A WEB-BASED SEASONAL GEOMORPHOLOGICAL AND COASTAL DYNAMICS MONITORING SYSTEM: CASE STUDIES IN MYANMAR

Dhyey Bhatpuria[1] **and Thanapon Piman**[1]

[1] Stockholm Environment Institute, 10th Floor, Kasem Uttayanin Building, 254 Chulalongkorn University, Henri Dunant Road, Pathumwan, Bangkok, 10330 Thailand
Email: dhyey.bhatpuria@sei.org; thanapon.piman@sei.org

ABSTRACT

Ayeyarwady River in Myanmar is one of the few free-flowing rivers in the South and Southeast Asian region. The river is also the most morphologically active in the region which is influenced by monsoon-induced high water levels and sediment loads. While such a morphologically active river in its natural state provides immense benefits for aquatic biodiversity and the ecosystem, it also poses a significant risk to riverine villages, urban infrastructure, agricultural lands, and ship navigation. In the coastal zone, the Sittaung River meets the Gulf of Mottama forming the Sittaung Estuary region which records powerful tidal surges resulting in erosion of its banks. The banks of this estuary experience cycle of extreme erosion rates, of up to 1.6 km/y, which forces local communities to abandon their villages and farms, while elsewhere in the estuary accretion and growth of tidal flats allow for the development of new agricultural land.

A web-based monitoring system called "More Rivers" was developed for the Ayeyarwady River and Sittaung estuary region using long-term time-series Landsat (5,7,8) and Sentinel-1 imagery in Google Earth Engine (GEE). Pre-monsoon and Post-monsoon seasonal composites of satellite images are used to differentiate land-water pixels using Modified Normalized Difference Index (MNDWI) and Otsu thresholding for Landsat and Sentinel-1 respectively. Utilizing change detection method pre and post water surface, erosion, and deposition areas were identified for Ayeyarwady River as well as Sittaung estuary. For river morphology, River width change was quantified by estimating lateral changes in the demarcated stream centerlines and bank lines that were derived from the pre-and post-monsoon channel masks. Land Cover/Land Use data is integrated into the system to determine to affect land cover types and area loss and gain. It was observed that changes in river course in the upper estuarine region resulted in higher land loss whereas tidal impacts along with riverine water fluctuations resulted in changes of coastline in the lower part of the Sittaung estuary.

This information disseminated through stakeholder-centric User Interface (UI) will help government agencies to monitor changes and trends of the river and coastal dynamics as well as to conduct a rapid assessment of riverbank/coastline protection and investment needed. The major impact of this system stems from generating timely, user-required information for improved decision-making towards better river management.

1. INTRODUCTION

Rivers of South and Southeast Asia experience complex geomorphic changes like changes in flows, sediment, landuse, and anthropogenic factors apart from Monsoon which exemplifies the complexities in the form of large variations in seasonal discharge and sediment loads (Abbas and Subramanian, 1984; Kummu and Varis, 2007). These induced geomorphic alternations in one season, in turn, influences local flood patterns in subsequent monsoon seasons. Over a long period, the local scale geomorphologic process may jointly function to alter the catchment scale process (Grabowski et al., 2014).

Floodplains of morphologically active rivers in Asia like the Ayeyarwady and Ganges-Brahmaputra-Meghna system hosts large populations and swathes of agricultural lands vital for the region's food security. Seasonal morphological change in these rivers erodes settlements and agricultural lands located in the floodplains thus directly affecting the riverine communities. Besides, these rivers also serve as key inland transport corridors, which are affected by seasonally changing river planforms. Monitoring river morphological change at high temporal and spatial resolutions is imperative to support sustainable river management. However, government agencies are constrained by the limited technology, human and financial outlays available to repeatedly cover the large spatial area while preferring to focus on field-based monitoring only in locations deemed critical (Newson and Large, 2006).

Freely accessible remote sensing data from multiple satellite platforms offer an efficient way to map river planform changes over large geographical domains at high temporal resolution which supports rapid assessment. Cloud-based remote sensing processing platforms like Google Earth Engine (GEE) (Gorelick et al., 2017), enables planetary and regional scale computations using freely available satellite data like MODIS, Landsat, Sentinel series from their cloud repository without the need for downloading datasets. This facilitates focus on analysis and development of solutions with less dependence on remote sensing software techniques. This paper focuses on the development of a web-based, operational, large-scale seasonal river morphology monitoring system "More Rivers" for the Ayeyarwady river to map spatial and temporal erosion and accretion areas.

