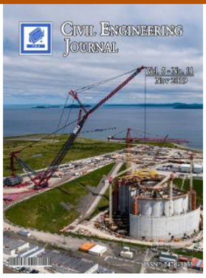
Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 5, No. 11, November, 2019



Historical Morphodynamics Assessment in Bridge Areas using Remote Sensing and GIS Techniques

Myint Myat Oo [a], Cho Cho Thin Kyi [a], Win Win Zin [a*]

[a] *Department of Civil Engineering, Yangon Technological University, Yangon and 11181, Myanmar*.

Received 27 June 2019; Accepted 14 September 2019

Abstract

Currently the Ministry of Construction is responsible for planning and construction of bridges across the country but remote sensing and satellite data are not widely used in the Ministry's routine process. Although the inspection and monitoring are carried out by the conventional methods, the remote sensing and GIS techniques are available as an alternative way with time and cost saving. From this study, the channel migration in the locations of Ayeyarwady bridges will be analyzed and mapped by identifying temporal changes of channels. Google Earth Engine is used as the primary application in this study and surface water extraction from historical Landsat satellite imagery is done by GEE. River centerline processing and erosion-deposition area identifications are carried out by GIS technique. Study period of each bridge is between 1987 and 2017. Bo Myat Tun Bridge and Ayeyarwady Bridge (Pakokku) are toped in the list with highest migration and erosion-deposition rate according to the study. The goal of this study is to assist the bridge inspections and channel monitoring works by means of remote sensing and GIS techniques which are currently undertaking by Ministry of Construction with conventional techniques.

Keywords: Remote Sensing; GIS; Channel Migration; Change Detection; River Morphology.

1. Introduction

Rivers and streams are self-regulatory in that they adjust their forms in response to environmental changes which may occur naturally or sometimes may be results of human activities. Climatic events like heavy rain and volcanic activities are natural factors while other activities like river training, damming, diversion, sand and gravel mining, channelization, bank protection, and bridge and highway construction can be considered as human activities. Both activities distort the natural quasi-equilibrium of a channel. In order to restore or maintain the balance between its ability to transport and the load provided, one or more of the following characteristics may necessary to adjust such as its slope, roughness, bed material size, cross-sectional shape, or meandering pattern [1, 2].

River morphology is a scientific field dealing with changes in the shape of rivers, mainly due to sedimentation and erosion processes. The morphology of rivers is also a complex issue, which can be subdivided into several areas including overland flow and channel flow, drainage systems and channel networks, discharge and basin area, stream erosion-deposition and transportation [3]. The focus of this study is monitoring the changes of the channels in bridge areas.

River monitoring can be recognized as a key issue for river management and training. Recent developments in remote sensing technologies opened up unprecedented capabilities to perform high quality monitoring program for a wide range

* Corresponding author: winwinzin@ytu.edu.mm

http://dx.doi.org/10.28991/cej-2019-03091429

of environmental fields including river systems [4]. One of the most promising applications in river science is the delineation of the water channel for water discharge estimation based on water channel widths which can be the valuable applications especially for ungauged rivers [5].

Monitoring of changes using remote sensing technology is widely used in different application, such as land use/land cover change, disaster monitoring, forest and vegetation change, urban sprawl and hydrology [6]. Surface water is one of the irreplaceable strategic resources for human survival, social development and ecosystems [7]. Reliable information about the spatial distribution of open water is critically important in various scientific disciplines, such as the assessment of present and future water resources, climate models, agriculture suitability, river dynamics, wetland inventory, watershed analysis, surface water survey and management, flood mapping, and environment monitoring [8]. Remote sensing satellites at different spatial, spectral, and temporal resolutions provide an enormous amount of data that have become primary sources, being extensively used for detecting and extracting surface water and its changes in recent decades [9].

Several image processing techniques have been introduced in recent decades for the extraction of water features from satellite data. Single-band methods utilize a selected threshold value to extract water features. In this type, errors are common because of mixing of water pixels with those of different cover types. Classification techniques adopted to extract surface water are normally more accurate compared with single-band methods. Multi-band methods combine different reflective bands for improved surface water extraction. Surface water change detection is usually conducted by extracting water features individually from the multi-date satellite images, before making comparisons to detect their changes [10-12].

The monitoring works for bridge along Ayeyarwady River are currently undertaking by conventional methods. Nowadays, the remote sensing techniques are available as alternative tools for river and channel monitoring with more time and cost saving. In this study, the water surface of the locations along the Ayeyarwady River where bridges are existed were extracted and investigated the channel migration and bank erosion by means of remote sensing in order to assist the channel monitoring works especially in bridge areas. It is vital to monitor the migration of channel which can provide the important information for analysis of river morphology.

2. Study Area

2.1. Ayeyarwady River

The Ayeyarwady River is the most important commercial waterway and the backbone of the country. It is originated from the confluence of Maikha and Malikha Rivers and flows relatively straight North to South before emptying through the Irrawaddy Delta into the Andaman Sea. The total length of Ayeyarwady River is about 2,210 km and has a total drainage basin of about 415,000 sq-km [13]. The course of Ayeyarwady River can be divided into three sections in order of ages: (i) the Upper Ayeyarwady, the oldest, (ii) the Middle Ayeyarwady, which did not exist in the early tertiary period, and (iii) the Lower Ayeyarwady, the delta which is the most recent part of the river [14]. In the upper Ayeyarwady portion, which is between confluence and Mandalay, there are some places with high channel migration rate such as Sinbo, Katha, Bhamo, Tigyaing. Other parts in this portion have a limited amount of channel migration due to geological characteristics of the region. In the middle portion, starts from Mandalay, and Delta portion, most parts of the channel are considered as high migration rate. Only the channel between Thazi and Pyay has the low channel migration in this portion.

