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An Investigation of DEM Resolution Influence on Flood Inundation Simulation

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Abstract

This study investigates the influence of DEM resolutions on flood inundation simulation. Sanyei drainage area of Tainan City is taken as a case study. The catchment of Sanyei area is 43.7 km2 with a main stream of 6.7 km and elevations running from 2 m to 30 m. This study uses 1x1 m LiDAR DEM of Sanyei area as a basis. To do pure 2D flood simulation, the channel elevation is adjusted based on the cross-sectional measurements. The channel adjusted 1x1m DEM is later used as basis to aggregate several DEMs including: 5x5m, 10x10m, 20x20m, 40x40m. Five flood inundation models were built based on the 5 DEMs mentioned above with a same model setting. Results show that the inundation area evaluation increases with coarser DEMs. Specifically, the inundation area given by the 40x40m DEM is 1.5 times greater than that given by the 1x1m DEM. This may not only lead to different decision making in evacuation route and responses, but also the evaluation of economic loss and project planning, etc.

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Keywords:

1. Introduction

Flood modelling and urban flood risk management draw increasing attention due to population growth and large economic values of areas vulnerable to flooding. In recent years large-scale flood disasters have taken place in large

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cities and caused large economic loss, such as: Manila, Philippines (2013); Beijing, China (2012); New York, USA (2012); Bangkok, Thailand (2011); and Brisbane, Australia (2011). Cities like Jakarta, Indonesia and Ho Chi Minh City, Vietnam are more flood-prone that experience floods almost every year. In order to reduce flood risk more insight in the detailed behaviour of urban drainage systems is needed.

In flood inundation modelling, DEM resolution plays an important role in terms of the modelling resolution and accuracy. Most flood inundation maps are evaluated using coarse DEM, such as 10x10m spatial resolution and/or coarser because of model limitation on and/or trade-off between computational grids and computational time. Though topographic information derived from light detection and ranging (LiDAR) data is nowadays available, LiDAR DEM is rarely and directly applied in flood inundation modelling; and yet the influence of DEM resolution on flood inundation simulation is rarely investigated.

This study uses 3Di, a newly developed hydrodynamic computing program [1] by Prof. Guus Stelling and the 3Di consortium, to investigate the influence of DEM resolution on flood inundation simulation. 3Di takes the advantages of both quadtree [2] and subgrid [3] techniques to both reduce large computational grid number and maintain computational resolution to the DEM pixel. The details of 3Di theoretical basis may refer to [1]. Five models are built with a same model setting and external forcing based on five DEMs, including 1x1m, 5x5m, 10x10m, 20x20m, and 40x40m.

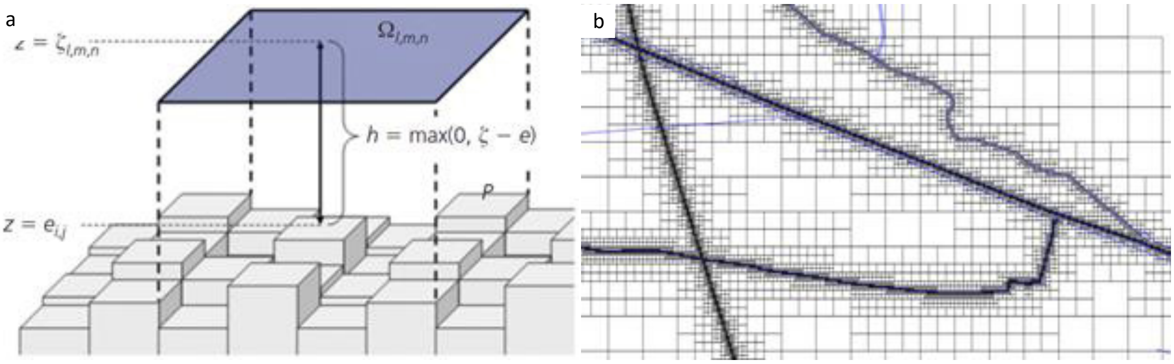

Fig. 1. (a) Example of sub-grid [1]; (b) Example of quadtrees [1].

