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ASSESSMENT OF IMPACTS OF THE ROAD SYSTEM ON FLOOD REGIME IN THE COASTAL FLOODING AREA OF VU GIA - THU BAN RIVER BASIN, QUANG NAM PROVINCE

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Abstract. Flooding is one of the dangerous types of natural disasters, which has been causing great damage to human values and even human life, leading to negative impacts on socio-economic development, specifically in the lowland areas of the Vu Gia - Thu Bon river basin. The road system contributes to promoting intra-regional and inter-regional connectivity and is an important factor for socio-economic development. However, in certain cases, the road system continues to be expanded and enhanced, turning them into "dyke systems", interfering with the natural flood regime, increasing the area and flooding time. To assess the impact of the road system on the flood regime, the paper uses the *Mike Flood* modeling module to simulate the change of flood regime for flood events in 1999, 2007, 2020, and the 5% flood scenario. The comparison between the current road system and the old road system shows a certain increase in both depth and flooded area, especially in the case of 5% flood, the flood depth increases by 0.1 - 0.2 m in the upper part of the basin but only a small change in the lower part of the basin from 0.01 - 0.04 m.
Keywords: flood, Quang Nam, coastal zone, road system.

1. Introduction

The two-way relationship between road systems and flood regimes is well known in the scientific community, but most scientists are only concerned with the flood aspect that damages structures, obstruct traffic, and leaves many other long-term impacts on socio-economic development and the environment [1]. Flooding results in significant repair costs for road authorities make it difficult to access emergency services [2] and disrupts traffic in general. The consequences for business and the economy at large can be significant [3]. Since the time and cost required to rebuild are quite large, long-term, sustainable planning is very important [4]. In general, the approach to this problem is to

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consider and analyze flood risk as an important input for traffic planning, and develop emergency response plans to consistently control the situation and efficiently allocate resources to prevent, reduce, and restore transportation systems [5]. Although there is a two-way relationship, most only focus on the impact of the floods on the transportation system, and rarely mention the opposite relationship, such as the USS EPA [6] which just mentioned the effects of road network development on ecosystem structure and their function.

This paper studies the impact of the current road system on the natural flood regime by using the *Mike Flood* model for the sensitive lowlands of the Vu Gia - Thu Bon basin, in the area of Quang Nam Province. This is the initial study to explore this scientific aspect in Vietnam.

Quang Nam province has a large area (10,406 km^2), belongs to the central key economic region, and is home to two cultural heritages (My Son sanctuary, Hoi An ancient town) and a biosphere reserve (Cu Lao Cham) recognized by UNESCO. In the future, Quang Nam plans to double the size of the economy by 2025 with high per capita income, together with Da Nang - Quang Ngai to become a new growth pole, creating spillover effects in the Central - Central Highlands region. Occupying 92% of the area of Quang Nam province, the Vu Gia - Thu Bon river basin has the largest water resources compared to the 9 largest river basins in Vietnam. Besides fresh water, the high potential of hydropower resources has also been exploited to serve the socio-economic development of Quang Nam province, but the disadvantage of "excess" water in the flood season has affected the growth of Quang Nam province.

In the previous literature, many studies focused on coastal flooding and inundation in Quang Nam province, but now due to the rapid development of the infrastructure system, especially the road system. Due to the fact that the problem of flooding occurs in traffic, urban areas, and industrial zones, there are many adverse fluctuations, so it is necessary to have a study taking into account certain situations to create a scientific basis and propose appropriate solutions to minimize damage caused by floods and inundation to the economy and the safety of people's lives [7]

In Vietnam, the national transport mostly relies on the road transport system, which has become a strong driving force for socio-economic development. The Central Coast region has urban areas distributed in lowland plains, affected by high tides, and also areas with a high risk of flooding. The situation is more serious because the upper part of the basin has steep terrain, and short rivers, causing water rapidly flows downstream. In addition, the coastal dune system plays as a flood barrier. A common solution used to deal with this risk in low-lying areas is the regulation of building structures with foundations exceeding the flood level. But raising the local foundation of each project, including transportation projects, without a comprehensive strategic urban development plan will lead to topographic changes and change the regional flood regime. Therefore, the inundation issue remains unresolved but only moves from one place to another, and those topographical changes cause significant changes in the flooding mechanism, making it more difficult to forecast. Besides, the rapid urbanization of the area, accompanied by concreting, significantly reduces the infiltration capacity of water into the soil, which also affects the regional inundation regime.

