APPLICATION OF WEATHER RADAR FOR URBAN FLOOD EARLY WARNING SYSTEM. CASE STUDY OF CHATUCHAK DISTRICT, BANGKOK, THAILAND

THEERAPOL CHAROENSUK

Hydro - Informatics Institute, Bangkok, Thailand, theerapol.c@hii.or.th

NARONGRIT LUANGDILOK

Hydro - Informatics Institute, Bangkok, Thailand, narongrit@hii.or.th

TICHA LOLUPIMAN

Hydro - Informatics Institute, Bangkok, Thailand, ticha@hii.or.th

WATIN THANATHANPHON

Hydro - Informatics Institute, Bangkok, Thailand, watin@hii.or.th

PIYAMARN SISOMPHON

Hydro - Informatics Institute, Bangkok, Thailand, piyamarn@hii.or.th

ABSTRACT

Urbanization is considered as one of the most significant anthropogenic alterations to the land cover change. There are a lot of effects from urbanization, for example population growth, building construction, and rapid occurrence of urban runoff. Bangkok, the capital city of Thailand, has its notorious for frequent flooding. Apart from heavy rainfall becomes more extreme than in the past, land use change due to rapid economic growth is one of the key factors that affect the city planning. The drainage system i.e., pipes and diversion channel to the tunnel is full with sediment and debris and not capable of draining the urban runoff in time. In general, Bangkok's drainage system is designed based on rational formula. This study presents the development of urban flood early warning system by applying flood threshold estimated from rational formula using observation and 1 hr. now-casting from weather radar data. The system is designed with data overlay concept by integrating real time observation, now-casting data and calculated flood threshold. Flood risk area is identified and alerted for warning. Bangkok's flood management polder is divided into 22 zones or polders according to flood characteristic and operational management i.e. dike. In this study Chatuchak polder was selected as a pilot area. The calibration has been done using the flood events from 2017-2018. The accuracy was found satisfactory with 70% effectiveness.

Keywords: Urban, Radar, Bangkok, Flood, Early warning system

1. INTRODUCTION

Currently, urban areas of Thailand have a problem of flooding due to the rain that falls for a long time and higher than normal rainfall causing flooding in urban areas such as Bangkok, Pattaya, and Chiang Mai provinces Characteristic of the rain in the urban areas of Thailand is the convectional rain caused by the heat rising to the point of condensation and falling into heavy rain in a short time, which has affected the depth of the flood to increase rapidly. Urban flood warnings systems using urban models cannot warn flooding on time. The convectional rain forecasting is difficult to predict. Therefore, in this study development of urban flood early warning system by applying flood threshold estimated from rational formula using observation and 1 hr. now-casting from weather radar data.

2. STUDY AREA

Bangkok is a capital city, located in central part of Thailand. Topography is a plain area with low elevation from 0.00 to 1.50 M.SL. Annual rainfall is 1,648.4 mm and high frequency rainfall is in August until mid of October. Southwest Monsoon from India Ocean impacts to rainfall (May – October). Flood management in Bangkok is handled by Department of Drainage and Sewerage. Bangkok is divided into several zones or polders, where depend on flood characteristic. There are 22 polders cover entire Bangkok as shown in Figure 1. Drainage system of each polder links together. The study focuses on Polder number 3.
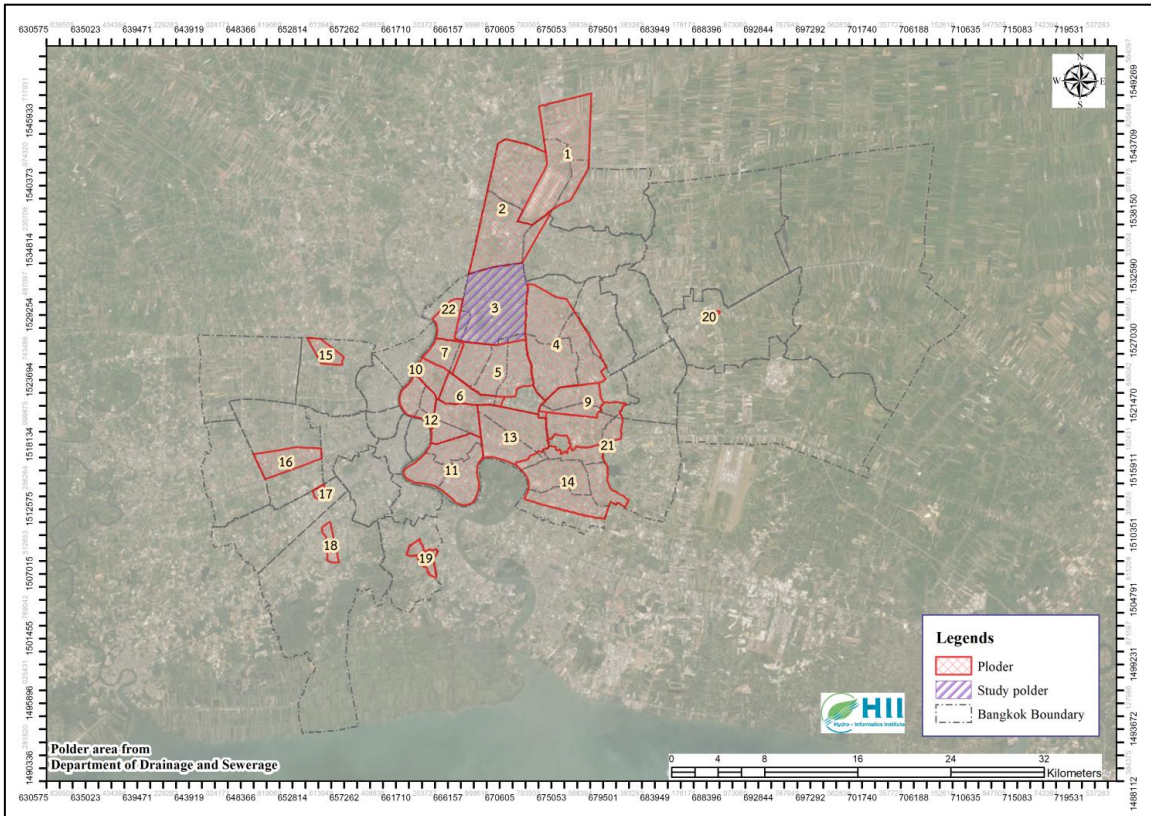
Figure 1. Map of all polders in Bangkok

