Riverbank Change Detection and Impact of Water Level Rise along Mekong River in Nong Khai Province of Northeast Thailand using Geo-Informatics Approach

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Abstract
This study aims to examine the riverbank changes and the impacts of water level rise on the right bank of the Mekong River in Nong Khai province, northeast Thailand. The Normalized Difference Water Index (NDWI) technique was applied for the extraction of water features from LANDSAT imagery to detect the change. The result shows both erosion and accretion in the study area during the dry season between the year 2000 and 2014 analyzed by LANDSAT-7 TM images recorded on February 13, 2000 and LANDSAT-8 OLI images recorded on March 31, 2014. The total area of erosion is 0.89 sq.km or 555.90 Rais at average rate of 1.31 m/year whereas total area of accretion is 3.93 sq.km or 2,457.27 Rais at an average rate of 2.03 m/year. The morphological change of sandbars and river islets finds eroded/submerged area of 5.92 sq.km or 3,698.58 Rais and accreted area of 1.85 sq. km or 1,153.21 Rais. Digital Elevation Model (DEM) is applied together with the Mekong River channel data year 2014 to simulate the water level rise scenarios. The result identifies that agricultural land would be the most at risk of flooding, next are miscellaneous land (water body, sandbar, islet, etc.) and forest land respectively.

1. Introduction

River channel process is a natural process, but often human activities can also have an impact on discharge or sediment transport process that will drive morphological change in river channel (Gregory, 2006). River channel changes, such as bank erosion, down cutting and bank accretion, are natural processes for an alluvial river. Developments like sand mining, infrastructure building on the riverbank, artificial cutoffs, bank revetment, construction of reservoirs and land use alterations have changed the natural geomorphological dynamics of rivers (Kummu et al., 2008, Lane and Richards, 1997, Surian, 1999, Fuller et al., 2003, Rinaldi, 2003 and Li et al., 2007). Morphological change in river channels can impact the ecology of riverine environments. Natural alluvial channels are dynamic, structurally complex environments containing a high degree of biodiversity (Ward et al., 2002 and Richardson and Fuller, 2010).

The Mekong is one of the world's great rivers. Like other great rivers, it rises in high mountains, traverses a floodplain and enters the sea via a wide delta, each landform with its own opportunities and challenges. From its source, the Mekong continues south for approximately 4,800 km to the South China Sea, draining a total catchment area of 795,000 km² within the six countries of China, Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam (MRC, 2005 and 2011). In the Lower Mekong Basin, the river is characterized by large areas of an alluvial channel (Gupta and Liew, 2007). Those of the lower basin are much more complex with around 125 small and large watersheds (MRC, 1997 and 2003). The total watersheds area span larger than 10,000 km² harbor large areas of forest, paddy fields, streams and creeks forming a complex, rich and diverse ecosystem supporting over 65 million people (Snidvongs and Teng, 2006). Among 11 hydropower projects in the Lower Mekong Basin (MRC, 2009), there is only Xayaburi Dam located in Xayaburi town of northern Lao PDR currently under construction (DWR, 2014).

Riverbank erosion is one of the most serious problems for land management especially in developing countries in Asia. The monsoon climate clearly divides rainy and dry seasons, resulting in significant water fluctuation to cause eventually large-scale erosions (Matsuki, 2013). Identifying the areas where bank erosion is severe in the Lower Mekong River is important for discussing the stability of the river channel (Miyazawa et al.,

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2008). The reaches with severe bank erosion include the meandering reach between Vientiane and Nong Khai (JICA, 2004 and Rutherfurd et al., 1996).

There have been several studies on riverbank change detection using remotely sensed data and geo-informatics (Kummu et al., 2008, Hung et al., 2008, Islam, 2010 and Yang et al., 2014). Hence, the application of geo-informatics is chosen as the scientific method in this study to: 1) study the riverbank changes on the right bank of the Mekong River in Nong Khai province, northeast Thailand 2) study the impacts of water level changes on the right bank of the Mekong River in Nong Khai province, northeast Thailand.

2. Study Area and Methods

2.1 Study Area

The right bank of the Mekong River runs through Nong Khai, Thailand's northeastern province about 196.5 kilometers from Loei province to Bueng Kan province. Nong Khai lies in the valley of Mekong River downstream from the Laotian capital Vientiane and is part of the Lower Mekong Basin. The long thin province is subdivided into 9 districts and 62 sub-districts with 8 districts and 28 sub-districts are located on the banks of the Mekong River. Its dominant landform is plain of the Korat-Sakon Plateau. The plateau is drained mainly by the Nam Mun, Nam Chi and Nam Songkhram rivers (tributaries of the Mekong River). These rivers are generally incised several meters below the predominantly sandstone plateau (Snidvongs and Teng, 2006).

