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Human Impact on Geomorphic Index Alteration at the Chi River in Kosum Phisai, Maha Sarakham, North-eastern Thailand

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Abstract

This paper investigates the impact of human interventions on geomorphic index alteration, especially the effect of sand mining on the floodplain of the Chi river (8.5 Km long) at Kosum Phisai district, Maha Sarakham province, north-eastern Thailand. Four geomorphic indexes, including sinuosity index, channel width, widening rate, and migration rate, were measured and analyzed in five different periods: A.D. 1952, A.D. 1992, A.D. 2006, A.D. 2015 and A.D. 2020. As a result, the widening rate of sand mining area dramatically increased from -0.15 m/year in period A.D.1992 to 2006 (before sand mining) to 16.98 m/year in period A.D. 2006 to 2015 (after sand mining operated). Migration rate also changed from 0.37 m/year in period A.D. 1992 to 2006 to – 9.05 m/year (mid channel migrated to right bank) in period A.D. 2006 to 2015. Both alterations confirm direct human intervention to the river. Our analysis also suggests that river bank protection only reduced the widening rate.

Keywords: Geomorphic Index, Sinuosity, Widening rate, Sand mining, Chi river

Introduction

Geomorphological alteration in the meandering river can be caused by natural processes and intervention from humans, including artificial cutoff, digging, bank protection, and dam (Hooke, 1995, Biedenharn et al., 2000, Fuller et al., 2003, Li et al., 2007, Tiron et al., 2014). For example, bank protection affects the erosional degree of the channel (Li et al., 2007). The dam affects to downstream’s channel geometry and sediment supply (Williams and Wolman, 1984, Petts and Gurnell, 2005, Phillips 2009, Makaske et al., 2012, Lai et al., 2017, Li et al., 2019). Understanding the human impact on geomorphological alteration is the crucial information leading to appropriate river management in each area (Zhou et al., 2017).

The Chi river is one of the main rivers on the Khorat Plateau, northeast of Thailand, with the length of more than 700 km. The Chi River flows from the Phetchabun mountain upstream, then, runs eastward through the centre of north-eastern Thailand (Chaiyaphum, Khon Kaen, and Maha Sarakham), then turns south in Roi Et, runs through Yasothon and joins the Mun in the Kanthararom district of Srisaket province (Kuntiyawichai et al., 2008). The Chi River has many artificial constructions such as weir, dam, and bank protection. However, the information on geomorphology in the Chi river is lacking.

This paper investigates the effect of intervention from humans in the Chi River in Kosum Phisai district, Maha Sarakham province using geomorphic indexes: sinuosity index (SI), widening rate, and migration rate. The study area is the downstream area of the irrigation dam that was constructed between A.D. 1988 to 1992. The study area has two significant artificial constructions: sand mining and riverbank protection. The bank protection was created after A.D. 2015, while the sand mining was operated after A.D. 2006. Results of this interpretation describe the human impact on geomorphological alteration in the Chi River. Furthermore, the geomorphological alteration can be used to predict the flow regime of the Chi River.

The Sinuosity Index (SI) is usually used for assessing the intensity of meandering of the river and describes the river pattern (Lagasse et al., 2004). The sinuosity index is calculated following the equation (1);

$$\text{Sinuosity Index} = AB/CD \quad (1)$$

While AB is the channel length and CD is down valley length (Leopold et al. 1957; Mueller 1968).

Channel width means the width of the main channel measured from one side to another side of the channel. In application, Hooke (2007) used channel width to describe planform alteration. River migration is the geomorphological process that means the lateral migration of a river channel across its floodplain. This process is reflected by the cutoff, erosion, and point bar deposition (Bierman and Montgomery, 2014). Migration rate reveals the rate of lateral movement of the river.

Methodology

The main methods used this paper consisted of two steps. First step was data selection that consisted of aerial photos taken by Royal Thai Survey in A.D. 1952 and A.D. 1992 and from Google Earth in A.D.2006, A.D. 2015 and A.D. 2020. This work applied only images that were taken in dry season because the sky was clear and water remained in the main channel (Gurnell et al., 1994). Next step was the calculation of sinuosity index, channel width, widening rate, and migration rate. The channel width and sinuosity index were measured in 5 periods: A.D. 1952, A.D. 1988, A.D. 1992, A.D. 2006, and A.D. 2020, while widening rate and migration rate were measured in 4 periods A.D. 1952-1992, A.D. 1992-2006, A.D. 2006-2015 and A.D. 2015-2020. The channel width, the widening rate, and the migration rate were measured for every river length 100 m.

