Especially in people with low immune systems, pregnant women, young children, and older adults tend to increase risk for developing these complications. There are many reports about the cause of deaths in children younger than five years old, in elderly patients, and immunocompromised patients (50).

2.5.3 Flood Management in Thailand including study area

Risk management in water resources is necessary to mitigate damage and the consequences of natural disasters such as flooding. During the seasonal monsoon in Thailand, many provinces have an impact from flooding. Risks assessment in water resources, such as flooding and drought, can mitigate the severe outcomes. Flooding is a natural process that causes widespread damage to infrastructure and human life. Therefore, sustainable water resource development and management can prevent the insufficient water supply and reduce the negative effects of lacking water resources.

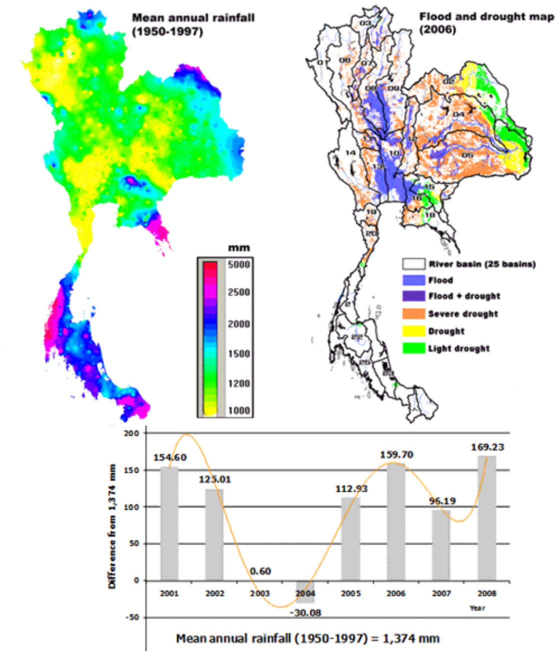


Figure 27 Mean annual rainfall (1950-1997)

The average rainfall in Thailand is more than 1,300 mm per year. There are frequently flooding during the seasonal monsoon (mostly in September to October). Some special areas have to face these conditions every year due to uncertain of monthly rainfall or inadequate management of the water drainage system. This picture shows the distribution of annual rainfall averaged from 1950 to 1997, flood map in 2006, and the recent changes in the amount of annual rainfall in Thailand from 2001 to 2008.

Flood management approach for the sustainable development of water supply by using flood risks to report in the planning process. This assessment can be categorized by the vulnerable area that tends to be flood.

2.5.3.1 Risk Management framework of Water Resources in Thailand

The risk management framework involves collecting information, establishing the context, identifying the risks, assessing the risks, and treating the risks that shows in the picture below. At each step, stakeholders should communicate, analyze and monitor the process and effectiveness of the management framework.

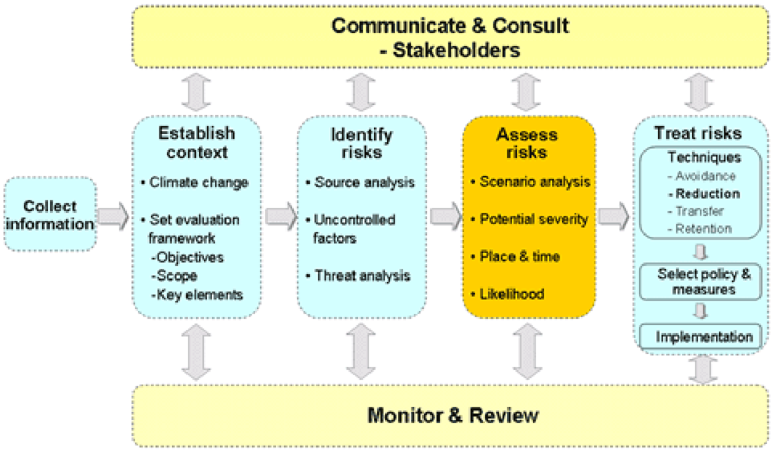


Figure 28 Risk Management framework of Water Resources in Thailand

The main source of risk in water supply is rainfall because we cannot control and measure where, when, and how much it rained. The risk affects serious impacts on economic development, agricultural and industrial sector, and water utilization and consumption in every household. Thailand in 2002, the floodings cause widespread damage in 72 provinces and loss of economic around 13,385 million Baht.

The types of risk analysis consist of the vulnerable areas, the period when the risk is probable to happen, and the severity of outcomes. On the other hand, we focus on the bigger picture including the further evaluation of socioeconomic, and environmental factors.

1. Traditional methods of risk assessment consist of analysis of rainfall, risk map of flooding, and stability of water in demand and supply. This conducts every year with statistical-based. However, it can make some

problems when the flooding occurs over a shorter time. The imbalance in using water between demand and supply also occurs in the seasonal monsoon. The over demand often begins in May and the oversupply increase from September to October.

2. An innovative approach to risk assessment relies on monthly analysis. It is physical-based and estimates for the spatial heterogeneity of a basin. The analysis produces on a sub-basin level. The purpose mitigates the risks by making policy and measure for individual area. The estimation of the monthly water balance in flooding, the water supply exceeds the reservoir or river capacity.

This picture shows the risk reduction framework which consists of macro and micro-management. The context of policy and implementing should follow this structure.

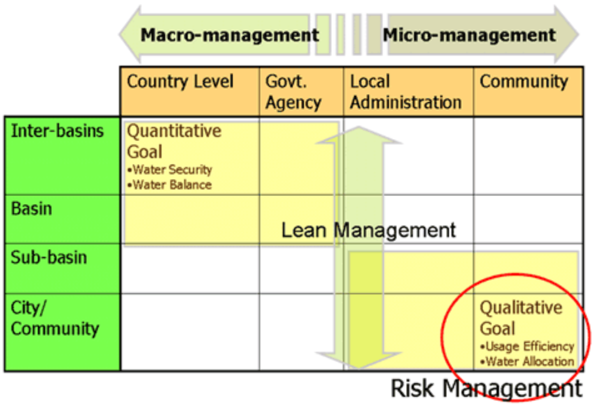


Figure 29 Risk reduction framework

2.5.3.2 Policy making for Risk Management in Thailand

The purpose of macro-management is to handle inter-basin and basin management. This is the responsibility of central and regional government agencies. The target approach includes water supply security and water balance between demand and supply. So, the policies and primary implementing should require the development of the main infrastructure of reservoirs, dams, and water supply systems. The picture describes below.

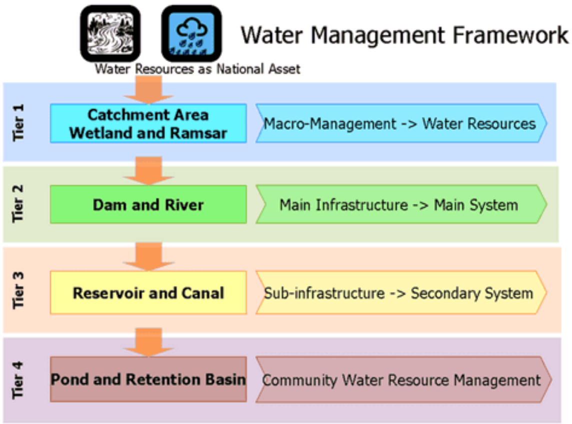


Figure 30 Water management framework [54]

The purpose of micro-management is to develop sub-infrastructure such as community water management and emergency water supply. The local system gives the flexibility and a barrier against flood risks. This should be effective especially in water utilization and consumption. The main stakeholders include local government and agencies. The essential key success is the adaptive ability and intersectoral collaboration in every community (51).

CHAPTER III: Research methodology

Research Design:

This study was a cross-sectional study on the assessment of human health risks from water consumption in flood-prone communities of Nakhon Si Thammarat province, Thailand.

Study period

This study was conducted during February-July 2020.

Study Area:

The study was conducted in Nakhon Si Thammarat province, specifically at Pak Phanang district in Thailand. Nakhon Si Thammarat province is in Southern part of Thailand and comprises of 23 districts or amphoe (Figure 2). The province has been affected by many natural disasters including floods. It is also considered as flood-prone area in Thailand. Geographical characteristics of Nakhon Si Thammrat province are varied according to the area, which are mainly separated into mountainous and plain areas. Both Pak Phanang and Chain Yai districts fall into plain area situated near the Gulf of Thailand. They are the flood-prone districts that have been experienced many flooding events.

Pak Phanang district has approximately 107,631 people and 32,173 registered households (Pak Phanang government office, 2018). It is among the top three districts with highest number population in the province, after Mueang Nakhon Si Thammarat district and Thung Song district (Nakhon Si Thammarat provincial statistical office, 2016). One of the landmarks of Pak Phanang district (and of Nakhon Si Thammarat province) is the elongated peninsula called “Talumphuk”. Chian Yai district is a neighbor of Pak Phanang district. It was a part of Pak Phanang district until February 1937, when it was separated and became a full district. Chian Yai district has about 43,457 people and 14,339 registered households (Nakhon Si Thammarat provincial statistical office, 2016). Both districts are situated in the Pak Phanang river’s catchment area, as the main river of Pak Phanang and Chian Yai districts. These two districts of Nakhon Si Thammarat province are especially prone to flooding during monsoon (Wipulanusat et al., 2009).

