Eco. Env. & Cons. 27 (2) : 2021; pp. (967-976)
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ISSN 0971–765X

Using Spatial Interpolation with Barriers to assess the spread of flood inundation on different land use types in Duc Tho district, Ha Tinh Province, Vietnam

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(Received 15 August, 2020; Accepted 20 April, 2021)

ABSTRACT

In Vietnam, every year, floods cause the submersion of large areas of land, especially agricultural land in flood plains. Flood mapping is important for adaptation and mitigation plans and is usually done by interpolation method using flood depth data. However, normal interpolation is inappropriate when barriers such as dykes exist causing interruption and discontinuity on the surface. The objectives of this study were to apply IDW Interpolation with Barriers to map the spread of flood inundation on land and to calculate the level and area of flood inundation for different types of land use in Duc Tho District of Ha Tinh Province, Vietnam. The inundation map of land-use types was established by overlaying the interpolated flood inundation map and land use map, which was divided into two areas including the outside and inside areas of La Giang dyke. Results showed that the interpolation was accurate as all the employed statistics including R^2, RMSE, and MAPE got acceptable value for both the outside-dyke and inside-dyke areas. The outside-dyke area was found to have an inundation area of 2,945.93 ha, which accounted for 65.05% of the total natural land area and the inundation depth was mostly over 2.0 m. The inundation areas of agricultural land, nonagricultural land, and unused land were 1,916.26 ha, 946.28 ha, and 83.39 ha, respectively. For the inside-dyke area, the total area of inundation was 7,003.74 ha, accounting for 43.91% of the total natural land area and the inundation depth was also mostly over 2.0 m. The inundation areas of agricultural land, non-agricultural land, and unused land were 5,314.46 ha, 1,627.65 ha, and 61.64 ha respectively. The findings indicate serious flood submersion upon agricultural land, and it should therefore be given priority in flood prevention and adaptation plans. The method of IDW with Barriers applied in this study has shown high accuracy. Thus, it is recommended to be applied to other areas with different topographic and flooding characteristics to further assess its strength and suitability.

***Key words** : Flood inundation, IDW, Interpolation with barriers, Land resource, Land use*

Introduction

In recent decades, the increasing number of disasters, particularly hydro-meteorological disasters, have threatened human life and infrastructure. Floods are identified as the most common type of natural disaster affecting life and property in vulnerable areas (IPCC, 2014; CRED-UNISDR, 2015). With the population growth along the river banks, the damage also increases during floods. Especially, climate change is strongly impacting the frequency of flooding. The large area that remained inundated for a longer period resulted in massive property damages, vast loss of crops, and affected human beings (Icaga *et al.*, 2016; Rind *et al.*, 2018).

Human enlargement has changed land-cover and

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land-use patterns dramatically on a global scale. This has influenced the characteristics and patterns of flooding or accumulated the dangers of flood for the inner urban human sphere. It has been acknowledged that agricultural land encroached by rural settlements. Besides, changes in climate and land-use patterns have an effect on water accessibility and run-off, which alters the flood regimes of streams. The power to forecast floods and inundation extents in river basins makes it doable to issue early warnings and thereby scale back flood injury to life and property (Jothityangkoon *et al.*, 2013; Vu, 2014; Mishra *et al.*, 2017; Hartanto and Rachmawati, 2017).

The flood mapping process is an essential part of flood risk management, as flood maps not only provide accurate spatial information about the extent of the flood but, when combined with a Geographical Information System (GIS), can also help decision-makers obtain other useful information to assess flood-related risks such as human loss, economic damage, and environmental degradation. For these reasons, flood maps are often used in practice to estimate the potential flood risk. For this approach, the flood depth, area, and duration of flood inundation for the peak level of a specific return period are determined using hydrologic models. During the extreme flood incidence, it is important to determine the rapid extent of flood inundation on land use and cover (Lingadevaru *et al*., 2019). The most important element for flood disaster management is the availability of spatial maps and timely information for decision-making and appropriate action by the administrative authorities. Many mathematical models have been developed that can be used as a tool to minimize flood plains bordering rivers and to calculate the associated risk taking into account the hypothetical floods of different return periods (Kadam and Sen, 2012; Icaga *et al*., 2016; Darabi *et al*., 2020).

Several techniques have been used in the literature to map floods such as empirical methods (Kadam and Sen, 2012; Grzelak and Kwinta, 2013; Scorzini *et al.*, 2018; Lingadevaru *et al.,* 2019), remote sensing techniques (Khan *et al*., 2011; Jung *et al.,* 2014), hydrodynamic modeling (Merwade *et al.,* 2008; Rind *et al*., 2018; Ureta *et al*., 2020; Kang *et al*., 2021; Malik *et al*., 2021). Besides, the environmental impact of inundation involves changes in the water quality, disturbance of vegetation, and agricultural land use was studied by Marfai (2011).