To assess the impact of the road system on the inundation regime in the study area, the paper used the *Mike Flood* model to simulate the flooding process of typical floods in the period before and after the road building. The results provide a scientific basis for proposing solutions to minimize the impact of floods on socio-economic development.

2. Content

2.1. Study area, data, and methodology

2.1.1. Study area

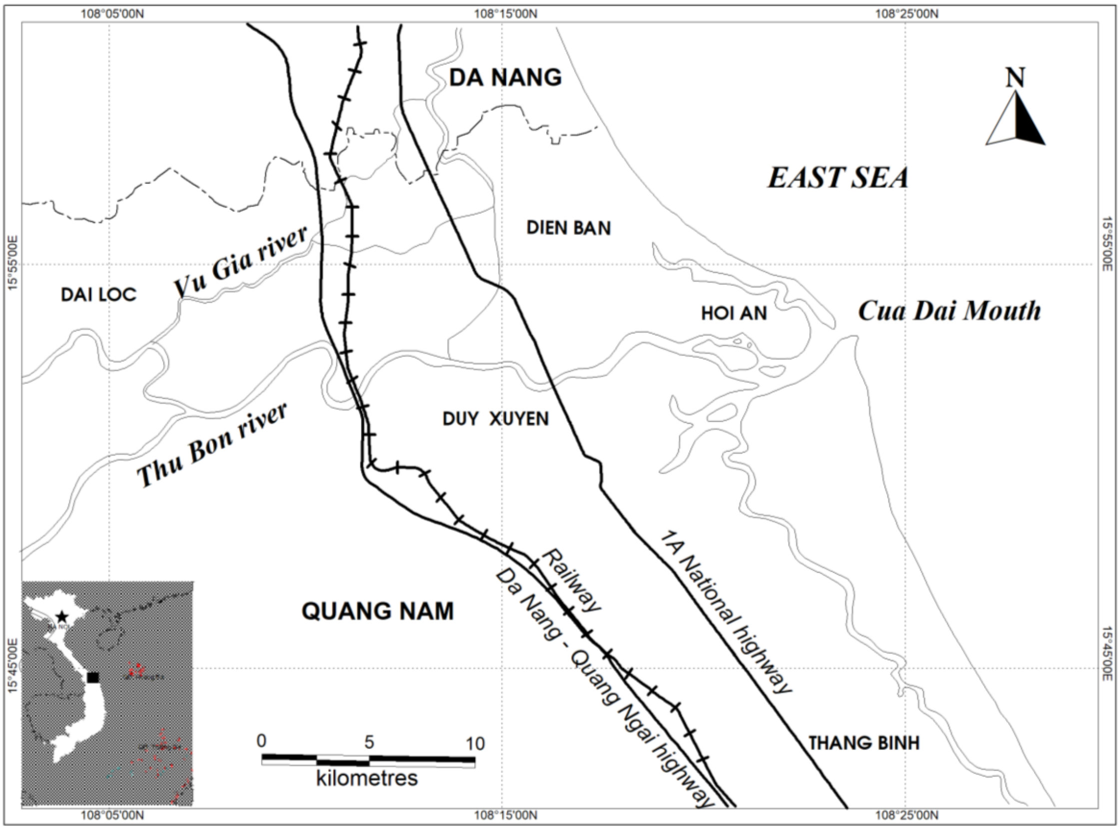

Figure 1. main traffic roads play an important role in the flood regime on the flood plain of Vu Gia - Thu Bon river basin