1.1. Sub-grid

The sub-grid technique is based on grids with different resolution. Bottom levels and friction values are given in a detailed DEM or Cartesian grid. For the computation of water levels and velocities the fine grid pixels are clustered into larger cells, as shown in Fig. 1(a); in which, ζl,m,n is the water level above the reference plane, ei,j is the bottom elevation above reference plane, and Ωl,m,n the hierarchical quad tree ordering. Instead of averaging the elevations of the detailed DEM to 1 average surface level used in the computations, 3Di is constructing and using a table describing the relation between water level and volume for the large cell, based on the information of the detailed DEM. Therefore the detailed information is not lost, but aggregated and used when solving the 2D shallow water equations. The friction information available on the detailed DEM is aggregated to the larger cell, resulting in a friction depending on water depth taking into account the specified local variations in friction of the detailed DEM.

1.2. Quad tree

Another aspect in the 3Di computational core is the use of quadtrees. This means that the grid cells used in the computation are not of constant size. The cell size is small on locations where large detail is required and large where this is not needed. Local grid refinements are made by recursively splitting cells in 4 quadrants, maintaining the orthogonality of the grid. In 3Di, the detailed DEM is specified as input data, and the user can define the desired minimum and maximum cell size to be used in the computations. 3Di will generate the quadtree grid as illustrated in the example of Fig. 1(b). In areas where the difference between the highest elevation and the lowest elevation from the detailed DEM is small, 3Di will generate larger cells. Manual input and correction is also possible, using polylines to define areas which need refinement.

2. Flood inundation model setup

The study area, Sanyei drainage area, is located in south Tainan City, Taiwan, with a main drainage channel of 6.7 km in the catchment of 43.7 km2, illustrated in Fig. 2. The ground elevation goes from 2m in southwest to 30m in northeast with an average slope of 1/1700. To build the Sanyei area model, several data are required to prepare, including: (1) DEM of several resolutions – 1x1m, 5x5m, 10x10m, 20x20m, and 40x40m; (2) roughness map: defined based on land use map; (3) infiltration map: defined based on land use map and experience; (4) Rainfall event.

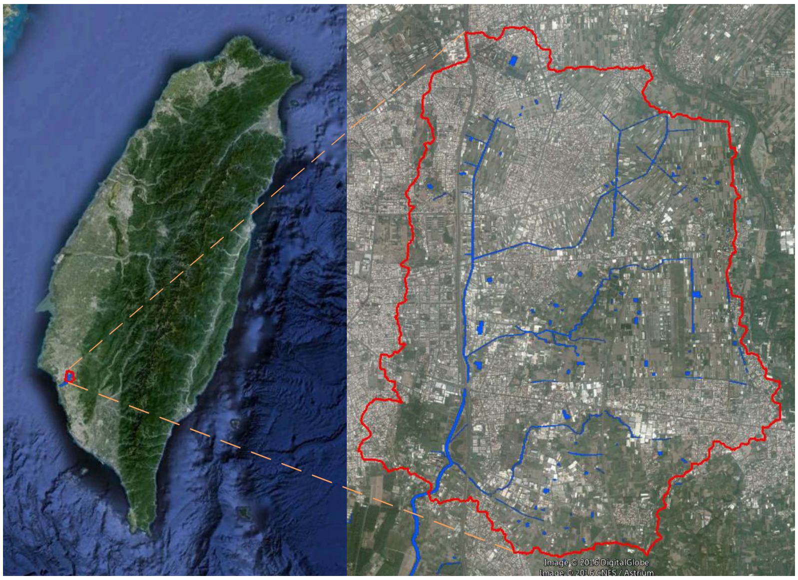

Fig. 2. Location of Sanyei area in Tainan City.