Study Area

The study area is characterized by meandering reach that covers 8 km long (Figure 1). It is located in the downstream area of irrigation dam that has two significant artificial elements: bank protection and sand mining. The sand mining has operated after A.D. 2006.

This paper investigates four geomorphic index: The sinuosity index, channel width, widening rate, and migration rate. The first geomorphic index is the sinuosity index that was measured in 10 scopes shown in Figure 2 in 5 periods: A.D. 1952, A.D.1992, A.D. 2006, A.D 2015 and A.D. 2020.

Figure 1. Location of the study area, part of the Chi River in Kosum Phisai District, Maha Sarakham Province, north-eastern Thailand. Sand mine is located in the middle part of the meander bend.

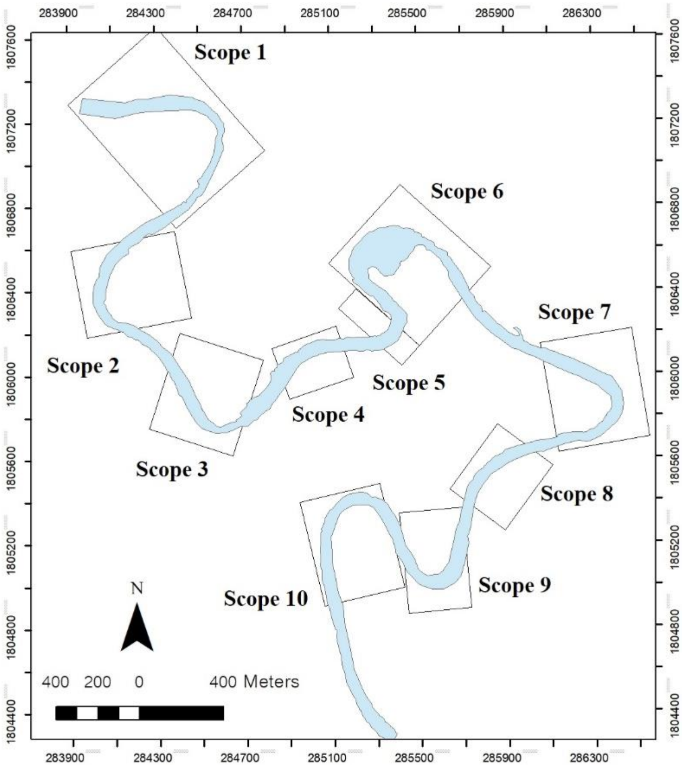

Figure 2. The boundary of 10 scopes in the study area. Scope 6 covers sand mining at meander neck. Close up of scope 5 is in Figure 7.

Figure 3 shows the graph of sinuosity index of each scope in 5 different periods: A.D. 1952, A.D. 1992, A.D. 2006, A.D. 2015 and A.D. 2020. According to the graph, the X-axis is the scope and the Y-axis is sinuosity index. The sinuosity index ranges from 1.03 to 3.17. The graph shows 4 scopes that have significant alteration of sinuosity index. First, scope 5's sinuosity index reduced from 3.17 in A.D. 1952 to just 1.91 in A.D. 1992. Second, scope 6's sinuosity index reduced from 2.90 in A.D. 2006 to 2.75 in A.D. 2020. Third, scope 9's sinuosity index increased from 1.96 in A.D. 1952 to 2.11 in A.D. 2020. Fourth, scope 10's increased from 2.12 in A.D. 952 to 2.52 in A.D. 2020.