Spatial interpolation has been an important tool for estimating continuous spatial environmental variables for effective decision-making (Brusilovskiy, 2009). Many modeling tools including GIS offer the earth and environmental scientists the ability to carry out spatial interpolation routinely to generate useful spatial continuous data for all kinds of analysis (Wasser and Goulden, 2020). Spatial interpolation methods give a means of predicting values of an environmental parameter at an unmeasured location using data from point measurements within the sample space (Burrough, 1986; Aronoff, 1989; Childs, 2004). In an ideal situation, a finite set of inputs establishes variations in an environmental parameter and they exactly conform to established physical law. If a relationship is established, the values of the desired parameter can be correctly estimated (Mitas and Mitasova, 2005; Ikechukwu *et al.*, 2017). These new technologies represent a major improvement to continuously monitor environmental disturbances such as flooding, land cover or land-use changes, and deforestation.

In addition, the determination of flood-prone areas for land use planning is crucial concerning the use of their natural properties for flood and natural hazard management. With the development of computer technology and the increasing availability of digitally formatted hydrological data such as precipitation, surface elevation, land use, and land cover, the numerical model-based approach has been actively studied and widely used. An alternative approach in delineating flood hazard areas through a straightforward interpolation process is using the Inverse Distance Weighting (IDW) interpolation method in ArcGIS (Ziary and Safari, 2007; Ureta *et al*., 2020.

According to the World Health Organization (WHO, 2016), Vietnam is one of the most disaster-prone countries in the world. Duc Tho, a rural and agricultural district located in the North Central Coast region of Vietnam is frequently affected by storms and floods. In this context, using IDW spatial interpolation with barriers to assess the spread of flood inundation of the 2016 flood (which is one of the biggest floods in recent decades) on land use types in Duc Tho district was studied. The main aim of this study was to establish flood inundation maps based on flood depth data and calculate the level and area of flood inundation for different types of land use in the study area. The study proved the power of GIS technology integrated with spatial interpolation in flood assessment, and its results provide helpful scientific information for the management of land resources in order to adapt to a more severe flooding condition

Study area

Duc Tho is a rural district of Ha Tinh Province in the North Central Coast region of Vietnam. It is bounded by 18°23'42"N to 18°34'40"N latitude and 105°32'E to 105°40'58"E longitude covering an area of nearly 20,350 ha. The district has a large land area for agricultural cultivation, and a variety of soil types that are suitable for various crops such as rice, corn, potatoes, and fruit trees, etc. The district is located on a narrow strip of land with a full range of terrain types, with hills, valleys, plains, rivers, with narrow space, in which mountains and hills account for 10.5% of the natural land area. The terrain is lower from the west to the east and is strongly divided. Duc Tho is located in the tropical monsoon area, and is influenced by the transitional climate between the North and the South, with typical tropical climate characteristics. The mean annual rainfall in the district is about 2100 mm, mainly concentrates in the autumn which causes flooding very frequently. Song La (La river) is the main river flowing through the territory of 9 communes of the district with a length of 12 km before merging to the Lam river. To protect large residential areas and agricultural fields from the annual river flooding, a dyke called La Giang was constructed in the 1930s with a length of 19 km. The dyke divides the district into two areas: Outside-dyke (area A) and inside-dyke (area B) (Fig. 1).

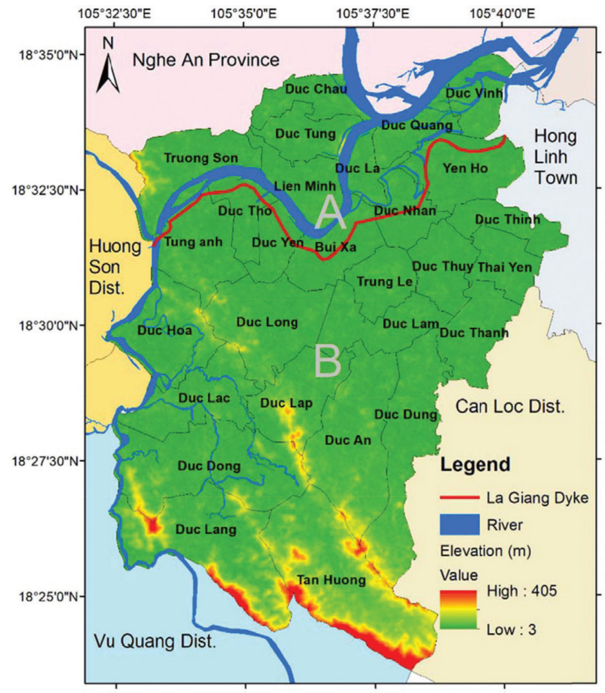

Fig. 1. Map showing location and characteristics of Duc Tho district. Area (A) is the outside-dyke area and Area (B) is the inside-dyke area.