Polder number 3 is located in Chatuchak district, Bangkok (Figure 2). There are a lot of landmarks in this area including university, Bus terminal, BTS station, and department store. Total area is 35.40 km². There are several types of stations including rainfall, water level, discharge, flood sensor, gate, and pumping station as summarize in table 1.
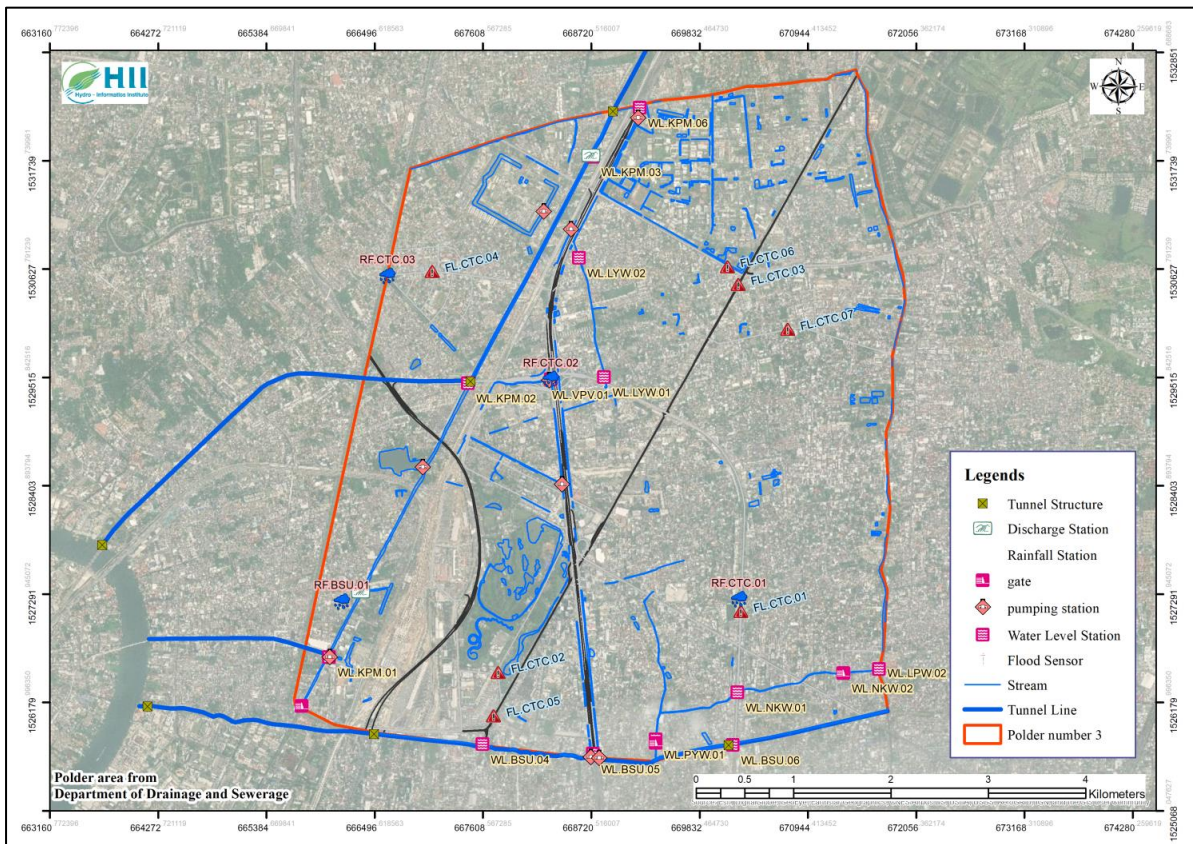