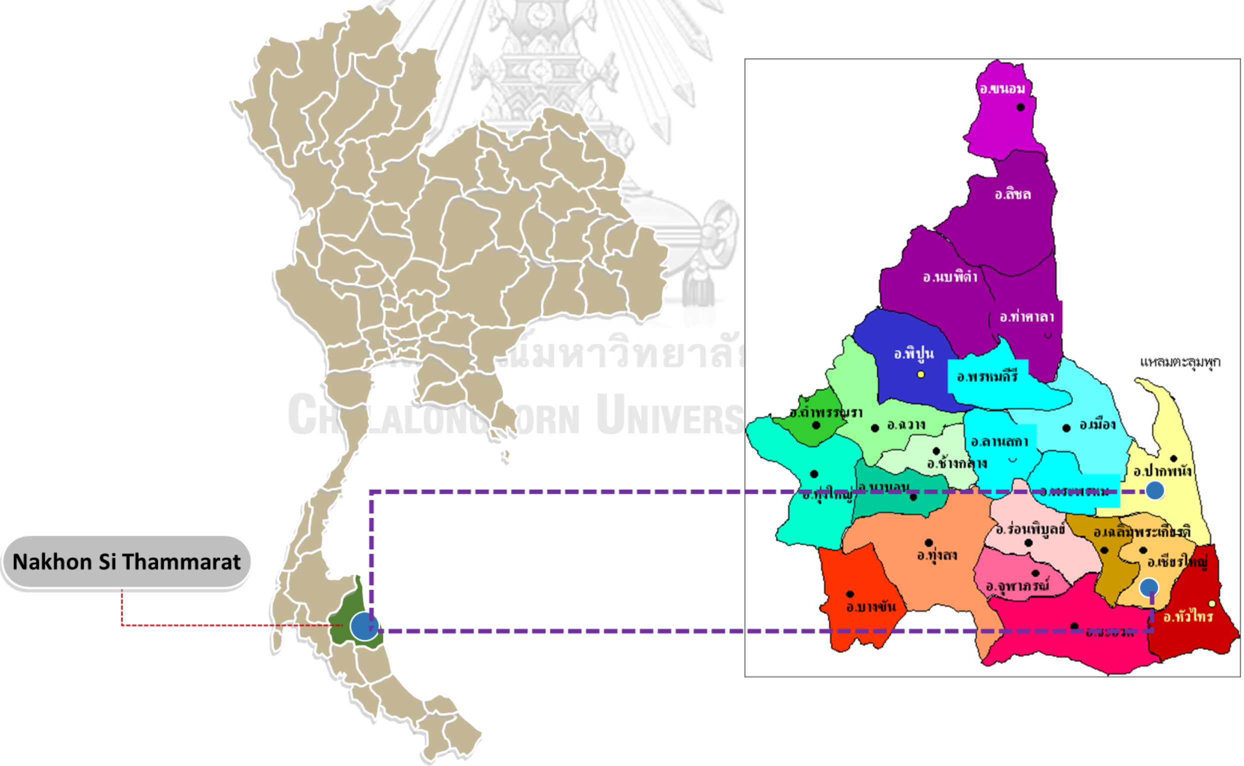


Figure 31 The study area

Study Population:

The study population was the households that had ever experienced floods in the flood-affected communities, which located in Pak Phanang and Chian Yai districts, Nakhon Si Thammarat province, Thailand

Inclusion criteria:

- A household member who lived Pak Phanang district or Chian Yai district, Nakhon Si Thammarat province, Thailand
- Had previous flood experience while living in the mentioned district
- Aged 18 years old and above
- Able to communicate in Thai

Exclusion criteria:

- Unwilling to participate in this study

Sample size:

The sample size of our study was using Taro Yamane (Yamane, 1973) equation with 95% confidence level. The equation of Taro Yamane is shown as follows:

$$n = \frac{N}{1 + N\,(e)^2}$$

Where: n = sample size required

N = number of people in the population

e = allowable error (%)

According to Taro Yamane formula and the Nakhon Si Thammarat provincial statistical data in 2018, Pak Phanang and Chian Yai districts have about 32,173 and 14,339 households, respectively (Nakhon Si Thammarat provincial statistical office, 2016). Therefore, the sample size can be calculated as:

$$n = \frac{(32{,}173 + 14{,}339)}{1 + (32{,}173 + 14{,}339)(0.05)^2}$$

$$n = 382$$

By adding 10% drop out rate, the final sample size of this study would be **420 households**

Sampling technique:

Nakhon Si Thammarat province, Thailand was purposively selected along with Pak Phanang and Chain Yai districts. The province and both districts were selected since they are flood-prone areas with history of many flooding events in the past. After, a random walk sampling technique (Magnani, 1999; Wingfield-Digby, 2010) was applied at the study areas, that was, Pak Phanang and Chian Yai districts (Figure 3). In this study, the primary healthcare center of both districts was selected at the starting location for a random walk sampling. Then, a direction of travel was selected by spinning a pen. The direction that the head of the pen pointing was selected as the direction for traveling. The nearest household closest to the selected primary healthcare center in the direction of travel was selected as the first participant and interview of this study. After the first household, the next nearest household was selected for the second interview and then the next nearest until the targeted sample size was reached.

From the selected households, the head of the household was approached for the interview if he/she fit the inclusion criteria and agreed to participate in the study. However, if he/she did not agree to participate, the presented members who agreed to participate in the study was selected instead.

Furthermore, out of 420 households, water samples from 28 households were collected by purposive selection the house that stored waters for consumption during floods and measure for turbidity. Out of 28 drinking water samples, 12 samples were purposively selected for the assessment of total coliform and *E. coli* contamination.

Sampling frame

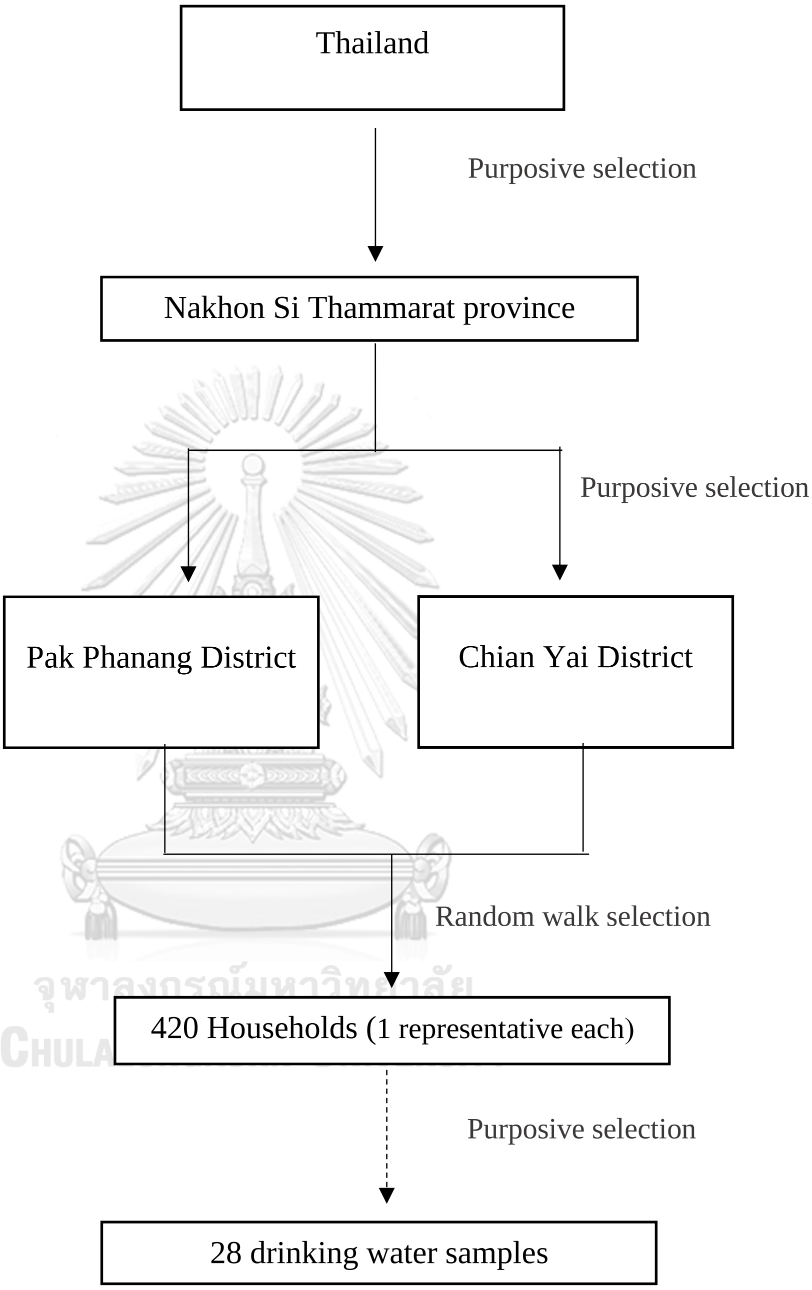


Figure 32 Sampling frame used in this study

Measurement Tools:

In this study, the structured questionnaire was developed for collection of data in the study area. The information on demographic characteristics, and consumption of water during floods among the household in flood-prone communities of Pak Phanang and Chian Yai districts were collected.

Assessment of microbial indicators

For microbial concentration, 3M Petriflim was applied for measuring of total/fecal coliform bacteria (including *E. coli*) concentration from water samples in this study according to the manufacturer instruction (52). The water was sampled from stored rainwater in the households those previously experienced flooding events in Pak Phanang and Chain Yai district in Nakhon Si Thammarat province, Thailand. The stored rainwater was for consumption and utilization during floods.

Assessment of turbidity

The stored rainwater was immediately assessed for turbidity (NTU) using the portable turbidity meter, HACH turbidity meter- model 2100Q, according to the manufacturer instruction (53).

Quantitative Microbial Risk Assessment

Human health risk from water consumption was assessed using the QMRA as follow:

- Hazard identification:

  In this study, *E. coli*, as a fecal indicator, was used to estimate the concentration of the pathogen of interest, namely *Cryptosporidum spp.* contaminated in the water used for consumption according to the previous studies (54). The ratio between *E. coli*: *Cryptosporidum spp.* was 10^5:1.

- Exposure assessment:

  Total amount of collected water consumed for each household was defined as 2 liters per day for adults consumption (55).

  Total amount of collected water consumed for each household was defined as 1.5 liters per day for children consumption (56).

- Dose-response assessment:

  The probability of infection was calculated using the following equation (57):

$$d = N \times V_{con}$$

where:

d = Dose of pathogens consumed during a single exposure (per day)

N = Concentration of pathogen in the water samples (per mL)

V_{con} = Volume of the water sample consumed in a single exposure (mL/day)

A dose-response exponential model (Haas, 1999) was applied for *Cryptosporidium spp.* as shown in the equation below:

$$P_{inf} = 1 - \exp(-rd)$$

Where:

P_{inf} = Probability of infection in a single exposure

r = a parameter of the exponential model

*For adult, r = 0.0042 (57).

d = Dose

- Risk Characterization:

The previous steps including hazard characterization, dose-response, and exposure assessment were incorporated to estimate the human health risk or adverse health outcomes by the following equation (57)

$$P_t = 1 - \left(1 - P_{inf}\right)^t$$

Where:

P_t = The probability of infection (pppy)

t = The number of exposures per year

Later, this study also assumed that it might not necessarily develop the disease when infected with the pathogen of interest; therefore, a disease/infection ratio was used to examine the probability of disease per person per year (pppy) as the following equation:

$$P_d = Kx\, P_t$$

Where:

P_d = probability of disease (pppy)

K = the disease/infection ratio

*The infection ratio of *Cryptosporidum spp.* was 0.3 (Disease/infection ratio) according to the previous study (58).