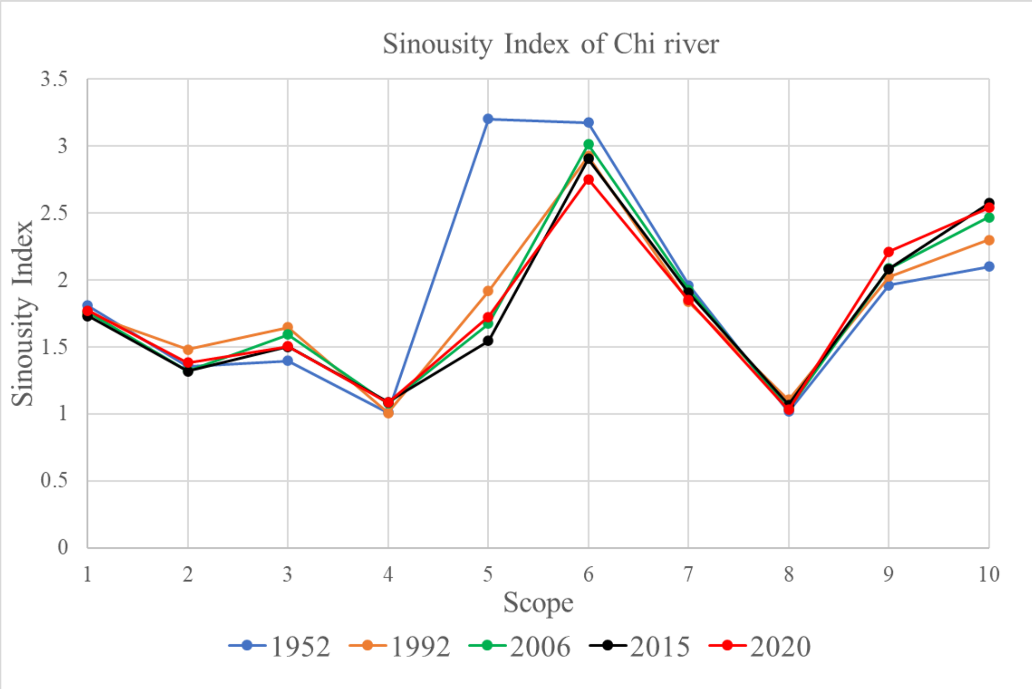

Figure 3. Change in sinuosity index of the Chi river in Kosum Phisai. Significant changes are located in between scopes 4 to 6 where sand mining is located.

The second geomorphic index is channel width that was measured at 85 stations. According to the graph (Figure 4), X-axis is the station and the Y-axis is channel width measured in meter. The channel width ranges from 16.8 m to 225.33 m. Station 40 (sand mining zone) has maximum channel width as 225.33 m in A.D. 2020.

The third geomorphic index is widening rate measured at 85 stations in four different periods: A.D. 1952 to 1992, A.D. 1992 to 2006, A.D. 2006 to 2015 and A.D. 2015 to 2020. According to the graph (Figure 5), the widening rate ranges from -5.01 m/year to 16.98 m/year. Station 40 (Sand mining zone) has maximum widening rate as 16.98 m/year in period A.D. 2006 to 2015.

The last geomorphic index is migration rate that was calculated from the changing of mid channel in four periods: A.D. 1952 to 1992, A.D. 1992 to 2006, A.D. 2006 to 2015 and A.D. 2015 to 2020. According to the graph (Figure 6), X-axis is the station for migration rate measurement and Y-axis is the migration rate that was measured in m/year. For the Y-axis, if the migration rate is more than 0, it means mid-channel migrates to the left side (observing direction is from upstream to downstream). On the other hand, if the migration rate is less than 0, it means mid-channel migrates to the right side (observing direction is from upstream to downstream). The migration rate of study area ranges from just 0.02 to more than 9 m/year. Station 40 has maximum migration rate as -9.05 m/year (mid channel migrated to the right bank) in period A.D. 2006 to 2015, while station 35 (scope 5) has second maximum migration rate as 6.47 m/year (mid channel migrated to left bank) in period A.D. 1952 to 1992.

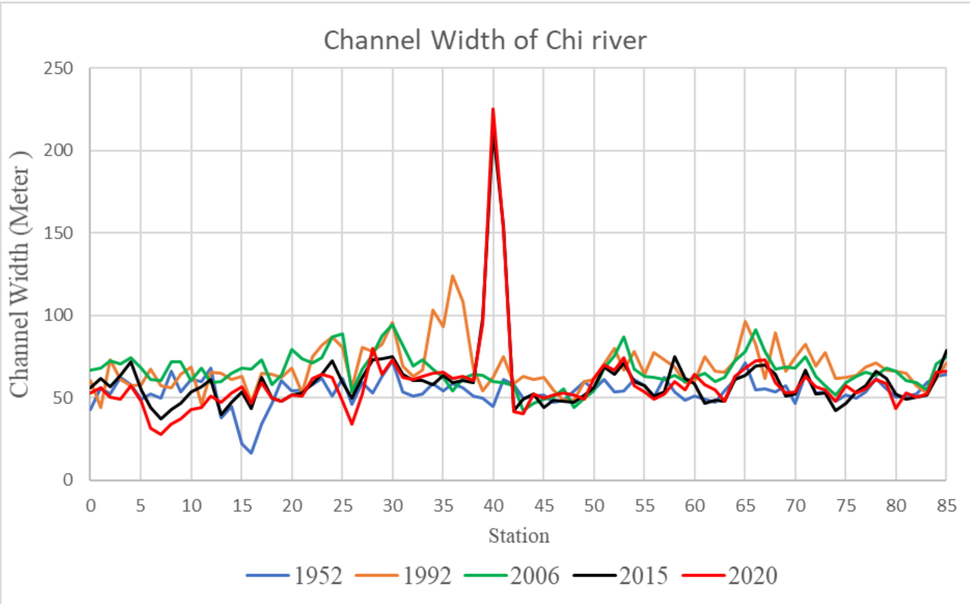

Figure 4. Graph showing channel width of the Chi River in Kosum Phisai. Dominant peak was found in station 40 (detail in text).