2. Materials and Methods

2.1 Study Area

Ayeyarwady River flows through Myanmar from North to South dividing the country into East and West half. Ayeyarwady River basin consists of Upper Ayeyarwady, Chindwin which merges downstream to Lower Ayeyarwady. The total length of the river is 2,170 km with a total basin covers 413,710 km². The river originates in Eastern Himalayas and receives high volumes of water during the monsoon months of May to October. The majority of cities within Myanmar like Yangon, Mandalay, Magway, etc. are along the Ayeyarwady River.

The Gulf of Mottama, located in the southwest of Myanmar and bordering the Andaman Sea, at its mouth is around 100 km wide and narrows into a funnel-shaped bay towards Sittaung River in the north. This region experiences a tidal bore phenomenon leading to high waves in the upper regions of the estuary which has resulted in a large mudflat area stretching a few 100 km. This forms the Sittaung river estuary.

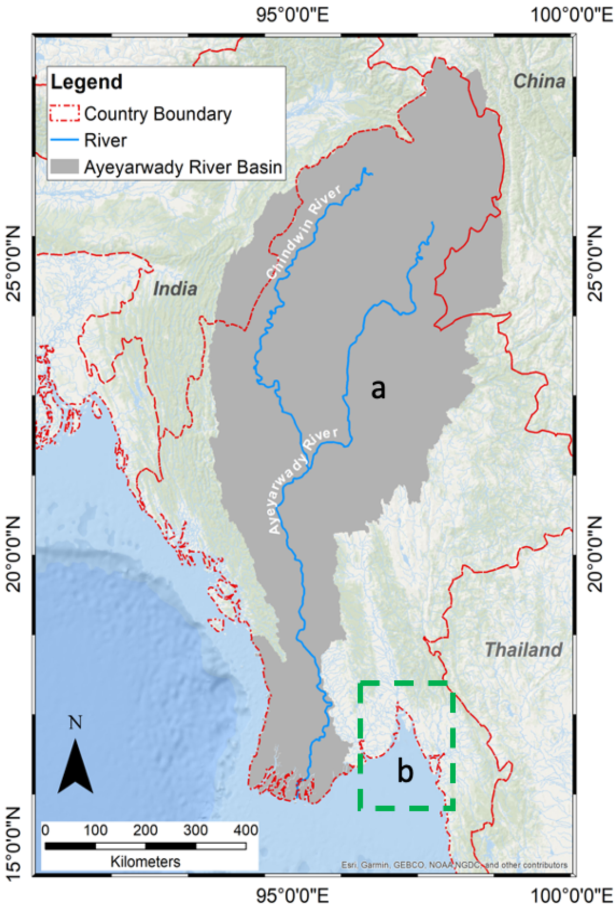

Figure 1: Study Area. Here *a* is the Ayeyarwady river basin and *b* is the Sittaung river Estuary including the Gulf of Martaban.

2.2 Methodology

In this study, long-term time-series Landsat (5,7,8) from 1988-2019 and Sentinel-1 imagery from 2017-2019 available in Google Earth Engine (GEE) is used. Detailed methodology is shown in figure 2. For riverbank erosion, Pre-monsoon and Post-monsoon seasonal composites of satellite images are used to differentiate land-water pixels using Modified Normalized Difference Index (Xu, 2006) and Otsu thresholding (Otsu, 1979) for both Landsat and Sentinel-1. The formula for Modified Normalized Difference Index (MNDWI) used is

$$\frac{Green - SWIR}{Green + SWIR} \tag{1}$$

Here, Green is the visible green band of Landsat series and SWIR is the Short Wave Infrared band of Landsat series.