The study area in Quang Nam province has a road system that is classified into two categories: crosses and runs along the flood relief channel. Traffic routes crossing the flood relief channel from West to East include Ho Chi Minh road (175 km), Da Nang - Quang Ngai highway (90 km), 1A National Highway (85 km), and coastal road (48 km, from Cua Dai to Nui Thanh), Thong Nhat railway (85 km). In the future, there will be a Lien A railway. The roads extending along the flood relief channel include 14B National Road (42 km), 14D National Road (74.4 km), and 14E National Road (89.4 km). Additionally, there are 20 provincial roads with a total length of about 465 km, and more than 7,905 km of rural and urban roads, forming local flood cells in the general flood regime of the region. Coastal roads play the role of flood barrier, usually with elevations of about 1 - 5 m higher than the surrounding area, and together with the road system along the flood relief canals and locally interconnected roads, they act as dyke systems, which fragment the terrain, reduce flood capacity as well as interfering with the regional flood regime.

2.1.2. Data sources

Rainfall data are collected at weather stations: Hien, Kham Duc, Thanh My, Nong Son, Giao Thuy, Hoi Khach, Ai Nghia, Cau Lau, Hoi An, Da Nang, Tra My, Tien Phuoc, Hiep Duc.

Water flow data was collected at the hydrological stations of Thanh My and Nong Son. Hourly tide levels at Cua Han and Cua Dai were collected at Cam Le and Cau Lau stations.

Reservoir operation parameters were collected at the management boards of Song Bung 4, A Vuong, Song Bung 4A, Song Bung 5, Dak Mil, and Song Tranh 2. The system of 6 reservoirs is operated following the Vu Gia - Thu Bon inter-reservoir process.

Table 1. Parameters of reservoir following the inter-reservoir operation procedure [8]

Name of Reservoir	**Volume**	**Operation volume**	**Flood storage volume**	**Dead volume**	**Maximum discharge flow**
	10^6 m^3	10^6 m^3	10^6 m^3	10^6 m^3	m^3/s
A Vương	344	267	35	77	579
Đak My 4	312	158	31	154	440
Song Tranh 2	729	521	62	208	1528
Song Bung 4	511	234	75.3	277	883.7
Song Con 2	29	25	0	4	0
Song Bung 5	20	2	0	18	0
Song Bung 6	3	0	0	3	0
Sum	**1948**	**1207**	**203.3**	**741**	**3431**

Table 2. Technical parameters of dams [9]

No.	**Name**	**Disigned water level (m)**	**Discharge water level (m)**	**Outlet number**	**Sized**	
					B (m)	H (m)
1	An Trach	+2.0	-2.00	12	4.00	4.50
2	Bau Nit	+2.0	-2.00	6	4.20	3.80
3	Ha Thanh	+2.0	0.56	7	2.35	1.85
4	Thanh Quyt	+2.0	-0.50	6	3.80	2.50
5	Duy Thanh	+1.1	-1.10	4	20.00	2.20

Topographic data: topographic map 1:10,000 collected at the Ministry of Natural Resources and Environment; topography of riverbed cross-sections, road, and railway data were collected and surveyed by the authors.

2.1.3. Study method

Simulation of flood regime in downstream Vu Gia - Thu Bon, taking into account the influence of road and railway systems, based on collected and measured data using *Mike Flood* module (the one-dimensional model in *Mike 11*) to simulate river flooding, and use a 2-D *Mike 21* model to simulate bankfull flow [10]. The steps are the following:

- Set up 1D model - *Mike 11*;