2.1. DEMs

Fig. 3 illustrates the general DEM error in channel parts derived from the LiDAR data, which may only show water surface of non-transparent water. According to Fig. 3, channels on DEM should be adjusted based on the real world channels before building a flood inundation model. This study takes the cross-sectional measurements for adjusting the channel topography on the 1x1m LiDAR DEM. As cross-sectional measurements only provide the information of the measured locations, the channel topography between two locations shall be interpolated. Once the channel raster layer is created, the original DEM may be updated with it (Fig. 4).

Moreover, to investigate the flood inundation influenced by DEM resolutions, 5x5m, 10x10m, 20x20m, 40x40m DEMs are prepared by aggregating based on the 1x1m channel adjusted DEM. Fig. 5 demonstrates two DEMs of 10x10m and 1x1m; in which, channel width smaller than 10m is being averaged by its surrounding grid elevations (Fig. 5[a]). For a narrow channel, the averaging could make the channel characteristics disappear in the DEM. Fig. 5(b) demonstrates 1x1m LiDAR DEM may keep as much topographic information of the real world. In which, the channels are perfectly kept on the DEM.

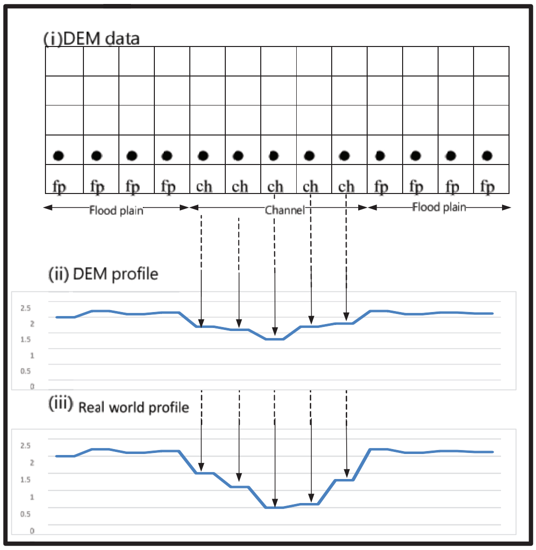

Fig. 3. Example of LiDAR DEM data and error.

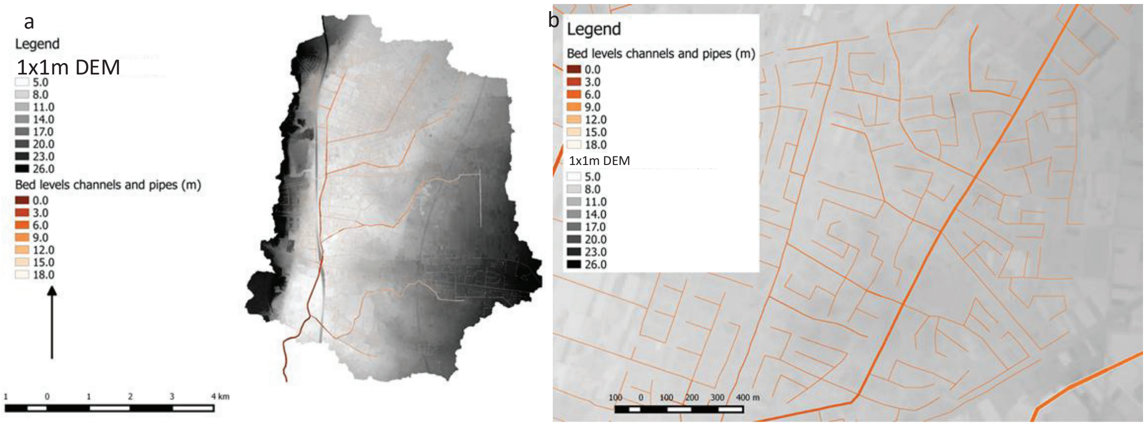

Fig. 4. (a) Channel adjusted DEM; (b) Drainage channels and smaller pipe network burned in the DEM.

