Assessment of human impact on flooding for Thai East coast - gulf basin

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Abstract. Due to a rapid increase in urban and built-up areas, the East Coast – Gulf basin of Thailand faces flood hazards more frequently than in the past. In this study, we aim to assess the effects of building construction on flooding, and any link between them. The FloodMap model is used to simulate flooding in the study area in September 2015. Two flooding scenarios were designed; one based only on land surface elevation and the other one with building construction included on the land surface. According to the result, we found that human construction increases flood hazard in the study areas, particularly flood depth. Flood areas are also found to increase if the human factor is added into the model, but in a lesser extent. With human construction, paved road is found to have the highest flood potential compared to other types of road. Built up areas are more flooded, while flooding extent is almost similar to results from the scenario of no human construction in forest and agricultural areas.

1. Introduction
Flooding can be caused by heavy or prolonged precipitation. Flood could occur when the rainfall is beyond the average rate of the particular land that could accept. However, currently, human activities become one of the most influenced factors which cause flooding. To settle down, humans clear the land, removing native plants and land characteristics, which can increase the rainfall runoff [1]. Moreover, urbanization causes a decrease in land infiltration due to an increase in the number of impervious features such as roads and pathways [2].

East Coast - Gulf basin is located in the eastern region of Thailand. Most of the basin is mainly in four provinces, which are Chonburi, Rayong, Chanthaburi, and Trat, and some parts in Chachoengsao and Sakaeo [3]. The Department of Public Works and Town & Country Planning: DPT indicated that in 2013 there was an increase in the number of buildings around 575 km² or 129% rising in the basin [4]. The expansion of built-up areas may have resulted from the urbanization in the basin caused by the Eastern Seaboard economic region development program. Industrial support in the eastern region and growth in the tourism sector also caused the growth of building in the region. Flood events frequently occur in the basin. Major floods occurred three times in the last decade [4]. Furthermore, an ineffective drainage system due to inappropriate land use zoning could interrupt runoff and the settlement in the lower basin, therefore, causing the hazard of flooding in low areas of this basin.

This study aimed to investigate human influence on flooding in the East Coast - Gulf basin. The impact of building construction on the level of flood risk was analyzed. The assessment was done by the application of ArcMap program [5] and FloodMap-HydroInundation2D model [6]. The result of this study would help the stakeholders to gain better understanding of human impact on flooding and could enhance the effectiveness of urban planning for flood prevention.

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2. Methodology

2.1. Study area
The western sub-basin of the East Coast-Gulf basin is selected as a study area, as shown in Figure 1. This sub-basin is located in Chonburi and Rayong province. Many famous places are located in this sub-basin, including one of the most popular tourist attractions; Pattaya city, and several industrial estates. Moreover, DPT indicated that flooding in this sub-basin was caused by manmade obstruction such as building and industrial estates, which would reduce the drainage capacity [4].

![Figure 1. Elevation map of the western sub-basin with flood observed points](image)

2.2. Model Description
FloodMap model is used to investigate the effects of building construction on urban flooding. FloodMap model is developed as a physically based two-dimensional flood inundation model on topographically complex floodplain [7-8]. The model has been applied under various conditions and proven as robust for different purposes, such as flooding prediction in the UK [9], sediment delivery problems in rivers [10].

The model simulates flooding in the urban areas in two stages. In the first stage, the model calculates the amount of surface runoff generated at each grid cell as an excess amount of effective rainfall after infiltration [11]. Infiltration capacity at time step, t, on the ponded surface is approximated using Green-Ampt infiltration equation [12].

\[
f(t) = K_f \left( \frac{q_f - h_0}{Z_f} \right) + 1
\]  

(1)
Where $K_s$ is the hydraulic conductivity of the soil at saturation area (m/h), $\phi_f$ is the capillary potential across the wetting front (m), $h_0$ is the ponding water on the soil surface (m), and $Z_f$ is cumulative depth of infiltration (m).