Data Collection:

Face-to-face interview was conducted by the main researcher and trained research assistants to collecting the questionnaire. Water samples were collected from the household aseptically directly from the sources of water using sterilized bottles. To measuring the microbial concentration, the collected water samples were kept on ice and were tested with 3M Petrifilm. Briefly, 3M Petrifilm was placed on a flat and level surface. The petrifilm cover was lifted, and 1 mL of the sample was pipetted perpendicular to the inoculation surface onto the center of bottom film. Then, the petrifilm cover was slowly dropped to avoid air bubbles and left undisturbed for one minute to permit the gel to form. Later, the petrifilms were incubated at 37 °C. The total coliform and *E. coli* counts were performed after 24 hours and 48 hours of incubation, respectively. In term of turbidity, the collected water samples were immediately assessed for turbidity (NTU). Each sample was measured with repetition three times.

Data Analysis:

Information from the questionnaire on sources of demographic characteristics, sources of water consumption, and experience of illnesses during floods were applied in the QMRA framework. For analysis of demographic characteristics sources of water consumption, and experience of illnesses during floods, descriptive statistics such as frequency, percentage, mean and standard deviation were applied.

Validity

The content validity was done to confirm clarity, accuracy and appropriateness of the questionnaire. Three experts in the related fields were consulted to evaluate the content of the questionnaire by Item-Objective Congruence (IOC) Index. The IOC was assessed on the basis of a scale as: +1 indicating the agreement between item and the study variable, 0 indicating undecided and -1 denoting disagreement between item and the study variable. IOC of ≥ 0.7 was accepted. The calculation of IOC was as follow: IOC = $Sum\ \frac{R}{n}$

Where, R = total score of the i-th item,

n = number of experts

Reliability

The reliability of the questionnaire was done by re-testing the questionnaire. The researcher was conducted the pre-test in 30 participants in a community that had experienced flood in the past. The internal consistency was tested by using Cronbach's Alpha coefficient. The alpha value of 0.7-0.9 was considered as an indication of good internal consistency (Tavakol & Dennick, 2011).

Ethical Consideration:

The study was conducted after obtaining an ethical approval from Chulalongkorn University (COA No. 148/2563), under the research topic in the title of “An action plan for health relief measures from water utilization during flood through a multidisciplinary approach). Later, the researcher contacted the local authorities responsible to and involved in flooding actions for reaching and accessing the affected communities and the secondary data. For household survey, respondents in the study were asked for their voluntarily and willingness to participate in the study. The respondent was informed that they could refuse to participate in the study at any time. The anonymity and confidentiality of respondent was maintained by using coding in the questionnaire instead of the respondent’s name.

CHAPTER IV:

RESULTS AND DISCUSSION

4.1 General characteristics of study population

The questionnaire surveys were conducted among 425 participants (households) in the flood-affected communities, which located in Pak Phanang and Chian Yai districts, Nakhon Si Thammarat province, Thailand. Table 1 presents the general characteristics of participants which consisted of gender, age, educational level, occupation, income, and number of household members. The majority of participants were female 294 people (69.5%). Most of participants aged between 46-60 years old (36.7%) and more than 60 years old (36.5%). Participants mostly had educated in primary school level, which accounted of 65.2%. The was a variety of occupation in both districts, but most of them were farmers (20.3%). However, about 21% of the participants were “fishermen or had other occupations” (21.0%). The average of income per household was 7305.13 ± 7016.56 Baht per month. Moreover, most of the households had about 3-4 family members/household (46.1%).

Table 1 General characteristics of study population

	Number	Percentage
Gender (n=425)		
Male	129	30.5
Female	294	69.5
Age (n=425)		
<30 year	17	4.0
30 – 45 year	97	22.8
46 – 60 year	156	36.7
>60 year	155	36.5
Educational level (n=425)		
Below primary school	42	9.9
Primary school	276	65.2
Secondary school	82	19.4
Diploma	10	2.4
Bachelor's degree or higher	13	3.1
Occupation (n=425)		
Farmer	86	20.3
Merchant	61	14.4
General career	68	16.1
Housewife	66	15.6
Private employees	2	0.5
Government officer	5	1.2
Unemployed	46	10.9
Other/ fisherman	89	21.0
Average income per household (Baht) (n=425)	7305.13 ± 7016.56	
Number of household members (n=425)		
1 – 2	100	23.5
3 – 4	196	46.1
>4	129	30.4

4.2 Sources of water consumption during floods

Sources of water for consumption during floods were showed in Table 2. The sources of water were separated into 7 types including Provincial Waterworks Authority, Municipal Waterworks Authority, stored water, stagnant water, free water distributed by the government/local authorities, bottled water with FDA approval, and bottled water without FDA approval. The data revealed that during floods, free bottle water from the government was the main source of water for consumption (51.06%), followed by the stored water within their households (32.24%).

Table 2 Sources of water for consumption during floods (n=425)

Water sources	**Number**	**Percentage (%)**
Provincial waterworks authority	44	10.35
Municipal waterworks authority	42	9.88
Stored water	**137**	**32.24**
Stagnant water	5	1.18
Free bottle water	217	51.06
Bottle water with FDA	123	28.94
Bottle water without FDA	80	18.82

4.3 Situation of water consumption during floods

The situation of water consumption during floods in the study area was presented in Table 3. It was found that most of the participants had adequate water for consumption (84.9%), with only 15% of all participants had inadequate water for consumption during flooding events.

Table 3 Situation of water consumption during floods

	Number	Percentage
The amount of water consumption during flood (n = 424: 99.67%)		
Adequate	360	84.91
Inadequate	64	15.09

Water shortage was one of the important problems during flooding events. Even though the results from the survey indicated that most participants had enough water for consumption, the challenging was on the cleanliness and safety from the water sources. We assumed that the free bottle waters distributed by government or local authorities were safe for drinking. Therefore, the second highest source of water for consumption during floods, which was stored water, was examined instead.

From the observation during the survey, it was found that most of the participants stored the rainwater in the big earthen jar for drinking and cooking activities during flooding events (Figure 35). Nonetheless, the collected rainwater might contaminate with pathogens during the processes of water collection. Therefore, water quality measurements via assessment of turbidity and microbial indicator to detect bacterial contamination, especially *E. coli* as a fecal indicator, was very important to ensure the safety stored water for consumption purpose.

Figure 33 Stored rainwater in a big earthen jar

4.4 Turbidity

From a total of 28 water samples, the results of turbidity assessment were presented in Figure 36. Majority of the samples had lower than 1 NTU, with the lowest of 0.15 NTU from sample 19. The highest turbidity found in this study was from sample 25 at 5. 36 NTU. In addition, it was found that only one out of 28 samples had more than 5 NTU. The result suggested in term of turbidity, almost all the stored water samples passed the WHO's standard for drinking water, for not exceeding 5 NTU.

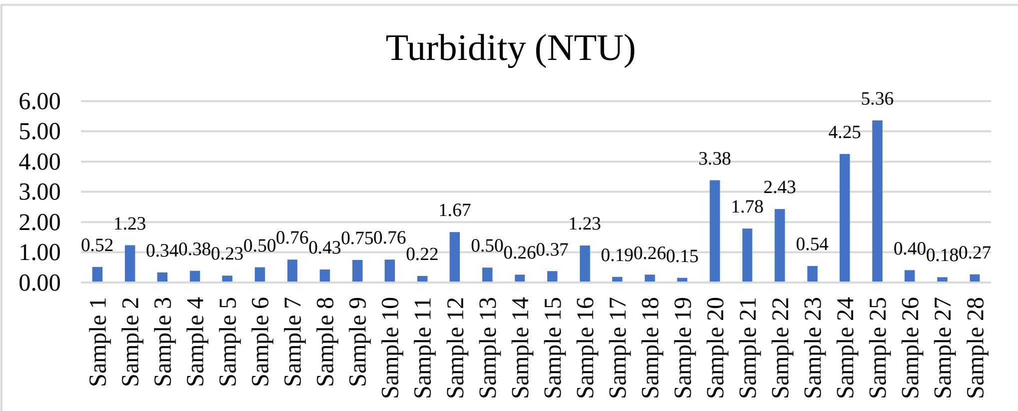


Figure 34 Turbidity (NTU) of water samples for consumption

Discussion of turbidity

Turbidity is a visible measurement of water clarity and quality. Water with turbidity will show opaque, cloudy, or colored. Measurements of water turbidity are usually used as an indicator of water quality and calculated total suspended solids in water. Although turbidity and total suspended solids are related, turbidity is not a correct estimation of the total suspended materials in water. Turbidity is regularly applied as changes in the concentration of the total suspended substance in water. Total suspended solids (TSS) are particles which larger than 2 microns in the water column. Anything smaller than 2 microns is called a dissolved solid. Most suspended solids are formed inorganic materials and bacteria (59).

Figure 35 The muddy appearance of the river shows high turbidity.

There are various causes of water turbidity, including suspended sediment such as sand or mud, organic and inorganic substances such as algae. Turbidity is the visible indicators of water quality. Clearwater is regularly recognized as an indicator of good water. These suspended solid substances are from soil erosion, water runoff, and contamination. It can be possible for rainwater or some rivers with naturally high levels of suspended solids (60).

Turbid stored rainwater from contamination cause is considerably important for human health concern when drinking or cooking. Pollutants such as heavy metals and pathogens, especially bacteria, can connect to dissolved particles, so it will increase water turbid and decrease water quality at the same time. These bacteria and heavy metals can affect both aquatic organisms and human health when drinking contaminated water because turbid water is not easy to purify. For other pathogens such as cholera, cryptosporidiosis, and giardiasis can provide waterborne diseases (61).

Figure 36 Both organic and inorganic particles can perform the suspended solids concentration (61).

Since water turbidity is generally utilized as a representative measure for the risk of microbial contamination and the effectiveness of the treatment of public drinking water. Many studies have revealed a significant correlation between the level of turbidity and microbial contamination of water. Higher turbidity levels are regularly associated with higher levels of pathogenic bacterial contamination. Inorganic or organic suspended solid substances are normally the cause of turbidity in rainwater (62, 63). It was reported that the high level of turbidity in rainwater were the results from physical, chemical, and/or biological pollutants such as bird waste, chemical used for coating roof tiles, and microorganisms in air, respectively (64, 65).

4.5 Microbial indicator

Figure 39 presents microbial contamination of indicator bacteria, namely total coliform and *E. coli*, from the stored water samples collected from Pak Phanang and Chian Yai districts, Nakhon Si Thammarat province. However, please note that the sample 13 to sample 28 were not measure for the contamination since the storage period of the samples after the time of collection were far exceed recommendation of laboratory protocol. The highest concentration of total coliform bacteria was found in the sample 10 from Pak Phanang district after incubation period at 235 CFU/mL. Whereas the lowest concentration of total coliform bacteria was found in the samples from Chian Yai district after the incubation at 5 CFU/mL. From the study, it was found that the average of total coliform bacteria concentrations was greater in the samples from Pak Phanang district than Chian Yai district. Interestingly, only two collected samples were contaminated with *E. coli* with 1 and 2 CFU/mL.