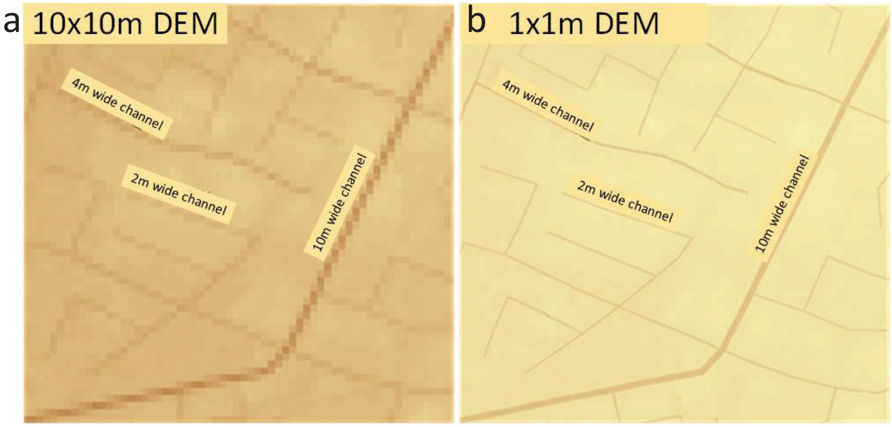

Fig. 5. (a) Channels of different widths on 10x10m DEM; (b) Channels of different widths on 1x1m DEM.

2.2. Roughness and Infiltration maps

The spatially distributed roughness map which was derived from the land use map. Based on literature [4] and previous projects, Manning's n roughness values have been selected. The spatial distribution of the Manning's n values is shown in Fig. 6(a). Likewise, the infiltration map (Fig. 6[b]) is created based on maximum infiltration rate of different land uses given in Table 2. Infiltration rate, in fact, is influenced by many factors, such as soil type, soil moisture, surface vegetation conditions, etc. However, it requires detailed investigation, not financially allowed in this study. Thus, the infiltration values in this study are based on a straightforward approach and determined based on the land use map. The model takes into account the maximum infiltration as a constant rate in time.

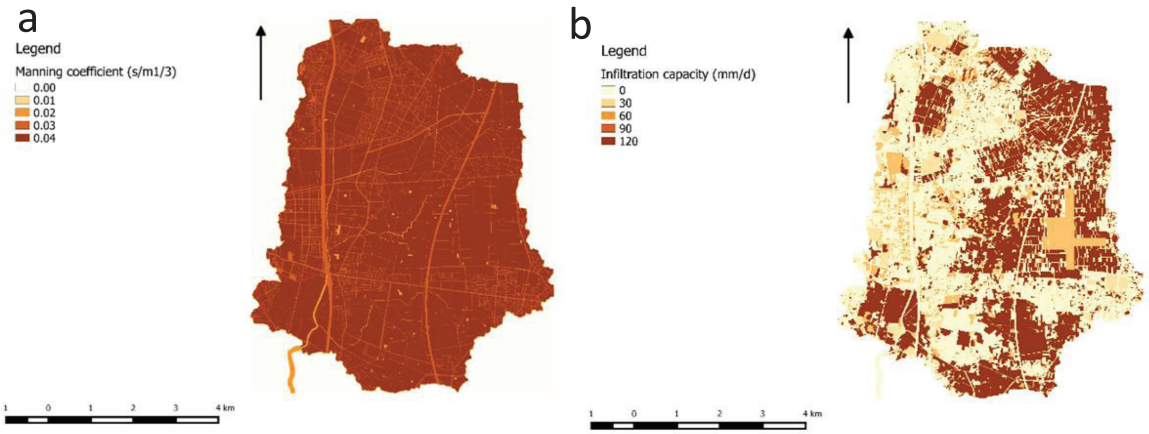

Fig. 6. (a) Roughness map; (b) Infiltration map.