2.2. Bridge on Ayeyarwady River

There are total of 15 bridges along the Ayeyarwady River according to data available from Ministry of Construction. All of Ayeyarwady bridges are constructed as steel truss bridges with concrete pier foundation. The lengths of bridges are ranged between 750 m and 4120 m. Among these, the Innwa Bridge (also known as Ava Bridge) which is constructed in 1934, located near Mandalay, is the only bridge constructed before the study period of this study. According to Ministry of Construction data, although Maubin Bridge and Daydaye Bridge are named as Ayeyarwady Bridge, both bridges are excluded from study because they are not situated on the main Ayeyarwady River, but on the distributaries of the Ayeyarwady Delta. The bridge locations and years of bridge construction completion are shown in Fig. 1. Total of 13 bridge locations are analyzed for temporal changes in this study [15, 16].

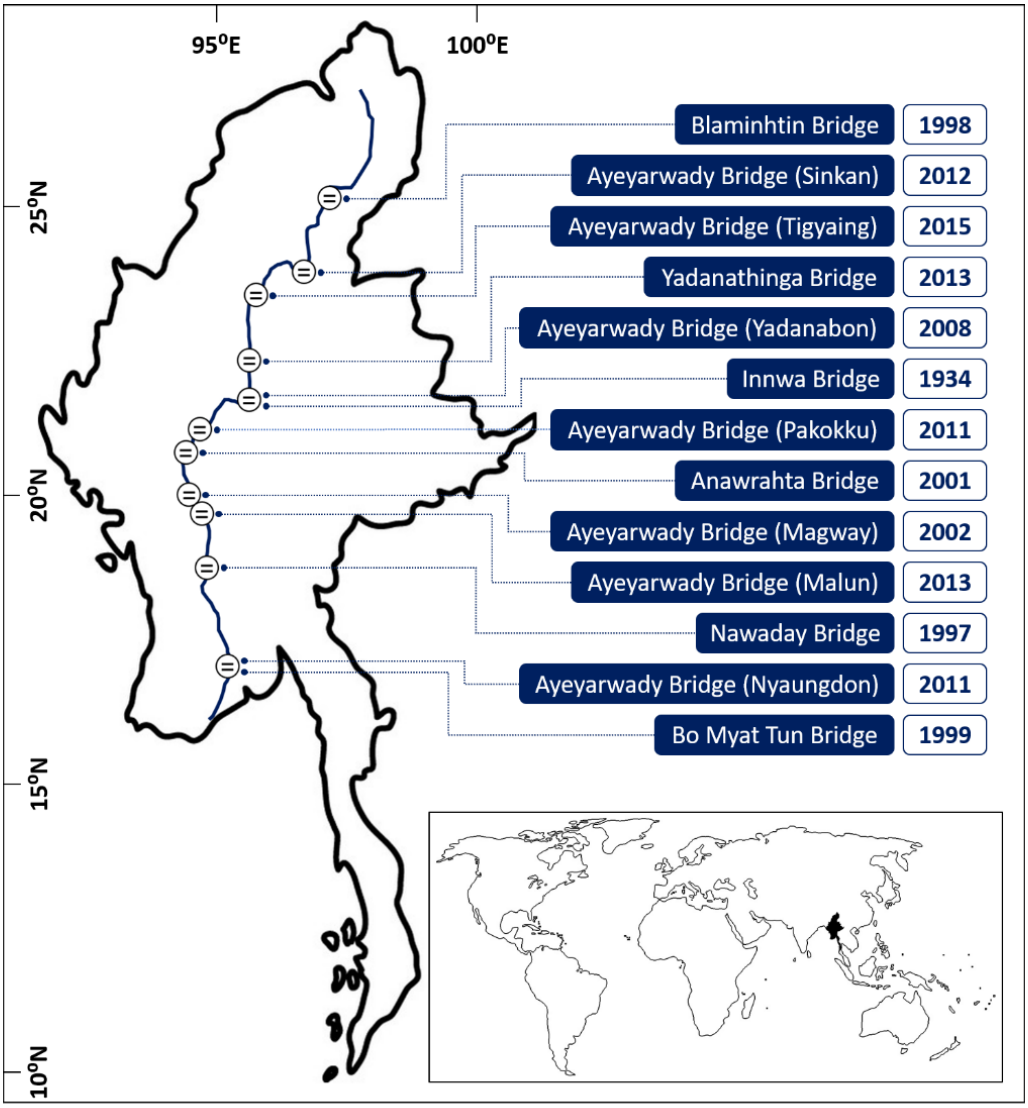


Figure 1. Bridges on Ayeyarwady River

3. Data Collection

The data set of Landsat Imagery is obtained from the US Geological Survey (USGS) Global Visualization Viewer. It includes the archives of Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager acquired between 1987 and 2017 which is the study period of this research. Table 1 presents the data set using for this research [17, 18].

Table 1. Used Data Sets

Satellite	Sensor	Year	Resolution
Landsat-5	TM	1987-2011	30 m
Landsat-7	ETM+	1999-2015	30 m
Landsat-8	OLI	2013-2017	30 m

Data Source: US Geological Survey

4. Research Methodology

4.1. Application

For the processing and analysis of satellite imagery, Google Earth Engine is used. It is an advanced cloud-based geospatial processing platform launched by Google and designed mainly for planetary-scale environmental analysis. It combines a multi-petabyte catalog of satellite imagery and geospatial data sets, which allow users to visualize, manipulate, edit and create spatial data in an easy and fast way [19, 20]. Figure 2 shows the basic flow chart of the study.