Figure 2. Map of Chatuchak polder or polder number 3

Table 1. Number of stations in Chatuchak polder.

Station Type	No. of station
Rainfall	4
Water Level	14
Discharge	2
Flood Sensor	7
Gate	3
Pumping Station	10

Bangkok is located in tropical zone and affected from southwest monsoon from May to October. Summer thunderstorm is from August to October. Annual rainfall in Bangkok is 1500 mm. and highest number of rainfalls is in September approximately 310 mm. as Figure 3.
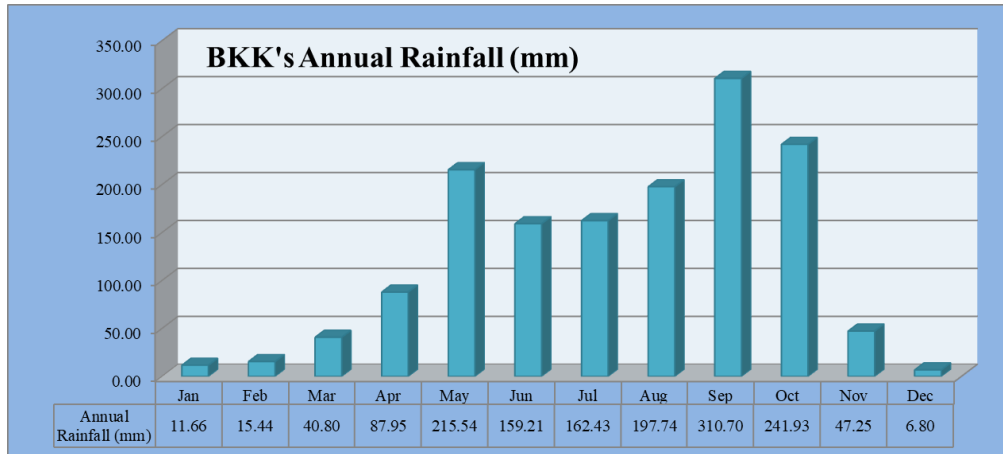

Annual Rainfall (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	11.66	15.44	40.80	87.95	215.54	159.21	162.43	197.74	310.70	241.93	47.25	6.80

Figure 3 Graph of annual rainfall in Bangkok

3. CAUSES OF FLOOD IN BANGKOK

3.1 HYDORLOGY CAUSES

Rainfall in Bangkok is mostly from the southwest of Monsoon and convective rain. Southwest Monsoon from India Ocean impact on rainfall (May – October) around 30% and 70% of rainfall in Bangkok is from convective rain Because of high temperatures and construction in Bangkok, high levels of urban heat are produced, and urban heat affects convective weather, resulting in high rainfall frequencies and severe rainfall in the past decade.

3.2 PHYSICAL CAUSES

Bangkok's drainage systems are the main physical cause of flooding in Bangkok. The amount of canal, ditch, and the pipe are not enough for the drainage. Due to urban planning in Bangkok, there is a lot of building that blocks natural floodways, so the floodwater could not drain the water to the river. The shallow canal and garbage that clogs the drain. It is another important reason that water cannot be drained.

4. LIMITATION OF URBAN FLOOD EARLY WARNING SYSTEM

4.1 Hydrology Characteristics

4.1.1 Rain Characteristics in urban area.

Rainfall in urban area is caused by monsoon and convective rain. Bangkok has heat island. Due to the expansion of the city, there has been an increase in population, fuel combustion, fume and dust from various activities. The temperature difference is usually larger at night than during the day. The rainfall is higher in some cities due to the heat island.