The climate of the Mekong River Basin ranges from temperate to tropical as is influenced by southwest and northeast monsoons. Moreover, the annual tropical depression from the South China Sea brings heavy rainfall into the area in the wet season. Meteorological data from Nong Khai weather station monitored by Thai Meteorological Department during 1980 to 2009 reported the average annual temperature was 25.4 degree Celsius with the highest in April at 29.4 degree Celsius and the lowest in December at 22 degree Celsius. Average annual rainfall was 1,622.2 millimeters.

The study area is located on the right bank of the Mekong River in Nong Khai province northeastern Thailand. The on-site gauge station is Nong Khai station operated by Department of Water Resources. Figure 1 below showed the study area and location of gauge station.

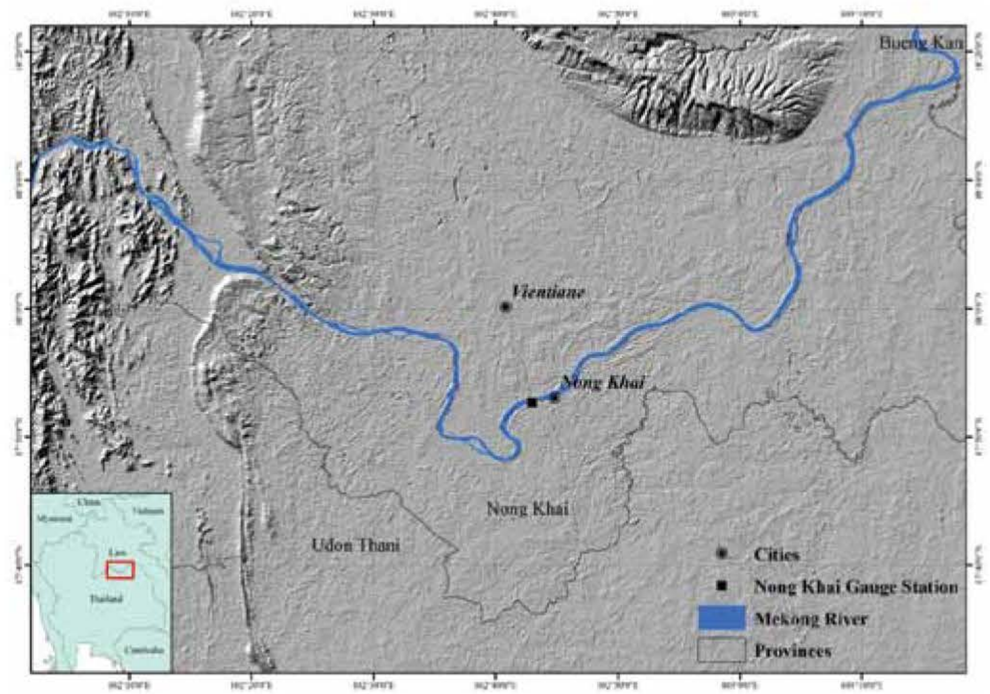

Figure 1: Study area and location of gauge station

Table 1: LANDSAT imagery year 2000 and 2014 at the study area

Path/Row	LANDSAT-7 ETM+		LANDSAT-8 OLI	
	Date	Time (GMT+7)	Date	Time (GMT+7)
128/047	13/02/2000	10.23	31/03/2014	10.30
128/048	13/02/2000	10.23	31/03/2014	10.31

2.2 Data Acquisition

The study collected geospatial data from satellite imagery produced by the LANDSAT-7 ETM+ year 2000 as well as the LANDSAT-8 OLI year 2014 from the United States Geological Survey (USGS) with a spatial resolution of 30 meters as shown in Table 1 with careful images selection of dry season and cloud-free scenes of the right bank of the Mekong River, northeast of Thailand.

The study also adopted the Digital Elevation Model (DEM) a continuous 3D representation of a terrain surface elevation at 30 meters resolution from the ASTER GDEM v.2 a joint product developed and made available to the public by the Ministry of Economy, Trade and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) (ASTER GDEM Validation Team, 2011). In addition, data acquisition included the administrative boundary from Department of Provincial Administration for use in GIS and similar software, daily water level data at Nong Khai gauge station from Department of Water Resources and land use data of Nong Khai province in 2010 from Land Development Department, etcetera.