- Identify river network and hydraulic works: The river network used in the hydraulic analysis is the main river of the Vu Gia - Thu Bon river system, downstream from Nong Son station (Vu Gia river), from Thanh My station (Thu Bon River) and some other main rivers at downstream. In addition, due to the lack of monitoring data in the Bung, Con, Tuy Loan, and Ly rivers, the water flow in those rivers is simulated by a hydraulic model, which is included in the simulation of the river system as the boundary. The river network established in the model includes 14 rivers and 477 cross-sections;

- Set up the 2D-*Mike 21*;

- Topographic maps scaled 1:10,000 and elevation data measured in 2020 are applied to create the grid in *Mike 21*. When the calculation grid was built, the riverbed topography was not included in the computational domain because it is available in *Mike 11* HD. Besides, the traffic network is created in the elevation grid to simulate the terrain change.

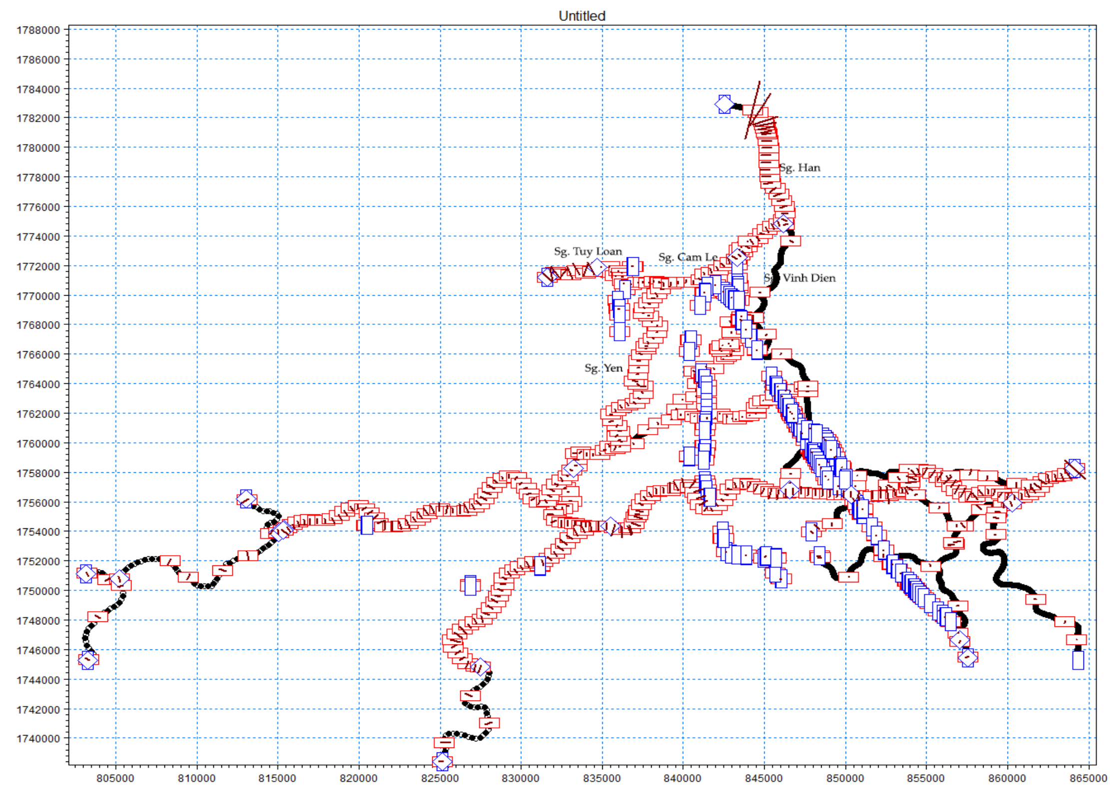

Figure 2. Hydraulic network (Mike 11) of Vu Gia - Thu Bon basin

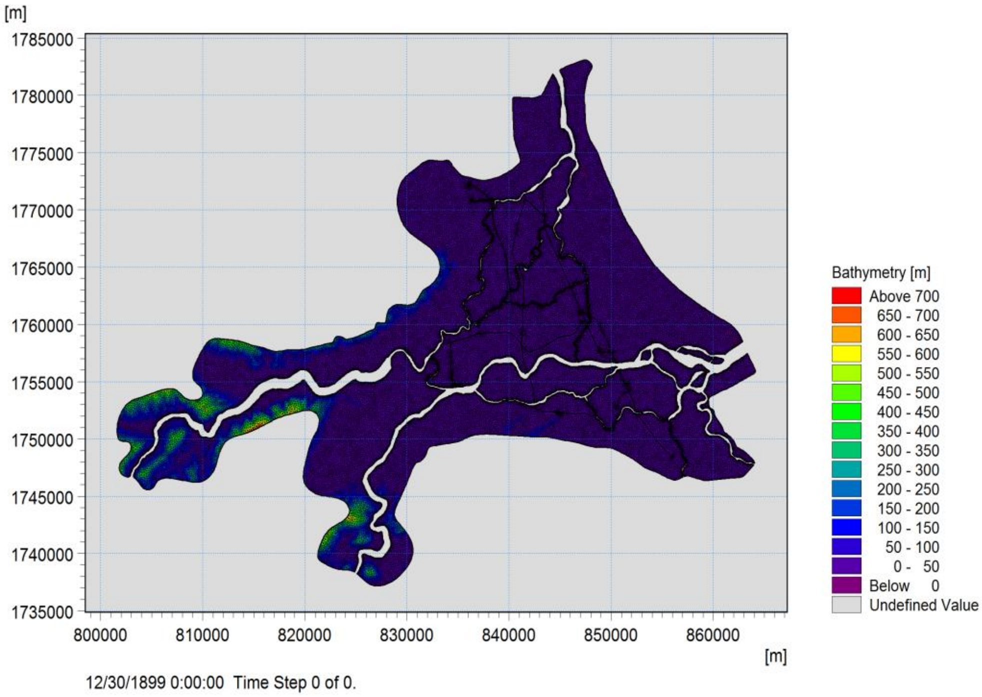

Figure 3. Computational area in Mike 21

Combine *Mike 11* and *Mike 21*: *Mike Flood* module;

Mike 21 and *Mike 11* models were linked by 2 types of connections: side connection and standard connection. The rivers were connected to the flooded plain area through a side connection while the sewers are connected to the flooded plain area through a standard connection (Figure 4).