In the second stage, surface runoff generated at grid cells is routed on the gridded surface. Surface flow is decoupled in x and y direction following the drainage pattern defined as the steepest topographical slope descent. Flow rate is modelled using the Saint-Venant equation. In case of surface runoff, the convective acceleration term in the full version of Saint-Venant equation can be neglected in the momentum equation with respect to the discretised time step of simulation becomes:

$$q_t + \frac{\Delta t}{\Delta x} (q_t + g h_0 \phi(h+z) + \frac{g n^2 q^2}{R^2 h} = 0 \quad (2)$$

Where $q$ is the flow per unit width, $g$ is the acceleration due to gravity (m²/s), $R$ is the hydraulic radius (m), $z$ is the bed elevation (m), $h$ is the water depth and $n$ is the Manning’s roughness coefficient.

2.3. Model input and parameterization

The model requires topographical and meteorological inputs to simulation flooding. For topographical data, we use a digital elevation model (DEM) map derived from the ASTER Global Digital Elevation Model which is under the collaboration of the Ministry of Economy, Trade, and Industry of Japan (METI) and the National Aeronautics and Space Administration (NASA) [13]. DEM resolution was resampled to 50x50 m to reduce model run time.

Three-hour precipitation data were derived from the meteorological station located in Pattaya City. In this study, we chose the rainstorm event between 15th – 18th September 2015 that was caused by Tropical Depression Vamco and induced flash floods in the study area [14-19]. In this rain storm event, we only focused on the rainfall period over 15 hours between 16th to 17th September 2015, where the highest amount of rainfall in the study area was recorded. As there were no other rainfall records at three-hour resolution in the study area, uniform rainfall distribution was assumed in the model simulation.

Land use data was provided by the Land Development, which represents the land cover of the study areas in 2016. Infiltration parameters were assumed constant over the study area with $K_s$ 0.015 m/h and $\phi_f$ 0.73 m. The evapotranspiration rate is set at 0.05 mm per day as described in [11]. The drainage capacity for the flood modeling is set as 15 mm/h, which is the drainage capacity of Pattaya city reported by the director of Pattaya city sanitation division [20].

2.4. Model Evaluation

Performance of the FloodMap model is evaluated against validated using the observed flood levels (Table 1). Due to the scarcity of the observed flood levels in the study period, we used flood levels reported in the newspaper and websites measured by local news reporters. We also used online geolocated photos from news reporter websites [18-19], to estimate the flood depth at the particular areas by referring to nearby objects in the pictures, such as pathway and car. In total, seven estimated flood level data were used in the model evaluation. Table 1 summarized the collected flood level. Locations of the flood events are shown in Figure 1. Geolocated photos are presented in Figure 2.
Table 1. Estimated observed flood depth level at locations where online geo-located photos are available

| Location                                                   | Flood depth (cm) | Sources of evidence |
|------------------------------------------------------------|------------------|---------------------|
| Jomtien Soi 7, Chonburi (P1)                              | 30               | car, pathway        |
| Keha Eua Arthorn Na Jomtien, Chonburi (P2)                | 40               | car, people         |
| Sukhumvit road before J intersection, Chonburi (P3)       | 30               | billboard           |
| Pattaya Technical College, Chonburi (P4)                  | 25               | car                 |
| Jakkachet temple, Chonburi (P5)                           | 40               | news report         |
| Noen Kra Prok Intersection, Rayong (P6)                   | 100              | news report         |
| Maneewannitaya school gate, Rayong (P7)                   | 80               | news report         |

Figure 2. Evidence of flood events during Tropical Depression Vamco

The root mean square error (RMSE) is used as an evaluation criteria on the model performance, which is widely and frequently used in the hydrological model [21 - 24]. And the definition of RMSE is in the following form:

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{N}(O_i-P_i)^2}{N}}
\]  
(3)
Where \( N \) is the number of samples of \( O_i \) and \( P_i \) which represent the observed data and estimated model result. RMSE can be from 0 to \( \infty \), where 0 is the perfect value of RMSE [21].

