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Half century of meander evolution from the Mun River, Surin Province, northeastern Thailand

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Abstract

The Mun River, a major tributary of the Mekong River, exhibits a dynamic meandering pattern within its catchment basin. This study reveals a half century of geomorphological changes of the Mun River in Surin Province based on geomorphological parameters. Satellite images from 1973 to 2023 were analyzed together with subsurface surveys. The identified landforms alongside the floodplain of the Mun River include paleo-channels, oxbow lakes, and meander scars. To quantify geomorphological changes, four geomorphic metrics were employed: channel width (W), channel length (L), sinuosity index (SI), and radius of curvature (RC). Significant variations in channel width were observed, primarily due to bank erosion and long-term sedimentation in the river. The channel length and sinuosity index have shown a decreasing trend, indicating frequent cut-off process. Erosion rates were found to be higher in the lower reaches, where the river is actively migrating and bending. The upper and middle reaches have experienced past cut-offs and channel patterns were likely stabilized. RC began to decrease after 1990 possibly by increasing river bank protection and settlement expansion.

Keywords: Geomorphological change, Paleo-channel, Sinuosity index, Mun River, Meander evolution

1. Introduction

In the Khorat Basin, northeastern Thailand, the Mun and Chi Rivers are the main agents of erosion and deposition, significantly shape the floodplain morphology. Through processes like scouring and lateral erosion, rivers carve out their channels, deepening them and widening their banks. As they flow, they transport sediment, often depositing it downstream to form new landforms (Glover & Johnson, 1974). One prominence of the Mun River process is meandering, where a river channel winds back and forth across a floodplain. This dynamic process involves erosion on the outer bank of the bend, where the current is strongest, and deposition on the inner bank, where the current is slower. Over time, meanders can migrate and evolve, leading to the formation of oxbow lakes and other distinctive landforms (Choowong, 2011).

Recent advance research have shed light on the complex behavior of meandering rivers as they become the zone where flooding occur more frequently. River morphology is also being challenged as geoscientists uncover diverse patterns of river evolution and equilibrium. The factors that influence river meandering, such as channel geometry, sediment transport, and hydrological conditions are recently interesting and will be discussed in this paper.

In this study area, the Mun River floodplain is focused (Figure 1). The Mun and Chi Rivers are two dominant rivers, generally flowing from the west to the east in the Khorat Basin. In general, the Mun River traverses a dynamic landscape characterized by active meandering and frequent changes in its course (Nimnate et al., 2017; Srisunthorn & Choowong, 2019). The Mun River catchment basin is prone to both flooding and drought, necessitating effective water management strategies (Wattanachareekul et al., 2022).

Given these factors, the Mun River offers a valuable opportunity to study sediment dynamics, paleochannel morphology, river mechanics, and evolutionary processes. This study aims to analyze satellite imagery and topographic maps from various time periods, to assess the geomorphological changes within the upper Mun River basin. By examining key geomorphological parameters such as channel sinuosity (SI), bend radius of curvature (Rc), width (W) and length (L) over a period of 50 years, we expect to gain insights into the natural processes shaping the river's landscape.