Methodology

Flood level interpolation

In this study, inundation maps of the October 2016 flood were established based on flood depth data using the IDW interpolation method. The map of inundated land was established by overlaying the flood inundation map and land use map. 266 flood points were collected throughout the district, including 65 points outside La Giang dyke and 201 points inside La Giang dyke. These points include flood markers (flood level measurement poles) which were constructed by the government and data points from a field survey conducted with the participation of local people. To perform the interpolation process and evaluate the accuracy of the interpolation results, these flood points were then divided into two datasets including a dataset used for interpolation (called Training Points, including 240 points) and a reference dataset used to test the accuracy of the interpolation results (called Reference Points, consisting of 26 points, equivalent to more than 10% of the points used for interpolation). The reference points including 8 points outside La Giang dyke and 18 points inside la Giang dyke, and were randomly selected from 266 points. The location of the training points and reference points is shown in Figure 2.

In the IDW interpolation method, the sample points are weighted during interpolation such that the influence of one point relative to another declines with the distance between the points. Weighting is assigned to sample points through the use of a weighting coefficient that controls how the weighting influence will drop off as the distance from the new point increases. The greater the weighting coefficient, the less the effect points will have if they are far from the unknown point during the interpolation process. As the coefficient increases, the value of the unknown point approaches the value of the

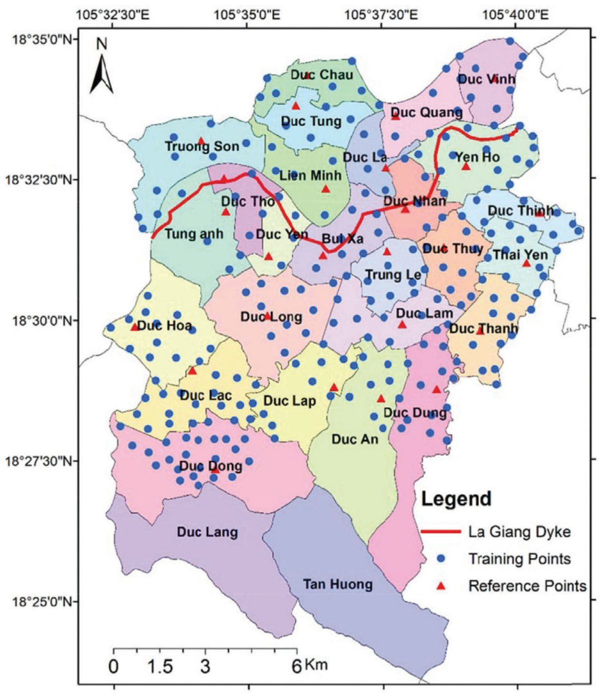

Fig. 2. Training points and reference points used for spatial interpolation

nearest observational point. IDW works based on the following equation:

$$Z_0 = \frac{\Sigma_{i=1}^{N} Z_i . d_i^{-n}}{\Sigma_{i=1}^{N} d_i^{-n}} \quad (1)$$

Whereas: *Zo* is the estimation value of variable Z at point *i*; *Zi* is the sample value at point *i*; d_1 is the distance of sample point to estimated point; *n* is a coefficient that determined weigh based on the distance; *N* is the number of sample points.

One of the challenges when applying spatial interpolation is when barriers like dykes, roads, mountains exist in the study area causing interruption and discontinuity on the surface. The advantage of the IDW method is that it allows to include barriers in the analysis. The barrier prevents the interpolator from using sample points on one side of it. Figure 3 demonstrates how IDW works with a barrier.

In this study, the La Giang dyke is the barrier that divides the study areas into two areas: the outside dyke area (the side with the river) and the inside dyke area (the side without the river). The process of interpolation of flood level and construction of inundation map on land use in this study is described in Figure 4.