Table 1. Roughness values used in study.

Land use	Manning's n (s.m-1/3)	Land use	Manning's n (s.m-1/3)	Land use	Manning's n (s.m-1/3)
Agriculture	0.044	Water Conservancy	0.025	Recreational	0.035
Forest	0.055	Construction	0.05	Mine and salt	0.04

		land			
Transportation	0.035	Public use	0.035	Others	0.04

Table 2. Infiltration values used in study.

Land use	Infiltration rate (mm/day)	Land use	Infiltration rate (mm/day)	Land use	Infiltration rate (mm/day)
Agriculture	120	Water Conservancy	0	Recreational	40
Forest	200	Construction land	0	Mine and salt	40
Transportation	0	Public use	0	Others	40

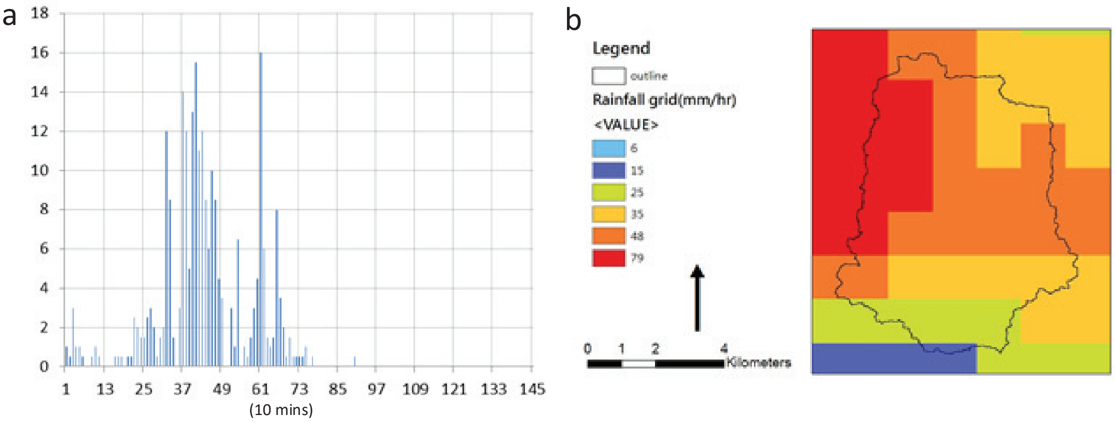

Fig. 7. (a) 0520 Rainfall gauging record; (b) Example of radar rainfall grid imposed on model.