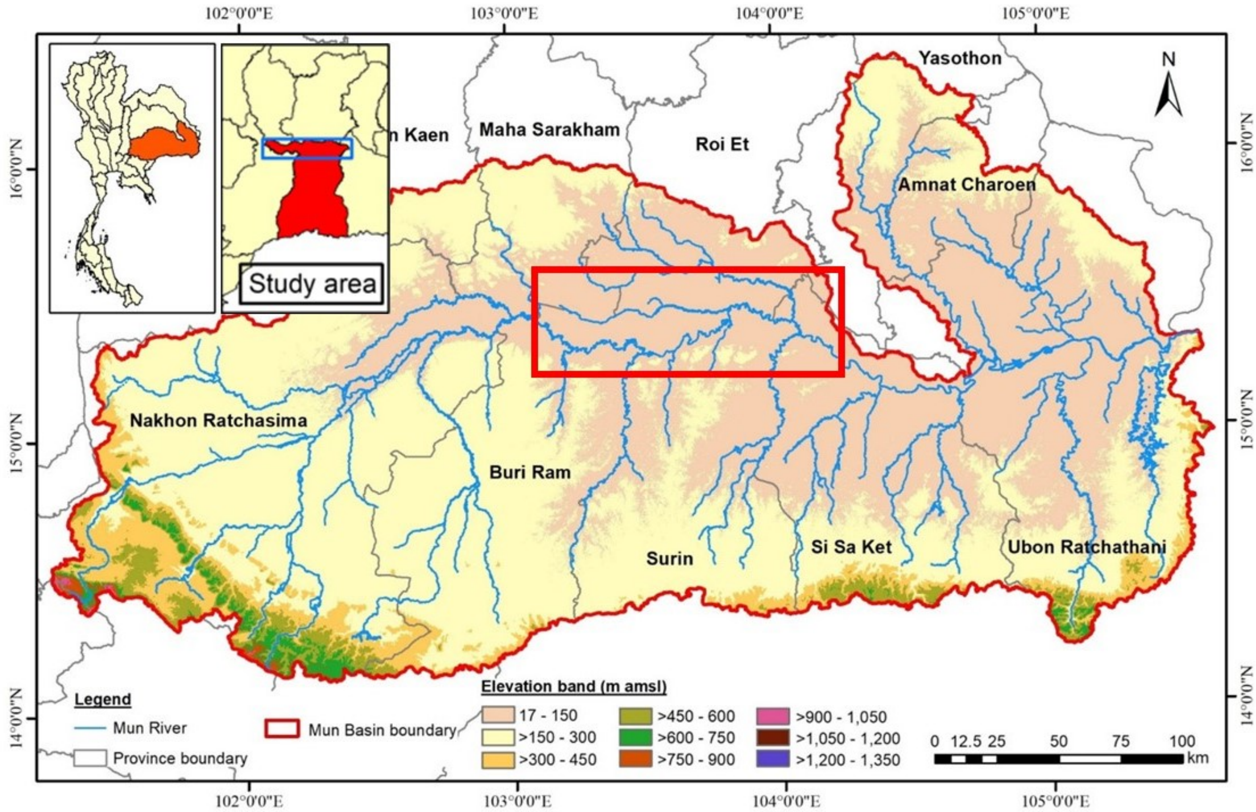


Figure 1. The geographic location of study area (red box) the Mun River in Thailand (modified from Prabnakorn et al, 2021).

2. Geological setting

Originating in the Khao Yai National Park in Nakhon Ratchasima Province, the Mun River stretches across 640 km before joining the Mekong River near Khong Chiam District in Ubon Ratchathani Province. The river flows through the Korat Plateau within extensive sedimentary basin characterized by a thick layer of Cenozoic sediments that form flat to gently undulating plains. The Korat Basin itself has a sequence of sedimentary deposits, where sandstone, siltstone, and mudstone layers dominated, deposited primarily during the Mesozoic era. The latitudinal and longitudinal ranges of the Mun River cover approximately 14º 00' N to 15º 30' N and 101º 30' E to 105º 00' E.

The Mun River Basin, spanning around 50,000 km^2, is a vital area for agriculture, supporting extensive rice paddies, especially in Surin Province, where fertile alluvial plains flank the river. These alluvial deposits are the result of the river’s lateral erosion and seasonal flooding, which distribute fine sediment over the plains, enriching the soil. The basin itself is bound by the Phu Phan and Dong Phaya Yen Mountain ranges, which supply tributaries and sediment that flow into the Mun River.

Geologically, the Khorat Basin has undergone multiple tectonic events, influencing its stratigraphic structure (Udomsak et al., 2021). Studies indicate that the Mun River Basin went through several sedimentary cycles, beginning with fluvial deposits from braided streams and progressing to lake and floodplain environments, which were interspersed with episodes of tectonic uplift. These cycles have led to the formation of thick sediment layers that underline the region today. The Mun River's journey takes it through a variety of terrains, initially flowing through narrow, steep-sided valleys before transitioning into the expansive plains of the Korat Plateau. It then flows eastward through Surin Province, where it provides critical irrigation and water resources, before eventually merging with the Mekong River.

3. Methodology

3.1 Satellite image interpretation

We created a set of 1:400,000 scale geomorphological maps using satellite imagery from the Landsat 1-5 MSS (1973), Landsat 4-5 TM (1990), and Landsat 8-9 OLI/TIRS (2014 and 2023) that covered 50 years. With spectral bands covering visible, near-infrared (NIR), shortwave infrared (SWIR), and thermal infrared (TIR) regions, as well as a 15-meter panchromatic band in Landsat 8-9, these images enabled detailed identification of land-water boundaries and geomorphological features. Their spatial resolutions ranged from 60 meters (MSS) to 30 meters (TM and OLI/TIRS). The photos, which were processed with ESRI ArcGIS 10.5 software, were examined to compare and describe the geometries of river channel landforms over time, emphasizing variations in parameters like length, curvature, width, and sinuosity to comprehend sedimentary processes and geomorphological changes in the study area.

3.2 Delineate the geomorphic characters

3.2.1 Geomorphological mapping

All satellite images were employed to identify and delineate the geometry of channel landforms across both historical and contemporary periods, enabling year-by-year comparisons of morphological changes. Using ArcGIS, the study meticulously mapped geomorphic boundaries, capturing key features such as active channels, paleo-channel traces, oxbow lakes, meander scars, scroll bars, and floodplains. This detailed analysis facilitated a nuanced understanding of shifting geomorphological features, offering valuable insights into the historical and current geomorphic transformations within the study area.