4.1.2 Climate Change

Thailand has been affected by climate change and climate variability resulting in more frequent flooding and drought. Over the last 10 years, rainfall has been higher and rainfall is lower than normal, with more frequent alternations. In 2009 – 2010, Thailand was affected by drought, but the rains in 2011 were high. The 2011's

rainfall was 24 percent higher than normal rainfall, causing severe flooding in the country as shown in Figure 4 shows the percentage of rainfall anomalies in Thailand.
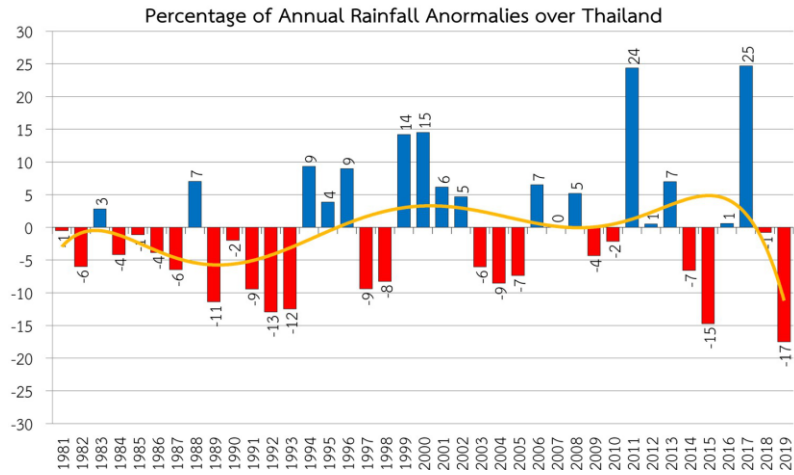

Figure 4. Percentage of rainfall anomalies in Thailand.

4.2 Physical Characteristics

4.2.1 Land-use change and growth of urban

In the past, Bangkok was filled with a lot of canal and space so that the rainfall can drain quickly. Currently, the lack of urban planning and bad land use control affect the growth of cities. The community is growing quickly. The drainage system cannot respond to the growth of cities.

4.2.2 Expansion of infrastructure

Infrastructure work is an important factor for national development in areas such as the economy, society, culture, and national security. Infrastructure work expanded due to the requirements of use and the need for country development. The expansion in the form of construction investment or maintenance is increasing at all times. The result of the infrastructure expansion, which affects the current drainage capacity is not able to support the changing of the expansion of the infrastructure at all times.

4.3 Rainfall Forecast

Currently, the rainfall forecasting system can still be difficult and low accuracy. With rain characteristics and climate change (Section 4.1) have an effect on rainfall forecasting system.

4.4 Time

4.4.1 Time of transfer Data

Data collection processes, transfer data, process data, backup data and publication take time. Meanwhile, the flood in urban areas is rapidly occurring. If the data are sent slowly or after the flood has occurred, the flood warnings in urban areas will not be effective enough to give warnings. As shown in figure 4, The red line receives data from the data logger system, time of transfer used a short delay time. Flood warning system can alert floods in time. If data receive from the process data, it will increase the delay time. Flood warning systems can't alert floods in time.
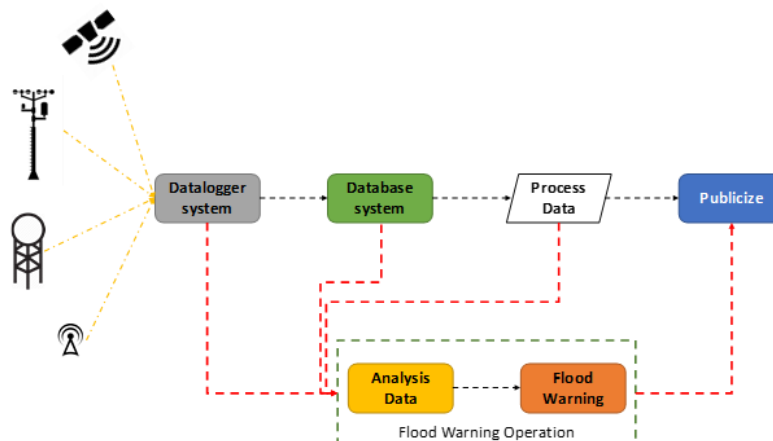

Figure 5. Real time data transfer System

4.4.2 Flood Warning Time

Floods in urban areas are caused by heavy rainfall in a short period. The calculation of flood alarm must be very fast and efficient. If the analysis time is delayed, it is not possible to warn the flood immediately.

5. METEOROLOGY

Drainage system of Bangkok is designed by Rational Method Equation to determine size and capacity of pipe of each area. Flood threshold development has used the same concept from the drainage system design to determine the runoff capacity of sub-catchment areas.