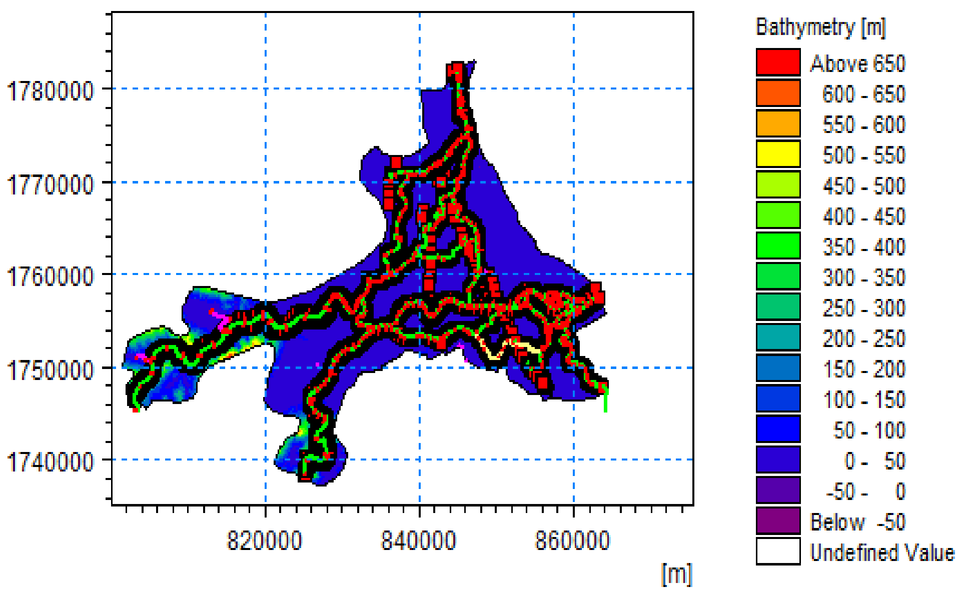

Figure 4. The connection between Mike 11 and Mike 21 in Mike Flood module

**** Calibration and Validation***

In this study, we selected the data of floods in 2016 (from December 11, 2016 to December 22, 2016) for calibration and the flood from November 2, 2017 to November 9, 2017 to validate the model. These are three floods with synchronous monitoring data, consistent with the riverbed topographic data measured in 2020 by the Institute of Geography. The Nash index at the hydrological stations all reached from 0.72 to 0.97, showing that the established model is good enough and can be used to calculate the research scenarios.

Table 3. Nash index to compare calculated and measured water levels in 2016, 2017

Station	Hoi Khach	Giao Thuy	Ai Nghia	Cam Le	Cau Lau	Hoi An
2016	0.75	0.80	0.76	0.85	0.97	0.97
2017	0.82	0.93	0.77	0.92	0.77	0.72

Table 4. Compare Hmax at validating stations in early 10/2020

Area	Calculated Hmax (m)	Measured Hmax (m)	Difference (m)
Hoi Khach	16.84	16.83	0.01
Ai Nghia	9.82	9.82	0.00
Cam Le	2.15	2.15	0.00
Giao Thuy	8.72	8.74	-0.02
Cau Lau	4.49	4.50	-0.01
Hoi An	2.74	2.72	0.02

The results of model testing with the flood event in October 2020 at monitoring stations show that simulated water levels are close to the measured water level. The difference between the measured and calculated peak water levels is from 0.01 - 0.02 m.

2.2. Study results

2.2.1. Flood simulation result with the hydraulic input of extreme flood event in 1999

The model inputs include hydraulic parameters (similar to the flood event recorded in 1999), topographic data for 2020, and a detailed road and rail system. The model results show a significant increase in flood depth as well as flood area. For example, comparing the measured flood data in 1999 and the simulation results for the new topographic data in 2020, the flood depth increases by +2.29 m at Hoi Khach station, +0.76 m at Ai Nghia station, +0.53 m at Giao Thuy station, and +0.49 m at Cau Lau station (Table 5). On the other hand, some small areas have a decrease in flooded depth such as Cam Le station (-0.3 m).

Table 5. Comparison of Hmax before and after the flood event in 1999 (m)

Criteria \ Station	Hoi Khach	Ai Nghia	Cam Le	Giao Thuy	Cau Lau
Measured in 1999	20.11	11.03	3.98	9.92	5.72
Modelling result (flood hydraulic data of 1999, and topographic data of 2020)	17.82	10.27	4.28	9.39	5.23
Changes	+2.29	+0.76	-0.30	+0.53	+0.49

Model results show that 60,905.12 ha are at risk of flooding, occurring in 85 communes, wards, and towns of Dai Loc, Dien Ban, Duy Xuyen, Que Son, Thang Binh, and Hoi An district, of which about 5/6 of the area can reach a deep flood level, posing a risk to human life (depth > 2 m) (Table 6).