3.2.2 Geomorphic criteria calculation

We employed a detailed analysis of geomorphic trends through four primary parameters: channel width (W), channel length (L), sinuosity index (SI), and radius of curvature (Rc), each providing crucial insights into temporal changes in channel geometry. Comparative measurements of contemporary and paleo-channels were conducted using the distance measurement tool in ArcGIS 10.5, with channel length derived systematically from channel centerlines on temporal vector layers. Additionally, fifty strategically selected cross-sections provided accurate width measurements, capturing lateral shifts of centerlines over time and contributing to a comprehensive understanding of geomorphic dynamics. This rigorous analysis, supported by advanced geospatial tools, enabled precise assessments of temporal changes in river morphology, offering valuable insights into the processes governing geomorphic evolution.

4. Results

4.1 Geomorphological map

Geomorphological changes over four periods were systematically analyzed. Satellite imagery from each period was used to identify and assess features such as paleochannels, neck cut-offs, oxbow lakes, and meander scars, illustrating geomorphic shifts over the past 50 years (1973–2023). The analysis indicates that the Mun River area has experienced only minor adjustments in meander patterns, underscoring the stability of its geomorphology.

4.2 Geomorphological criteria analysis

4.2.1 Sinuosity Index (SI)

SI measurements resulted from this study varied from 1.987 to 1.689 from 1973 to 2023. The sinuosity value was significantly highest in 1990 at

1.987, and the lowest in 2023 is 1.689. As the total sinuosity values of the Mun River have decreased over time after 1990 as seen in Figure 2, it assumed that the river had decreased the natural meandering evolution in 1990. However, SI values from 1973 to 2023 illustrate in meander river type (SI of the meander is 1.25 to 2).

4.2.2 Radius of curvature (Rc)

RC was measured from four different locations covering the entire research area from 1954 to 2019. All RC values in areas 1, 2, 3 and 4 are approximately the same distance from each other to describe how Rc changes across areas and whether the changes are consistent, as shown in Figures 3 and 4. Where Rc is the thickness of the arch, with a high value the river arches are close together. Conversely, wider arches have low Rc values.

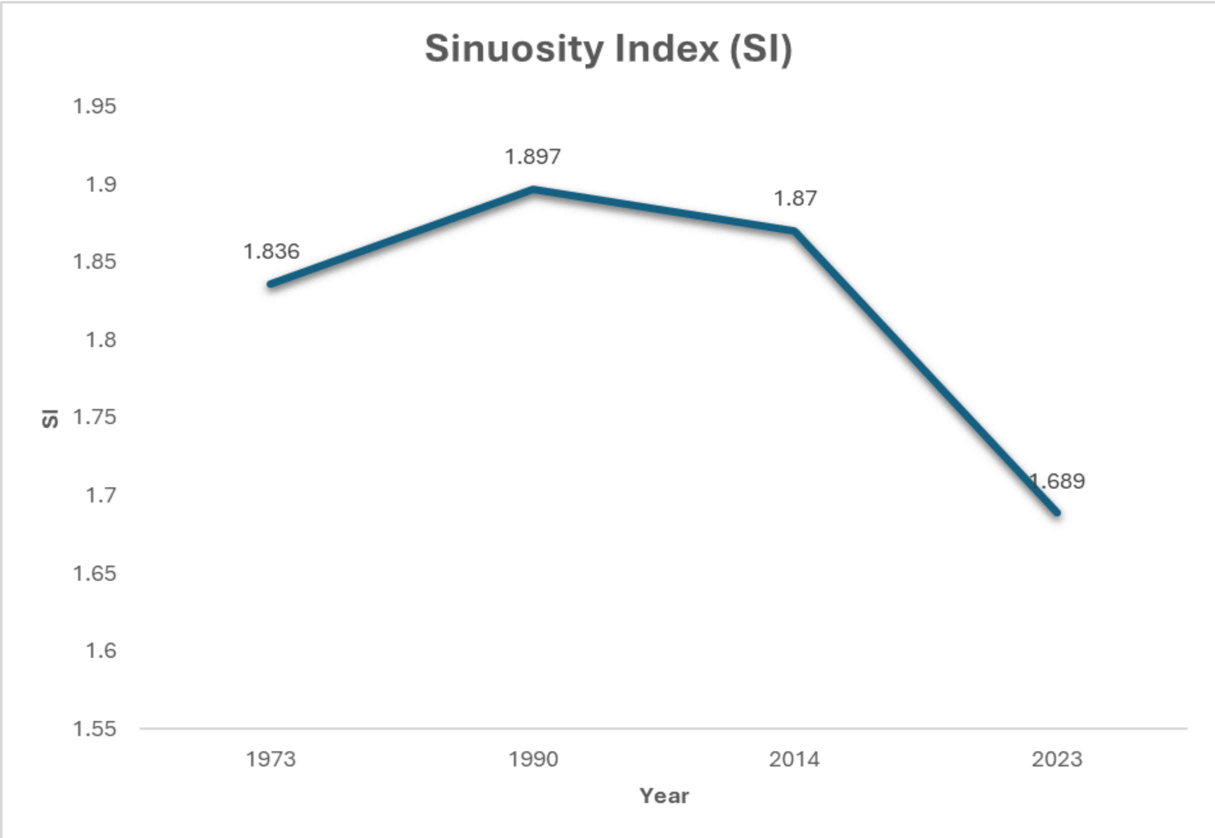


Figure 2. The graph of SI values from 1973 to 2023 shows the decreasing trend.