This study applies the equation $Q = CIA$ to set the flood threshold in sub-catchment areas.

$$Q = \text{Runoff (cms.)}$$
$$C = \text{Runoff Coefficient}$$
$$I = \text{Rainfall Intensity (mm/hr.)}$$
$$A = \text{Area (m}^2)$$

5.1 SUB-CATCHMENT AREAS

The elevation in study area is very low and topography is a low plain area, water is drained by pipes. Sub-catchment area delimitation is important because each pipe receives water from different areas, so each zone should be determined by water capacity to set an effective threshold for each zone. To divide the sub-catchment areas of polder 3, it will divide sub-catchment areas according to the flow direction of the pipe and size of the pipeline. Total sub-catchment areas are 160 sub-catchment areas in polder 3 (Fig 6).
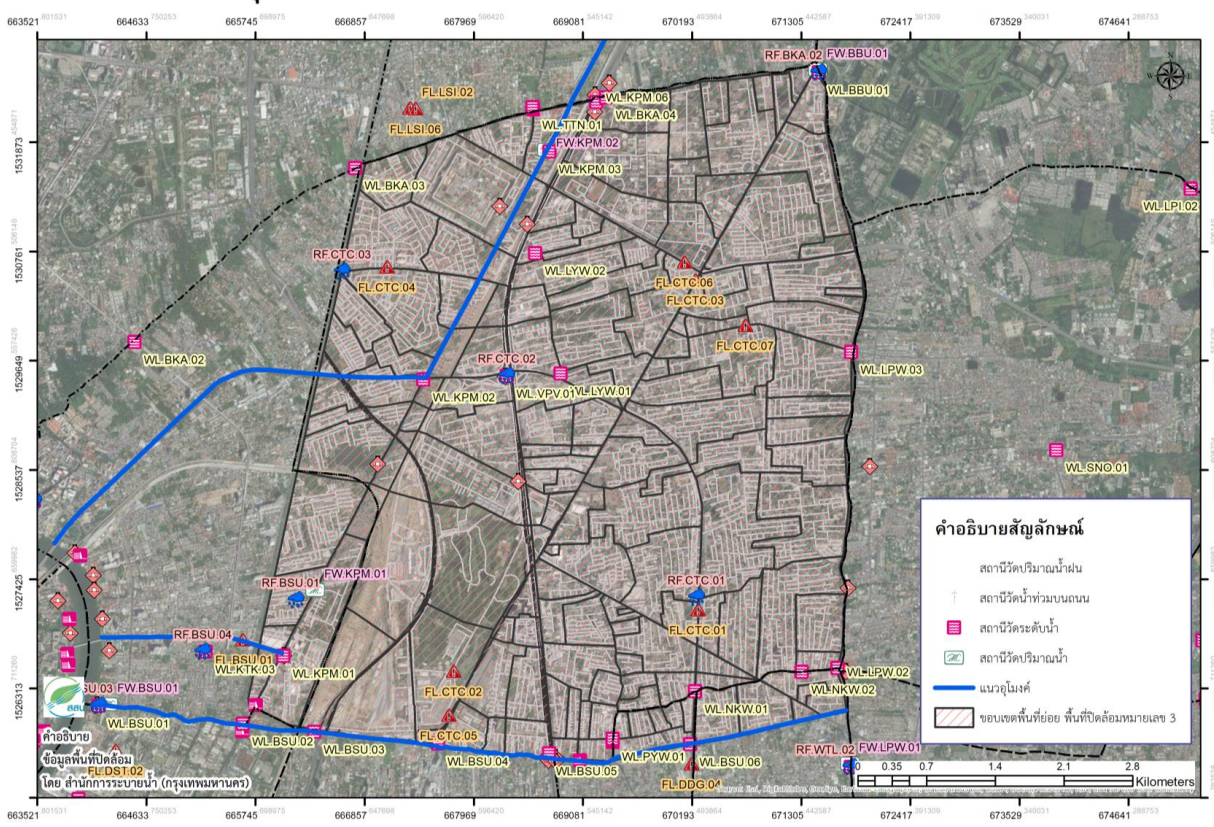

Figure 6. Sub-Catchment areas in Polder 3

5.2 INTENSITY-DURATION-FREQUENCY CURVE (IDF CURVE)

In Bangkok, the drainage system was designed by a design storm with a 5-year return period and a 60-minute duration to determine size and length of pipe from the Department of Drainage and Sewerage. This study used rainfall intensity as same as a storm design in the design drainage system to determine flood threshold or runoff capacity such as table 2.

Table 2. Intensity-Duration-Frequency Curve (IDF Curve)

Return Period	Intensity Rainfall (mm./hr.)								
	5 min	10 min	15 min	30 min	1 hr.	2 hrs.	6 hrs.	12 hrs.	24 hrs.
2	135.5	121.1	99.8	84.9	58.7	36.2	14.3	7.5	3.9
5	168.9	152.0	126.7	108.6	76.0	47.5	19.0	10.0	5.1
7	178.3	161.4	134.9	115.9	81.5	51.1	20.5	10.8	5.6
10	188.3	170.2	142.7	122.9	86.8	54.6	22.0	11.6	6.0
12	188.3	185.9	156.9	135.7	96.5	61.2	24.9	13.1	6.8

(Department of Drainage and Sewerage,2019)

5.3 FLOOD THRESHOLD

Flood threshold analyzed by Rational Method Equation (Q = CIA). The runoff coefficient (c) is a function of the soil type, land-use and drainage basin slope. The runoff coefficient is shown in Table 3. From Table 3, sub-catchment areas can define the runoff coefficient shown in Figure 7 (a). Output is a flood threshold of each zone as Figure 7 (b). The flood threshold represents water capacity of drainage system. The system will alert if runoff from accumulated rainfall is higher than flood threshold.