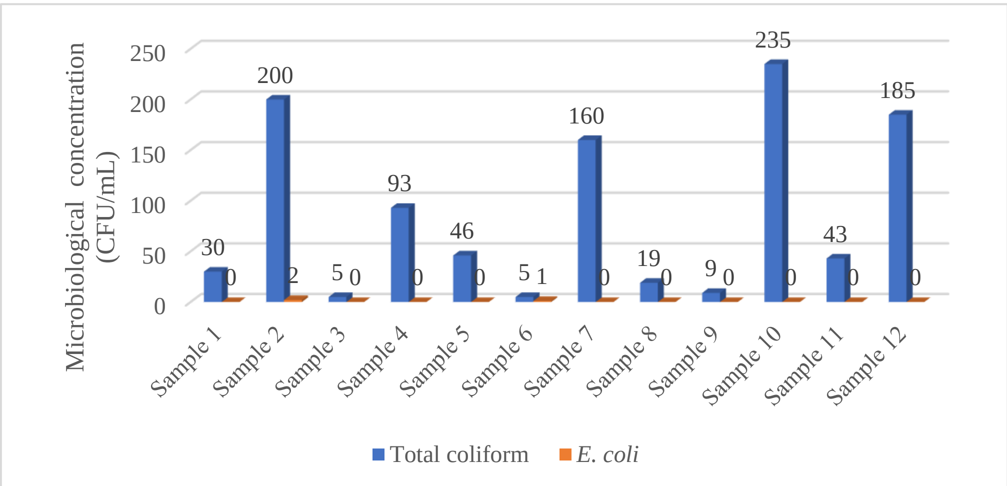


Figure 37 Microbiological contamination in the stored water samples

Discussion of microbial indicator

Ensuring the microbial safety for drinking water depends on various factors such as an adequate water treatment process, an appropriate barrier, and a clear pathway from the storage to the consumer. The process of preventing and removing the pathogens in water resources is necessary before utilization. As usual, the highest microbial risks are associated with drinking or cooking with contaminated water, especially with humans or animal feces, because it is a source of pathogenic bacteria like *E. coli*. Faecalis acquired *E. coli* are the major concerns for human health targets of microbial safety. Bacterial concentration can increase the trigger outbreaks of waterborne disease in short-term periods. When the bacterial contamination is exposed and evaluated, many people get infected from drinking water (66).

For microbial indicator like fecal *E. coli* is expected to analyze water quality. Escherichia coli presents certainly evidence of current fecal contamination and should not be existing in drinking water. Moreover, rainfall can raise the levels of microbial contamination in waters, and waterborne outbreaks often occur after rainfall.

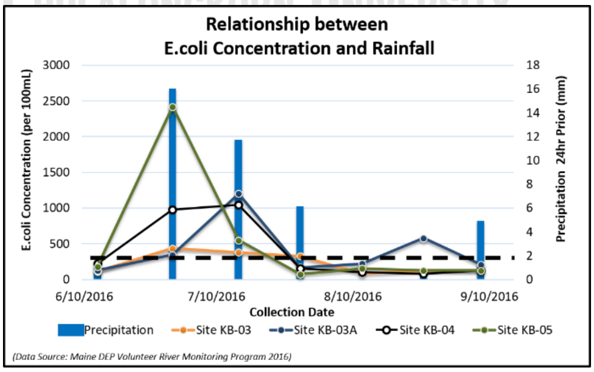


Figure 38 The concentration of E. coli in the river during the significant rainfall

Stored water in the big earthen jar is commonly used in every household in the rural area for drinking and cooking in case of the water shortage during floods. In this study, part of the water samples was distributed from the runoff of rainwater, typically from rooftops, and collected via pipes or roof tiles. However, for some households, the stored rainwater was collected through water tap that connected to the earthen jar or using a clean water bowl (The picture shows in figure 35). Although rainwater was originally approximately free from pollutants, the quality may consequently decline during the setting of pathway storage in each household. Fecal droppings from birds and insects on roofs tile and tanks can contaminate stored rainwater. So, proper cleaning of roof surfaces and a collected pathway should be applied. Materials used in the water storage should be accepted for drinking and cooking and make sure that it will not be contaminants or change the tasting or coloring. Because of the lightly acidic in rainwater, it can dissolve some metals of the storage. Most solid roof materials are proper for collecting rainwater, but some coatings are generally not recommended when it leaches dangerous substances or cause taste or color problems. Poor hygiene from storage containers or when drinking can make a human health concern (67) .

The major problem in public health aspects is the consumption of contaminated water with feces. Infectious diseases caused by pathogenic bacteria, especially *E. coli*, are the most common and extensive human health risks associated with contaminated drinking water. The public health responsibility is defined by the severity and incidence of the diseases from each pathogen. The outbreak with the waterborne disease is associated with poor treatment of water supplies. This situation has associated with the inappropriate treatment of the water processor supplies and inadequate control of drinking water administration. Some pathogens can be spread through contaminated water that results in severe health problems and life-threatening diseases. For example, infected gastroenteritis caused by Shigella spp. and pathogenic *E. coli*.

Although *E. coli* exists in the intestinal tract of humans and animals as normal flora and does no harm, some serotype can cause severe health problems such as enterotoxigenic *E. coli* or known as ETEC. EHEC serotypes, especially *E. coli* O157: H7, cause infected bloody diarrhea and hemorrhagic enterocolitis. Approximately 5% can develop a hemolytic uremic syndrome that results in acute renal failure respectively. The infectivity of these strains is extensively higher than other strains (68).

From the interview and observation, we found that the process of collecting rainwater might contribute to the different of the turbidity and microbial concentration between the samples from two districts. In Chian Yai district, rainwater was transported and collected through pipe (some are polyvinyl chloride pipe). Whereas in Pak Phanang district, rainwater was transported and collected using old roof tiles as shown in Figure 35. Nevertheless, since drinking water should have a turbidity of 5 NTU or less, and no *E. coli* detected as of the guidelines by World Health Organization, all samples could be considered as passing WHO guidelines for water intended for drinking (69, 70).

In addition, we also noticed that the samples with high turbidity (NTU), also had higher total coliform bacterial concentration. Therefore, there might be some correlation between turbidity and total coliform bacterial concentration. Comparable finding from previous study indicated that turbidity was significantly correlated with the concentration of *E. coli* and *Enterococci* spp (71).

QMRA

Hazard identification

According to the interview with the community, the study identified that the problem with stored drinking water could be from the contaminations during the water collection processes. Since old roof tiles were frequently use for collecting rainwater from the rooftop into an earthen jar within the study community, there was a possibility of microbiological contaminations from animal waste such as bird feces in the stored water. Therefore, *Cryptosporidium* was selected as the pathogen of interest in this study. It is a protozoan parasite which affects both human and animal. This parasite normally infects the lining cells of the epithelium in the digestive tract resulting in a diarrhea in the infected individuals. The disease caused by this parasite is called cryptosporidiosis with the symptoms of watery diarrhea, stomach pain, nausea, vomiting and fever. *Cryptosporidium* is commonly found in soil and water or contaminated in the feces of infected individuals. Ingestion of the oocyst is the main cause of the disease. Therefore, without proper hand hygiene, the parasite can be spread from dirty hands to other people. The incubation period of the disease is about 7 days and can range from 2 to 10 days, with the disease duration of 6 to 9 days. All age can be affected but children, elder, and immunocompromised persons are most susceptible (72) (73) .

Exposure assessment

The study aimed to estimate the contamination of *Cryptosporidium* from the samples by estimation from ration of *E. coli*: *Cryptosporidium.* The first step was to determine the concentration of the *E. coli* contamination from the samples. The study found that there was 200 CFU/100 mL in the stored water sample (by selected sample with the highest of *E. coli* contamination). This study considered route of exposure as ingestion of stored water and assumed the water consumption as followed:

- For adult, we considered 2000 mL/ person/ day.
- For children, we considered 1500 mL/ person/ day.

according to the *E. coli*: *Cryptosporidium* ratio, it was estimated that there was 0.02 oocyst per one liter of stored water (55).

Dose-Response assessment

Exponential model was assumed as the best fit model for dose-response relations of *Cryptosporidium* infection. Firstly, dose of pathogens consumed for a single exposure, which was one day, was calculated according to the equation mentioned in chapter 3 under the section of dose-response assessment.

Since the study assumed that 2 liters of water was consumed per day in adult; therefore, the oocysts consumed per day was 0.04 oocyst per day. Following this result, dose-response relation was determined using exponential model according to the equation mentioned in chapter 3 under the section of dose-response assessment. Probability of infection in a single exposure for adults was calculated as:

$$P_{inf} = 1 - \exp(-0.0042\ x\ 0.04)$$

Therefore, probability of infection in a single exposure for adults was 0.000168.

For children, we assumed that 1.5 liters of water was consumed per day; therefore, the oocysts consumed per day was 0.03 oocyst per day. Following this result, dose-response relation was determined using exponential model according to the equation mentioned in chapter 3 under the section of dose-response assessment. Probability of infection in a single exposure for adults was calculated as:

$$P_{inf} = 1 - \exp(-0.0042\ x\ 0.03)$$

Therefore, probability of infection in a single exposure for adults was 0.000126.

Risk characterization

In adult:

The probability of infection pppy was calculated as:

P_t =1-(1-0.000168)^{158}

* 158 days was selected because it was the longest duration of flooding in Thailand, which happened in 2011/2012 (74).

Therefore, the probability of infection pppy was 0.026195

Then the study assumed that the infection might not necessarily cause the disease; therefore, the probability of disease pppy was calculated as:

P_d = 0.3 x 0.026195

Therefore, the probability of disease pppy was 0.007858 or 7.858 x 10^{-3}

In children:

The probability of infection pppy was calculated as:

P_t =1-(1-0.000126)^{158}

* 158 days was selected because it was the longest duration of flooding in Thailand, which happened in 2011/2012 (74).

Therefore, the probability of infection pppy was 0.019712

Then the study assumed that the infection might not necessarily cause the disease; therefore, the probability of disease pppy was calculated as:

P_d = 0.3 x 0.019712

Therefore, the probability of disease pppy was 0.005914 or 5.914 x 10^{-3}

In this study, the QMRA was conducted to examine the probability of disease pppy using *E. coli* as a fecal indicator to estimate the contamination of *Cryptosporidium* oocysts. This was because it had been previously demonstrated the positive relation between *Cryptosporidium* and *E. coli* (75). Therefore, *E. coli* was selected as the indicator in this study. From the results, a disease risk of 10^{-3} per person per year indicated that 0.1% of the people in the study area would get infected with the disease annually from drinking the stored water. Additionally, according to guidelines from WHO (76), it stated that the tolerate risk of waterborne disease derived from drinking water was also as 10^{-3} per person per year.

