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Assessing the Instability of Dong Nai River in Bien Hoa District Using Bank Erosion Hazard Index (BEHI) and Remote Sensing and GIS

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Abstract. In this study, a method for developing a quantitative prediction of river bank erosion in Bien Hoa district in Dong Nai River is presented. The river bank erosion hazard index (BEHI) was estimated to assess the stability of the river bank erosion in consultation with bank height, bank slope, rooting depth, rooting density and surface protection. The estimated BEHI of Dong Nai River in Bien Hoa district are high which indicates the riverbank instability. The estimated BEHI along the left bank is about 25-30. The satellite data of LANSAT TM 5, LANDSAT ETM 7 for the year 1995, 2005 and 2015 were used to assess the nature of shifting of the river bank and to estimate the land loss from river bank. All the derived images were transported on GIS environment to extract the course of the river. 13 sites were considered along the Dong Nai River in Bien Hoa District to estimate the leftward shifting of the bank line and to assess the shifting distance of the river bank line. There is a strong relationship between bank instability BEHI, shifting distance of the bank line and eroded bank area in this study.

1. Introduction

Riverbank erosion is one of the most severe phenomenon in the rural area of Vietnam, including Dong Nai province. Once an erosion occurs, the natural disaster has a negative impact on people's life and community's activity. There are many methods of assessing riverbank erosion, one of which is the method of using the Bank Erosion Hazard Index. Stream bank assessment includes the measurements of bank heights, angles, materials, presence of layers, rooting depth, rooting density and percentage of bank protection which are used to develop the Bank Erosion Hazard Index (BEHI). BEHI was estimated after Rosgen (2001a and 2001b) to assess the nature of credibility of the river bank in Manikchak. The BEHI methodology evaluates a stream bank's susceptibility to erosion as a function of five factors, including:

1. The ratio of stream bank height to bank full stage.
2. The ratio of riparian vegetation rooting depth to stream bank height.
3. The degree of rooting density.
4. Stream bank angle (i.e., slope)
5. Bank surface protection afforded by debris and vegetation.

The changes in the flow character as a result of siltation and sedimentation as well as variation in discharge invited severe river bank erosion in Bienhoa of Dong Nai. The present study is dealt with the study of river bank erodibility based on BEHI as well as nature and extent of the bank line shifting

leftward with the help of RS & GIS which revealed the impact of the fluvial dynamics of river Dong Nai on bank erosion hazards in the concern area.

2. Study Area

Bien Hoa City is located in the west of Dong Nai province, borders Vinh Cuu district in the north, Long Thanh district in the south, Trang Bom district in the east, Di An town, Tan Uyen district of Binh Duong province and District 9 of Ho Chi Minh in the west. Bien Hoa City has a total area of about 263,55 km^2.
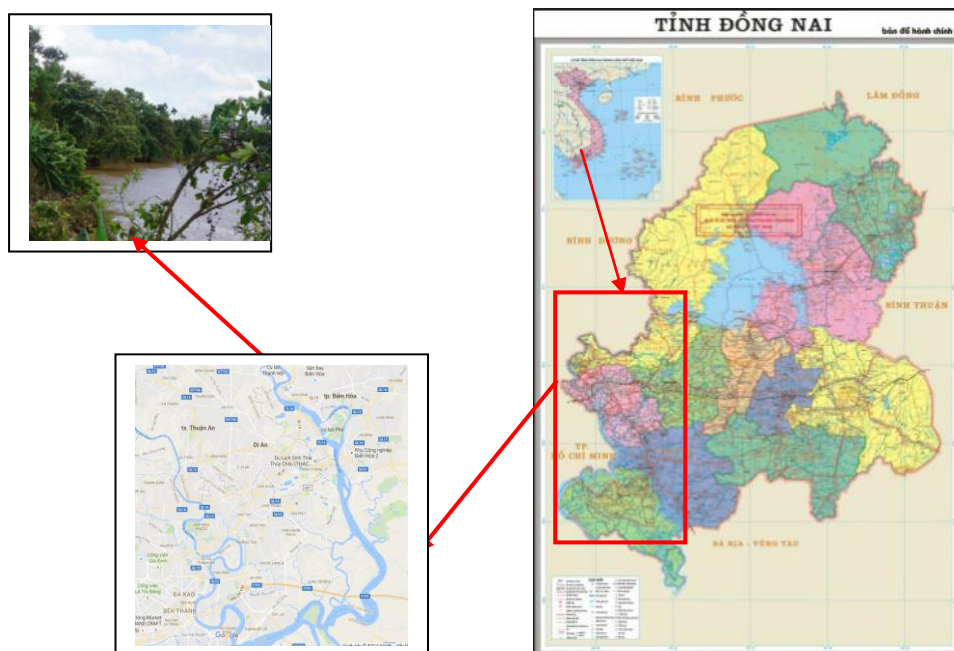

Figure 1. Location of bank erosion in Bien Hoa – Dong Nai.