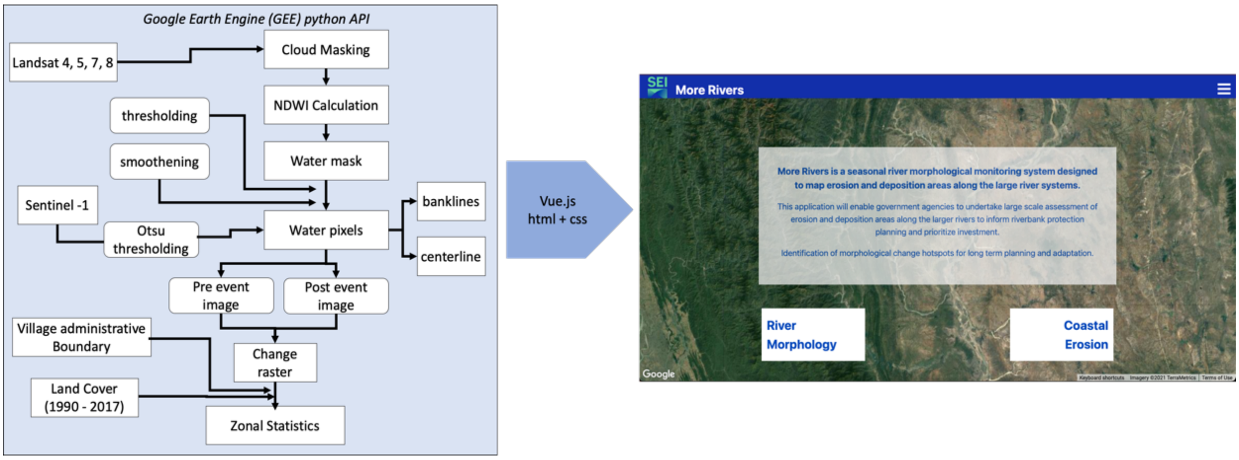

Figure 2: Methodology

For Coastal erosion, tidal and inter-tidal dates were determined for each month, and images were aggregated to compare similar tidal conditions for pre and post-changes. Utilizing change detection method pre and post water surface, erosion, and deposition areas were identified for Ayeyarwady River as well as Sittaung estuary. Time-series changes in the area for each section were calculated. For river morphology, River width change was quantified by estimating lateral changes in the demarcated stream centerlines and bank lines that were derived from the pre-and post-monsoon channel masks. Land Cover/Land Use data is integrated into the system to determine to affect land cover types and area loss and gain. This was estimated at the village level using zonal statistics to estimate changes in each village administrative unit.

For ease of access to stakeholders, this methodology is transformed into an operational tool. A web-based tool "More rivers" is designed and developed which enables the user to select region/State, period of analysis to visualise and analyse changes in a particular area of interest. It also provides an estimation of landuse changes in form of spatial output apart from time-series changes in riverbank width. To support decision-making, the user can select 3 states to generate an automated 4-page report. "More rivers" is developed using a technology stack of GEE python api as backend with vue.js and html5.

3. Results

On comparison of the annual binary rasters river course of 2018 with 1988 is shown in figure 3. This is area is downstream of the confluence of the Upper Ayeyarwady and Chindwin rivers and is observed to be highly dynamic. The red color represents the active river channel at the end of the study period (2019), the blue color represents the river channel during the start of the study period (1989). The river is highly braided in this region and hence in the figure.3a island formations are ignored to get the final banks of the river. Figure 3b illustrates eroded and current river channel, and the green color is the accreted channel and depositions shows that a high degree of erosion and accretion occurred in multiple areas within this section of river along both banks. This is more prominent in the location of the confluence of upstream rivers and the following bend downstream. Ayeyarwady's riverbank dynamics can be more clearly understood by observing at inter-annual intervals.