CHAPTER V:

CONCLUSION

A cross-sectional study was performed for household survey using a questionnaire with a face-to-face interview to determine the general characteristics and water consumptions during flooding events in flood-prone communities, Pak Phanang and Chian Yai district, Nakhon Si Thammarat province, Thailand between February-July 2020. A total of 425 households were interviewed in this study. In conclusion, majority of the participants were female 2 (69.5%), and two third of the participants aged 46 years old and above. The average of income per household in the study area was 7305.13 ± 7016.56 Baht per month. The results indicated that the main sources of water for consumption during flooding events were free bottle water from the government (51.06%), and stored water in their own houses (32.24%). Moreover, the study found that almost 85% of all participants had enough drinking water during floods.

From the survey, it was found that the stored water was typically collected from the runoff of rainwater and collected via roof tiles or pipes or through water tap that connected to the earthen jar or using a clean water bowl. The community use the water for drinking and cooking during floods from the water shortage. Therefore, this study also collected 28 stored water samples to serve two main purposes, which were 1) to determine the water quality through turbidity and microbial indicator (Total coliform bacteria and *E. coli*); 2) to estimate the health risk from consumption of stored water using QMRA. The study used *E. coli* which is a fecal indicator to estimate the presence of *Cryptosporidium* oocysts in the water samples. In term of water quality, the results show that 27 out of 28 water samples passed the turbidity standard from WHO for drinking water (≤ 5NTU). Whereas, the total coliform bacteria found from 12 samples ranging from 5 CFU/mL to 235 CFU/mL. In general, the samples from Pak Phanang district showed higher concentration of total coliform bacteria compared to samples from Chian Yai district. In addition, only two samples had *E. coli* contamination at 1 and 2 CFU/mL. However, WHO's standard for drinking water, there should be no *E. coli* presence in the water.

QMRA is one of the best methods that use for measurements about microbial behavior to identify where they can become a hazard and evaluate the risk that they affect human health. It can be used to estimate the association between health risk and water safety management by applying scientific information with a systematic approach. Four steps approach of QMRA consist of hazard identification, exposure assessment, dose-response assessment, and risk characterization.

In this study, the QMRA was conducted to examine the probability of disease pppy using *E. coli* as a fecal indicator to estimate the contamination of *Cryptosporidium* oocysts. For hazard identification, we selected *Cryptosporidium* as the pathogen of interest. It commonly found in soil and water or contaminated in the feces that infected human health and caused watery diarrhea. For exposure assessment, we used a ratio of *E. coli*:*Cryptosporidium* to estimate the contamination of *Cryptosporidium* oocysts from the samples. The exponential model was considered as the best model for dose-response relations of *Cryptosporidium* infection. The route of exposure was ingestion of drinking water, which assumed to be 2L per person per day in adults and 1.5L per person per day in children. From the results, it was estimated that there was 0.02 oocyst per one liter of stored water. From the dose-response relation, the study found that probability of infection with *Cryptosporidium* oocysts in a single exposure for adults was 0.000168 and 0.000126 for children. In conclusion, after performing risk characterization the study found that the probability of disease per person per year was 0.007858 or 7.858 x 10^{-3} in adults and 0.005914 or 5.914 x 10^{-3} in children. From the results, a disease risk of 10^{-3} per person per year indicated that 0.1% of the people in the study area would get infected with the disease annually from drinking the stored water.

Further study should be conducted to directly assess the *Cryptosporidium* oocysts contamination in stored water within the community for better estimation of QMRA. In addition, simple water treatment protocol for drinking/cooking water may be useful for the flood-prone communities in order to reduce the health risk from waterborne diseases during flooding events.

Recommendations

1. The infectivity of *Cryptosporidium* is lost within 60 seconds when the temperatures over 72°C or maintain at least 64°C for 2 minutes {EPA, March 2001 #80}. Therefore, boiling stored water before consumption can reduce the risk of infection directly. Another way is to apply a large surface but shallow container to allow the UV light shining thoroughly.

2. Since *Cryptosporidium* can be found in bird feces, cleaning the roof tile, pipe, and water collecting system is important to decrease these parasites' contamination.

3. In the public health aspect, educating in proper hand hygiene and using a clean water bowl can reduce the chance of *Cryptosporidium* contamination in drinking stored water. Moreover, an active surveillance system for cryptosporidiosis intends to collect health information and beware of the outbreaks of water-borne disease in the flood-prone community effectively.

Limitations

1. This study was a cross-sectional study. Therefore, the causal relationship could not be determined.
2. There might be a recall bias from asking the participants to recall the previous experiences during floods by using the questionnaire.
3. The surveys in this study only conduct within two districts in Nakhon Si Thammarat province; therefore, the study could not be generalized to the whole population.
4. This study applied single-point estimates of risk instead of multiple descriptors; therefore, there were little information about uncertainty and variability on the risk estimate.

REFERENCES

APPENDIX II

QUESTIONNAIRE

จุฬาลงกรณ์มหาวิทยาลัย

CHULALONGKORN UNIVERSITY

แบบสอบถาม

โครงการวิจัย แผนปฏิบัติการเพื่อบรรเทาผลกระทบต่อสุขภาพจากการอุปโภคบริโภคน้ำในกรณีอุทกภัย – การวิจัยเชิงบูรณาการ

โดย ภาควิชาวิศวกรรมสิ่งแวดล้อม คณะวิศวกรรมศาสตร์ และวิทยาลัยวิทยาศาสตร์สาธารณสุข จุฬาลงกรณ์มหาวิทยาลัย และคณะสาธารณสุขศาสตร์ มหาวิทยาลัยวลัยลักษณ์

แบบสอบถามนี้เป็นส่วนหนึ่งของของโครงการการศึกษาแผนปฏิบัติการเพื่อบรรเทาผลกระทบต่อสุขภาพจากการอุปโภคบริโภคน้ำในกรณีอุทกภัย – การวิจัยเชิงบูรณาการ โดยมีวัตถุประสงค์เพื่อระบุช่องว่างของแผนปฏิบัติการที่ส่งผลกระทบต่อสุขภาพจากการอุปโภคบริโภคน้ำในกรณีอุทกภัย *ผลการสำรวจในครั้งนี้จะเป็นประโยชน์ในการให้ข้อเสนอแนะจากภาคประชาชนต่อแผนปฏิบัติการเพื่อบรรเทาผลกระทบต่อสุขภาพจากการอุปโภคบริโภคน้ำในกรณีอุทกภัยของภาครัฐ และพัฒนาแนวทางการสร้างแผนปฏิบัติการที่เหมาะสมของประเทศไทยต่อไป*

แบบสอบถามนี้แบ่งออกเป็น 5 ส่วน ดังนี้ *(แบบสอบถามนี้ใช้เวลาประมาณ 20-30 นาที)*

ส่วนที่ 1 คุณลักษณะทั่วไปของผู้ตอบแบบสอบถาม

ส่วนที่ 2 ผลกระทบทางด้านสุขภาพและการได้รับความช่วยเหลือจากภาครัฐระหว่างภาวะอุทกภัย

ส่วนที่ 3 สภาพปัจจุบันและสภาพพึงประสงค์ของการจัดการด้านน้ำอุปโภคบริโภค

ส่วนที่ 4 ความเห็นเกี่ยวกับความอ่อนไหวต่อน้ำท่วม

ส่วนที่ 5 สภาวะป่วยทางจิตใจเมื่อเผชิญกับเหตุการณ์ที่กระทบกระเทือนจิตใจอย่างร้ายแรง

***อุทกภัย คือ เหตุการณ์ที่น้ำท่วมพื้นดินสูงกว่าระดับปกติ ซึ่งอาจจะเกิดได้จากหลายสาเหตุ ได้แก่ ปริมาณน้ำฝนมากจนทำให้มีปริมาณน้ำส่วนเกินมาเพิ่มเติมปริมาณน้ำผิวดินที่มีอยู่ในสภาพปกติ จนเกินขีดความสามารถการระบายน้ำของแม่น้ำ ลำคลอง และมีสาเหตุมาจากการกระทำของมนุษย์*

ส่วนที่ 1 คุณลักษณะทั่วไปของผู้ตอบแบบสอบถาม

1. เพศ ☐ ชาย ☐ หญิง
2. อายุ ....ปี
3. น้ำหนัก.................................กิโลกรัม
4. ส่วนสูง..................................เซนติเมตร
5. ระดับการศึกษาสูงสุดของสมาชิกในครัวเรือนของท่าน

   ☐ ต่ำกว่าประถมศึกษา ☐ ประถมศึกษา ☐ มัธยมศึกษา

   ☐ อนุปริญญา / ปวส ☐ ปริญญาตรีหรือสูงกว่า
6. อาชีพปัจจุบัน

   ☐ เกษตรกร ☐ ค้าขาย ☐ รับจ้าง

   ☐ แม่บ้าน/พ่อบ้าน ☐ พนักงานเอกชน ☐ รับราชการ

   ☐ ว่างงาน ☐ อื่นๆ (โปรดระบุ..)
7. รายได้เฉลี่ยรายเดือน ....บาท
8. หัวหน้าครอบครัวคือ.............