The Dong Nai River runs through Bien Hoa City with a length of 21km and plays an important role in the development of Bien Hoa City, Dong Nai Province in particular and the Southern Key Economic Zone in general. Crossing the river is the North-South railway (through Ghenh bridge and Rach Cat bridge), National Highway 1A (Dong Nai bridge), Hoa An bridge. Along the banks of the river are provincial agencies, residential areas, commercial areas, factories, industrial parks, wharves, etc. of Ho Chi Minh City.

The morphological characteristics of the Dong Nai river in the river section through Bien Hoa city are shown in the following tables:

Table 1. Morphological characteristics of Dong Nai River through Bien Hoa City.

No.	The River	Length L (m)	River width (m)			Level Z (m) lowest bottom Z_{min}	$\dfrac{\sqrt{B}}{h}$
			B_{max}	B_{min}	$B_{avarage}$		
1	Isle of Tortoise to Hoa An bridge	4200	750	210	600	-15.29 ÷ - 16.24	2.23 ÷ 3.99
2	Hoa An Bridge to Cu Lao Pho	2800	810	450	620	-17.32 ÷ - 18.62	1.40 ÷ 4.01
3	Cu Lao Pho to Dong Nai Bridge	950	580	330	515	-15.57 ÷ -19.76	1.46 ÷ 2.11
4	Dong Nai Bridge to Ba Xê, Ba Sang	1450	680	330	460	-13.02 ÷ -13.69	1.68 ÷ 2.94

No.	The River	Length L (m)	River width (m)			Level Z (m) lowest bottom Z_{min}	$\dfrac{\sqrt{B}}{h}$
			B_{max}	B_{min}	$B_{avarage}$		
5	Rach Cat river	7937	390	110	180	-8.09 ÷ -8.79	2.16 ÷ 2.72
6	The main river Dong Nai	3100	420	275	378	-15.11÷ -15.95	1.43 ÷ 1.92

River morphology of the Dong Nai river section flowing through Bien Hoa city falls into the category of the slightly curved river and creeks division. River-bed morphology demonstrates the characteristics of intertidal rivers, semi-diurnal regime of the East Sea, and the flow regulating effect of Tri An reservoir in the upstream.

In the river bed formed many local erosion holes (06 erosion with bottom elevation Zmin> -10m). The erosion formed into the confluence zone with Zmin = -19.76m, the curve's tip Zmin = -20.14m, the contraction zone Zmin = -20.56m.

The Dong Nai River section in Bien Hoa City forms creek division, this formation stems from water flow, sediment flow and riverbank geology with low ability to resist erosion, river-bed expanding and narrowing along the river (narrowing's effect is to control river's morphology) where sediment flow divided, and the expanding section where more sediment depositing.

Under cutting or loss of underlying support is the primary cause of bank erosion at Dong Nai River. As a result of hydraulic action, the soil particles of underlying layer is detached and carried far away by stream flow which results in overhanging layer at the top. This overhanging layer with time collapse and execute rapid bank erosion.

Figure 2. Cohesive and non-cohesive layers at Dong Nai River.

This study is an attempt to examine the spatial bank erosion condition of Dong Nai River in Bien Hoa City. The study focus on the nature and extent of riverbank erosion of Dong Nai River, estimation of the ratio of stream bank height to bank full stage, ratio of riparian vegetation rooting depth to stream bank height, rooting density, riverbank angle and surface protection, the assessment of the bank erosion hazard index (BHEI) and to assess the potential erosion sites in the Dong Nai River.