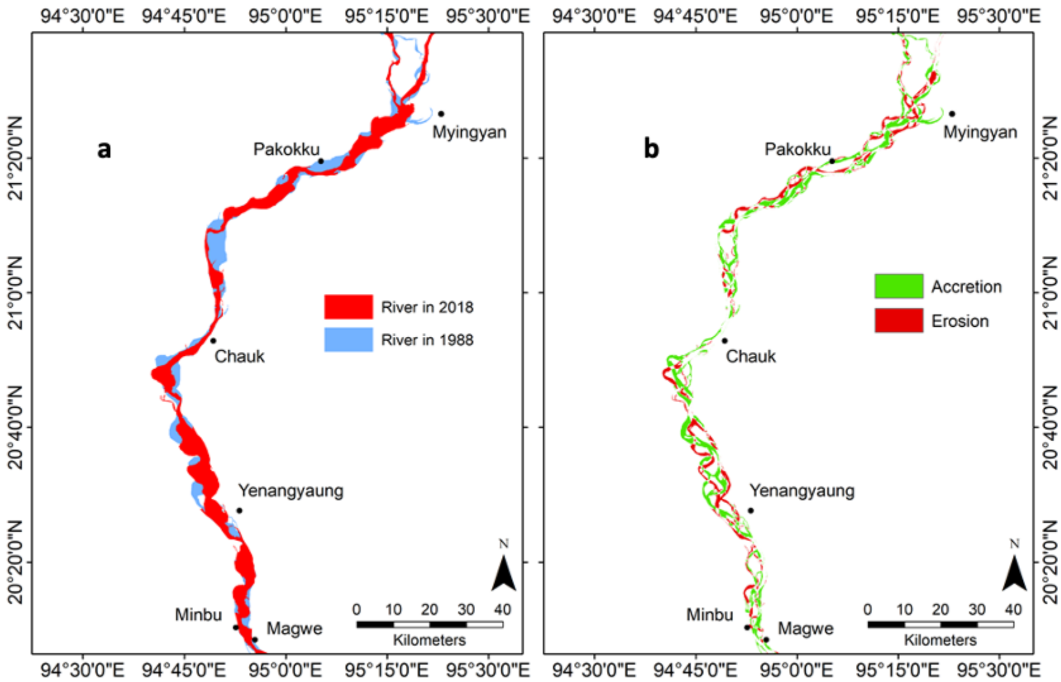

Figure 3: Changes in the river area during the study period. Figure a shows river area during 2018 (red) overlayed on river area during 1988. Figure b shows the difference of actual river area with all river braiding for the two years 1988 and 2018. Here Erosion (red) indicates the loss of land in 2018 while Accretion (green) depicts land gained in 2018 as compared to 1988.

Inter and Intra decadal changes in river course is shown in Figure 4 for 1988-1998 (a, d), 1999-2008 (b, e) and 2009-2018 (c, f). 4 a,b and c highlight Upper Ayeyarwady stretch from towns Tigyaing-Mya Taung to Takaung of Mandalay Region. 4 d,e and f shows s Lower Ayer stretch from Chauk town to Yenangyaung city of Magway Region. Here, binary annual river rasters are aggregated for each decade. Darker shades of blue represent low shifts in river course while lighter shades depict that river has been flowing through that location for few years only during that decade. In Upper Ayeyarwady (figure 4 a-c), the river shows shifting in the course more prominently along the right bank before moving further downstream towards Mandalay city. Yellow circle highlights location where river shows high oscillation during each decade while by last decade it stabilizes with a net movement towards right riverbank (figure 4a and c). Similarly in figure 4 d-f of the Lower Ayeyarwady also shows a significant shift in course gradually over three decades all along the stretch. Also, in the area highlighted by the red box, the river shows interdecadal oscillation in its course which causes high braiding downstream to that area.