   ☐ บิดาและ/หรือ มารดา (แต่งงาน/อยู่ด้วยกัน) ☐ พ่อเลี้ยงเดี่ยว

   ☐ แม่เลี้ยงเดี่ยว ☐ บุคคลทุพพลภาพ/พิการ

   ☐ อายุมากกว่า 60 ปี ☐ อายุต่ำกว่า 18 ปี
9. จำนวนสมาชิกในครัวเรือนของท่านทั้งหมดมีจำนวน..............................คน (รวมตัวท่านเอง)
10. สมาชิกเพศชายและเพศหญิงในครัวเรือนของท่านมีจำนวน:

สมาชิกเพศชาย <u>ใน</u> <u>แต่ละช่วงอายุ (ปี)</u>	**จำนวน (คน)**				
0 - 4 ปี	☐ ไม่มี	☐ 1 คน	☐ 2 คน	☐ 3 คน	มากกว่า 3 โปรดระบุ..............คน
5- 17 ปี	☐ ไม่มี	☐ 1 คน	☐ 2 คน	☐ 3 คน	มากกว่า 3 โปรดระบุ..............คน
18-54 ปี	☐ ไม่มี	☐ 1 คน	☐ 2 คน	☐ 3 คน	มากกว่า 3 โปรดระบุ..............คน
มากกว่า 55 ปี	☐ ไม่มี	☐ 1 คน	☐ 2 คน	☐ 3 คน	มากกว่า 3 โปรดระบุ..............คน

สมาชิกในครอบครัวที่ป่วยทางกายหรือทางจิต	☐ ไม่มี	☐ 1 คน	☐ 2 คน	☐ 3 คน	มากกว่า 3 โปรดระบุ..............คน
สมาชิกเพศหญิง <u>**ในแต่ละช่วงอายุ (ปี)**</u>	**จำนวน (คน)**				
0 - 4 ปี	☐ ไม่มี	☐ 1 คน	☐ 2 คน	☐ 3 คน	มากกว่า 3 โปรดระบุ ....คน
5- 17 ปี	☐ ไม่มี	☐ 1 คน	☐ 2 คน	☐ 3 คน	มากกว่า 3 โปรดระบุ ....คน
18-54 ปี	☐ ไม่มี	☐ 1 คน	☐ 2 คน	☐ 3 คน	มากกว่า 3 โปรดระบุ ....คน
มากกว่า 55 ปี	☐ ไม่มี	☐ 1 คน	☐ 2 คน	☐ 3 คน	มากกว่า 3 โปรดระบุ ....คน
สมาชิกในครอบครัวที่ป่วยทางกาย หรือมีโรคประจำตัว	☐ ไม่มี	☐ 1 คน	☐ 2 คน	☐ 3 คน	มากกว่า 3 โปรดระบุ ....คน
สมาชิกในครอบครัวที่ป่วยทางจิต	☐ ไม่มี	☐ 1 คน	☐ 2 คน	☐ 3 คน	มากกว่า 3 โปรดระบุ ....คน

11. ท่านมีโรคประจำตัวหรือไม่

☐ ไม่มี

☐ มี (โปรดระบุ) 1..

2..

12. ท่านอาศัยอยู่ในพื้นที่แห่งนี้มาเป็นระยะเวลานาน...ปี

13. การเข้าถึงน้ำประปาและแหล่งน้ำเพื่ออุปโภคและบริโภคในครัวเรือน (ในสภาวะปกติ) (ตอบได้มากกว่า 1ข้อ)

ประเภทของแหล่งน้ำ	**ระยะทางจากที่พัก (กิโลเมตร)**	**ปริมาณการใช้ (ลิตร/สัปดาห์)**
การประปาส่วนภูมิภาค		
ประปาเทศบาล/หมู่บ้าน		
น้ำที่รองเก็บไว้ใช้		
น้ำดื่มบรรจุขวดผลิตในชุมชน		

ประเภทของแหล่งน้ำ	ระยะทางจากที่พัก (กิโลเมตร)	ปริมาณการใช้ (ลิตร/สัปดาห์)
น้ำดื่มบรรจุขวดมีฉลากและได้รับการรับรอง		
บ่อน้ำบาดาล บ่อน้ำตื้น		
อื่นๆ...ระบุ		

14. โครงสร้างของบ้านที่ท่านอาศัยอยู่ (โปรดเลือกใส่เครื่องหมาย ☑ ในข้อย่อยเพียงข้อเดียว)

1) ผนังบ้านสร้างจาก

☐ อิฐ ปูน หรือ โลหะ ☐ บ้านดิน ☐ ไม้อัด ไม้ไผ่ ไม้ที่มีมวลเบา

☐ อื่นๆ โปรดระบุ...

2) หลังคาบ้านสร้างจาก

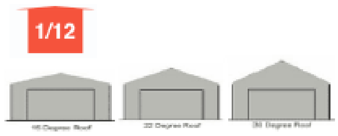
☐ กระเบื้องว่าวคอนกรีต ดินเผา ☐ สังกะสี แผ่นกระเบื้องลอน ☐ ฟางและวัสดุธรรมชาติ

☐ แผ่นโพลีคาร์บอเนต ☐ อื่นๆ โปรดระบุ...

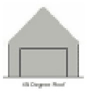
3) ความลาดเอียงของหลังคาบ้าน

☐ มีความลาดเอียงน้อย (3–5 องศา)

☐ มีความลาดเอียงปานกลาง (15–30 องศา)



☐ มีความลาดเอียงมาก (มากกว่า 30 องศา)



4) โครงสร้างรองรับหลังคาบ้าน

☐ เหล็กกล้า หรือไม้แปรรูป (ใหม่) ☐ ไม้ที่ไม่ผ่านการแปรรูป (เก่า) ☐ หิน

☐ อื่นๆ โปรดระบุ...

5) ประตู

☐ ประตูบานพับ บานเลื่อน ☐ ประตูบานเพี้ยม ☐ ประตูบานม้วน

☐ ประตูเหล็กยืด ☐ อื่นๆ โปรดระบุ...

6) หน้าต่าง

☐ โลหะ หรือ ไม้ ☐ กระจกขนาดเล็ก ☐ กระจกขนาดใหญ่

☐ อื่นๆ โปรดระบุ...

15. บ้านที่ท่านอาศัยอยู่มี:

1) ไฟฟ้าเพื่อประกอบกิจวัตรประจำวัน ☐ มี ☐ ไม่มี

2) น้ำประปาเพื่อการอุปโภคบริโภค ☐ มี ☐ ไม่มี

3) ห้องน้ำ/สุขา ☐ มี ☐ ไม่มี

16. บ้านที่ท่านอาศัยอยู่เป็น:

☐ บ้านเช่า ☐ บ้านของท่านเอง ☐ อื่นๆ โปรดระบุ...................

17. บ้านที่ท่านอยู่อาศัยมีระดับต่ำกว่าถนน

☐ ใช่ ☐ ไม่ใช่

ส่วนที่ 2 ผลกระทบทางด้านสุขภาพและการได้รับความช่วยเหลือจากภาครัฐระหว่างภาวะอุทกภัย

1. ท่านมีความกังวลต่อการเกิดน้ำท่วมมากเพียงใด

☐ 5 = มากที่สุด ☐ 4 = มาก ☐ 3 = ปานกลาง ☐ 2 = น้อย ☐ 1 = ไม่กังวลเลย

2. จำนวนครั้งที่ประสบอุทกภัย ในรอบ 10 ปี

☐ 1 ครั้ง ☐ 2 ครั้ง ☐ 3 ครั้ง

☐ มากกว่า 3 ครั้งขึ้นไป

3. อุทกภัยส่งผลกระทบต่อท่านอย่างไร (ตอบได้มากกว่า 1 ข้อ)

☐ อพยพ ☐ ทรัพย์สิน (บ้าน รถ เก้าอี้ เตียง เป็นต้น)

☐ ขาดรายได้ ☐ เจ็บป่วย (ไม่ต้องรับการรักษาพยาบาล)

☐ เจ็บป่วย (ต้องได้รับการรักษาพยาบาล) ☐ ถึงแก่ชีวิต

☐ ไม่มีผลกระทบ ☐ อื่นๆ โปรดระบุ.........................

4. ช่วงอุทกภัย ท่านมีอาการเจ็บป่วยอย่างไรบ้าง

	ความรุนแรงของโรค				
	1	2	3	4	5
☐ ไม่มี					
☐ ตาแดง					
☐ ท้องร่วง					
☐ โรคผิวหนัง (น้ำกัดเท้า / ผิวหนังอักเสบ)					
☐ โรคระบบทางเดินหายใจ (ไข้หวัด/ปอดบวม)					
☐ โรคฉี่หนู					
☐ โรคที่มียุงเป็นพาหะ (ไข้เลือดออก/มาลาเรีย)					
☐ ผลกระทบด้านจิตใจ					
☐ อื่นๆ ....ระบุ					

5. ท่านรักษาอาการเจ็บป่วยดังกล่าวอย่างไร

☐ ปล่อยให้หายเอง

☐ ได้รับความช่วยเหลือจาก อสม หรือ รพ.สต.

☐ ไปโรงพยาบาลด้วยตนเอง

☐ รับประทานยาที่มีอยู่ในบ้าน โปรดระบุชนิดของยา...

6. ระหว่างภาวะน้ำท่วม ท่านใช้**น้ำเพื่ออุปโภค** สำหรับการชำระร่างกาย หรือชำระล้างจากแหล่งใด (ตอบได้เพียงข้อเดียว)

ประเภทของแหล่งน้ำ	**ปริมาณการใช้ (ลิตร/ สัปดาห์)**
การประปาส่วนภูมิภาค	
ประปาเทศบาล/หมู่บ้าน	
น้ำที่รองเก็บไว้ใช้	
น้ำที่ท่วมขังบริเวณบ้าน	
น้ำแจกจากภาครัฐ	
น้ำดื่มบรรจุขวดผลิตในชุมชน	
น้ำดื่มบรรจุขวดมีฉลากและได้รับการรับรอง	

ประเภทของแหล่งน้ำ	**ปริมาณการใช้ (ลิตร/ สัปดาห์)**
บ่อน้ำบาดาล บ่อน้ำตื้น	
อื่นๆ โปรดระบุ...	

7. **ระหว่างภาวะน้ำท่วม ท่านใช้น้ำเพื่อการบริโภค** สำหรับการดื่ม และประกอบอาหารจากแหล่งใด (ตอบได้เพียงข้อเดียว)

ประเภทของแหล่งน้ำ	**ปริมาณการใช้ (ลิตร/ สัปดาห์)**
การประปาส่วนภูมิภาค	
ประปาเทศบาล/หมู่บ้าน	
น้ำที่รองเก็บไว้ใช้	
น้ำที่ท่วมขังบริเวณบ้าน	
น้ำแจกจากภาครัฐ	
น้ำดื่มบรรจุขวดผลิตในชุมชน	
น้ำดื่มบรรจุขวดมีฉลากและได้รับการรับรอง	
บ่อน้ำบาดาล บ่อน้ำตื้น	
อื่นๆ โปรดระบุ...	