2.3 Methods

The methods of this study were composed of systematic processes and steps shown in Figure 2 as follows:

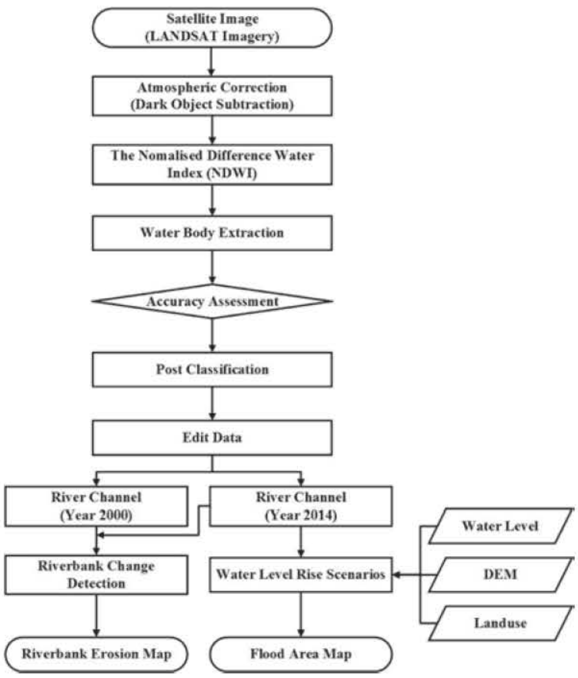

Figure 2: Flowchart of methodology

2.3.1 Image pre-processing

The detection of riverbank change in this study was analyzed using the LANDSAT data Level-1 Terrain Corrected (L1 T) product which was pre-georeferenced to UTM zone 48 North projection using WGS-84 datum. The Dark Object Subtraction (DOS) method, an image-based technique to cancel out the haze component caused by additive scattering from remote sensing data (Chavez Jr, 1988), was subsequently used for atmospheric correction of Landsat image conversion to reflectance.

2.3.2 Image classification

The Normalized Difference Water Index: NDWI: NDWI was first proposed by McFeeters in 1996 (McFeeters, 1996) to delineate open water features and enhance their presence in remotely-sensed digital imagery, therefore, the index greatly improves the accuracy of water bodies retrieval. NDWI index was calculated by equation 1 as follows:

$$NDWI = \frac{(GREEN-NIR)}{(GREEN+NIR)}$$

Equation 1

Where GREEN referred to the green reflectance and NIR referred to the near-infrared reflectance. This equation of NDWI produced the index varies between -1 to 1. The values of NDWI greater than 0 correspond to the water areas whereas the values lower than or equal to 0 correspond to non-water areas. Consequently, the NDWI enhanced and extracted water information for a water region with a background dominated by built-up land areas.

Data Classification: Statistical computation was used to prove the histogram distribution of NDWI numerical data sets. The NDWI threshold approach was also used to extract the river channel and water body from the images.

Accuracy Assessment: The Overall Accuracy and KAPPA Index of Agreement (KIA) were used to assess the accuracy of the river channel and water body extraction by generating 150 random samples for both the water and non-water areas as references to differentiate water from non-water classes of NDWI images each year. For each point, the reference point class (non-water and water) was assigned by visual identification. The Confusion Matrix Approach was then used for accuracy assessment.

Post Classification: The Post-Classification Enhancement for data fine-tuning and data consolidation was applied to improve the optimum result of land and river channels classification of LANDSAT image data.

2.3.3 Post-processing

The change of riverbank erosion, river channel, sandbar, and river islet was analyzed:

- Using spatial data from field survey as reference data for accuracy assessment including picturing, geo-referencing and recording water level at base gauge station in the study area on the exact same date and time when satellite images were taken.

- Exporting geospatial data in GIS data format after processing and classifying river channel data from satellite imagery, then digitizing riverbank location and identifying attributes for sandbar and river islet.
- Using overlay analysis to analyze the change of riverbank erosion, river channel, sandbar and river islet in comparison to the historical and present datasets of the dry season in the year 2000 and 2014.
- Calculating erosion area and accretion area to determine the extent of erosion and accretion of the Mekong riverbank in Nong Khai province, northeastern Thailand.
- Using End Point Rate (EPR) method derived from the GIS-based approach to calculate the rates of change. The widely applied EPR is calculated by dividing the distance of bankline movement by the time elapsed between the earliest and latest measurements (Liu, 1998, Galgano and Douglas, 2000 and Xing et al., 2012). Equation 2 showed the EPR calculation as follows:

$$EPR = \frac{(Y_2 - Y_2)}{(t_2 - t_2)}$$

Equation 2

Where, y_1 and y_2 were the bankline positions respectively at time t_1, t_2. Usually, the t_1 and t_2 were the earliest and latest time of the available times

- Generating maps of morphological changes of riverbank erosion and along the river channel, sandbar and river islet of the Mekong River in the northeast of Thailand.