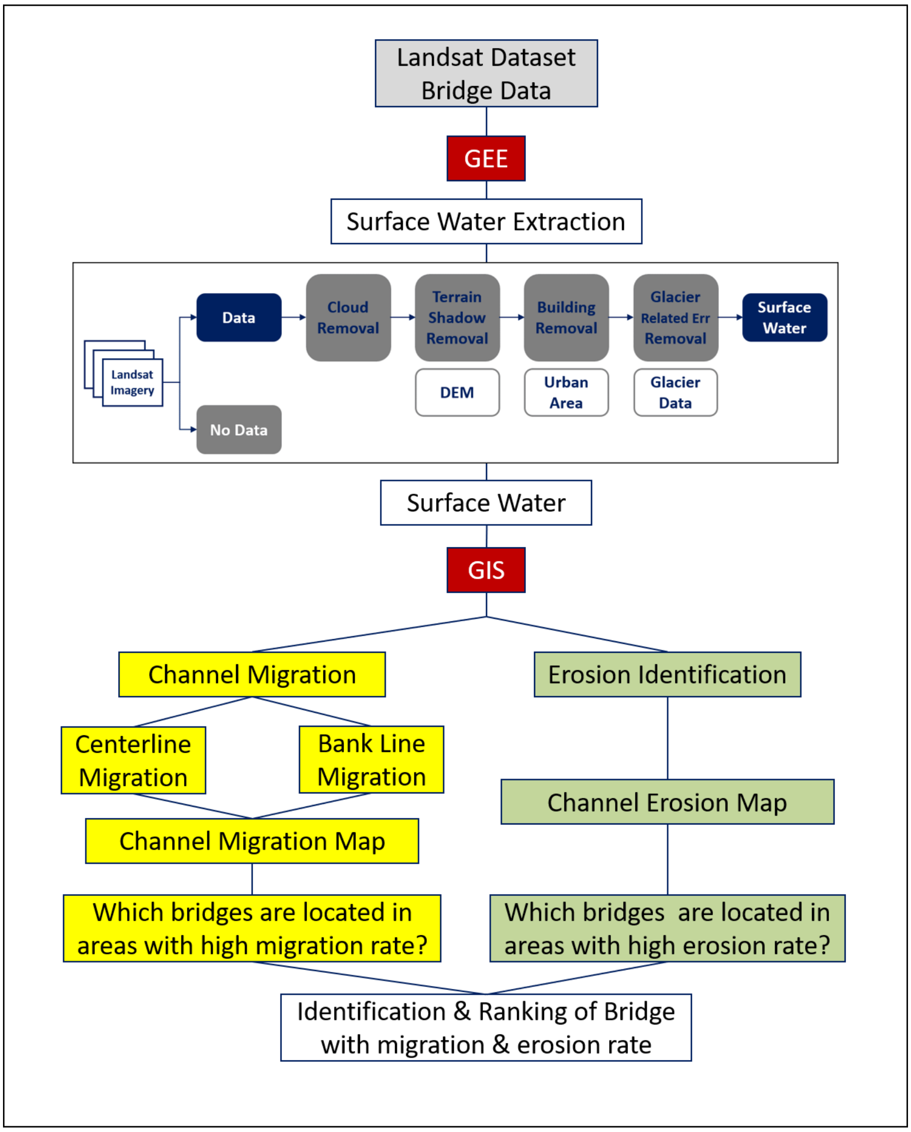


Figure 2. Flowchart for Erosion Identification and Channel Migration Detection

4.2. Surface Water Extraction

In order to detect the changes of the channel between 1987 and 2017, the surface water of the river in each temporal image was extracted individually. In doing so, the performances of different satellite-derived indexes including Normalized Different Water Index (NDWI) [21], Modified Normalized Different Water Index (MNDWI), Normalized Different Moisture Index (NDMI) [22], Normalized Different Vegetation Index (NDVI), and Automated Water Extraction Index (AWEI) were examined for the extraction of surface water from Landsat data [23]. A land-water threshold was manually applied to classify the image into two classes, land and water. For visual interpretation of water bodies, the near-infrared (NIR) band is usually preferred, because NIR is strongly absorbed by water and strongly reflected by the terrestrial vegetation and dry soil [24, 25].

4.3. Change Detection

After the surface water is extracted for each year, the channel migrations in specified areas are detected by comparing the historical images processed from extracted surface water. Erosion and deposition can also be found in the comparison, such as the area which was the water at the start and land at the end of study period can be considered as area deposited. On the other hand, the area which was the land at the start and water at the end of study period can be considered as area eroded [26, 27].

4.4. Flow Path Comparison

Next analysis is the identification of area with lowest channel migration rate near existing bridge areas. This process is carried out but the historical channel centerline observed from extracted surface water by using GIS techniques. Mapping and Analysis of 13 locations with 15 bridges were carried out using GEE and Landsat data sets.

5. Results and Discussion

The study period of my research is between 1987, when the earliest satellite image available which cover the study area, and 2017. The images for each year of study period were processed by using Google Earth Engine (GEE). All thirteen bridge locations were processed and analyzed by means of remote sensing techniques using GEE. Most of the bridges situated in delta and middle Ayeyarwady have the obvious amount of changes during study period. The processed images for 13 bridge locations can be ranked as Figure 3 by means of change rate. Among these locations, (a) Nyaungdon area has the noticeable changes during study period and thus the findings are discussed in this paper. Other locations such as (b) Ayeyarwady Bridge (Magway), (c) Nawaday Bridge, (d) Anawrahta Bridge, (e) Ayeyarwady Bridge (Pakkoku), (f) Innwa Bridge and Ayeyarwady Bridge (Yadanabon) also have the high change rate. Other bridges such as (g) Balaminhtin Bridge, (h) Ayeyarwady Bridge (Tigyaing), (i) Yadana Thinga Bridge have moderate change rate and (j) Ayeyarwady Bridge (Sinkhan) and (k) Ayeyarwady Bridge (Malun) are the areas with least change rate. The differences of detected water surfaces of above mentioned bridge locations are as shown in Figure 3.