4.2.3 Channel width (W)

According to the results of measuring 25 values along the river in four periods (Figure 5), the average channel width in 1973, 1990, 2014, and 2023 is 68.64 m, followed by 68 m, 109.96 m, and 123.56 m, respectively. The width of the Mun channel has been extremely increase from 1990 to 2023. It has changed dramatically from 68.64 m to 123.56 m

4.2.4 Channel length (L)

The channel length of the Mun River was measured along the midpoint between the left and right banks of the channel polygon. The longest channel length recorded over the study period was in 1973, at 243.4 km, whereas the shortest was observed in 2023, measuring 230.9 km. This indicates an overall reduction in channel length of 12.5 km from 1973 to 2023 (Figure 6).

5. Discussions

5.1 Geomorphological evolution

Satellite imagery of the Mun River from 1973 to 2023 reveals the dynamic of natural meandering process. The process often lead to the formation of two main types of cut-offs (chute and neck cut-offs), where segments of the river's meanders become abandoned as the river seeks a more efficient path. In some cases, chute cut-offs occur quickly, driven by high stream power, and result in rapid, noticeable changes to the river's width. In most places, neck cut-offs, however, are slower and occur when gradual erosion narrows the land between two parts of a meander until the river eventually cuts through, creating a shorter, straighter path and abandoning the loop. Neck cut-off processes are relatively slow, often taking several decades to complete.

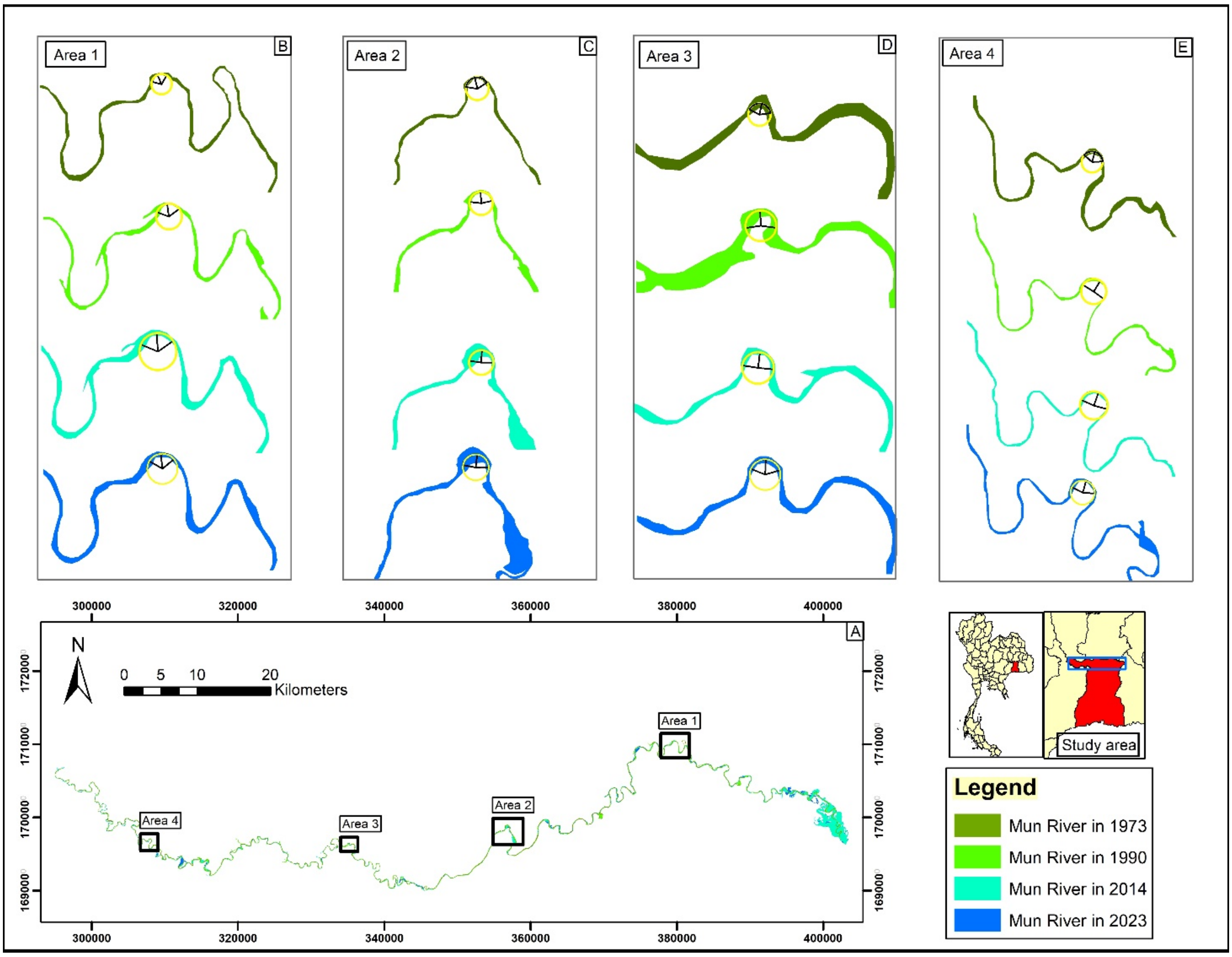
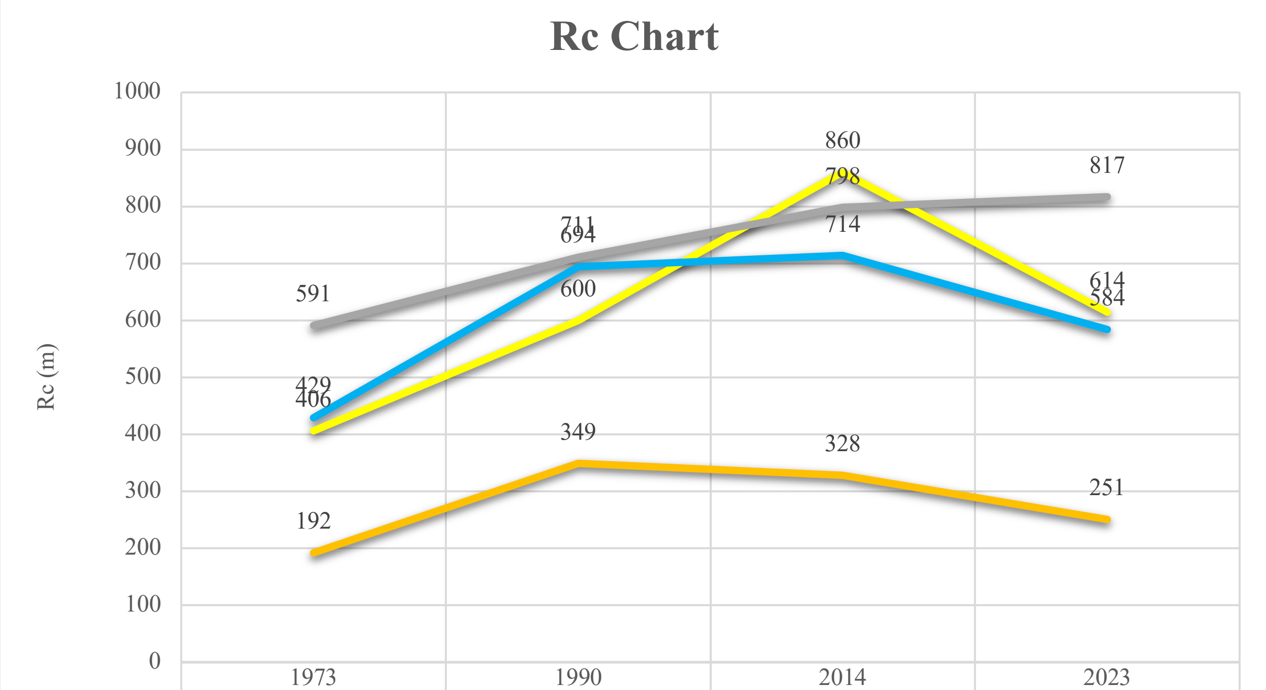