The multiple water level rise scenarios affecting the Mekong riverbank were simulated:

- Analyzing the potential impacts on the bank of the Mekong River from base case to multiple water level rise scenarios. DEM by ASTER GDEM Version 2 was used to visualize the simulation at 30-meter resolution together with the current year river channel data and water level data from the Mekong River recorded on the same day of the geospatial data analysis.
- Calculating the affected areas where the water levels were higher than the base case and exceeded the height of the riverbank throughout the channel. The GIS Spatial Analysis was applied. Figure 3 showed the water surface elevation and the flood area as the potentially affected area predicted by the simulation-based water level rise scenarios except for the base case scenario.
- Generating maps of affected and high-risk areas from the multiple simulated scenarios on the bank of the Mekong River.

3. Results

3.1 Mekong River Water Level on the Date of Satellite Imagery Analysis

By monitoring and comparing water level data of the Mekong River at Nong Khai station by Department of Water Resources the same date of LANDSAT-7 imagery recorded in 2000, twelve years prior to the construction of Xayaburi Dam on the lower Mekong River in northern Lao PDR and LANDSAT-8 imagery recorded in 2014, two years after the Dam was constructed as details shown in Table 2 below. According to the study, water levels of the Mekong River at Nong Khai gauge station in Nong Khai province on February 13, 2000 reached 2.12 meters while reached 2.73 meters on March 31, 2014. The water level on the analysis date of the year 2014 was higher than of the year 2000 at 0.61 meters as shown in Figure 4. During the dry season from December to April, the water level at Nong Khai gauge station in 2014 was higher than in 2000 in the same period of time also higher than the average water level over the 1967-2014 period as well.

Regarding flood stage, the level reached 12.2 meters at Nong Khai gauge station. The difference between water level and flood level in 2014 was at 9.47 meters.

Table 2: Mekong River water level on the date of satellite imagery analysis

Gauge station	**Year 2000**		**Year 2014**		Difference of water level (m.) past year - previous year
	Acquisition of Landsat data	Average daily water level (m.)	Acquisition of Landsat data	Average daily water level (m.)	
Nong Khai	13/2/2000	2.12	31/3/2014	2.73	0.61

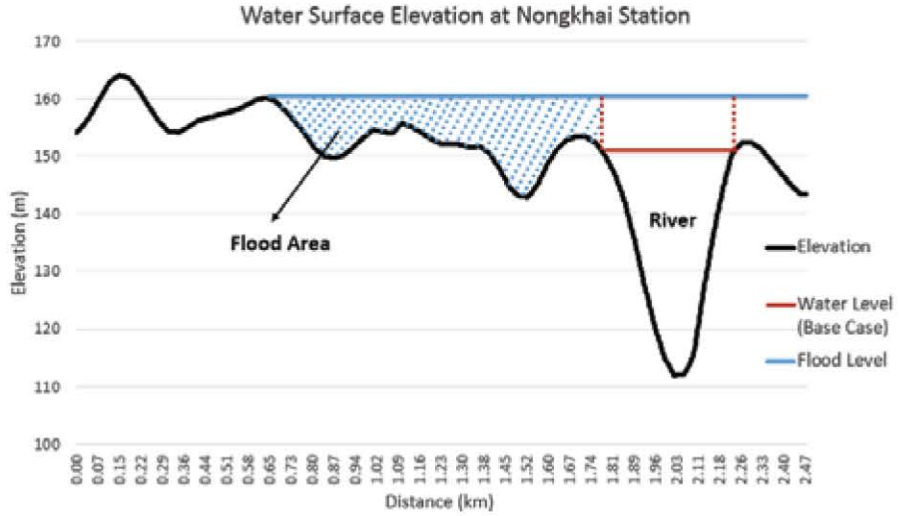

Figure 3: Schematic cross-section of water surface elevation at Nong Khai gauge station