Table 3. Runoff Coefficient

Area Description	Runoff Coefficient C	Character of surface	Runoff Coefficient C
Business		Pavement	
Downtown	0.70-0.95	Asphaltic and concrete	0.70-0.95
Neighborhood	0.50-0.70	Brick	0.70-0.85
Residential		Roofs	0.75-0.95
Single-Family	0.30-0.50	Lawns, sandy soil	
Multiunit, detached	0.40-0.60	Flat, 2 percent	0.05-0.10
Multiunit, attached	0.60-0.75	Average, 2-7 percent	0.10-0.15
Residential (suburban)	0.25-0.40	Steep, 7 percent	0.15-0.20
Apartment	0.50-0.70	Lawns, heavy soil	
Industrial		Flat, 2 percent	0.13-0.17
Light	0.50-0.80	Average, 2-7 percent	0.18-0.22
Heavy	0.60-0.90	Steep, 7 percent	0.25-0.35
Parks, cemeteries	0.10-0.25		
Playgrounds	0.20-0.35		
Railroad yard	0.20-0.35		
Unimproved	0.10-0.30		

(Amer. Soc. of Civil Engin.,1969)

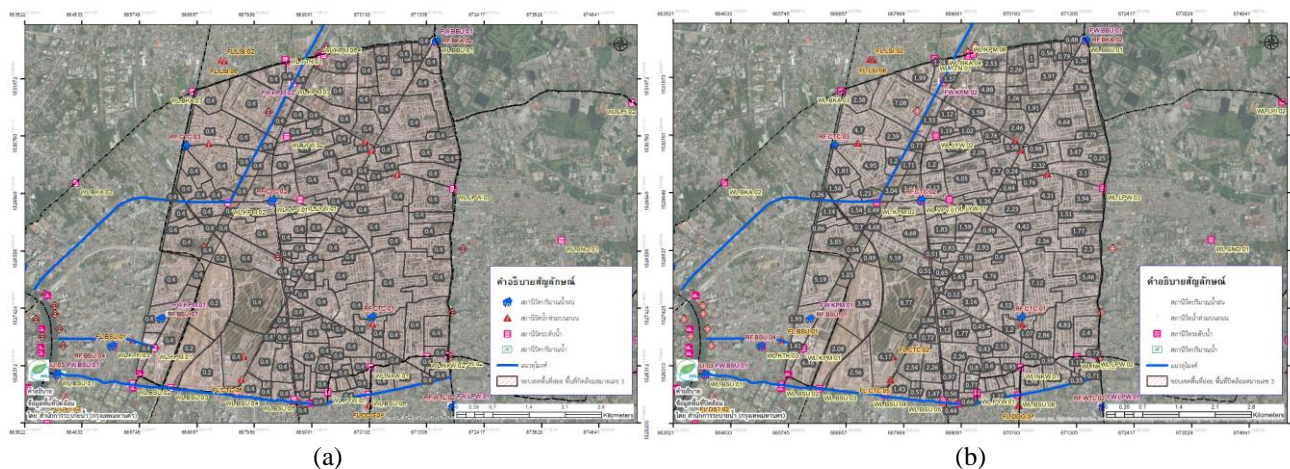<table>
<tr><td>(a)</td><td>(b)</td></tr>
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Figure 7. (a) Runoff coefficient in each area (b)Flood threshold in each area.