Figure 3. Rc measurements from four locations from 1973-2023.

For example, in Tha Tum District, the formation of a neck cut-off was evident, but the process took over 30 years. These abandoned meanders frequently become isolated as oxbow lakes, and the surrounding landscape often retains distinct geomorphological features like scroll bars and cut-off lakes. Such features demonstrate the river's natural tendency to shift across its floodplain over extended periods.

The floodplain in the study area is a flat, flood-prone landform where varying topography influences how erosion and deposition shape the river's meander bends, creating features like meander scars and oxbow lakes (Schmudde, 1997).

In flatter areas, the Mun River has been shifted more freely, leaving a range of geomorphological features as it changes course, while in narrower, densely populated sections. After 1990, human development has restricted lateral migration, reduced cut-off formation and altering natural processes. The upper and middle reaches of the Mun River course with wider floodplains show more evidence of cut-offs. Meander bends within and between rivers vary in characteristics due to differences in topography and planform, which affect erosion patterns and result in diverse channel remnants shaped by local conditions (Hooke, 2007; Alho & Mäkinen, 2010).



	1973	1990	2014	2023
Area 1	406	600	860	614
Area 2	591	711	798	817
Area 3	192	349	328	251
Area 4	429	694	714	584

Figure 4. Rc values from 1973 to 2023 shows trends of Rc in each area.