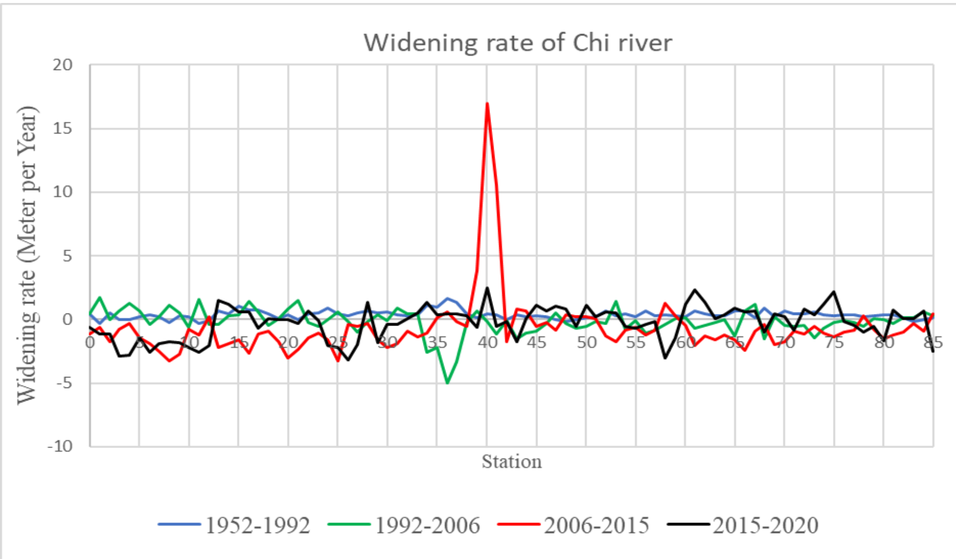

Figure 5. Plot of widening rate of the Chi river in Kosum Phisai. Peak at station 40 is dominated the area where sand mining is located.

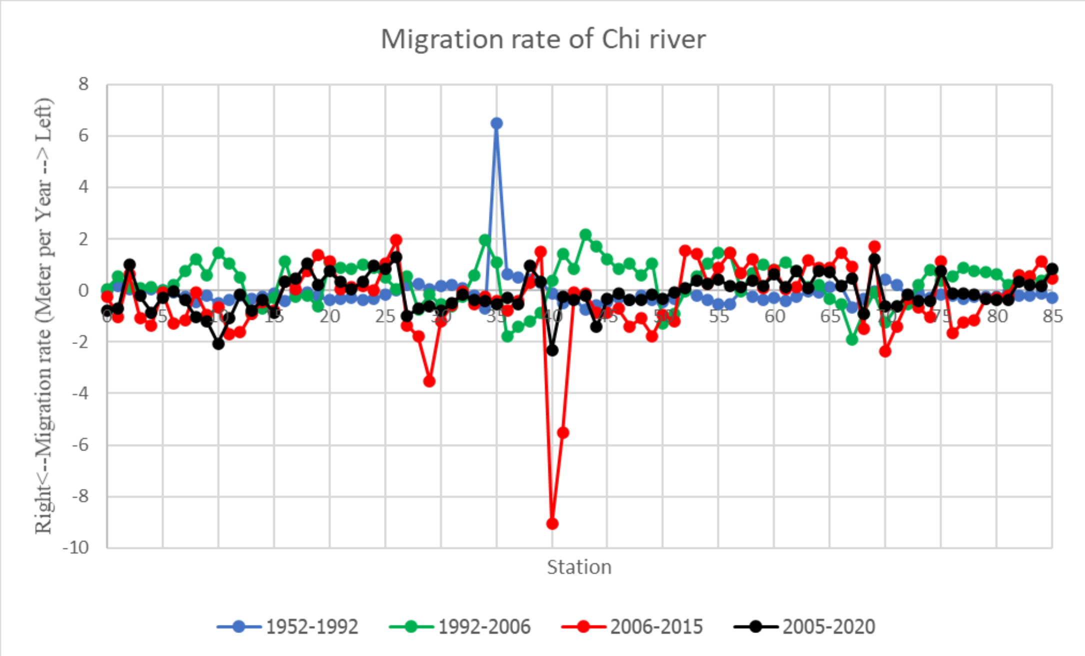

Figure 6. Plot of migration rate along the Chi River in Kosum Phisai where positive peak is located at station 35 and negative rate is at station 40 (detail explanation in text).