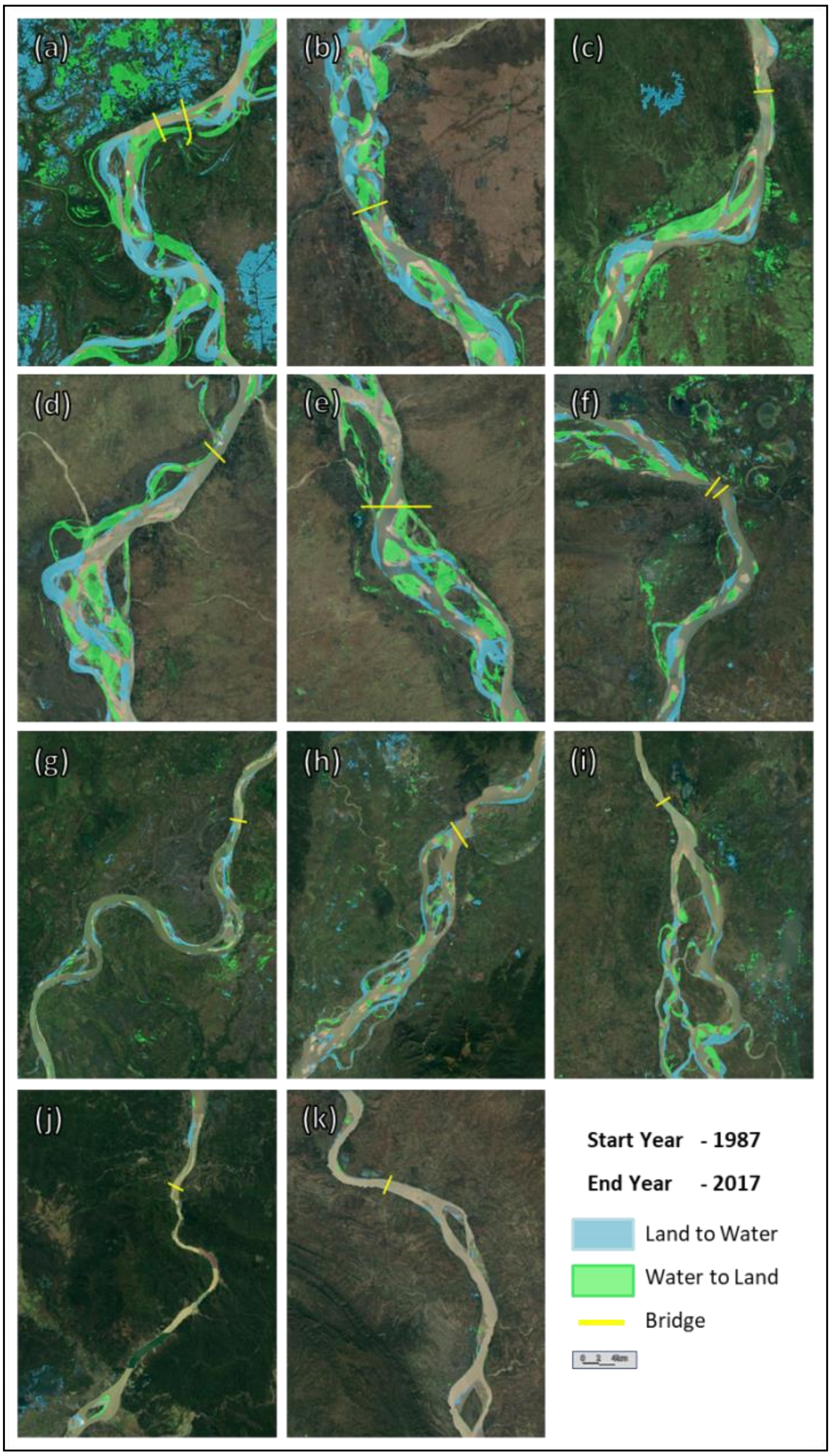


Figure 3. Water Surface Changes in Bridge Locations (1987-2017)

5.1. Findings in Nyangdon Area

There are two bridges located on Ayeyarwady River 2.2 km apart near Nyaungdon, which situated in the middle of Ayeyarwady Delta. The first one, Bo Myat Tun Bridge is completed in 1999 and it became the longest bridge of Myanmar at this time with total length of 2604 m and has seventeen piers in the river. Before its existence, Z-crafts were used to cross the Ayeyarwady River in this region. There were great delays and inefficiency in transportation through the river. After the completion of the Bo Myat Tun Bridge, there is no such grave situation and it shortens the travel time in an incredible scale. So, it is important to maintain the bridge sustainability and guarantee the safety of the bridge. Bank erosion has started at the right bank of the bridge just after the completion of the bridge. The erosion is being caused near No. 17 Pier of Bo Myat Tun Bridge. Although the erosion protection works were carried out, the erosion has not been controlled according to DWIR's river training reports.