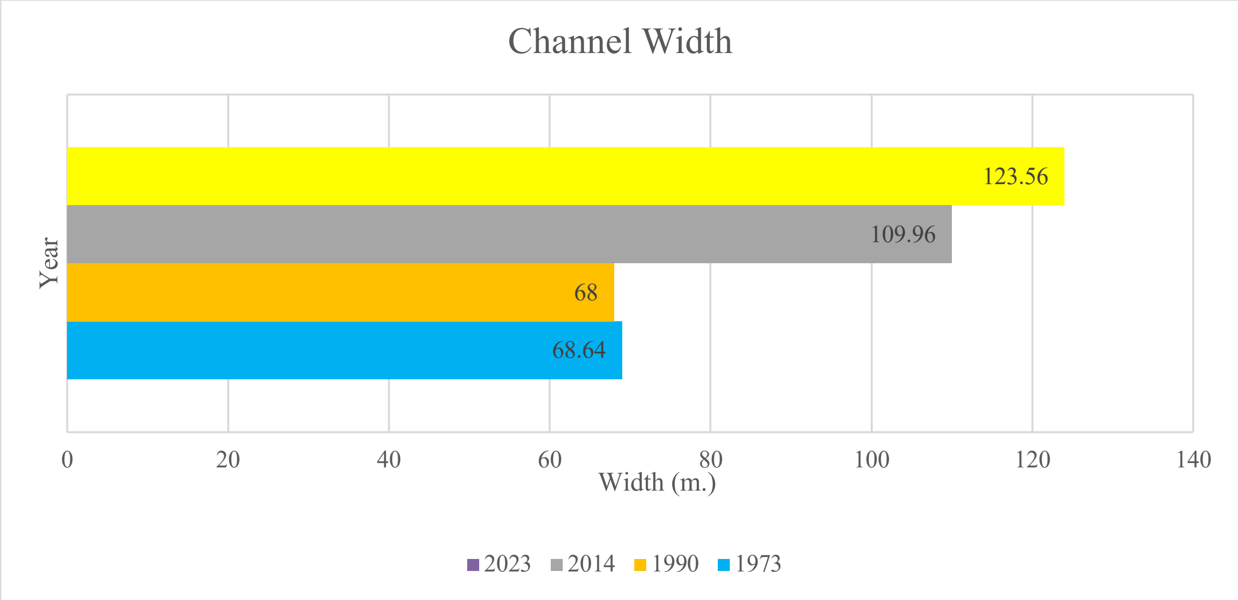


Figure 5. The graph shows the width of Mun River from 1973 to 2023.

5.2. Change in geomorphic criteria

The investigation into meander planforms of rivers impacted by both human activities and environmental factors has been widely documented. Research has highlighted that actions such as reservoir construction, urbanization, and agricultural expansion significantly alter flow dynamics and sediment transport within river systems (Knighton, 1998). For instance, Kondolf (1997) and Surian and Rinaldi (2003) found that altered sediment regimes from land-use changes and hydrological modifications due to reservoir construction can substantially reshape meander morphology. Additionally, studies have shown that climate-driven variations in precipitation and temperature exacerbate these changes, impacting flow and sediment dynamics, though isolating human-induced effects from natural variability is complex (Gregory, 2006; Wohl, 2014).

This analysis examines five main planform parameters-channel width (W), length (L), sinuosity index (SI) and radius of curvature (RC) to track how human-induced and environmental changes affect river meandering over time. In agreement with Williams (1984) that these parameters generally exhibit a declining trend, indicating a tendency toward channel narrowing and reduced sinuosity, which suggests altered flow regimes and sediment supplies. These measurements provide insights into shifts in river behavior, underscoring the cumulative impacts of human and environmental factors on meander evolution.