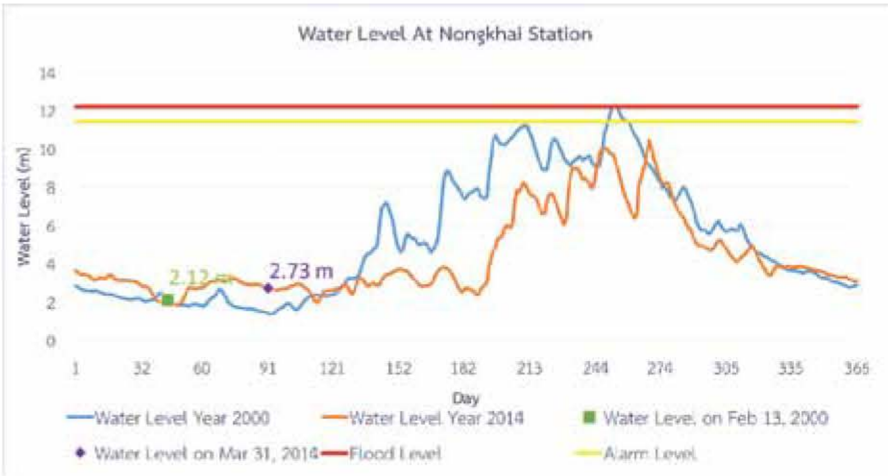

Figure 4: Mekong River water level at Nong Khai gauge station year 2000 and 2014 on the date of satellite imagery analysis

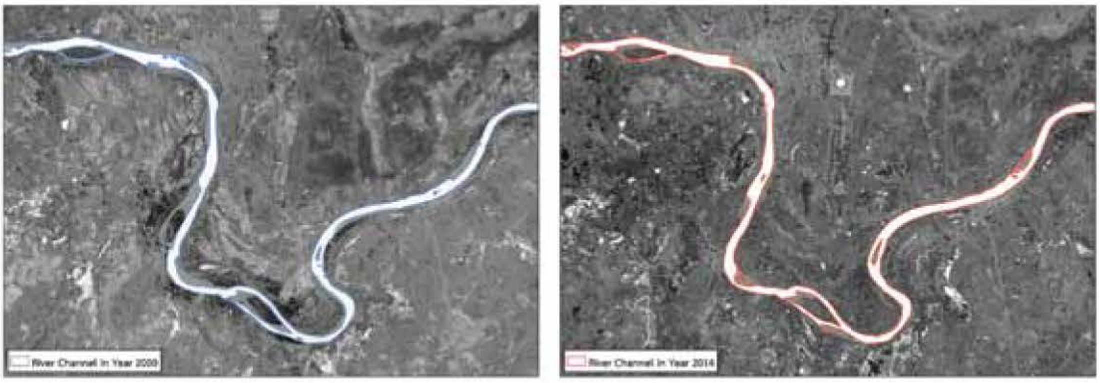

Figure 5: Mekong River channel extracted from NDWI in 2000 and 2014

3.2 Image Classification

The Mekong River channel was extracted from LANDSAT satellite images recorded in the year 2000 and 2014 using threshold technique on NDWI values to classify land and river channel then produced in GIS file format as shown in Figure 5. In this study, a threshold value of 0.52 was applied to extract the river channel the from NDWI image captured by LANDSAT year 2000 and value of 0.12 for 2014 respectively.

The Overall Accuracy and KAPPA Index of Agreement (KIA) were applied for the classification accuracy of water and non-water areas year 2000 and 2014 as showed in Table 3.

Table 3: Classification accuracy assessment

Year	Overall Accuracy (%)	KAPPA Index (%)
2000	95.38	90.39
2014	97.69	95.14

3.3 Morphological change along the Mekong River Channel and Bank Erosion

The change of the right bank of Mekong River, northeastern Thailand in Nong Khai province in the dry season in 2000 and 2014 analyzed by LANDSAT-7 TM images recorded on February 13, 2000 and LANDSAT-8 OLI images recorded on March 31, 2014, the result showed the change of riverbank both erosion and accretion. For erosion, the land to water was 0.89 sq.km or 555.90 Rais. For accretion, the water to land was 3.93 sq.km or 2,457.27 Rais as shown in Figure 6. The rate of change of the right bank of Mekong River in Nong Khai province, the analysis was conducted by firstly generating the administrative boundary line as a reference baseline then generating the transect lines with 200 meters spaces along Nong Khai border area parallel to the Mekong River. The EPR method was applied to determine the rates of change. The result showed the average erosion rate was 1.31 m/year and average accretion rate was 2.03 m/year as shown in Figure 7. Regarding the result of a morphological change of sandbar and river islet in 2000 and 2014 showed that erosion/submerged area was 5.92 sq.km or 3,698.58 Rais and accretion/leveling was 1.85 sq.km or 1,153.21 Rais.