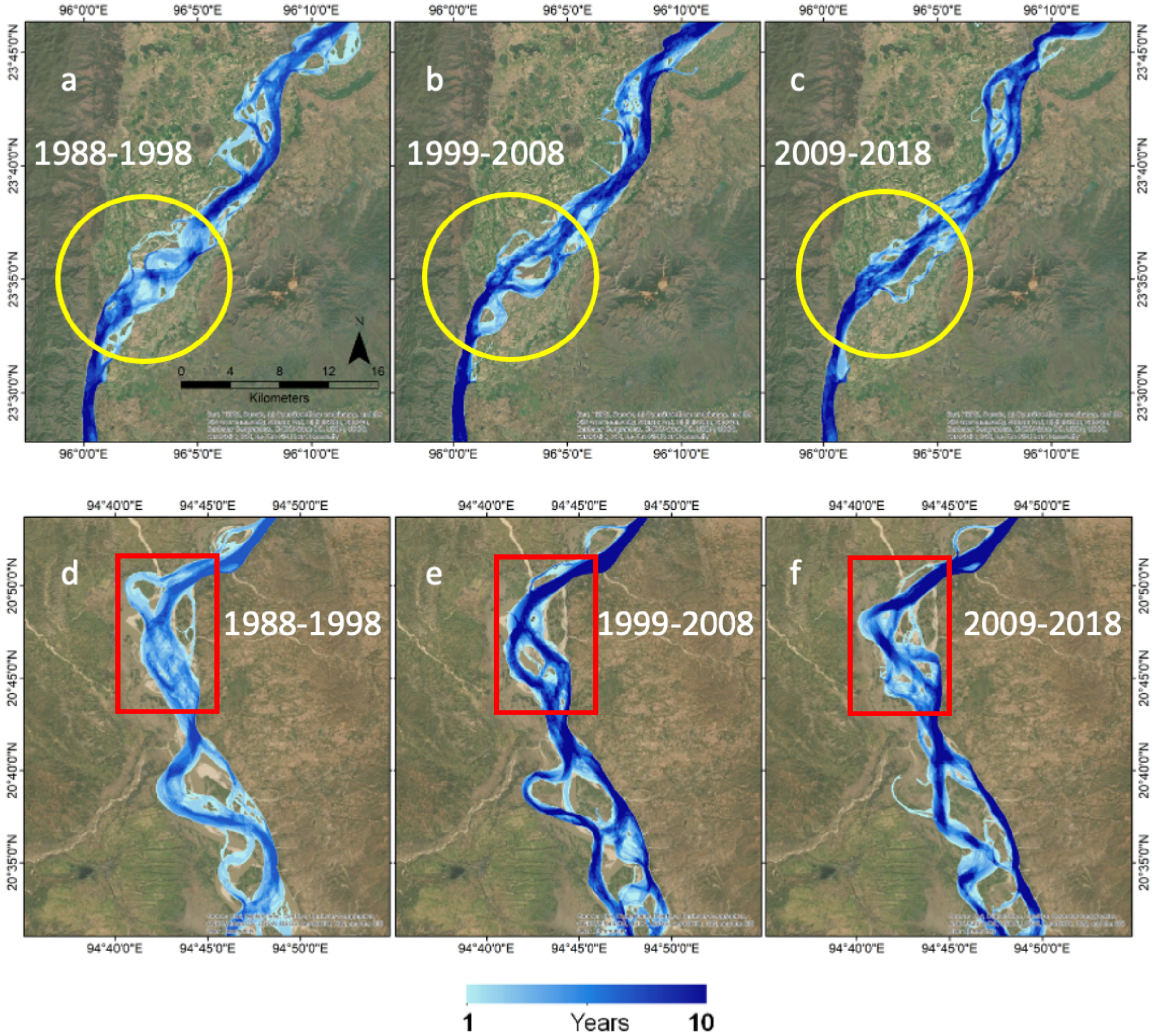

Figure 4: Decadal River course dynamics in Ayeyarwady from 1989-2019 for Upper Ayeyarwady(a,b,c) and Lower Ayeyarwady (d,e,f)

Figure 5 shows decadal changes in the river mouth region from 1989 to 2019 in false-color composite and land-sea map generated using Otsu thresholding of MNDWI. There have been conspicuous changes in the coastline along the geographic western side of the river mouth during the past 30 years. Also, during previous years, the river course was more convoluted as seen in 1989 which has been gradually changing to a more straight course, which would have led to change in streamflow and have an impact on the erosion of geographic western river mouth land. In 1999 we observe the formation of an intertidal island on the west coast which is downstream to areas with higher erosion while the lower part of the river mouth is comparatively unaffected by coastal erosion. Similarly, along the eastern side of the river mouth, we observe the development of a similar island in 2009 which gradually resulted in the gain of land.