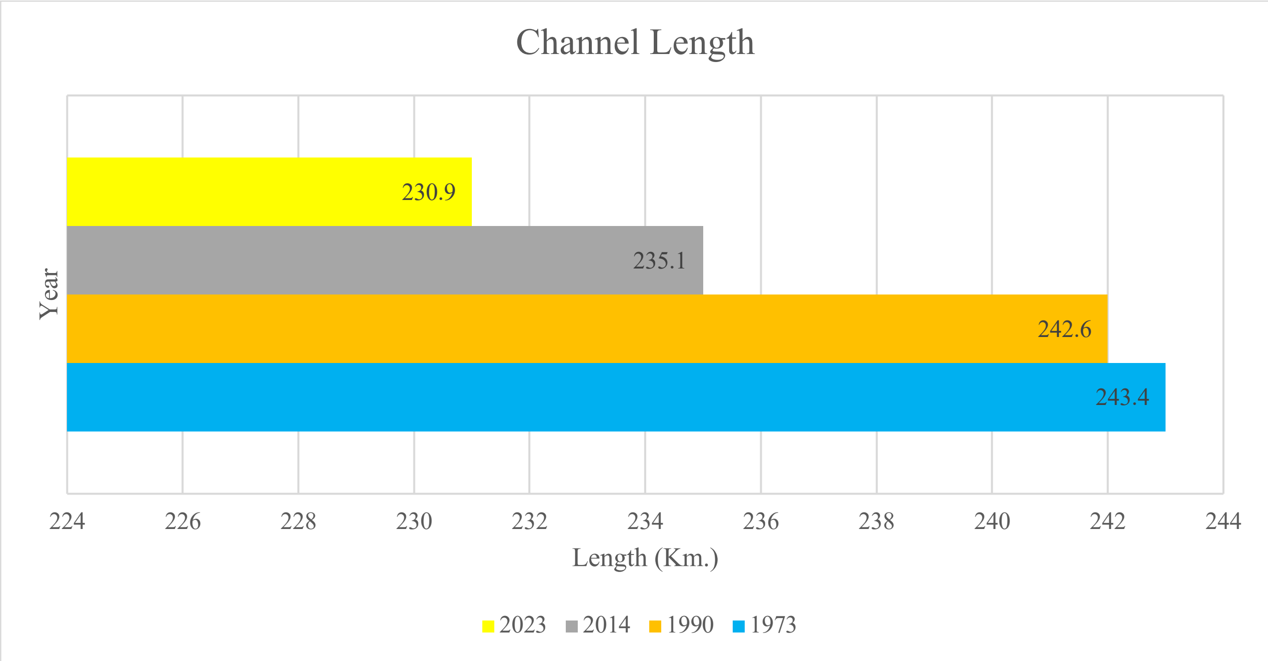


Figure 6. The graph shows the length of Mun River from 1973 to 2023.

1. Changing in length (L) and sinuosity index (SI)

The Mun River, located in Surin Province, Thailand, has undergone significant morphological changes between 1973 and 2023, including shifts in channel length and sinuosity index (SI). These changes are influenced by a combination of natural processes and anthropogenic activities, including the impact of upstream dams.

The lower part of Mun River, as an upstream channel of the Rasi Salai dam (Srisaket Province), may has affected by the dam's presence. Like other rivers impounded by dams, the lower Mun River has experienced a loss of its natural meandering characteristics due to backwater effects from the reservoir. Studies on rivers such as the Elwha River have shown that reservoirs behind dams disrupt the river’s natural dynamic meandering process by reducing the river's ability to elongate its channel. Similarly, the formation of the Pak Mun Dam reservoir (Ubon Ratchathani) likely decreased the Mun River's channel lengthening processes, stabilizing its upstream reaches. The backwater effects reduce the river's kinetic energy and sediment transport capacity, further slowing meander formation (McCully, 1996).

Between 1973 and 1990, the Mun River displayed increased sinuosity, indicating more meandering, likely driven by land use changes and agricultural expansion. However, after the completion of the Pak Mun Dam and the resultant backwater effects, upstream meandering began to stabilize. As the river's flow became more controlled by the dam, sediment transport decreased, which slowed the formation of new meanders and contributed to the stabilization of the channel. This pattern is consistent with studies of other rivers with upstream dams, such as the Mekong River (Kummu & Sarkkula, 2008), where reduced sediment transport and loss of kinetic energy led to a decrease in the formation of new meanders. Downstream of the dams, sediment flow reduction has led to bed degradation and channel narrowing due to scouring as the river compensates for the sediment deficit. This effect is well-documented in the Colorado River, where sediment retention by Glen Canyon Dam has resulted in narrowing and erosion of downstream channels (Bridhikitti et al., 2022).

2. Channel width (W)

Over the past five decades, the Mun River in Thailand has experienced considerable geomorphological changes influenced by dam constructions and land-use shifts. Sediment accumulation upstream of dams, like the Pak Mun Dam, has created delta-like formations due to sediment retention, leading to channel widening and habitat alterations in these regions (Bridhikitti et al., 2022). Similar patterns are observed in dam-impacted rivers globally, such as the Yangtze and Colorado Rivers, where sediment build up above dams has resulted in upstream channel expansion.

Additionally, since the 1970s, increased agricultural activity and deforestation have exposed the Mun River's banks to erosion, making the area more susceptible to seasonal flooding. Conservation strategies such as reforestation and sediment control are vital to manage these impacts and stabilize riverbanks in the Mun River Basin (Champangern et al, 2019).

3. Radius of curvature (Rc)

The radius of channel curvature is a significant factor influencing the river's dynamics, as it impacts flow velocity, sediment transport, bank erosion, and the river's morphology. A study on this past to the present, indicating that it was frequently cut off at the neck and chute. Rc of the Mun River began to decrease after 1990, with pronounced meandering and erosion exacerbated by natural flow dynamics and human activities like land use changes and dam construction. In meandering rivers, smaller radius of curvature (sharper bends) increase flow velocity along the outer banks, leading to higher rates of bank erosion (Leopold, 1960). Conversely, the inner banks of bends have reduced flow velocity, which promotes sediment deposition and forms point bars. These contrasting processes drive lateral migration of the channel and can result in the formation of chute and neck cut-offs in areas with tight curvature, continually reshaping the river's path over time.

Studies of the Mun River indicate that the radius of curvature of the majority of the river is now reduced compared to the past. It exhibits pronounced meandering and channel migration due to the interaction between high flow velocities during the rainy season and the natural tendency of the river to erode and deposit sediments (Blake et al., 2007). These processes may be exacerbated by anthropogenic activities, such as land use changes and dam construction, which modify the flow regime and sediment supply.