8. **ปริมาณน้ำดื่มน้ำใช้** ในช่วงการเกิดอุทกภัย มีความพอเพียงกับจำนวนสมาชิกในครอบครับหรือไม่ (1 ถัง = 20 ลิตรต่อคนต่อวัน)

☐ พอเพียง (ระบุ.......................ถัง/ลิตร) ☐ ไม่พอเพียง (ระบุ........................ถัง/ลิตร)
☐ ไม่ทราบ

9. **มีการขาดน้ำอุปโภคบริโภค**จากแหล่งน้ำ/การแจกจ่ายน้ำจากหน่วยงานภาครัฐ ในช่วงประสบอุทกภัยหรือไม่

☐ มี (โปรดระบุระยะเวลา,,,,,,,,,,,,,,,,วัน / เดือน / ปี) ☐ ไม่มี ☐ ไม่ทราบ

10. **น้ำดื่มน้ำใช้** ที่ท่านใช้ในช่วงการเกิดอุทกภัย มีระดับของความสะอาดอยู่ในช่วงใด

☐ มีสะอาดมาก ☐ ค่อนข้างสะอาด ☐ ค่อนข้างสกปรก ☐ สกปรกมาก

11. มาตรการใดที่ใช้ในการปรับปรุงคุณภาพน้ำให้**<u>สามารถดื่มได้</u>** ในช่วงการเกิดอุทกภัย

☐ ต้มให้เดือด ☐ ใส่คลอรีน ☐ กรองด้วยผ้า ☐ ตากแดด ☐ ตั้งทิ้งไว้เฉยๆ
☐ มีวิธีอื่นๆ (โปรดระบุ...) ☐ ไม่ทราบ ☐ ไม่มีวิธีการปรับปรุง

12. ระหว่างภาวะน้ำท่วม ท่านได้รับความช่วยเหลือด้านน้ำเพื่อการอุปโภคบริโภคน้ำจากหน่วยงานใดมากที่สุด

☐ การประปาส่วนภูมิภาค

☐ ประปาเทศบาล/หมู่บ้าน

☐ อบต

☐ สสจ

☐ รพสต

☐ ไม่ได้รับความช่วยเหลือ

13. ความพึงพอใจต่อการตอบโต้สถานการณ์ภัยพิบัติจากหน่วยงานภาครัฐ

	ความพึงพอใจ (จากน้อยไปมาก)				
	1	2	3	4	5
☐ ไม่ได้รับความช่วยเหลือ					
☐ อบต อบท เทศบาล					
☐ สาธารณสุขจังหวัด/สาธารณสุขอำเภอ					
☐ ป้องกันและบรรเทาสาธารณภัยจังหวัด					
☐ การประปาส่วนจังหวัด					
☐ ประปาเทศบาล/หมู่บ้าน					
☐ อื่นๆ ....ระบุ					

14. ท่าน<u>ประเมินการเข้าถึงบริการ</u>ใน**การจัดการขยะ** (เช่นมีการจัดหาถุงบรรจุและถังขยะรองรับขยะจากบ้านเรือนของท่าน) ในช่วงภาวะน้ำท่วม อย่างไร

☐ 1 = ไม่พอใจ ☐ 2 = น้อย ☐ 3 = ปานกลาง ☐ 4 = มาก ☐ 5 = พอใจมากที่สุด

15. ท่าน<u>ประเมินการเข้าถึงบริการ</u>ใน**การจัดการน้ำเสีย** (เช่นมีการจัดหาสุขาเคลื่อนที่ ถุงบรรจุของเสียปฏิกูลจากการขับถ่าย ในบ้านเรือนของท่าน) ในช่วงภาวะน้ำท่วม อย่างไร

☐ 1 = ไม่พอใจ ☐ 2 = น้อย ☐ 3 = ปานกลาง ☐ 4 = มาก ☐ 5 = พอใจมากที่สุด

ส่วนที่ 3 สภาพปัจจุบันและสภาพพึงประสงค์ของการจัดการด้านน้ำอุปโภคบริโภค

1. สภาพปัจจุบันและสภาพพึงประสงค์ของการช่วยเหลือของภาครัฐในเรื่องการอุปโภคบริโภคน้ำในกรณีอุทกภัย

คำชี้แจง ทำเครื่องหมาย ✓ ให้ตรงกับช่องระดับความคิดเห็น

1 → 4	
มีการปฏิบัติน้อยที่สุด	มีการปฏิบัติมากที่สุด

ประเด็นการการช่วยเหลือของภาครัฐในเรื่องการอุปโภคบริโภคน้ำในกรณีอุทกภัย	**สภาพที่เป็นจริงในปัจจุบัน**				**สภาพที่คาดหวัง**			
	1	2	3	4	1	2	3	4
แหล่งข้อมูลการแจ้งเตือนภัย ท่านได้รับการแจ้งเตือนภัยจากหน่วยงานต่างๆ ดังต่อไปนี้								
อบต อบท อสม อปพร เทศบาล								
สาธารณสุขจังหวัด/สาธารณสุขอำเภอ								
ป้องกันและบรรเทาสาธารณภัยจังหวัด								
การประปาส่วนจังหวัด								
กรมอุตุนิยมวิทยา								
กรมชลประทาน								
ภาคเอกชน								
หน่วยงานที่เข้ามาให้ความช่วยเหลือเป็นอันดับแรก ท่านได้รับความช่วยเหลือจากหน่วยงานต่างๆ ดังต่อไปนี้								
อบต อบท อสม อปพร เทศบาล								
สาธารณสุขจังหวัด/สาธารณสุขอำเภอ								
ป้องกันและบรรเทาสาธารณภัยจังหวัด								
การประปาส่วนจังหวัด								
กรมอุตุนิยมวิทยา								
กรมชลประทาน								
ภาคเอกชน								
หน่วยงานที่เข้ามาให้ความช่วยเหลือด้านน้ำอุปโภคบริโภค ท่านได้รับความช่วยเหลือจากหน่วยงานต่างๆ ดังต่อไปนี้								
อบต อบท อสม อปพร เทศบาล								

ประเด็นการการช่วยเหลือของภาครัฐในเรื่องการอุปโภคบริโภคน้ำในกรณีอุทกภัย	สภาพที่เป็นจริงในปัจจุบัน				สภาพที่คาดหวัง			
	1	2	3	4	1	2	3	4
สาธารณสุขจังหวัด/สาธารณสุขอำเภอ								
ป้องกันและบรรเทาสาธารณภัยจังหวัด								
การประปาส่วนจังหวัด								
กรมอุตุนิยมวิทยา								
กรมชลประทาน								
ภาคเอกชน								
หน่วยงานที่เข้ามาให้ความช่วยเหลือด้านปัญหาสุขภาพ ท่านได้รับความช่วยเหลือจากหน่วยงานต่างๆ ดังต่อไปนี้								
อบต อบท อสม อปพร เทศบาล								
สาธารณสุขจังหวัด/สาธารณสุขอำเภอ/ รพสต								
ป้องกันและบรรเทาสาธารณภัยจังหวัด								
ภาคเอกชน								
การรับรู้แผนปฏิบัติการเพื่อตอบโต้ ในกรณีเกิดอุทกภัยของหน่วยงานต่างๆ ท่านรับรู้ถึงแนวทางการแก้ปัญหา ตอบโต้ หรือแผนงานของหน่วยงานต่างๆ ดังต่อไปนี้								
อบต อบท อสม อปพร เทศบาล								
สาธารณสุขจังหวัด/สาธารณสุขอำเภอ/ รพสต								
ป้องกันและบรรเทาสาธารณภัยจังหวัด								
การประปาส่วนจังหวัด								

2. ท่านทราบและเข้าใจต่อแผนการรับมือ และข้อมูลที่เกี่ยวข้องต่อไปนี้กับการรับมือต่อปัญหาน้ำท่วมในพื้นที่ของท่าน (ตอบได้มากกว่า 1 ข้อ)

☐ การแจ้งเตือนภัยล่วงหน้า ☐ แผนที่เสี่ยงน้ำท่วมของชุมชน

☐ แผนการปรับตัวต่อภัยพิบัติ (เช่นชีวิตประจำวัน/อาชีพ) ☐ การฝึกอบรมผู้นำชุมชน

☐ การถอดบทเรียนและถ่ายทอดประสบการณ์ ☐ แผนการอพยพภัย/แผนฉุกเฉิน

3. ท่านมีความพร้อมและเข้าใจต่อวิธีการรับมือต่อปัญหาการเจ็บป่วยในช่วงภาวะน้ำท่วม (เช่น ท้องเสีย ตาแดง โรคฉี่หนู ฯลฯ) ในพื้นที่ของท่าน มากน้อยเพียงใด

☐ 5= พร้อม/เข้าใจมากที่สุด ☐ 4= พร้อม/เข้าใจมาก ☐ 3= ปานกลาง

☐ 2 = พร้อม/เข้าใจบางส่วน ☐ 1 = ไม่พร้อมเลย

4. * ท่านคิดว่าท่านพักอาศัยอยู่ในพื้นที่ที่มีความเสี่ยงต่อปัญหาน้ำท่วมมากในระดับใด

☐ 5= เสี่ยงมากที่สุด ☐ 4= เสี่ยงมาก ☐ 3= ปานกลาง

☐ 2 = เสี่ยงน้อย ☐ 1 = ไม่มีความเสี่ยง

5. * ท่านมีการเตรียมตัวรับมือสำหรับปัญหาน้ำท่วมที่อาจเกิดขึ้นในพื้นที่ของท่านในอนาคตหรือไม่

☐ ไม่มี

☐ มี

5.1 ท่านมีความพร้อมสำหรับปัญหาน้ำท่วมที่อาจเกิดขึ้นในพื้นที่ของท่านในอนาคตระดับใด

☐ 5= มากที่สุด ☐ 4= มาก ☐ 3= ปานกลาง

☐ 2 = น้อย ☐ 1 = ไม่ทราบ

6. เทียบกับการเกิดปัญหาน้ำท่วมในปีก่อนๆ ท่านและครอบครัวของท่านสามารถรับมือกับปัญหาน้ำท่วมได้เป็นอย่างไร?

☐ ดีขึ้น ☐ เหมือนเดิม

☐ น้อยลง **เพราะเหตุใด** (ตอบได้มากกว่า 1 ข้อ)

☐ ตกงาน ขาดแหล่งรายได้ ☐ ได้รายได้ลดลง

☐ สมาชิกในครอบครัวถึงแก่ชีวิต หรือมีการอพยพ

☐ สมาชิกในครอบครัวมีการเจ็บป่วย จนไม่สามารถประกอบอาชีพได้

☐ ปัญหาการเงินในครอบครัวเนื่องจากค่าครอบชีพที่เพิ่มขึ้น

☐ อื่นๆ โปรดระบุ..........................