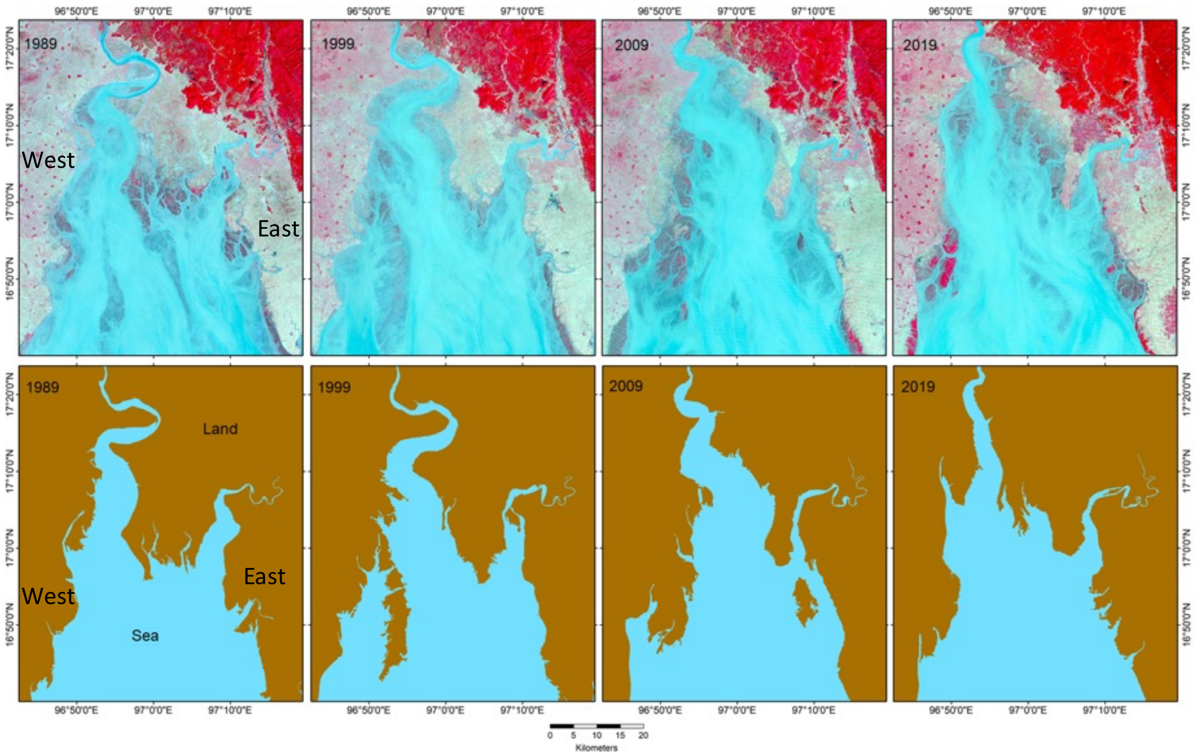

Figure 5. Decadal changes in the river estuary and coastal boundaries

4. Capacity Building and Stakeholder Engagement

Need assessment/stakeholder meetings were organized during intial development phase of the tool to incorporate needs of the end users and decision makers. Directorate of Water Resources and Improvement of River Systems (DWIR) of Myanmar which is a national governmental agency with a responsiblity for managing river systems was identified as one of the primary stakeholder. DWIR conducts extensive task of monitoring river morphological change over several thousand kilometres of river in the country. During stakeholder meetings, challenges in conduting monitoring as well as expected outputs which would augment existing methods along with addressing knowledge gaps were discussed. Web tool is being used by the key stakeholders to build better plans for management of riverbank and coastal erosion.

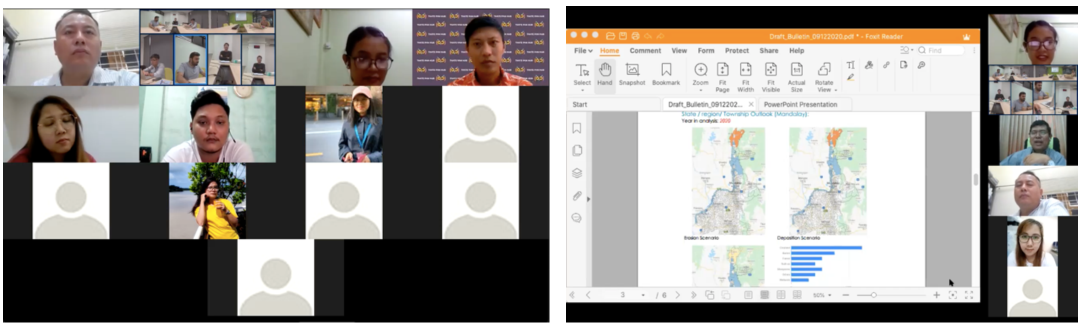

Figure 6. Online Stakeholder meeting on web tool with DWIR,Myanmar

5. Conclusion

Long-term seasonal analysis of Ayeyarwady reveals a significant change in the riverbank width. This change in river width is the consequence of erosion or deposition. Also in specific sections near Magway and above Mandalay cities, changes in form of oscillation of river course are observed. Sittaung estuary region shows a high impact of tidal waves which causes a high degree of erosion. There is more land gain in the eastern bank of the estuary in recent years which was witnessing higher erosion in previous decades, while the opposite trend is observed for the western bank of the Sittaung estuary. Google Earth Engine's repository of freely available satellite data and powerful cloud computing capabilities facilitate rapid calculations and on-the-fly analysis. The development of a web application equipped with processed data and results creates a digital playground for the end-users and stakeholders to visualise and analyse information to actionable intelligence.

6. REFERENCES

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