6. Conclusions

Channel migration, neck cut-off, oxbow lakes, and meander scars are landform indicators of the changing geomorphology of the Mun River that has occurred during the past 50 years (from 1973 to 2023). In the study area, neck cut-off traces were found throughout the area. The width (W) of the Mun River's paleochannel has altered dramatically in recent years because of continuous increases in bank deposition brought on by human activities. Changes in land use might have additional impacts on the runoff or the supply of sediment. The longest channel length recorded over the study period was in 1973, at 243.4 km, whereas the shortest was observed in 2023 with 230.9 km. Between 1973 and 2023, SI varied between 1.987 to 1.689. In 1990, the sinuosity rating was its greatest (1.987), while in 2023, it was at its lowest (1.689). Mun River's total length and sinuosity reflect a downward tendency from the past to the present, indicating that it was frequently cut off at the neck and chute. Rc of the Mun River began to decrease after 1990, with pronounced meandering and erosion exacerbated by natural flow dynamics and human activities like land use changes and dam construction.

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References

Alho, P. & J. Mäkinen (2010) Hydraulic parameter estimations of a 2D model validated with sedimentological findings in the point bar environment. Hydrological Processes, 24, 2578-2593.

Blake, D., Saffel, M., Foran, T., & Manorom, K. (2007). Pak Mun Dam: Perceptions of the fisheries impact study and the Thai Baan research. Water Alternatives, 2(2), 80-99.

Bridhikitti, A., Ruamchalerm, P., Keereesuwannakul, M., Prabamroong, T., Liu, G., & Huang, C. (2022). Magnitude and factors influencing soil loss and sedimentation in the Mun River Basin, Thailand. CATENA, 210, 105872.

Champangern, K., Prasertsri, W., Wuttipan, T., Soontorn, N., Chalermpong, P., & Suepa, T. (n.d.). (2019) Suspended sediment dynamics in the Chi-Mun River Basin, Thailand: Impact of climate change and anthropogenic activities.

Choowong, M. (2011) Basic Geomorphology. Tienwattana Printing, Co., LTD, 202 p.

Glover, B. & P. Johnson (1974) Variations in the natural chemical concentration of river water during flood flows, and the lag effect. Journal of Hydrology, 22, 303-316.

Gregory, K. J. (2006). The human role in changing river channels. Geomorphology, 79(3-4), 172-191.

Hooke, J. M. (2007) Spatial variability, mechanisms and propagation of change in an active meandering river. Geomorphology, 84, 277-296.

Kondolf, G. M. (1997). Hungry water: effects of dams and gravel mining on river channels. Environmental Management, 21(4), 533-551.

Knighton, D. (1998). Fluvial Forms and Processes: A New Perspective. Arnold, London.

Kummu, M., & Sarkkula, J. (2008). The Impacts of Dams and River Regulations on Sediment Transport in the Mekong River Basin. Environmental Management, 42(4), 576-590.

Leopold, L. B. (1960). Flow resistance in sinuous or irregular channels. US Government Printing Office.

McCully, P. (1996). Silenced Rivers: The Ecology and Politics of Large Dams. Zed Books.

Nimnate, P., Thitimakorn, T., Choowong, M., & Hisada, K. (2017). Imaging and locating paleo-channels using geophysical data from meandering system of the Mun River, Khorat Plateau, Northeastern Thailand. Open Geosciences, 9(1).

Prabnakorn, S., Ruangpan, L., Tangdamrongsub, N., Suryadi, F. X., & de Fraiture, C. (2021). Improving flood and drought management in agricultural river basins: An application to the Mun River Basin in Thailand. Water Policy. 23(5). 1153–1169.

Schmudde, T. H. (1997). FLOODPLAIN Flood plain. In Geomorphology, 359-362. Berlin, Heidelberg: Springer Berlin Heidelberg.

Srisunthon, P., & Choowong, M. (2019). Quaternary meandering evolution and architecture of a point bar in the Mun River on the sandstone-dominated Khorat Plateau from northeastern Thailand. Quaternary International, 525, 25-35.

Surian, N., & Rinaldi, M. (2003). Morphological response to river engineering and management in alluvial channels in Italy. Geomorphology, 50(4), 307-326.

Udomsak, S., Choowong, N., Choowong, M. & Chutakositkanon, V. (2021). Thousands of Potholes in the Mekong River and Giant Pedestal Rock from North-eastern Thailand: Introduction to a Future Geological Heritage Site. Geoheritage, Vol. 13, No. 5

Wattanachareekul P, Choowong N, Pailoplee S, Choowong M (2022) Resilience to unusual flooding from 2021 tropical storms from part of mainland Southeast Asia. Front ecol and evol 10: 1072993

Williams, G. P. (1984) Paleohydrologic equations for rivers. Developments and applications of geomorphology, 343-367.

Wohl, E. (2014). Rivers in the Landscape: Science and Management. Wiley Blackwell.