3. Materials and methods

3.1. Estimation of Bank Erosion Hazard Index (BEHI)
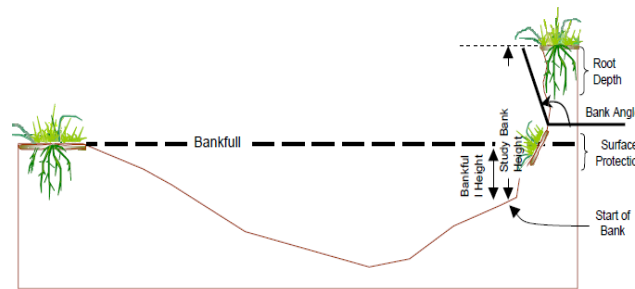The River bank with various BEHI parameters as following figure:

Figure 3. River bank with various BEHI parameters.

Rosgen (2001) calculated this index by summing the scores for each individual metric using the values assigned for measuring complete BEHI as following:

Table 2. Guidelines for measuring complete BEHI (After, Rosgen, 2001).

BEHI Category	Bank Height/ Bankfull Height	BH/BFH Score	Root Depth (% of BFH)	Root Depth Score	Root Density (%)	Root Density Score	Surface Protection (Avg. %)	Surface Protection Score	Bank Angle (degrees)	Bank Angle Score	Total Score, by Category
Very low	1.0-1.1	1.45	90-100	1.45	80-100	1.45	80-100	1.45	0-20	1.45	≤ 7.25
Low	1.11-1.19	2.95	50-89	2.95	55-79	2.95	55-79	2.95	21-60	2.95	7.26-14.75
Moderate	1.2-1.5	4.95	30-49	4.95	30-54	4.95	30-54	4.95	61-80	4.95	14.76 – 24.75
High	1.6-2.0	6.95	15-29	6.95	15-29	6.95	15-29	6.95	81-90	6.95	24.76 – 34.75
Very high	2.1-2.8	8.5	5-14	8.5	5-14	8.5	10-14	8.5	91-119	8.5	34.76 – 42.50
Extreme	>2.8	10	< 5	10	< 5	10	< 10	10	> 119	10	42.51 – 50

3.2. Estimation of the Shifting of the river bank leftward

Landsat images for the year 1988 - 2016 were used in ERDAS IMAGINE PC software (9.2) using WGS 84 projection system which was inbuilt in the Landsat data where root mean square error was approximately 0.982 and, an acceptable limit (Pham Thi Huong Lan, 2017). All data was integrated in a GIS environment to understand the controls and mechanism of river dynamics as following:

Table 3. Specification of the satellite Data.

No.	Dry season		Flood season		Data Type
	Details	Year/ Date	Details	Year/ Date	
1	125-025	12/3/1988	125-025	27/09/1988	Landsat TM
2	125-025	4/2/1990	125-025	13/10/1990	Landsat TM
3	125-025	2/2/1995	125-025	9/10/1995	Landsat TM
4	125-025	21/02/1999	125-025	6/10/1999	Landsat ETM
5	125-025	25/02/2000	125-025	12/10/2000	Landsat 7 ETM
6	125-025	13/02/2002	125-025	15/10/2002	Landsat 7 ETM
7	125-025	27/02/2003	125-025	11/10/2003	Landsat 7 ETM
8	125-025	3/2/2008	125-025	12/10/2008	Landsat 7 ETM
9	125-025	21/02/2014	125-025	18/09/2014	Landsat 8 ETM

No.	Dry season		Flood season		Data Type
	Details	**Year/ Date**	**Details**	**Year/ Date**	
10	125-025	9/2/2015	125-025	12/10/2015	Landsat 8 ETM
11	125-025	31/03/2016	125-025	19/08/2016	Landsat 8 ETM

4. Results and discussion

4.1. Estimated BEHI and Instability of the river bank

In this study, the authors used primary collected data from 2008, 2015 and 2016. Site's specific information was derived after four-day intensive field investigation in October 2016 with GPS, Clinometer, and measuring tape, measuring staff and hanging rope.