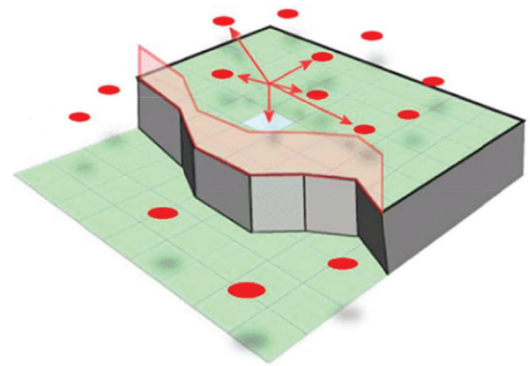

Fig. 3. Interpolation with a barrier (Srinivasan, 2020)

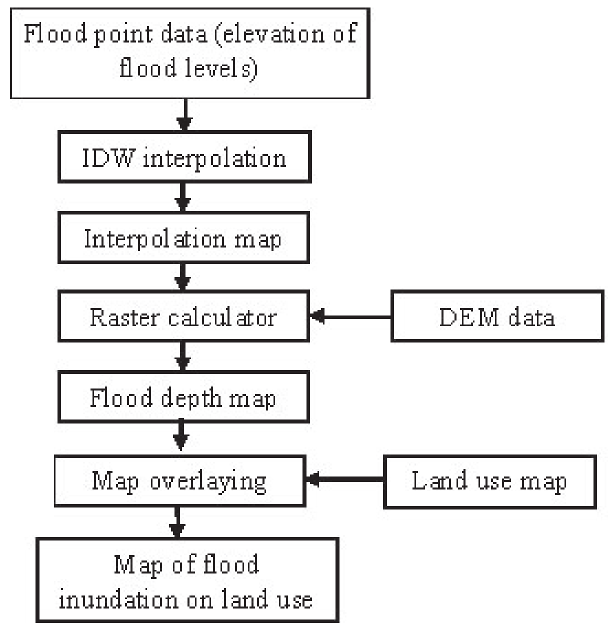

Fig. 4. Flow chart of spatial interpolation process for assessing flood on different types of land use

Accuracy assessment of the interpolation result

To assess the accuracy of the interpolation results, this study used three indicators, including the Coefficient of Determination (R^2), Mean Absolute Percent Error (MAPE), and Root Mean Square Error (RMSE).

The coefficient of determination (R^2) was used to determine the correlation between the interpolated flood level and the observed flood level. The coefficient of determination is determined based on the following formula:

$$R^2 = \left(\frac{\sum_{i=1}^{n}(A_i - \bar{A})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(A_i - \bar{A})^2}\sqrt{\sum_{i=1}^{n}(P - \bar{P})^2}} \right)^2 \quad (2)$$

Whereas: Ai is the actual (observed) value of flood level at the reference point i

$\overline{A}$ is the average of the observed values of flood level

$\overline{P}_i$ is the predicted (interpolated) value of the flood level at the reference point i

P is the average of the interpolated values of flood level

n: is the number of reference points

The closer the R^2 is to 1, the better the interpolation

The Mean Absolute Percent Error expresses the accuracy as a percentage, thus evaluating the relative difference (%) between the set of interpolated values and the set of actual measured values. The MAPE is defined as follows:

$$MAPE = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{Ai - Pi}{Ai}\right| \tag{3}$$

Where all the variables are defined the same as in Equation (2)

MAPE values range from 0% to 100%, the smaller the MAPE value, the more accurate the interpolation.

The Root Mean Square Error is the square root of the mean of the square of all of the errors at reference points. RMSE is mathematically expressed as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Ai - Pi)^2} \tag{4}$$

Where all the variables are defined the same as in Equation (2)

RMSE ranges from 0 - ∞, the RMSE value of zero represents the absolute accuracy of the interpolation. The smaller the RMSE, the closer the interpolated value to the observed value, and thus, the higher the prediction accuracy.

Results and Discussion

Interpolation map and map of flood inundation

The result of the interpolation process was the interpolated flood level elevation surface as presented in Figure 5. It is worth noting that because the input data of the interpolation was the elevations of the flood level at the training points, the interpolation map, therefore, presents the surface of the elevation, which may include the areas that are in fact not flooded.