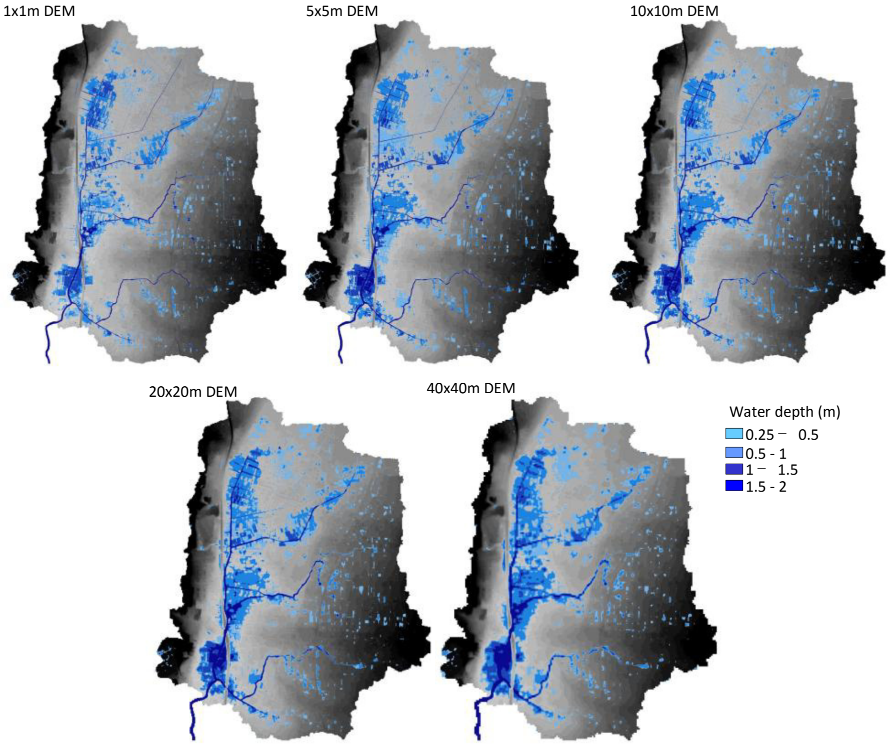

Fig. 8. Maximum flood extents given by 5 different grids.

2.3. Rainfall event

Taiwan is frequently hit by typhoons and severe rainfall events. The rainfall event on 20th May 2012 has been selected as the event to be simulated. The rainfall data of one of the rainfall stations is shown in Fig. 7(a). The maximum 10-minute precipitation for this station is 16 mm; the maximum of 6 consecutive time steps (a duration of 1 hour) is 70.5 mm, and the daily total is 245 mm. This total rainfall occurred within the first 13 hours.

For two other stations in the area, similar values are found: daily values between 228 and 271 mm, a maximum 10 minute rainfall between 15 and 22.5 mm and a maximum hourly value between 70 and 84 mm.

The radar gridded rainfall data has an areal average total of 255 mm/day, and 250 mm falls within the first 12 hours. An example of the gridded precipitation for a time step is given in Fig. 7(b).

3. Case study

Based on the data prepared in Section 2, models with five different DEM grids, including 1x1m, 5x5m, 10x10m, 20x20m and 40x40m, are built for simulating the selected rainfall event of May 20th 2012. Results show that the maximum flood extents given by the five models may demonstrate similar flood extent maps, as shown in Fig. 8. However, the inundation areas given by the five models have shown large differences. Table 3 shows that inundation area given by the model with 1x1m DEM grid is 603.46 ha at the water depth greater than 0.25m, while it is almost 1.5 times larger (893.38 ha) with the 40x40m DEM grid. The inundation areas in most of water depth categories, in Table 3, increases with grid sizes – the coarser DEM grids give larger inundation areas.