6. WEATHER RADAR

The weather radar station used is Satthahip Radar, which covers the study area (Figure 8). Rainfall estimation from weather radar measurements is commonly based on an empirical formula, which is the relationship between the radar reflectivity (Z) and rainfall rate (R). The general Z-R formula is shown in Eq.1 by Marshall and Palmer (1948), which has been widely used for radar rainfall estimation.
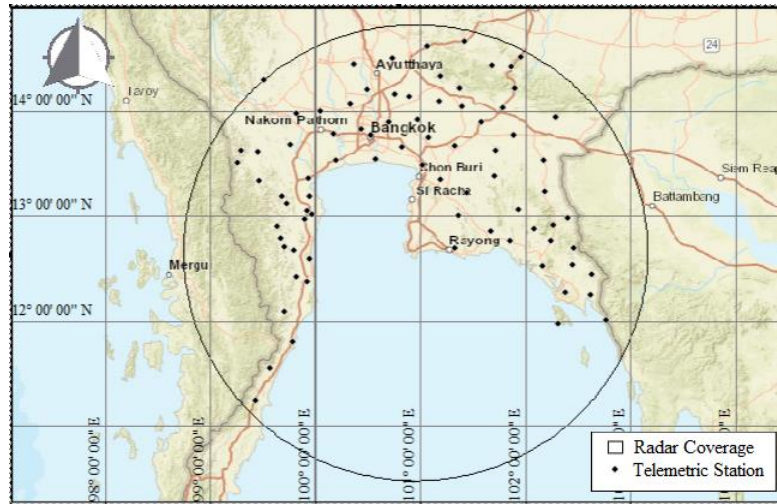

Figure 8. Satthahip radar

$$Z=aR^b \tag{21}$$

where Z is the radar reflectivity (mm-6 m3) and R is the rainfall rate (mm/hr).

This study used the Z-R equation is $Z = 161R^{1.6}$ (Narongrit, 2018). The result of the calibration of the root means square error (RMSE) is 4.6 - 4.8 mm / hr. Currently, Hydro - Informatics Institute (HII) has developed a near real-time and now-casting radar rainfall operation system for rainfall monitoring. Rainfall prediction with quantitative precipitation forecasting (QPF) produce 1-3-hour lead-time nowcasting of rainfall using image processing based on the centroid tracking method (Figure 9). The rainfall prediction results will be applied to urban flood early warning system.
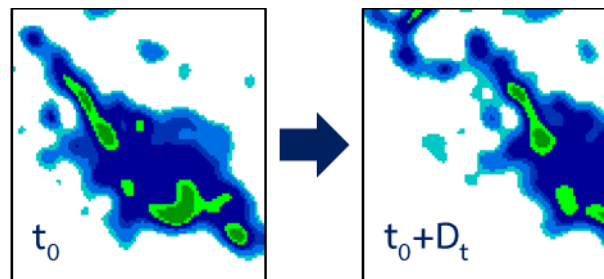

Figure 9. Centroid tracking method

7. APPLICATION OF WEATHER RADAR FOR URBAN FLOOD EARLY WARNING SYSTEM

The workflow of application of weather radar for urban flood warning system (Figure 10) is as follows
1. The data import process includes real-time data from weather radar, flood sensor, discharge data, rainfall data and water level.
2. The rainfall input to each sub-catchment represents the mean areal rainfall over the sub-catchment area. The rainfall intensities are estimate form weather radar reflectivity data using a power law relationship (Section 6) The rainfall time resolution is 15 min.
3. The runoff in each area is estimated by the Rational Method Equation.
4. If runoff in each area is higher than the flood threshold (Figure 11). It means that areas have flood risk. The system will alert.
5. The alerts process will show flood risk areas on dashboard. (Figure 12)
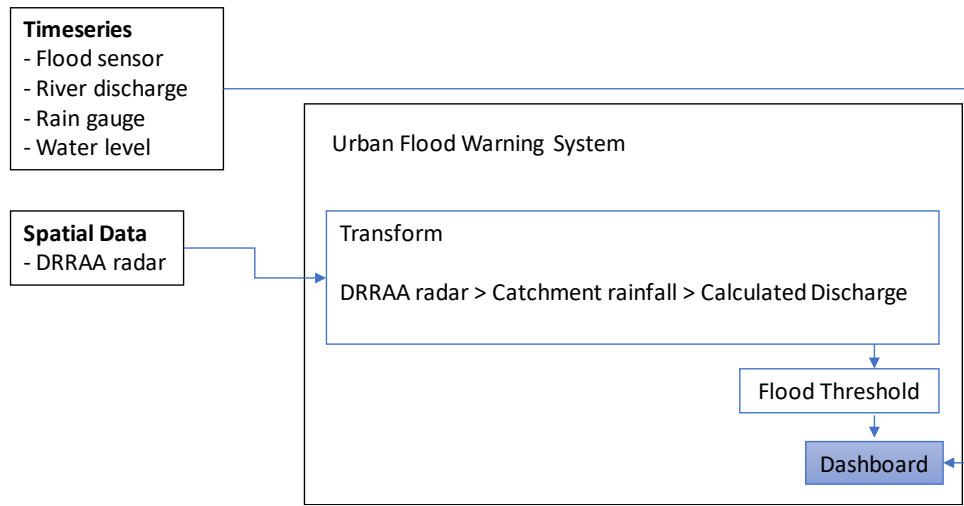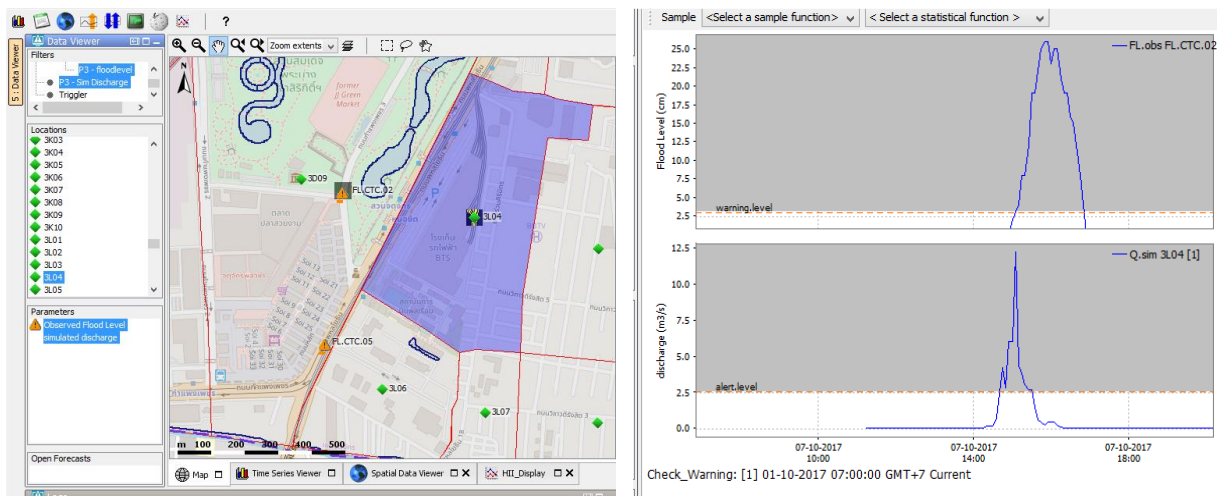
Figure 10. Urban flood early warning workflow