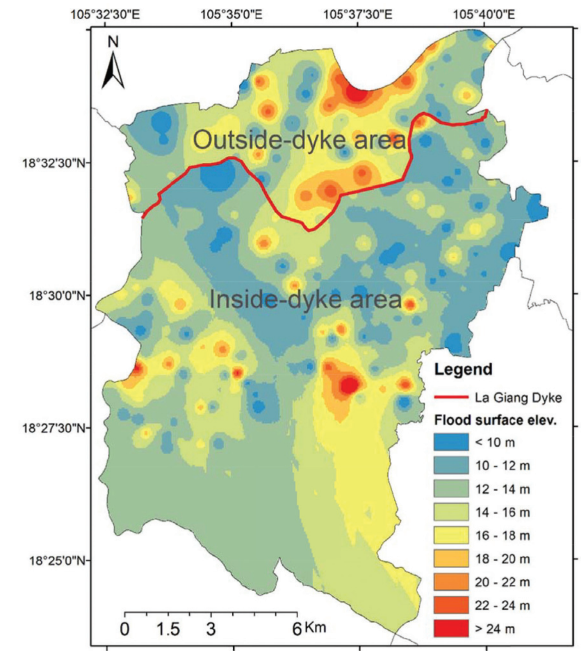

Fig. 5. Interpolation surface of flood level elevation

The flood inundation map was then generated by using IDW interpolation surface minus the elevation of the terrain stored on a Digital Elevation Model (DEM). On the inundation map, areas with positive values were inundated areas, areas with 0 or negative values were non-flooded areas. The inundation map was then classified into 5 categories based on flood depth: 0 : No flood; 1: Flood depth < 0.5 m; 2: Flood depth from 0.5-1.0 m; 3: Flood depth from 1-2.0 m; 4: Flood depth more than 2.0 m. It can be seen from the inundation map displayed in Figure 6 that both outside and inside areas of the La Giang dyke were inundated mostly with a depth of over 2.0 m, which indicates the seriousness of the flood in the study area. In addition, most areas of the district were flooded, except for the southern part of the district, where elevation is high.

Accuracy of the interpolation

The accuracy of the interpolation results was evaluated using R^2, RMSE, MAPE indicators which were described in the Methodology section. This process was conducted to compare the elevation value of the inundation level (shown in Figure 5) at the reference points (referred to as the actual measured value) and the value of the interpolated map at

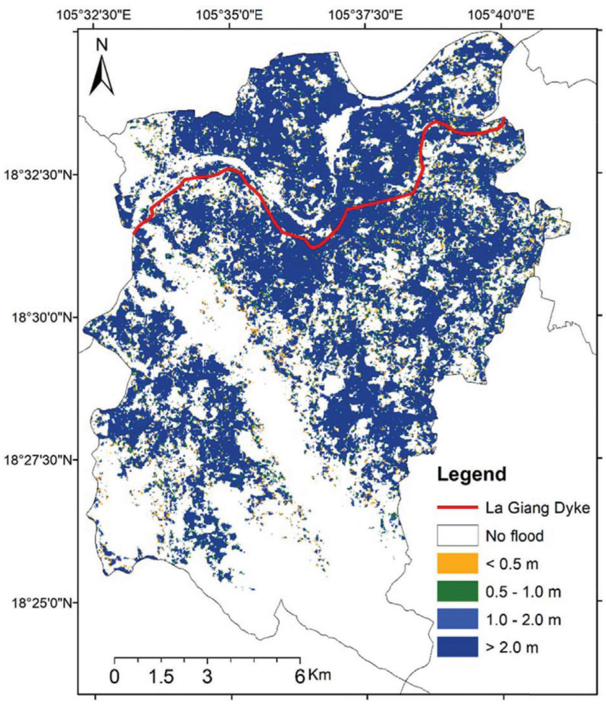

Fig. 6. Flood inundation map of Duc Tho district

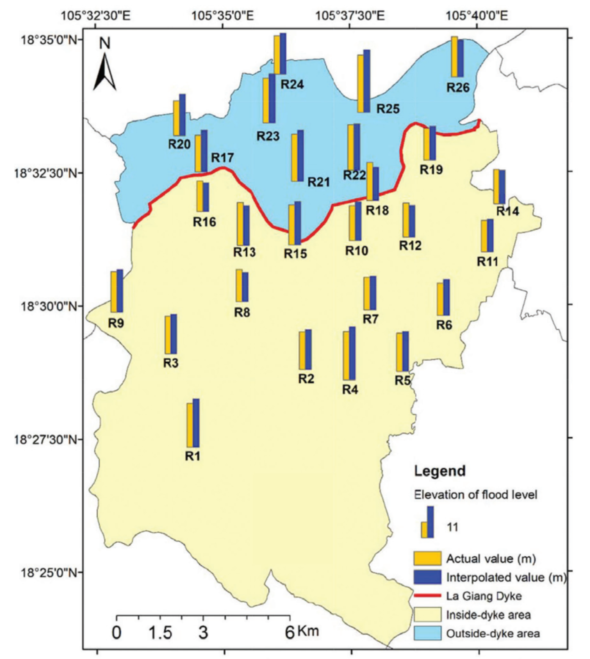

Fig. 7. Comparison between actual and interpolated values of flood level elevation at reference points

those points (called the calculated value of reference points). The comparison between the actual values and interpolated values of flood level elevation for each of the reference points was visualized and presented in Figure 7.