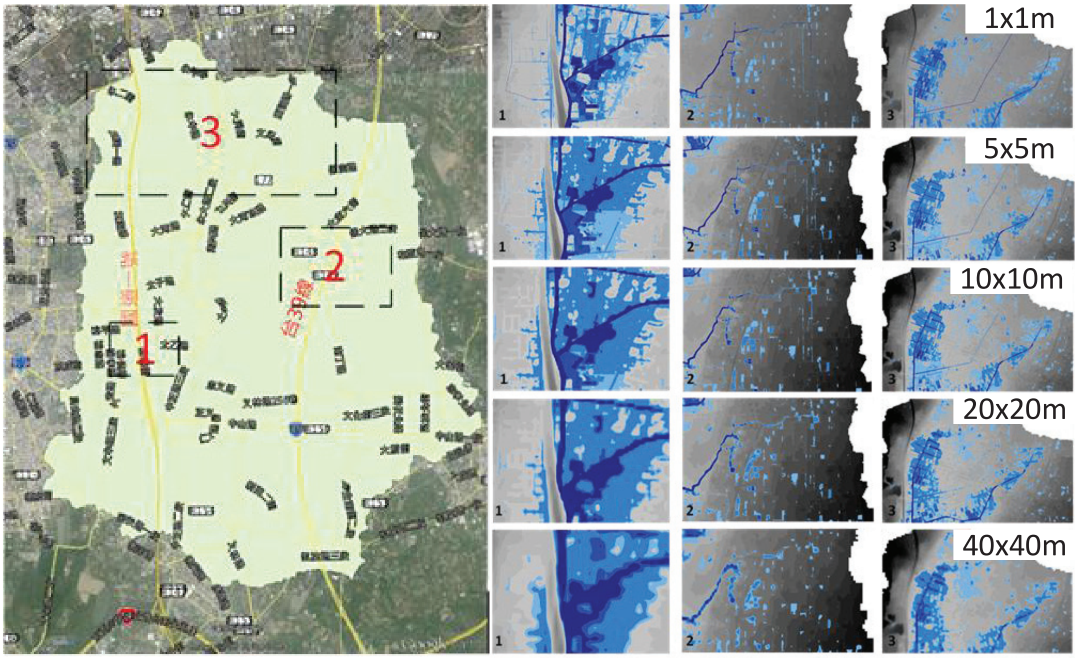

Fig. 9. Detailed flood inundation extent at 3 locations.

Moreover, Fig. 9 demonstrates the differences in flood inundation at 3 locations in detail.

- Location 1 with an elevated highway in the middle and a bottlenecked main stream shows that serious inundation could be predicted with the coarser DEMs, while the 1x1m DEM shows only scattered inundated areas. This could lead to different decision making in evacuation route and responses, as well as project planning, etc.
- Location 2 with a small tributary and a relatively flat landscape may not result in too much difference in the max flood extent.
- Location 3 in the upper stream shows that the inundation area also increases with coarser DEMs. The difference in inundation area evaluations given by the five DEMs may be caused by the hydraulic gradients due to degrees of topographic characteristics generalization.

As shown in Fig. 9, the detail of a DEM may determine the seriousness of the simulated flood inundation. Particularly on the left size at Location 1, one may notice that the water enters into channels with the 1x1m DEM. Nonetheless, the channel elevation has been averaged by the surroundings in the other four DEMs. The channel gradually disappear with coarser DEM grids; and hence, water couldn't successfully flow into the DEM channels. Fig. 5 may also show that the DEM channels still exist (Fig. 5[b]) or not (Fig. 5[b]) in the models, implying that the channel can work properly or not. Moreover, if 1D network linked to 2D grid system is included in the model, the channel bottlenecks can be better modeled.

Table 3. Inundation area evaluated based on maximum flood extents.

Water depth (m)	Inundation area (Ha)				
	1x1m	5x5m	10x10m	20x20m	40x40m
> 0.25	603.45	717.49	752.14	806.18	893.38
> 0.5	351.07	422.33	448.35	500.31	562.48
> 1	133.75	157.20	163.02	181.33	213.76
> 1.5	60.21	75.66	79.48	85.65	86.38

> 2	48.47	55.14	52.90	50.26	49.45

4. Findings

This study investigates the influence of DEM resolutions on flood inundation. Sanyei drainage area of Tainan City is taken as a case study. Five models were built based on five different grid-sized DEMs from 1x1m to 40x40m. Results show that:

- DEM resolution influences the topographic characteristics – coarser DEMs may simplify the topographic information; and hence, it influences hydrodynamic properties of the simulated area, such as the hydraulic gradients near channels. In which, water may or may not smoothly flow into channels. Inundation area may increase with the coarser DEMs, though much difference may not be seen in flood extent maps.
- Inundation area evaluation is important to economic loss estimation. The inundation area in previous studies might be overestimated. Nonetheless the water depth could be probably underestimated. Thus, estimating the economic loss may require high spatial resolution DEM for better estimation.
- Detailed flood extents in some locations by the five models show much differences. Especially, the location with an elevated highway and urban buildings. This also indicates the simplification of topographic information may reduce the accuracy of the flood inundation models. The model will be extended with more detailed information on the 1D system bottlenecks in a follow-up study.
- Flood inundation map is important to governments for project planning. Accurate and high resolution flood inundation map may influence the decision maker to make better decisions in engineering projects. Moreover, this could also lead to different decision making in evacuation route and responses.

Acknowledgements

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