Table 6. Model results of flood-able areas with hydraulic data in 1999 and topographic data in 2020

Classes \ Criteria	Depth levels (m)	Area (ha)
1	< 0.5	3,923.63
2	0.5 ÷ 1.0	3,775.85
3	1.0 ÷ 1.5	5,207.86
4	1.5 ÷ 2.0	7,110.55
5	2.0 ÷ 2.5	8,452.07
6	2.5 ÷3.0	9,083.98
7	3.0 ÷3.5	8,407.17
8	3.5 ÷ 4.0	5,360.61
9	> 4.0	9,583.40
Total floodable area		**60,905.12**

2.2.2. Flood simulation result with the hydraulic input of extreme flood in 2007

The model input includes hydraulic data (similar to the flood event recorded in 2007), topographic data for 2020, detailed road and rail system. The model results show a small increase in flood depth (less than 1 m). For example, flood depth increases by +1.00 m at Hoi Khach station, +0.45 m at Ai Nghia station, +0.35 m at Giao Thuy station, and +0.03 m at Cau Lau station (Table 7). On the other hand, some small areas have a decrease in the flooded depth such as Cam Le station (-0.49 m).

Table 7. Comparation of Hmax measured in 2007 and simulation resluts (m)

Criteria \ Station	Hoi Khach	Ai Nghia	Cam Le	Giao Thuy	Cau Lau
Measured in 2007	18.74	10.81	3.49	9.95	5.42
Modelling result (flood hydraulic data of 2007, topographic data of 2020)	17.74	10.36	3.98	9.60	5.39
Changes	+1.00	+0.45	-0.49	+0.35	+0.03

The model results in comparison between the hydraulic data in 1999 and 2007 show that there is no significant change in the areas that are likely to flood (about 2000 ha, a decrease of about 0.03%) (Table 7 and Table 8).

Table 8. Modeling result of the floodable area with 2007 flood hydraulic data and 2020 topographic data

Classes \ Criteria	Depth level (m)	Area (ha)
1	< 0.5	4,172.42
2	0.5 ÷ 1.0	4,563.07
3	1.0 ÷ 1.5	6,289.28
4	1.5 ÷ 2.0	7,383.82
5	2.0 ÷ 2,5	9,024.65
6	2.5 ÷ 3.0	9,246.76
7	3.0 ÷ 3.5	6,684.61
8	3.5 ÷ 4.0	4,063.77
9	>4.0	7,320.03
Total floodable area		58,748.41

2.2.3. Flood simulation result with the 2020 flood hydraulic data and 2020 topographic data

The model results show that the total flooded area is 49,223.92 ha, occurring in 80 communes, wards, and towns in the districts of Dai Loc, Dien Ban, Duy Xuyen, Que Son, Thang Binh, and Hoi An town, Quang Nam province, the districts of Hai Chau, Son Tra, Ngu Hanh Son and Hoa Vang of Da Nang city. The area of inundation by severity is shown in Table 9.

Table 9. Modeling result of the floodable area with 2020 flood hydraulic data and 2020 topographic data

Criteria / Classes	Depth level (m)	Area (ha)
1	< 0.5	6,715.89
2	0.5 ÷ 1.0	7,793.62
3	1.0 ÷ 1.5	9,154.79
4	1.5 ÷ 2.0	9,367.09
5	2.0 ÷ 2,5	6,805.58
6	2.5 ÷ 3.0	3,280.22
7	3.0 ÷ 3.5	1,673.66
8	3.5 ÷ 4.0	1,072.57
9	> 4.0	3,360.50
Total floodable area		49,223.92

2.2.4. Flood simulation result for the scenario of flood event reaching a high level at frequency 5%, and with 2020 topographic data

According to Decision No.33/QD-TTg dated January 7, 2020, the coastal areas of Quang Nam (belonging to the Vu Gia - Thu Bon river basin) have to assure safety against 5% flood. Therefore, the paper simulated the case of high flood reaching 5%, and with or without the present road system. The result is shown in Table 10 and Table 11.