The results of estimated BEHI from different location of Dong Nai River Bank is statistics in the table as following:

Table 4. Estimated BEHI from different location of Dong Nai River Bank

Location	X	Y	Study Bank Height / Bankfull Height	Root Depth/Bank Height	Root Density (%)	Surface Protection (%)	Bank Angle	Total BEHI Score
MC1	396523.5	1,211,275.93	2.3	9.2	20	50	75	34.9
MC2	397926.3	1,210,490.61	2.8	16.5	18	52	30	16.75
MC3	398333.8	1210174.10	3.5	12.1	25	50	35	17.5
MC4	398700.2	1209745.23	3.2	14.1	25	50	30	18.1
MC5	398935.5	1209479.08	1.8	6.1	25	50	50	14.65
MC6	399772.6	1210453.60	1.82	9.2	25	50	45	24.1
MC7	401508.1	1210425.10	1.81	7.1	20	50	45	24.8
MC8	401207.6	1209480.93	2.1	9.2	20	50	55	24.76
MC9	400652.8	1207700.96	1.9	6.8	20	52	70	16.25
MC10	398807.5	1208741.13	3.8	12.1	25	50	35	24.7
MC11	399096.0	1208404.61	2.1	6.5	20	50	25	34.7
MC12	399176.2	1207943.31	2.5	10.5	20	50	95	36.9
MC13	399939.6	1207700.39	2.8	15.58	20	50	110	34.54

Field survey took place at the location of Hoa An bridge at about 500m to the upstream of Dong Nai River (location MC1). A river cross profile was done along the left bank of Dong Nai River at Buu Long. The near bank river bed profile depicts that the depth is close to the river bank which plays a significant role to increase the velocity of water.
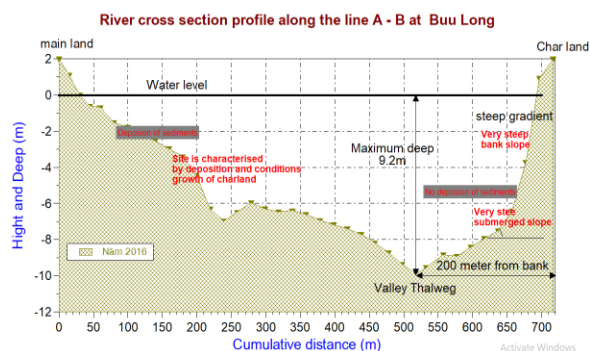
Figure 4. River cross profile between mainland and char land at Buu Long.

Figure 5: Vulnerable sites of bank erosion at Buu Long - Bien Hoa.

4.2. Shifting character of the bank of the Dong Nai river and estimated land loss

Based on a map of river morphology, the authors assess, analyze, and finally identify a number of rules required for each specific area for forecasting, such as rate and scale of riverbank erosion, rate of sedimentation in riverbank, rate of erosion development in the islet area, rate of erosion hole development and movement, level of shallow according to space and time, etc.; estimate the scale and rate of riverbank erosion and erosion site in the project area from 1988 to 2016, as shown in the following table:

Table 5. Shifting character of the river bank from 1988 to 2016.

Position	River bank	Length of landslide (m)	The maximum width of the landslide (m)	Average landslide rate (m/year)
Upstream of Hoa An bridge	Right	820	10	0.32
Lower section of Hoa An bridge	Left	700	30.5	1.2
The Cu Lao Pho area in the downstream of Bien Hoa	Left	192.5	17.7	0.63
Cu Lao Pho area		500	51.4	1.83
Cu Lao Pho district (about 550m from the downstream of Ghenh bridge)	Right	52	20	1.1
Cu Lao Pho (about 1200m downstream from Ghenh bridge)	Left	70	17.8	0.63
Rach Cat river at the crest of Thong Nhat, Tan Mai, Tam Hiep	Left	1550	16.25	0.65
Upstream of Buu Hoa Bridge (about 100m)	Left	128	16.27	0.58
Upstream of Dong Nai bridge	Left	300	36.4	1.3

5. Conclusion

Bank angle varies from 25^0 to 110^0. However, in most cases, the bank angle is $> 70^0$, which leads to the increase of the BEHI score. Surface protection helps to reduce the BEHI score. The BEHI score ranges between 14.65 - 36.90 which is categorized into moderate (from 14.76 to 24.75), high (from 24.76 to 34.75) and very high (34.76 to 42.500) levels. Therefore, it clearly indicates that the sites' scale is characterized by river bank instability and erosion. Since streambank erosion measurements

are very time consuming, extrapolation of these relations can extend the application and effectiveness of river assessments.

6. References

[1]   Rosgen 2001 *A practical method of computing stream bank erosion rate* (Nevada: 7th Federal Interagency Sediment Conference, March 24-29)

[2]   Pham Thi Huong Lan 2017 *River morphology assesment from Hoa An to Ghenh Brigde*

Acknowledgements