☐ ไม่ทราบ

ส่วนที่ 4 ความเห็นเกี่ยวกับความอ่อนไหวต่อน้ำท่วม
คำชี้แจง

1. โปรดเลือกคำตอบโดยการทำเครื่องหมาย ✓ ในวงกลมที่ตรงกับระดับความคิดเห็นของท่าน ○ ○ ○ ○ ● (1 2 3 4 5)

โปรดทำเครื่องหมาย ✓ ให้ตรงกับช่องลำดับความสำคัญตามความคิดเห็นของท่าน
1 = ไม่สำคัญ ; 2 =เล็กน้อย;
3 = ปานกลาง; 4 = มาก; 5 = มากที่สุด

ข้อคำถาม	ลำดับความสำคัญ				
	1	2	3	4	5
1. ครอบครัวของท่านอาศัยอยู่ในพื้นที่เสี่ยงภัยน้ำท่วม 1 = ไม่เสี่ยงเลย (น้ำท่วมรุนแรงในพื้นที่ก็ไม่มีผลกระทบต่อท่าน) 5 = เสี่ยงมาก (น้ำท่วมเล็กน้อยในพื้นที่ก็มีผลกระทบต่อท่าน) ○ ○ ○ ○ ○ (1 → 5)					
2. ในพื้นที่ของท่าน มีสถานที่สำคัญทางประวัติศาสตร์ที่จะถูกทำลายหากเกิดน้ำท่วม (1 = ไม่มี ไปจนถึง 5 = มีมากหลายแห่ง) ○ ○ ○ ○ ○ (1 → 5)					
3. ผลกระทบจากน้ำท่วมและตะกอนที่มากับน้ำท่วม 1 = ช่วยให้ดินมีคุณภาพมากขึ้น 5 = สกปรกและเป็นอันตรายต่อคน สัตว์และสิ่งแวดล้อม ○ ○ ○ ○ ○ (1 → 5)					
4. เมื่อเกิดปัญหาน้ำท่วม ท่านและครอบครัวสามารถอพยพออกจากพื้นที่ได้ทันท่วงที 1 = สามารถอพยพได้ทัน (รวมถึงคนป่วยในครอบครัว) 5 = ไม่สามารถอพยพหรือเคลื่อนย้ายได้ ○ ○ ○ ○ ○ (1 → 5)					
5. ท่านได้รับการเตือนภัยเกี่ยวกับน้ำท่วม 1 = ได้รับข้อมูลที่แม่นยำ และมีเวลาที่จะเตรียมตัวรับมือ 5 = ไม่ได้รับข้อมูลใดๆ ○ ○ ○ ○ ○ (1 → 5)					

ข้อคำถาม	ลำดับความสำคัญ				
	1	2	3	4	5
6. ท่านมีความตระหนักรู้เกี่ยวกับความเสี่ยงจากภัยน้ำท่วม 1 = รู้ เนื่องจากเคยได้รับอบรม / ได้รับคำชี้แนะ 5 = ไม่มีความตระหนักรู้เกี่ยวกับความเสี่ยงใดๆ ○ ○ ○ ○ ○ 1 ——→ 5					
7. หน่วยงานรัฐ / เทศบาลในพื้นที่ของท่านมีมาตรการป้องกันภัยจากน้ำท่วมหรือไม่ 1 = มี อย่างเช่น ระบบระบายน้ำ เขื่อนกักน้ำ 5 = ไม่มีมาตรการป้องกันใดๆ ○ ○ ○ ○ ○ 1 ——→ 5					
8. ท่านมีศูนย์พักพิง หรือพื้นที่อพยพ เมื่อเกิดน้ำท่วม หรือหลังจากมีภัยน้ำท่วมหรือไม่ 1 = มี อย่างเช่น โรงพยาบาล ศูนย์อพยพ และมีเพียงพอสำหรับผู้ประสบภัย 5 = ไม่มี ○ ○ ○ ○ ○ 1 ——→ 5					
9. ท่านมีความเตรียมพร้อมต่อภัยน้ำท่วมหรือไม่ 1 = มี เช่น มีถุงยังชีพ อาหาร หรือไม่ได้รับผลกระทบจากในกรณีที่เกิดภัยน้ำท่วม 5 = ไม่มี ○ ○ ○ ○ ○ 1 ——→ 5					
10. ท่านสามารถฟื้นตัวจากภัยน้ำท่วมครั้งที่แล้ว 1 = ฟื้นตัวได้ ในระยะเวลาสั้น 5 = ฟื้นตัวลำบาก ได้รับผลกระทบอยู่เป็นระยะเวลานาน ○ ○ ○ ○ ○ 1 ——→ 5					
11. ครอบครัวของท่านได้รับการช่วยเหลือจากคนในท้องที่/ชุมชนในกรณีที่เกิดภัยน้ำท่วม 1 = ใช่ เพื่อนและคนในชุมชนให้ความช่วยเหลือเป็นอย่างดี 5 = ไม่ได้รับความช่วยเหลือจากชุมชน ครอบครัวต้องช่วยเหลือตัวเอง ○ ○ ○ ○ ○ 1 ——→ 5					

ข้อคำถาม	ลำดับความสำคัญ				
	1	2	3	4	5
12. ท่านมีน้ำสะอาดสำหรับดื่มกิน (บริโภค) **เพียงพอ ระหว่างที่เกิด**ภัยน้ำท่วม 1 = มีเพียงพอ หรือสามารถทำน้ำสะอาดดื่มเองได้เหมือนก่อนเกิดน้ำท่วม 5 = ไม่มี ต้องใช้น้ำสำหรับอุปโภคมาดื่มแทน ◯ ◯ ◯ ◯ ◯ 1 ——→ 5					
13. ท่านมีน้ำสะอาดสำหรับดื่มกิน (บริโภค) **เพียงพอ หลังจาก**เกิดภัยน้ำท่วม 1 = มีเพียงพอ หรือสามารถทำน้ำสะอาดดื่มเองได้เหมือนก่อนเกิดน้ำท่วม 5 = ไม่มี ต้องใช้น้ำสำหรับอุปโภคมาดื่มแทน ◯ ◯ ◯ ◯ ◯ 1 ——→ 5					
14. ท่านสูญเสียรายได้ อาชีพ หรือธุรกิจหากเกิดภัยน้ำท่วมรุนแรง 1 = ไม่สูญเสีย (สามารถหาคืนมาได้ภายใน 1 อาทิตย์) 5 = สูญเสียรายได้เป็นเวลานาน ◯ ◯ ◯ ◯ ◯ 1 ——→ 5					
15. ท่านมีพลังงานต่างๆ เช่น ไฟฟ้า แก๊ส ถ่านเพื่อหุงต้ม ใช้**ระหว่างที่เกิด**ภัยน้ำท่วม 1 = มีใช้เหมือนก่อนเกิดภัยน้ำท่วม 5 = ไม่มีใช้เป็นเวลานาน ◯ ◯ ◯ ◯ ◯ 1 ——→ 5					
16. ท่านมีพลังงานต่างๆ เช่น ไฟฟ้า แก๊ส ถ่านเพื่อหุงต้ม **หลังจาก**ภัยน้ำท่วม 1 = มีใช้เหมือนก่อนเกิดภัยน้ำท่วม 5 = ไม่มีใช้เป็นเวลานาน ◯ ◯ ◯ ◯ ◯ 1 ——→ 5					
17. ท่านได้รับความช่วยเหลือจากหน่วยงานรัฐบาล/เทศบาล หรือสถาบันต่างๆ**ระหว่าง** ที่เกิดน้ำท่วมหรือไม่ 1 = ได้รับความช่วยเหลือ เช่น ได้รับเรือ อาหาร ที่พักพิง เป็นต้น 5 = ไม่ได้รับ ◯ ◯ ◯ ◯ ◯ 1 ——→ 5					

ข้อคำถาม	ลำดับความสำคัญ				
	1	2	3	4	5
18. ท่านได้รับความช่วยเหลือจากหน่วยงานรัฐบาล/เทศบาล หรือสถาบันต่างๆ **หลังจาก** ภัยน้ำท่วมหรือไม่ 1 = ได้รับความช่วยเหลือ เช่น ได้รับเรือ อาหาร ที่พักพิง เป็นต้น 5 = ไม่ได้รับ ○ ○ ○ ○ ○ 1 → 5					
19. ท่านได้รับเงินช่วยเหลือจากภัยน้ำท่วมหรือไม่ 1 = ได้รับ จากหน่วยงานรัฐบาล หรือสถาบันต่างๆ 5 = ไม่ได้รับ ○ ○ ○ ○ ○ 1 → 5					

ส่วนที่ 5 สภาวะป่วยทางจิตใจเมื่อเผชิญกับเหตุการณ์ที่กระทบกระเทือนจิตใจอย่างร้ายแรง

คำชี้แจง โปรดทำเครื่องหมาย ✓ ให้ตรงกับช่องลำดับความสำคัญตามความคิดเห็นของท่าน

5.1 **คำถามนำ:** บางครั้ง คนเราประสบเหตุร้ายแรง น่ากลัว และประสบการณ์ที่เจ็บปวด เช่น:

- น้ำท่วม หรือแผ่นดินไหว
- อุบัติเหตุรุนแรงหรือไฟไหม้
- การถูกทำร้ายร่างการ คุมคามหรือละเมิดทางเพศ
- สงคราม
- เห็นผู้อื่นบาดเจ็บหรือถูกทำร้ายอย่างรุนแรง หรือถึงแก่ชีวิต
- สูญเสียคนที่คุณรักจากการถูกฆาตกรรมหรือฆ่าตัวตาย

ท่านเคยประสบเหตุการณ์เหล่านี้หรือไม่

☐ เคย ☐ ไม่เคย (ถ้าไม่เคย จบการสอบถาม PTSD)

เริ่มต้นส่วนที่ 5.2 ในเดือนที่ผ่านมาท่านเคย........

1. ฝันร้ายเกี่ยวกับเหตุการณ์ที่เคยเกิดขึ้น โดยที่ท่านไม่ต้องการจะนึกถึง ☐ เคย ☐ ไม่เคย
2. พยายามที่จะไม่คิดหรือนึกถึงเหตุการณ์เหล่านั้น หรือหลีกเลี่ยงสถานการณ/สถานที่/สิ่งใดๆที่ทำให้ท่านนึกถึงเหตุการณ์ดังกล่าว ☐ เคย ☐ ไม่เคย

3. มีความตื่นตัว ขวัญผวา เฝ้าระวัง หรือตื่นตกใจง่าย อยู่เป็นประจำ ☐ เคย ☐ ไม่เคย

4. รู้สึกเฉยชา หรือไร้ความรู้สึก ปลีกตัวเองออกจากคนอื่นๆ หรือสิ่งต่างๆรอบตัว ☐ เคย ☐ ไม่เคย

5. รู้สึกผิดหรือไม่สามารถหยุดโทษตัวเองหรือผู้อื่นเกี่ยวกับเหตุการณ์ที่เกิดขึ้น หรือเกี่ยวกับปัญหาต่างๆที่ตามมา ☐ เคย ☐ ไม่เคย

ข้อเสนอแนะเพิ่มเติมเพื่อการวางแผนงานการตอบโต้ปัญหาในภาวะภัยพิบัติ

ด้านน้ำอุปโภคบริโภค

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ด้านสุขภาพ

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VITA

NAME Teeraphat attavinijtrakarn

DATE OF BIRTH 9 May 1992

PLACE OF BIRTH Kanchanaburi

INSTITUTIONS ATTENDED The College of Public Health Science, Chulalongkorn university

HOME ADDRESS 581 Sangchuto Road,
Pak prak subdistrict
Meung district
Kanchanaburi 71000

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