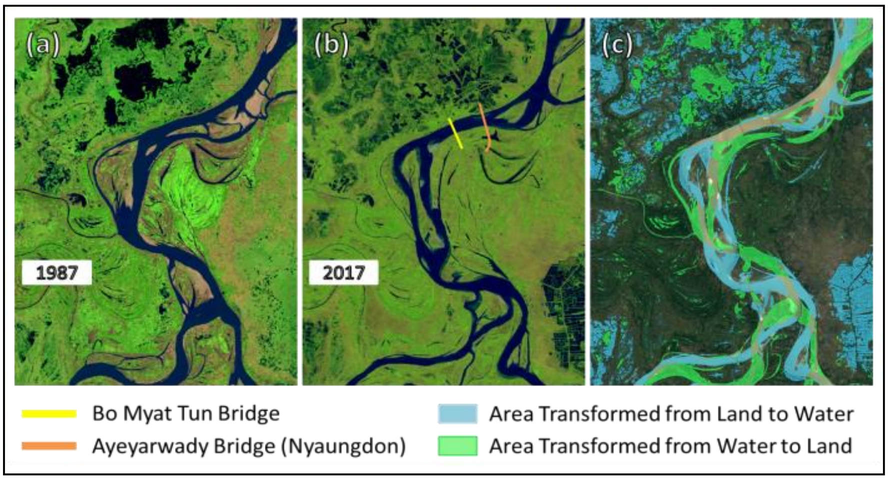


Figure 4. Processed Landsat Images of Nyaungdon Area

In Figure 4, (a) represents the detected water surface of 1987 and (b) represents that of year 2017. The changes between the two images were differentiate and visualized in (c). The channel migration in this area is noticeable that the main channel is shifted to the right side and river bend is moved forward just downstream of the bridge. The river island at the upstream of the bridge is combined with the left bank and formed a permanent land. The movements of river islands during study period are presented in the Figures 5 and 6 respectively.

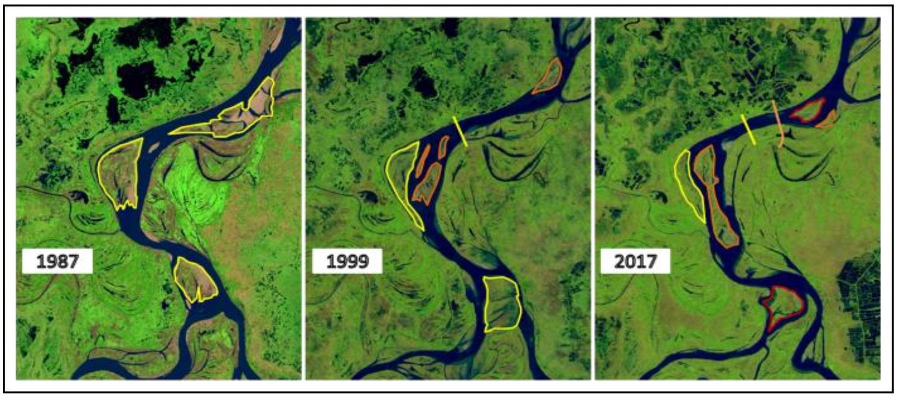


Figure 5. Movement of River Islands (Downstream)

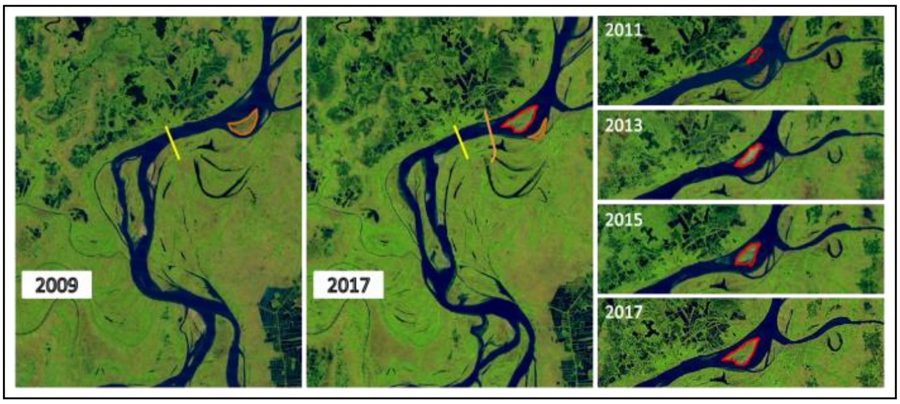


Figure 6. Movement of River Islands (Upstream)

In Figure 7, (a) and (b) are the detected surface water processed by using Google Earth Engine and Landsat Satellite Imagery data set. The detected surface water of year 1999, the year of the completion of Bo Myat Tun Bridge, and year 2017 were shown in (a) and (b) respectively. Figure 7 (c) shows the result of change detection between surface water of year 1999 and 2017. The light green colour indicates the areas transform from water in 1999 to land in 2017. In reverse, the light blue colour indicates the areas transform from land in 1999 to water in 2017. In general, light blue colour is the areas eroded and light green colour is areas deposited during study period. In Figure 7 (d) the yellow line indicates the main span of Bo Myat Tun Bridge and the light blue colour is the total areas of eroded since the bridge was completed. The eroded bank exists on the right bank of the Ayeyarwady River.