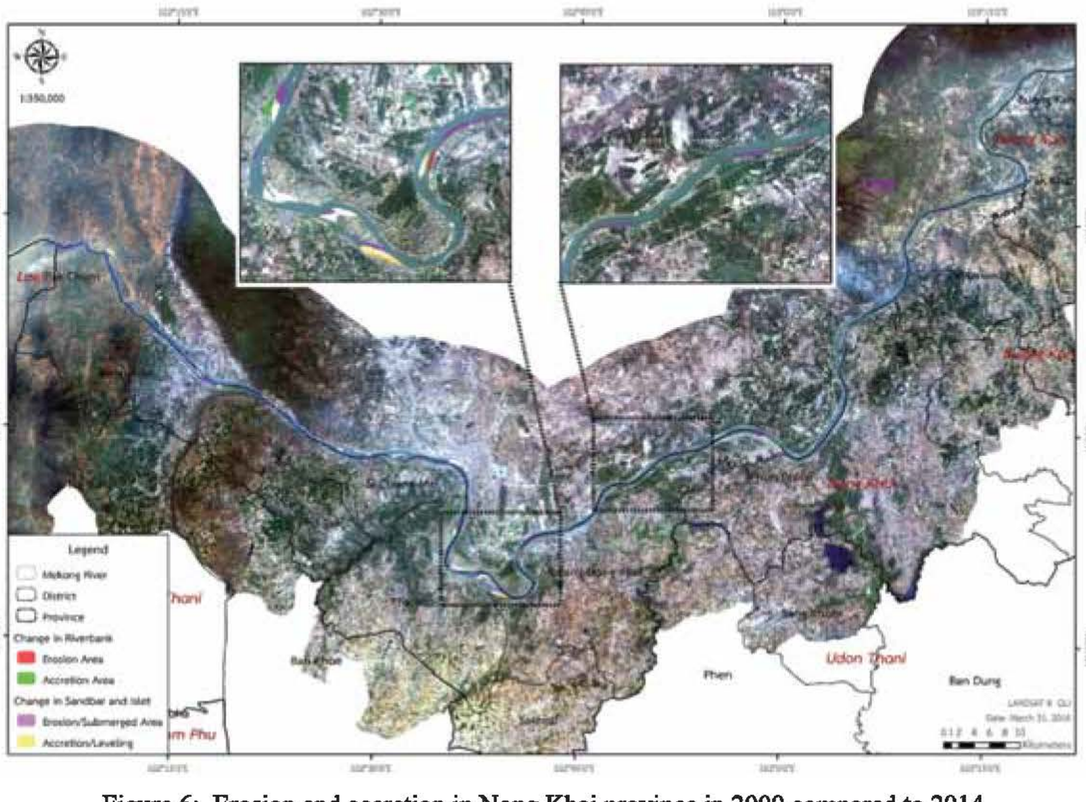

Figure 6: Erosion and accretion in Nong Khai province in 2000 compared to 2014

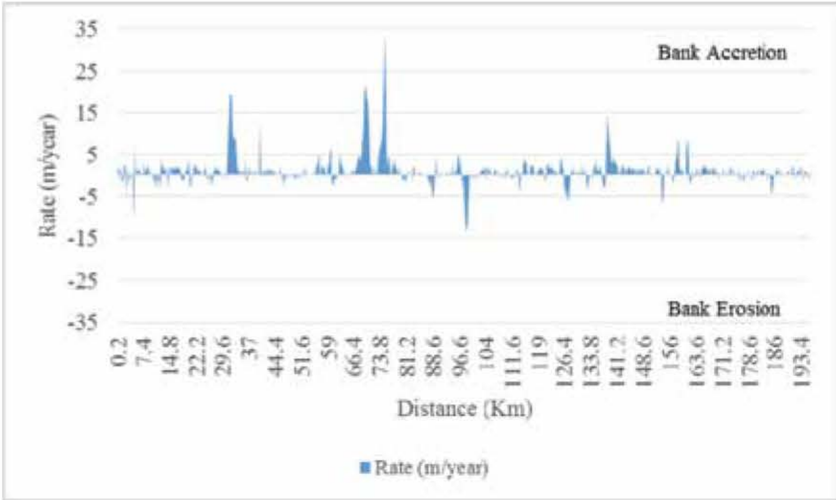

Figure 7: Rate of change along of the right bank in 2000 compared to 2014

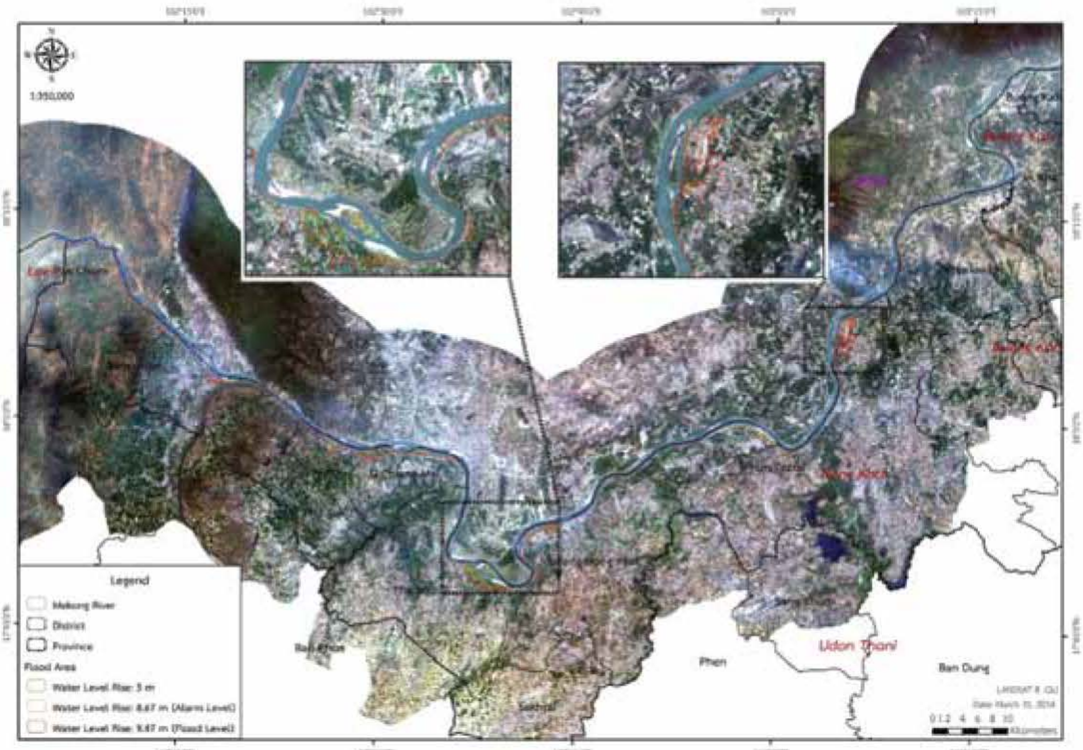

Figure 8: Affected areas predicted by simulated and base case water level rise scenarios

Table 4: Simulated scenarios of water level rise from base case affecting the bank of Mekong River in Nong Khai province

Simulated Scenarios	Flood Area	
	km²	Rai
5-meter water level rise	30.68	19,175.35
8.67-meter water level rise (alarm level = 11.4 meter)	44.12	27,573.16
9.47-meter water level rise (flood level = 12.2 meter)	48.59	30,367.28

Table 5: Comparative analysis and validation of simulated water level rise scenarios at flood level

Simulated Scenarios	Flood Area	
	km²	Rai
5-meter water level rise	30.68	19,175.35
8.67-meter water level rise (alarm level = 11.4 meter)	44.12	27,573.16
9.47-meter water level rise (flood level = 12.2 meter)	48.59	30,367.28

Note: Base case water level rise = 2.73 meter

Table 6: Flood risk predicted by simulated and base case water level rise scenarios

Land Use Types	Flood Area	
	km²	Rai
1. Agricultural Land	**25.68**	**16,047.50**