Results show that for the area outside La Giang dyke, the error of the interpolation was largest at point R20 with a value of 2.37 m and smallest at point R22 with a value of 0.35 m. Overall, the coefficient of determination R^2 was 0.71, the Root Mean Squared Error was 1.45 m. The mean absolute percent error MAPE was 17.5%. For the area inside La Giang dyke, the interpolation was accurate the most at point R14 with an error of 0.32 m. However, it got the least accuracy at point R18 with an error of 1.79 m. The overall values of R^2, RMSE, and MAPE of the interpolation area inside the dyke were 0.73, 1.32 m, and 14.2%, respectively. These values of the statistics indicate an acceptable level of accuracy of the interpolation method and demonstrate the suitability of this method for the interpolation of flooding in Duc Tho district.

Assessment of the spread of flood inundation on land use types

To determine the area of each land use type inundated by flood, overlaying of the flood map with the current land use map was conducted. Figure 8 presents the inundation map of land use types in the whole district, including both the inside and the outside area of La Giang dyke. The detail of the inundation area of each land-use type is shown in Table 1 and Table 2.

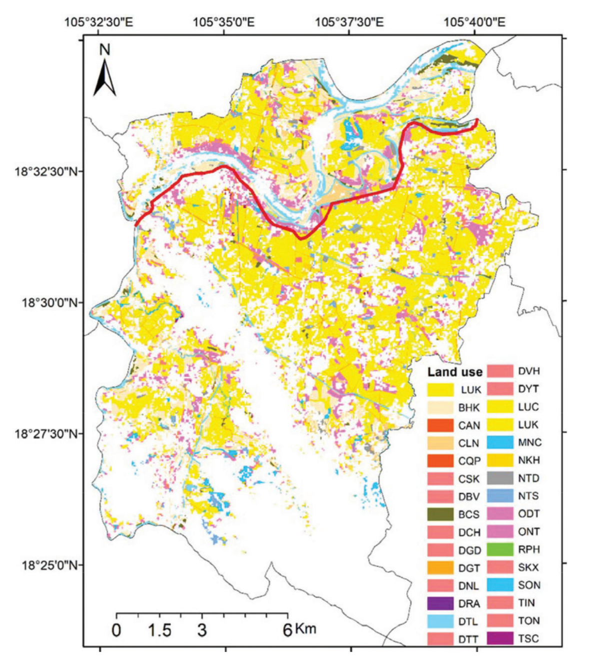

Fig. 8. Map of land use types inundated by flood

The total land area outside La Giang was 4.397,44 ha, of which 2,945.93 ha (66.7%) was inundated by flood. The inundation area of agricultural land, non-agricultural land, and unused land was 1,916.26 ha, 946.28 ha, and 83.39 ha, respectively. This result indicates that agricultural land was inundated the most as its inundated area accounted for 65.05 % of the total area of inundation outside La Giang dyke. The inundated area was largest at level 4 (flood depth of over 2 m) with 1,597.5 ha. In which, the area of paddy land was 1,106.8 ha, accounting for 37.57 %. For non-agricultural land, out of the total 946.28 ha of inundation, 725.0 ha (76.62%) was inundated with a flood depth of over 2 m. Land with special use was the largest flooded non-agricultural land with an area of 487.85 ha, followed by residential land with 343.58 ha, mostly flooded at level 4. Comparing among the communes, Lien Minh, a commune located completely outside La Giang dyke was flooded the most with an area of 451.13 ha. The area of inundation outside the dyke was large due to the lack of protection infrastructure (dykes), flat topography along the La River and the inadequate drainage system.

For the area inside La Giang dyke, the total area of land was 15,951.7 ha, of which 7,003.74 ha (43.9%) was inundated. The area of inundation with a depth of over 2 m was the largest with 4,915.95 ha, accounting for 70,19% of the total inundation area. The inundation area of agricultural land, non-agricultural land, and unused land inside the dyke was 5,314.46 ha, 1,627.65 ha, and 61.64 ha respectively. Similar to the outside-dyke area, agricultural land was flooded the most with a contribution of 75.88 % to the total inundation area. In particular, paddy land had the largest inundation area with 4,347.80 ha, out of which 3,195.57 ha was flooded deeper than 2 m. The inundation area of other annual croplands (such as corn, sweet potato, peanut, and bean, etc) was 703.40 ha, accounting for more than 10% of the total inundation area. Among non-agricultural land use types, residential land has the largest submerged area with 802.47 ha, which accounts for approximately 11.5 % of the total inundation area inside La Giang dyke. Land used by religious establishments, which is usually located in medium to high elevation areas was flooded the least among non-agricultural land use types with an area of approximately 2.7 ha (0.04 %). Comparing among the communes inside La Giang dyke, Duc Dong was the commune that had the largest inundation area with 615.91 ha, meanwhile, Tan Huong, a commune located in the south of the district with mostly high topography, was submerged the least with 31.25 ha.