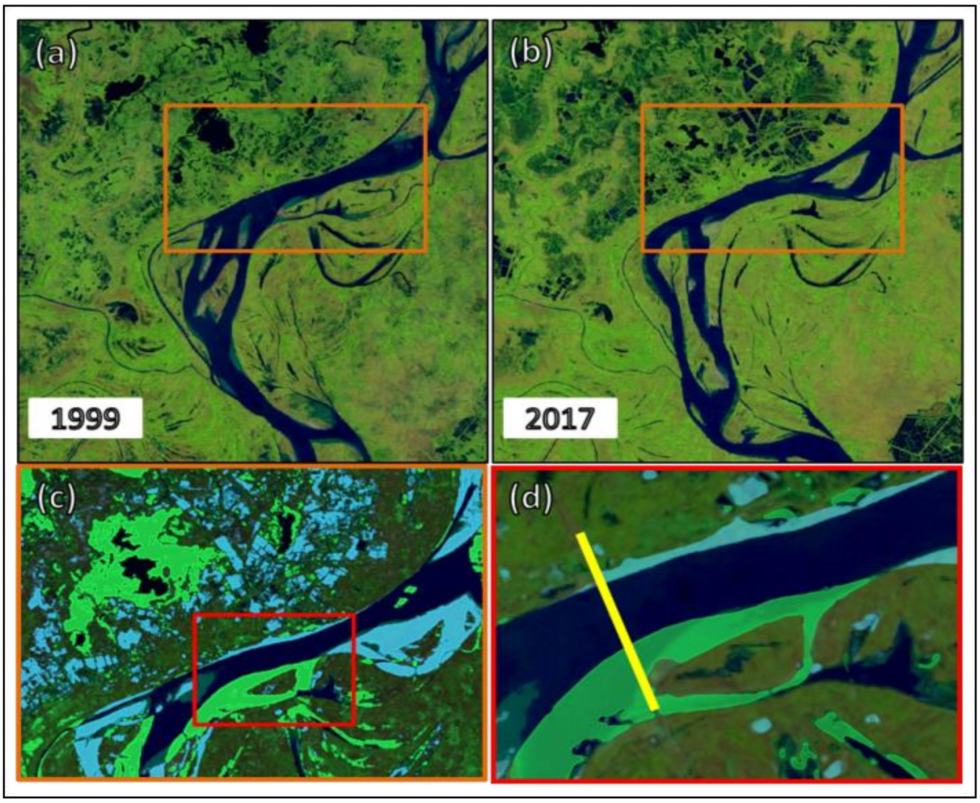


Figure 7. Erosion Identification of Nyaungdon Area

According to the processed images, the eroded area is situated along the outer bend of the river. As the area is situated in the delta of Ayeyarwady River, both upstream and downstream areas are braided with multiple channels. At the bridge location, the channel appears as a single channel with the width of almost 1900 m and this was the one reason to choose this place as the site of bridge construction. According to the change detection between the images of study period, it can be concluded that the channel has the tendency of shifting to the right by means of erosion at the right bank and deposition at the left bank.

As described in above findings, the bridge is situated in the area of river bend and the right bank is the outer bend of it. So, the right bank was prone to severe erosion and the erosion will continue until the erosive power of the channel ceases at the right side and the channel re-shifts to the left. It is a natural phenomenon if it is not protected by human interferences. No. 17 Pier which is situated at the right bank was in danger. The span between No. 17 and No. 16 Pier is only 120m and helical flow generated by the river bend become stronger due to narrow span. Severe erosion was caused by these effects of helical flow and channel constriction between the piers. Another factor that enhances the erosion is the skewness of pier with the direction of flow. The skewness is found to be 50 degrees and it causes turbulence of flow that erodes the vicinity of the piers and creates deep pools. Therefore, the main causes of erosion at the right bank near Bo Myat Tun Bridge can be described as (i) the helical flow generated by river bend, (ii) constriction effect between bridge piers (No. 17 and No. 16), (iii) skewness or piers with flow direction, and (iv) morphological changes of river.

In 2011, a new bridge, namely Ayeyarwady Bridge (Nyaungdon), is constructed 2 km upstream of the Bo Myat Tun Bridge. It is constructed near the Bo Myat Tun Bridge due to many reasons. Among these reasons, the situation of erosion problem near Bo Myat Tun Bridge is considered as a major factor. Another study in this research is the comparison of channel migration during past 30 years. Channel thalweg line which is the primary of the navigable channel of a river, is difficult to acquire from satellite imagery. Therefore, the centerlines of the detected water surface, which can be considered as flow path of the river in this research, are compared to analyze the channel migration. The centerlines of the past 30 years are processed based on detected surface water using GIS. The circled area shows the area with least channel migration rate during the study period of 1987 and 2017.

According to (a) of Figure 8, the new bridge, Ayeyarwady Bridge (Nyaungdon), is situated in more appropriate location than the Bo Myat Tun Bridge. In Figure 8, (b) shows the flow paths during the period of no bridge in the study area, (c) shows the period of only Bo Myat Tun Bridge and (d) shows the flow paths of the study area with both bridges. From the comparison of flow paths through the study period, significant changes can be found in both upstream and downstream areas of the bridges such as, Area U1, Area D1 and Area D2.