1.1 Other Agricultural Land	0.60	377.37
1.2 Paddy Field	9.56	5,973.75
1.3 Field Crop	12.59	7,869.62
1.4 Perennial	1.07	668.70
1.5 Orchard	1.72	1,077.93
1.6 Horticulture	0.13	80.14
2. Forest Land	**0.53**	**328.44**
3. Urban and Build-up Land	**8.22**	**5,135.47**
4. Miscellaneous Land (Water Body, Sandbar, Islet, etc.)	**14.17**	**8,855.88**
Totals	**48.59**	**30,367.28**

3.4 Simulation of Water Level Rise Scenarios Affecting the Banks of Mekong River

Analysis of multiple water level rise simulations affecting the banks of Mekong River was divided into base case and current scenarios using the dataset of the year 2014 interpreted from satellite imagery during the dry season along with the analysis of water level data monitored at Nong Khai gauge station in the same record time of the satellite images taken. DEM was used to simulate base case scenario of water level rise along with Mekong River channel data in the year 2014. The analysis found that water rise level affected both the riverbank area size and the extent of hazard area. The result of multiple simulated water level rise scenarios demonstrated the rising level at 2.73-meter would affect the bank area of Mekong River in Nong Khai province, northeast of Thailand as shown in Table 4 and Figure 8.