2.5. Scenario design
In this study, we designed two flooding scenarios based on the elevation surface height. The first scenario, the original surface elevation was used in the model. The DEM was modified for the second scenario by incorporating building features on the elevation height. Building and road data in 2016 of the study area were derived from the Department of Public Works and Town & Country Planning. The resolution of these data is 1:4000. For building data, each grid cell was defined as 10 m for representing the height of the building in the grid. Then, it was overlaid on the elevation map to see the impact of human activity on flooding. It is to see where would be inundated if there were buildings on the surface.

As discussed in [13], the flood depth, which could hinder travel and affect transportation, is more than or equal to 30 cm. This depth threshold is based on the heights of car’s inlets which many cities adopted to close the road if the water depth rises to 25 – 35 cm. In this study, we used this threshold to define the inundation depth. The depth of the inundated areas must be higher or equal to 30 cm. If, therefore, the water depth is lower than 30 cm, it will be defined as dry areas as it might not have much effect on road disruption.

To identify the impact of building structures on the water depth, flood maps of each scenario were derived to compare the difference of water depth in each grid cell. If the difference of the water depth is positive, it means that there is an increase in the water depth, or the dry area becomes a wet area. For zero result, it means that there is no change in water depth or still dry. And for negative differences, it means that there is a decrease in the water depth or wet areas become dry areas.

After that, the rasterized road and land use would be overlaid on the flood maps derived from the model simulation for both scenarios. Then, it could be seen the impacts of flooding on road and land use from two different scenarios. For flooding impact on roads, the total length of inundated roads was estimated based on types of road, which are hard surface (paved road or asphalt road), soft surface (dirt road) and soil surface (pathway/wagon track). For land use, flooding extent is calculated for each type of land use to evaluate the flooding impact separately, then summarized in total. There are four land use types in the analysis which are agriculture land, forestry land, build-up land, and miscellaneous land.

3. Results and discussion

3.1. Model performance
We compared the observed flood level with the model result. All are shown and summarized in Table 2. From the comparison, all observed places found affected by the flood in the flooding simulation. P6 is the only observed location in which the simulated flood level is equal to the observed level. There are four validated points, which the simulated level is higher than the observation (P1, P2, P4 and P5). Meanwhile the rest are lower than the observed level (P3 and P7). For the evaluation using RMSE, the error of flood depth from the model is 12.154 cm. However, it is important to note that there are many limitations which could cause any error such as, the wrong measurement in the observation. Because the flood level was referred to the nearest object, which is not directly measured.

|         | P1  | P2  | P3  | P4  | P5  | P6  | P7  |
|---------|-----|-----|-----|-----|-----|-----|-----|
| Observed level (cm) | 30  | 40  | 30  | 25  | 40  | 100 | 80  |
| Simulated level (cm) | 46  | 48  | 25  | 33  | 55  | 100 | 60  |
| Difference (cm)     | -16 | -8  | 5   | -8  | -15 | 0   | 20  |
3.2. Effect of building construction on flooding

The total area of land in the western sub-basin using the hydrological tool in ArcMap to identify was 1,626 km$^2$. With a 30 cm water depth threshold, we found that 177.5 km$^2$ of the study areas are inundated under the scenario with raw elevation map. For the scenario with the building's height, the inundated areas increase to 178.6 km$^2$. It could be seen that human activity has an impact on flood events causing more hazard areas. However, the number of inundated areas in the second scenario might not reflect the total impact of human activity on flooding due to the different data scales. Some small building construction are omitted because of the difference in data resolution. The original resolution of the building features is 4x4 m (1:4000), while resolution of the DEM is coarser (50x50 m). When the rasterization of the building was done, most of the small polygons were not included in the data. So, the human influence on flooding may be underestimated. Table 3 breaks down the inundated areas into 5 intervals according to the flood depth.