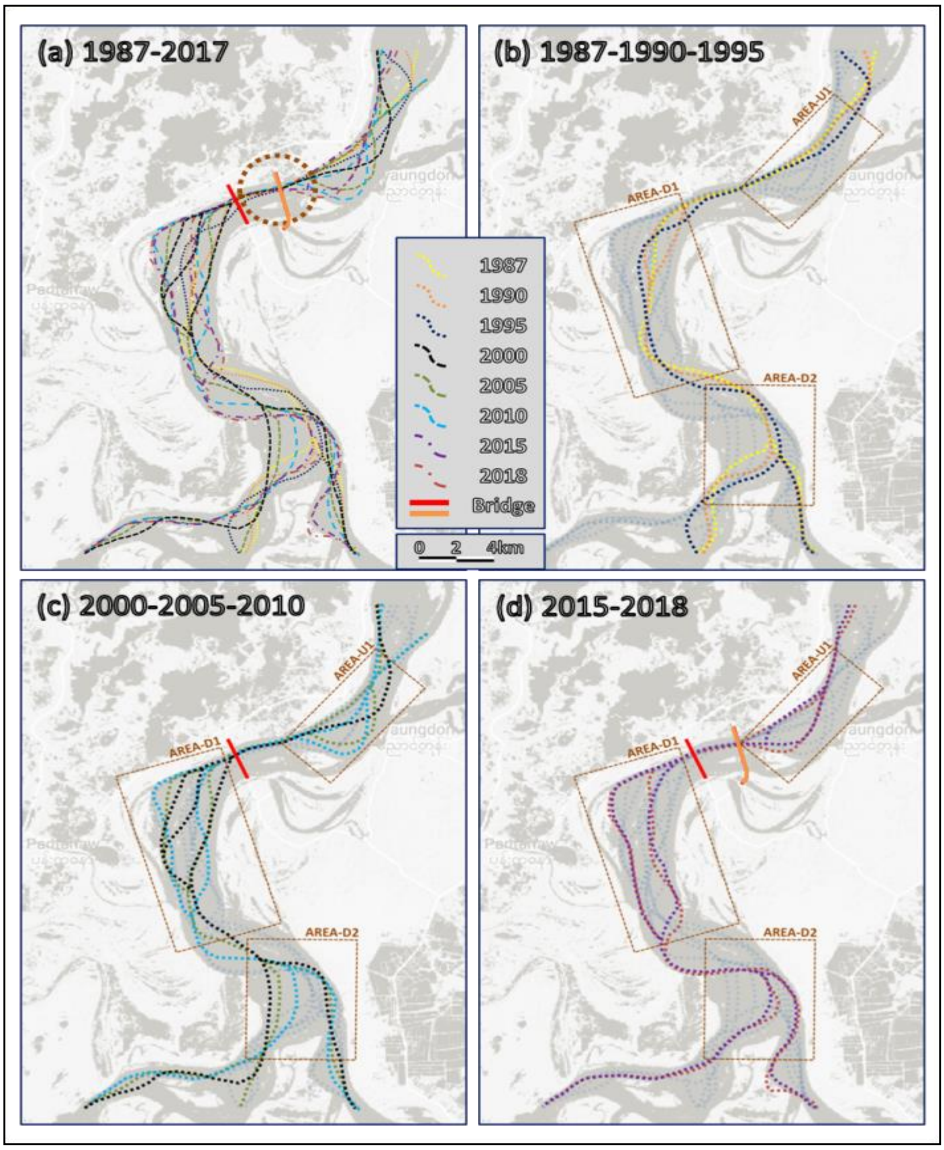


Figure 8. Flow Path Comparison of Nyaungdon Area

6. Conclusion

In this case study, it has become clear that remote sensing and satellite imagery data sets can give the better results than the conventional methods in analysis of historical temporal changes of river. The areas with least channel migration can easily be identified and areas with high migration rate along the Ayeyarwady River can also be found by comparing the flow paths throughout the study period. The locations such as Bo Myat Tun Bridge, Ayeyarwady Bridge (Magway), Nawaday Bridge, Anawrahta Bridge, and Ayeyarwady Bridge (Pakokku) and Ayeyarwady Bridge (Yadanabon) are locate in the areas with high migration rate resulted from surface water mapping and analyzing. In Nyaungdon area, bank erosion at the right bank of the Ayeyarwady River which was the major threat to bridge sustainability has been mapped by differentiating start and end point of the study period. Throughout this case study, the channel migration in the Nyaungdon Area is subjected to various causes and there is a need to provide more suitable river training works for this area to protect bank erosion. Based on flow path comparison, the location of the second bridge, Ayeyarwady Bridge (Nyaungdon) is more suitable than the location of first bridge Bo Myat Tun. Therefore, it can be stated that remote sensing can be very efficient tool in the process of mapping of river surface water and analysis of channel migration and identification of bank erosion. Finally, not only the Nyaungdon area also the other locations of bridge along Ayeyarwady can easily and efficiently be analyzed by means of remote sensing and GIS techniques with satellite imagery data sets.

7. Acknowledgements

The author would like to thank Dr. Cho Cho Thin Kyi (Associate Professor) and Dr. Win Win Zin (Associate Professor) of Yangon Technological University (YTU) for their supervision on this study. In the case of Landsat Satellite Imagery Data Sets, the author would like to thank U.S. Geological Survey (USGS). Special thanks are extended to Google Earth Engine (GEE) of Google Enterprise, and the data providers such as Ministry of Construction for bridge data, DWIR for data related to Ayeyarwady River. The author would like to appreciate collages for their timely help during this research study.

8. Conflicts of Interest

The authors declare no conflict of interest.

9. References

[1] D. Rosgen, H.L. Silvey." Applied River Morphology 2nd Edition". 1996.

[2] Nicholas, Andrew. "Morphodynamic Diversity of the World's Largest Rivers." Geology 41, no. 4 (April 2013): 475–478. doi:10.1130/g34016.1.

[3] C. A. Whaley. "Causes for Change in Stream-Channel Morphology". Department of Earth Sciences, University of South Alabama. 2007. Available online: http://www.southalabama.edu/geography/fearn/480page/2007/ChadWhaley.pdf (accessed on 1 May 2019).

[4] Langat, Philip Kibet, Lalit Kumar, and Richard Koech. "Monitoring River Channel Dynamics Using Remote Sensing and GIS Techniques." Geomorphology 325 (January 2019): 92–102. doi:10.1016/j.geomorph.2018.10.007.