Table 1. Flood area of all land use types in the outside-dyke area of the La Giang dyke

No. (1)	Land use (2)	Code (3)	Inundation area (ha) Level 1 (<0.5m)	Level 2 (0.5-1m)	Level 3 (1-2m)	Level 4 (>2m)	Total (ha)	% of total inundation area
	Total of flood inundation area		123.44	141.97	292.64	2,387.89	2,945.93	100.00
1	**Agricultural land**	NNP	67.52	80.94	170.30	1,597.50	1,916.26	65.05
1.1	Land for agricultural production	SXN	66.72	79.74	167.81	1,569.41	1,883.67	63.94
1.1.1	Annual cropland	CHN	62.05	75.34	156.19	1,490.40	1,783.97	60.56
1.1.1.1	Paddy land	LUA	38.75	45.80	93.30	928.95	1,106.80	37.57
1.1.1.2	Other annual croplands	HNK	23.30	29.53	62.89	561.45	677.18	22.99
1.1.2	Perennial cropland	CLN	4.66	4.40	11.62	79.01	99.69	3.38
1.2	Forest land	LNP	0.26	0.33	0.35	0.69	1.64	0.06
1.3	Aquacultural land	NTS	0.41	0.78	1.94	23.94	27.06	0.92
1.5	Other agricultural land	NKH	0.13	0.10	0.21	3.46	3.89	0.13
2	**Non-agricultural land**	PNN	51.61	56.31	113.36	725.00	946.28	32.12
2.1	Residential land	OCT	20.40	22.41	44.83	255.94	343.58	11.66
2.2	Land with special use	CDG	25.97	27.05	55.68	379.15	487.85	16.56
2.3	Land used by religious establishments	TON		0.11	0.16	0.61	0.88	0.03
2.4	Land used by belief establishments	TIN	0.51	0.63	0.86	5.60	7.60	0.26
2.5	Land used for cemeteries, graveyards	NTD	1.77	1.94	4.67	37.16	45.54	1.55
2.6	Land with rivers, streams, canals...	SON	1.36	1.63	2.69	11.50	17.19	0.58
2.7	Land with special-used water surface	MNC	1.60	2.53	4.47	35.04	43.64	1.48
3	**Unused land**	CSD	4.31	4.71	8.98	65.40	83.39	2.83

Besides, the communes with the terrain gradually decreases from west to east, relatively flat and low-lying, including Bui Xa, Trung Le, Duc Nhan, Duc Thuy, Duc Thinh, Thai Yen, Duc Thanh, Yen Ho were also flooded with a large area.

Discussion

This study applied the Inverse Distance Weighting interpolation method with barriers to establish a flood inundation map and calculate the level and area of flood inundation for different types of land use of Duc Tho district for the 2016 flood. One of the challenges when applying spatial interpolation is when barriers exist in the study area such as fractures, quailing, faults levees, dykes, and rivers which cause interruption and discontinuity on the surface. Most interpolation methods attempt to smooth over the barrier by incorporating and averaging values on both sides of the barrier. However, these approaches are not always appropriate, especially for variables that are prevented by the barrier such as water level. The advantage of the IDW method is that it allows to include barriers in the analysis. The use of barriers in interpolation clearly has great potential as a means of incorporating landscape structure and spatial processes in surface interpolation. The successful application of IDW with barriers method in this study demonstrated the power of this technology integrated with GIS.

According to the overview of the La river basin which covers Duc Tho district, the upper part of the basin is mostly covered by mountains (in Huong Son district) with steep topography and poor vegetation cover. Meanwhile, the lower part is divided by low mountains, including the plains that are often flooded due to inadequate drainage systems. This is the reason why the La river basin is always flooded every year.

For the area inside La Giang dyke, when there is heavy rain, most of the low-lying plains are often flooded due to inadequate drainage systems. Especially in the west, there is the Ngan Sau river and a system of small streams such as Do Trai, Minh Dien, and other canals and streams that lead water to the area within the dyke.

For flood interpolation, one of the challenges is when barriers such as roads, dykes, and other infrastructures exist and divide the area into different portions. The advantage of the IDW method is that it allows to include these barriers in the analysis.