| Flood depth (m) | Without building construction | With building construction |
|-----------------|------------------------------|---------------------------|
| 0.30 – 0.50     | 41.9                         | 43.2                      |
| 0.50 – 1.00     | 66.0                         | 66.4                      |
| 1.00 – 2.00     | 56.3                         | 55.9                      |
| 2.00 – 3.00     | 10.0                         | 9.8                       |
| 3.00 – 14.0     | 3.4                          | 3.4                       |
| Total           | 177.5                        | 178.6                     |

By water depth comparison, it is found that after including building construction in the simulation, there are 155 km$^2$ of the total study area where water depth increases. Only an area of 6 km$^2$ where flood depth decreases or becomes dry. And there is no change in water depth for the rest of the sub-basin; 1,464 km$^2$. Therefore, it could be implied that building construction has an impact on flood depth. The impacts of human construction on flood depth are more obvious than those on flood extent. Figure 3 illustrates (a) the inundated areas in the study area without building construction, (b) with building construction and (c) the change in flood depth.
Figure 3. (a) Inundated areas without building construction; (b) Inundated areas with building construction; (c) Change in flood depth between (a) and (b)
3.2.1. Impact on road. Table 4 shows that, with incorporation of building construction, part of the roads that are inundated by flood slightly increases by 0.4% compared to the scenario of no building construction. Paved road is most affected by flooding when building construction is included as can be seen from the largest increase in percentage of flooded distance. Pathway or wagon track, on the other hand, is least affected. However, this road type is more flooded than the others for both scenarios.

Table 4. Inundated road length

| Road type              | Total Length (km) | Without building construction | With building construction |
|------------------------|-------------------|--------------------------------|----------------------------|
|                        | Inundated length  | %                              | Inundated length  | %                              |
| Paved/asphalt surface  | 3,720.9           | 412.5                          | 11.09             | 431.6                          | 11.60             |
| Dirt surface           | 2,143.0           | 248.4                          | 11.59             | 252.2                          | 11.77             |
| pathway/wagon track    | 539.6             | 66.9                           | 12.40             | 67.2                           | 12.45             |
| Total                  | 6,403.5           | 727.8                          | 11.37             | 750.9                          | 11.73             |

3.2.2. Impact on land use. Overall, all land use types get affected by flood for both flooding scenarios as shown in Table 5. For the most affected land use is miscellaneous land and the least affected land is forestry. Results suggest that the inundated areas increase for most land use types under the second flooding scenario, except forestry. It is because there is no human construction in the forest. It could be implied that there is no human impact on flooding in forest areas.

Table 5. Inundated areas based on land use

| Land use               | Total Area (km²) | Without building construction | With building construction |
|------------------------|------------------|--------------------------------|----------------------------|
|                        | Inundated areas  | %                              | Inundated areas  | %                              |
| Agriculture land       | 541.3            | 61.7                           | 11.40             | 61.8                           | 11.42             |
| Forestry land          | 181.8            | 6.3                            | 3.46              | 6.3                            | 3.46              |
| Build-up land          | 660.4            | 79.1                           | 11.98             | 79.9                           | 12.10             |
| Miscellaneous land     | 176.0            | 21.3                           | 12.10             | 21.5                           | 12.22             |
| Total                  | 1,559.5          | 168.4                          | 10.80             | 169.5                          | 10.87             |

4. Conclusion
This study evaluates the effects of building construction on flooding in aspects of flood depth and flood extent in the west boundary of East Coast basin of Thailand. Application of the 2D flooding model to investigate the roles building construction in flooding shows that human constructions increase the flood depth up to 3 m in the study area. Flooding areas also expand, which mainly affects paved roads and built up areas. However, there are some limitations in this study, which may result in an underestimation of flood situation, such as the use of relatively coarse resolution topographical data and lacking detailed rainfall and land surface data. Future studies should focus on the use of high resolution of rainfall data and building construction. This can largely minimize model uncertainty and errors in the flood prediction.

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