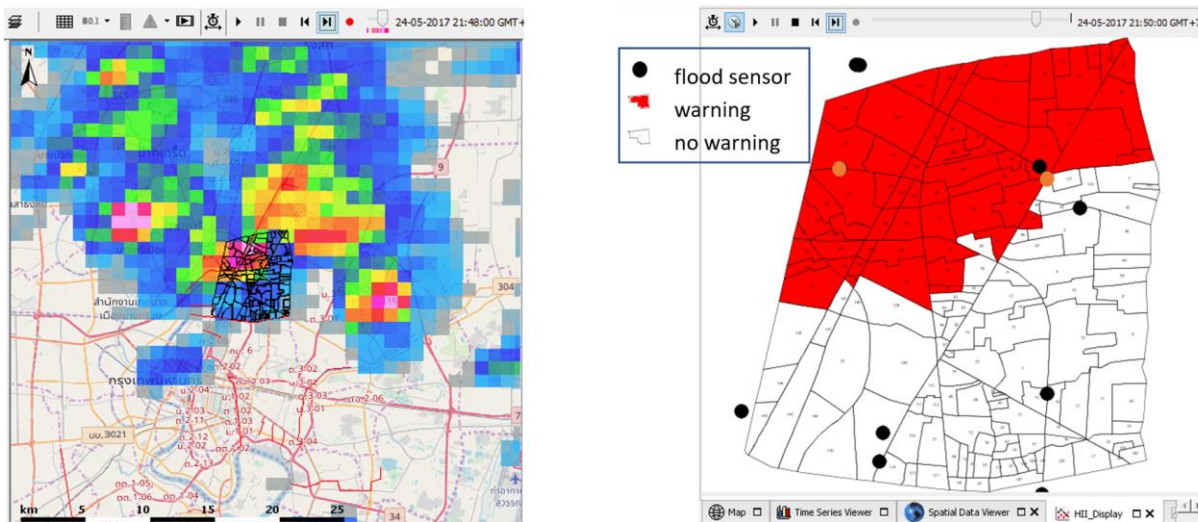Figure 11. (a) Map views (b) Flood threshold in urban flood early system

Figure 12. (a) Rainfall radar (b) Flood warning in each area

8.   CONCLUSIONS

Application of weather radar for urban flood warning system was developed in Polder No.3, Chatuchak District, Bangkok. The Flood threshold, according to the preliminary design of the drainage system in Bangkok and 1 hr now-casting from weather radar data can alert of flood risk in urban areas on time. The accuracy of the flood warning is 70%, which is still acceptable. However, the developed system also uses only 1 dimension as rainfall data. There are no considerations for water management variables, such as water pumps, tunnels, gates and drainage systems, which are important variables in the analysis of flood risk areas and urban flood warning systems.

KNOWLEDGMENTS

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