Table 2. Flood area of all land use types in the inside-dyke area of the La Giang dyke

No. (1)	Land use (2)	Code (3)	Inundation area Level 1 (<0.5m)	Level 2 (0.5-1m)	Level 3 (1-2m)	Level 4 (>2m)	Total (ha)	% of total inundation area
	Total of flood inundation area		486.53	516.67	1,084.61	4,915.95	7,003.74	100.00
1	**Agricultural land**	NNP	329.01	355.75	768.85	3,860.86	5,314.46	75.88
1.1	Land for agricutural production	SXN	310.48	332.87	734.79	3,743.44	5,121.57	73.13
1.1.1	Annual cropland	CHN	302.01	327.01	721.77	3,700.43	5,051.20	72.12
1.1.1.1	Paddy land	LUA	253.84	275.71	622.69	3,195.57	4,347.80	62.08
1.1.1.2	Other annual croplands	HNK	48.17	51.30	99.08	504.86	703.40	10.04
1.1.2	Perennial cropland	CLN	8.48	5.86	13.02	43.01	70.37	1.00
1.2	Forest land	LNP	9.10	9.09	11.29	29.12	58.59	0.84
1.3	Aquacultural land	NTS	7.54	10.63	16.49	68.95	103.61	1.48
1.5	Other agricultural land	NKH	1.89	3.16	6.29	19.35	30.68	0.44
2	**Non-agricultural land**	PNN	153.11	155.33	304.82	1,014.39	1,627.65	23.24
2.1	Residential land	OCT	85.47	90.64	157.04	469.33	802.47	11.46
2.2	Land with special use	CDG	45.63	45.89	100.54	405.21	597.27	8.53
2.3	Land used by religious establishments	TON		0.71	0.43	1.55	2.69	0.04
2.4	Land used by belief establishments	TIN	0.34	0.25	1.43	0.88	2.90	0.04
2.5	Land used for cemeteries, graveyards	NTD	6.01	4.56	15.75	54.91	81.23	1.16
2.6	Land with rivers, streams, canals...	SON	2.30	2.24	4.30	16.81	25.65	0.37
2.7	Land with special-used water surface	MNC	13.37	11.04	25.33	64.54	114.28	1.63
2.8	Other non-agricultural lands	PNK		0.00	0.00	1.16	1.16	0.02
3	**Unused land**	CSD	4.41	5.59	10.94	40.71	61.64	0.88

The barrier prevents the interpolator from using sample points on one side of it. The results of the application of the IDW method for the assessment of the spread of flood inundation on land use have proven that the proposed tool is appropriate and accurate. This finding, together with findings of similar studies (Merwade *et al.,* 2008; Jung *et al*., 2014; Icaga *et al.,* 2016; Hartanto and Rachmawati, 2017; Mishra *et al*., 2017; Rind *et al.,* 2018; Scorzini *et al.,* 2018; Lingadevaru *et al.,* 2019; Malik and Pal, 2021) indicate that hazard modeling is an important contributor to the assessment of direct flood damages and risk and, therefore, that the use of these tools can be considered suitable in prevention and protection in the inundation area. In the rainy season, local authorities should monitor water level and rainfall, combined with the flood map created by spatial interpolation method to forecast flood risk.

Therefore, applying this method is helpful for flood mitigation measures, disaster aversion, area development planning, and best management practices for land use.

Conclusion and Recommendation

This work employed the IDW interpolation method to study the spread of flood inundation on land use in Duc Tho District of Ha Tinh Province, Vietnam using flood level data. The special characteristic of this area is that it is divided into two areas by a dyke. The results for the outside-dyke area showed that the total area of inundation was 2,945.93 ha, accounting for 65.05% of the total natural land area and the inundation depth was mostly over 2.0 m. The inundation areas of agricultural land, non-agricultural land, and unused land were 1,916.26 ha, 946.28 ha, and 83.39 ha, respectively. For the inside-dyke area, the total area of inundation was 7,003.74 ha, accounting for 43.91% of the total natural land area and the inundation depth was also mostly over 2.0 m. The inundation areas of agricultural land, non-agricultural land, and unused land were 5,314.46 ha, 1,627.65 ha, and 61.64 ha respectively. The findings indicate serious flood submersion upon agricultural land, and it should therefore be given priority in flood prevention and adaptation plans. Further studies should apply this method in different areas and topographic characteristics to further assess the strength of this approach. The suggested flood mapping approach requires measured flood indicators such as inundation duration and flow velocity. These parameters also play an important role in assessing the impact of floods.

Acknowledgment

The authors acknowledge the Department of Natural Resources and Environment of Duc Tho District and the Centre for Meteorology and Hydrology of Ha Tinh Province for providing data for this study. The authors also thank local people in Duc Tho District for giving valuable information on flood and land use in the district. Appreciation is given to the anonymous reviewers for their valuable comments for the improvement of this article.

Contribution of authors:

Pham Quy Giang is the main author of the article, designed the study, collected and processed data, conducted spatial interpolation and analyzed the results, wrote and edited the manuscript. Nguyen Thi Tham contributed partly to the writing and discussion on the results of the study.

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