The satellite image captured on 10 January 2014 was used to validate the two comparative analyses between the simulation-based multiple water level rise scenarios at flood level and the base case on 31 March 2014. The water level at Nong Khai gauging station on 10 January 2014 was 3.11-meter which was 4.78% different from the water level at the flood area as shown in Table 5 . Furthermore, flood risk in the Mekong River in Nong Khai province increased due to the rise of water level and differed in each type of land use as shown in Table 6. The Table 6 showed that agricultural land was the most at risk of flooding at approximate area of 25.68 sq. km or 16,047.50 Rais, next was miscellaneous land (water body, sandbar, islet, etc.) at approximate area of 14.17 sq. km or 8,855.88 Rais. This study finding was consistent with the survey result conducted by the Department of Water Resources which 4 0 0 questionnaires were launched to local Thai people living in 8 Mekong provinces. The result found the Mekong right bank areas were impacted by flood incidents continually occurred since 2005 and worse in 2008 at 41.4% response rate. Household flood lasted for 8-15 days and less than 7 days at 45.9% and 37.8% response rate respectively. Farmland flood lasted longest for 8-15 days. (DWR, 2015)

4. Discussion

According to the result shown above at Nong Khai gauge station in the dry season in 2014 the year the study was conducted, the water level was higher than in 2000. Additionally, comparing the average water level between 1967 and 2014 with the dry season in 2014 found that the average water level in 2014 was also higher.

The morphological change along the riverbank of the Mekong River especially its bank erosion in 2000 and 2014 showed the similar erosion rate to the previous study of Kummu et al., (2008) which found that the average annual erosion rates was 0.9 m/year during 1961-1992 and 0.8 m/year during 1992-2005 for the right bank of the Mekong River in Vientiane-Nong Khai area. It has been found, finally, in this study that the changes of water level rise and morphological changes of the Mekong River caused the area along the riverbank of Nong Khai province both in physical and socio-economics effects. Besides, the eroded riverbank and seasonally submerged sandbar also caused tourism advantage as Jom Manee Beach for example.

Moreover, the multiple simulated water level rise scenarios clearly showed the agricultural land on the right bank of Mekong River in Nong Khai province northeastern Thailand would be affected at the highest risk which undoubtedly caused the economic loss. For erosion protection, engineered structures method was applied to strengthen and stabilize the riverbank and shoreline. Thailand is the only country in the Mekong basin that can invest extensive financial resources on bank protection and flood embankments along its critical riverbank stretches (Miyazawa et al, 2008). A database of Thailand's countrywide riverbank protection dams managed by Department of Public Works and Town & Country Planning from 1990 to 2005 (DPT, 2008) showed the total length of riverbank protection dikes along the long thin border of Nong Khai province was 21.39 kilometers.

5. Conclusions

This study emphasized the morphological changes towards the right bank erosion of the Mekong River in Nong Khai province northeastern Thailand in the dry season in 2000 and 2014 analyzed by LANDSAT imagery enhanced with NDWI in comparison with Mekong River water level data on the same date of satellite images taken. The result showed that bank erosion was 0.89 sq.km or 555.90 Rais and bank accretion was 3.93 sq.km or 2,457.27 Rais at average erosion rate of 1.31 m/year and average accretion rate of 2.03 m/year. The change of sandbars and river islets was carefully considered and found 5.92 sq.km or 3,698.58 Rais of riverbank was severely eroded/submerged. The result from multiple simulated water level rise scenarios conducted in conjunction with Digital Elevation Model showed the agricultural land would be affected at great risk of flood level. In addition, the results of this study identified the bank erosion hot spot of the Mekong River due to long-term impact of riverbank change. Consequently, the responsible authorities can properly prepare for the erosion protection plan such as building terracing and retaining walls as well as providing local people the information and basic understanding of erosion crises. Recommendations from the study, high to very high-resolution satellite imagery should be used for better accuracy of erosion hazard areas identification. Lastly, Lidar remote sensing technology should be considered in future studies in order to simulate the water level rise scenarios more precisely.

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