[5] Bizzi, S., L. Demarchi, R. C. Grabowski, C. J. Weissteiner, and W. Van de Bund. "The Use of Remote Sensing to Characterise Hydromorphological Properties of European Rivers." Aquatic Sciences 78, no. 1 (September 23, 2015): 57–70. doi:10.1007/s00027-015-0430-7.

[6] Mueller, N., A. Lewis, D. Roberts, S. Ring, R. Melrose, J. Sixsmith, L. Lymburner, et al. "Water Observations from Space: Mapping Surface Water from 25 Years of Landsat Imagery Across Australia." Remote Sensing of Environment 174 (March 2016): 341–352. doi:10.1016/j.rse.2015.11.003.

[7] G.E. Moglen." Fundamental of Open Channel Flow". CRC Press (April 17, 2015).

[8] Alsdorf, Douglas E., Ernesto Rodríguez, and Dennis P. Lettenmaier. "Measuring Surface Water from Space." Reviews of Geophysics 45, no. 2 (May 9, 2007). doi:10.1029/2006rg000197.

[9] Lu, Shanlong, Bingfang Wu, Nana Yan, and Hao Wang. "Water Body Mapping Method with HJ-1A/B Satellite Imagery." International Journal of Applied Earth Observation and Geoinformation 13, no. 3 (June 2011): 428–434. doi:10.1016/j.jag.2010.09.006.

[10] L. Shen, C. Li, "Water Body Extraction from Landsat ETM+ Imagery Using Adaboost Algorithm," In Proceedings of 18th International Conference on Geoinformatics. 2010.

[11] J. R. Jensen, K. Lulla. "Introductory Digital Image Processing: A Remote Sensing Perspective". 2008.

[12] Yamazaki, Dai, Mark A. Trigg, and Daiki Ikeshima. "Development of a Global ~90m Water Body Map Using Multi-Temporal Landsat Images." Remote Sensing of Environment 171 (December 2015): 337–351. doi:10.1016/j.rse.2015.10.014.

[13] J. G. Scott. "Irrawaddy," Encyclopedia Britannica 11th Edition. Cambridge University Press. 1911.

[14] A. Commandeur. "The Ayeyarwady River: A Graphical Introduction to Myanmar's Main River". 2014.

[15] Ministry of Construction. "2016-2017 Fiscal Year Report: Ayeyarwady Bridges". 2017.

[16] Directorate of Water Resources and Improvement of River Systems. "DWIR Yearly Announcement on Shipping Routes and Waterways". 2017.

[17] USGS Earth Explorer. "Landsat Imagery Dataset". Available online: https://earthexplorer.usgs.gov (accessed on 1 June 2019).

[18] USGS Global Visualization Viewer (GloVis). Available online: "Landsat Dataset". https://glovis.usgs.gov/app (accessed on 15 May 2019).

[19] Google Earth Engine. "Developer's Guide". Available online: https://developers.google.com/earth-engine (accessed on 5 March 2019).

[20] ADPC, SERVIR Mekong, OneMap Myanmar, MIMU. "Lecture Notes: Google Earth Engine Training at YTU". 2017.

[21] Mc Feeters, S. K. "The Use of the Normalized Difference Water Index (NDWI) in the Delineation of Open Water Features." International Journal of Remote Sensing 17, no. 7 (May 1996): 1425–1432. doi:10.1080/01431169608948714..

[22] Xu, Hanqiu. "Modification of Normalised Difference Water Index (NDWI) to Enhance Open Water Features in Remotely Sensed Imagery." International Journal of Remote Sensing 27, no. 14 (July 20, 2006): 3025–3033. doi:10.1080/01431160600589179.

[23] Feyisa, Gudina L., Henrik Meilby, Rasmus Fensholt, and Simon R. Proud. "Automated Water Extraction Index: A New Technique for Surface Water Mapping Using Landsat Imagery." Remote Sensing of Environment 140 (January 2014): 23–35. doi:10.1016/j.rse.2013.08.029.

[24] Tulbure, Mirela G., Mark Broich, Stephen V. Stehman, and Anil Kommareddy. "Surface Water Extent Dynamics from Three Decades of Seasonally Continuous Landsat Time Series at Subcontinental Scale in a Semi-Arid Region." Remote Sensing of Environment 178 (June 2016): 142–157. doi:10.1016/j.rse.2016.02.034.

[25] Du, Zhiqiang, Bin Linghu, Feng Ling, Wenbo Li, Weidong Tian, Hailei Wang, Yuanmiao Gui, Bingyu Sun, and Xiaoming Zhang. "Estimating Surface Water Area Changes Using Time-Series Landsat Data in the Qingjiang River Basin, China." Journal of Applied Remote Sensing 6, no. 1 (November 28, 2012): 063609. doi:10.1117/1.jrs.6.063609.

[26] Baki, Abul Basar M., and Thian Yew Gan. "Riverbank Migration and Island Dynamics of the Braided Jamuna River of the Ganges–Brahmaputra Basin Using Multi-Temporal Landsat Images." Quaternary International 263 (June 2012): 148–161. doi:10.1016/j.quaint.2012.03.016.

[27] Wang, Suiji, Ling Li, and Weiming Cheng. "Variations of Bank Shift Rates along the Yinchuan Plain Reach of the Yellow River and Their Influencing Factors." Journal of Geographical Sciences 24, no. 4 (May 13, 2014): 703–716. doi:10.1007/s11442-014-1114-2.

[28] Frizzell, Robbie L., Lyle W. Zevenbergen, and Ricardo Navarro. "Stream Channel Restoration at Bridge Sites." Critical Transitions in Water and Environmental Resources Management (June 25, 2004). doi:10.1061/40737(2004)403.