Table 10. Possible changes in maximum water level and corresponding Qmax at local hydrological stations

Station / Criteria	Ai Nghia	Giao Thuy	Cau Lau	Hoi An
Hmax (m, without road system)	10.82	9.68	5.56	3.50
Hmax (m, with road system)	10.93	9,88	5,60	3,49
Changes (m)	*+0.12*	*+0.19*	*+0.04*	*-0,01*
Qmax (m^3/s, without road system)	4,225.48	10,434.69	3,337.20	2,571.05
Qmax (m^3/s, with road system)	4,295.72	10,777.31	3,365.44	2.582.00
Changes (m^3/s)	*+70.25*	*+342.62*	*+28.24*	*+10.96*

The changes in Hmax values of stations located in the upper part of the basin was bigger compared to the station located in the lower part of the basin (+0.12 m at Ai Nghia station and +0.19 m at Giao Thuy station, compared to +0.04 m at Cau Lau station and -0.01 m at Hoi An station). The corresponding Qmax values at those stations also have a similar pattern. This indicates the impact of the road system on the flood regimes, especially on roads crossing the basin.

Table 11. Modeling result of floodable area in the scenario of flood 5% with 2020 topographic data

Depth level (m)	Flood area (ha, without road system)	Flood area (ha, with road system)	Changes value (ha)
< 0.5	3,442.66	3,264.38	-178.28
0.5 ÷ 1.0	3,874.95	3,754.04	-120.91
1.0 ÷ 1.5	5,480.37	5,208.45	-271.92
1.5 ÷ 2.0	6,666.28	6,320.96	-345.32
2.0 ÷ 2,5	8,158.48	8,088.14	-70.34
2.5 ÷ 3.0	8,136.31	8,281.12	+144.81
3.0 ÷ 3.5	5,421.43	5,581.77	+160.34
3.5 ÷ 4.0	3,560.26	3,765.68	+205.42
> 4.0	7,437.57	7,932.53	+494.96
Sum	52,178.31	52,197.07	+18.76

The road system affects not only the changing of hydrological factors (Q, H) but also changes the flood area and depth. Decrease of flood area with low depth levels (< 2.5 m), but a strong increase of flood area with higher depth, especially in the western part of Da Nang - Quang Ngai highway and 1A National Road.

3. Conclusions

The application of *Mike Flood*, and *Mike 11*, *Mike 21* to simulate flood events in 1999, 2007, 2020, and 5% flood scenario gives results that are relatively consistent with reality (the model validation gives a Nash index of 0.72 - 0.97). Therefore, the established models can be used to simulate previous floods or scenarios as required.

The flood simulation model with the topographic data, road system and river cross-section measured in 2020 show that there is an increase in the flooded area, and flooded depth, especially in the upper part of the road that crosses the basin. In the lower part of these roads, there is a slight decrease in these parameters, which shows the role of the transportation system in changing the regional flooding regime.

The Da Nang - Quang Ngai highway has a high terrain. The difference between the natural and surrounding terrain is big, up to 9.6 m high, so it has an impact on changing the water level in the upstream area at the highest point of 1.5 m; diverting flood flows to the main rivers, increasing the depth of flooding. Compared with all the routes, this is the route that has the strongest impact on flooding in the coastal area of the Vu Gia - Thu Bon river basin.

Other roads such as 1A National Highway, railway, and provincial roads are all located downstream of the Da Nang - Quang Ngai expressway, so their impacts on flood flows as well as inundation are not significant.

It can be seen that for the current road system, the highway is likely to increase flooding and inundation in the lower Vu Gia - Thu Bon river basin. Therefore, in order to minimize flood and inundation here, it is necessary not only to develop direct options for traffic routes but also to have a comprehensive solution and to develop an integrated flood management plan to meet the demand of sustainable development, maximizing benefits from flood plains, mitigating flood damage, protecting and maintaining the stability of rivers and ecosystems, establishing suitable flood relief corridors across the Vu Gia - Thu Bon river.

The main traffic routes continue to be built and upgraded such as Da Nang - Quang Ngai Expressway, 1A National Highway, and Thong Nhat Railway. These traffic routes will surely bring many benefits to socio-economic development. However, the model results show that these routes will further change the flood regime with the trend of increasing flood time, flood depth, and increasing local flooding.

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