Discussion

According to the geomorphic index, four scopes have significant alteration. Scope 5 consists of stations from 32 to 36, Scope 6 consists of the station from 37 to 45, and Scope 9 to 10 consist of the station from 61 to 85. Figure 7 shows the alteration of the flow direction of scope 5 in five periods: A.D. 1952, A.D. 1992, A.D. 2006, A.D. 2015 and A.D. 2020. According to Figure 7, it can be seen that this meander loop had retracted to flood plain from A.D. 1952 to 2006 that was caused by the cut-off process. This cut-off has influenced the sinuosity index and migration rate. The sinuosity index of scope 5 reduced from 3.17 in A.D. 1952 to just 1.91 in A.D. 1992. Also, the migration rate of station 35 reduced from 6.41 meters per year in period A.D. 1952 to 1992 to just 1.01 in period A.D. 1992 to 2006.

The second scope 6 is the location of sand mining. Sand mining has operated since A.D. 2006. According to Ramkumar et al. (2015), sand mining is one of the essential factors that doctorates the fluvial systems. Sand mining has many impacts on morphological characteristics such as channel incision in mining zone (Chen and Liu, 2009, Rinaldi et al., 2005, Zawiejska et al., 2015), erosion of riverbank, and planform alteration (Collins and Dunne, 1990, Sear and Archer, 1998). In the study area, we found that sand mining has affected the riverbank erosion. Figure 8 shows the channel of scope 6 in two different periods: A.D. 2006 and A.D. 2015. It can be seen that the channel width of the sand mining zone increased from 60.01 m in A.D. 2006 to 212.90 m in A.D. 2015 and 225.33 m in A.D. 2020. Also, the widening rate and migration rate have dramatically increased. The widening rate dramatically rose from only -0.15 m/year in period A.D. 1992 to 2006 (before sand mining operation) to 16.98 m/year in period A.D.2006 to 2015 (after sand mining operation). Then, the widening rate in the sand mining zone decreased to 2.48 m/year in the period A.D.

2015 to 2020. The migration rate dramatically increased from 0.37 m/year in period A.D. 1992 to 2006 (before sand mining operation) to – 9.05 meters per year in period A.D. 2006 to 2015. It can be seen that the sand mining bar has changed the rate and direction of the mid-channel's migration. However, the sinuosity index did not dramatically change. Instead, it slightly decreased from 3.01 in A.D. 2006 to 2.75 in A.D. 2020. Therefore, it was found that the impacts of sand mining in the study area are similar to the previous study (Collins and Dunne, 1990, Sear and Archer, 1998) in terms of bank erosion, but the channel planform of the study area does not alter.

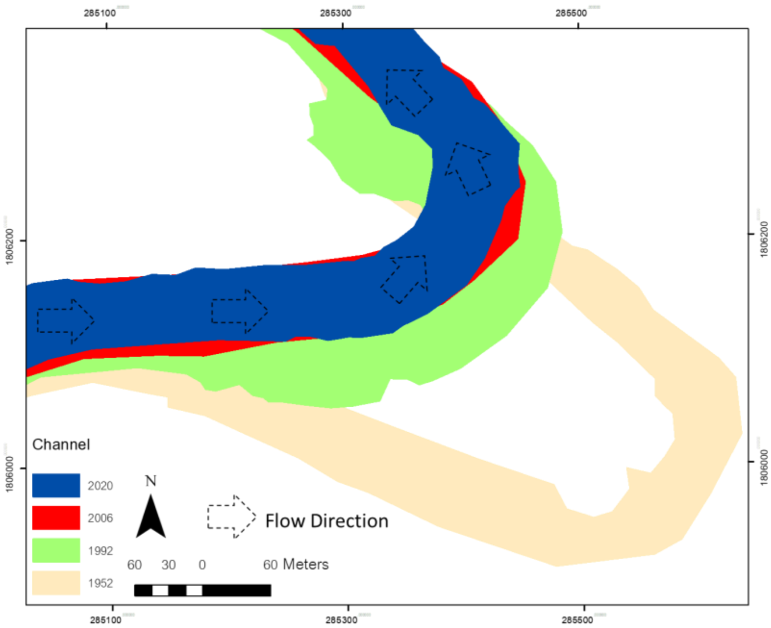

Figure 7. The boundary of channel in scope 5 in 4 different periods: A.D. 1952, A.D. 1992, A.D. 2006, A.D. 2015 and A.D. 2020. Chute cut-off started at middle part of point bar in A.D. 1992, followed by channel adjustment until A.D. 2020.

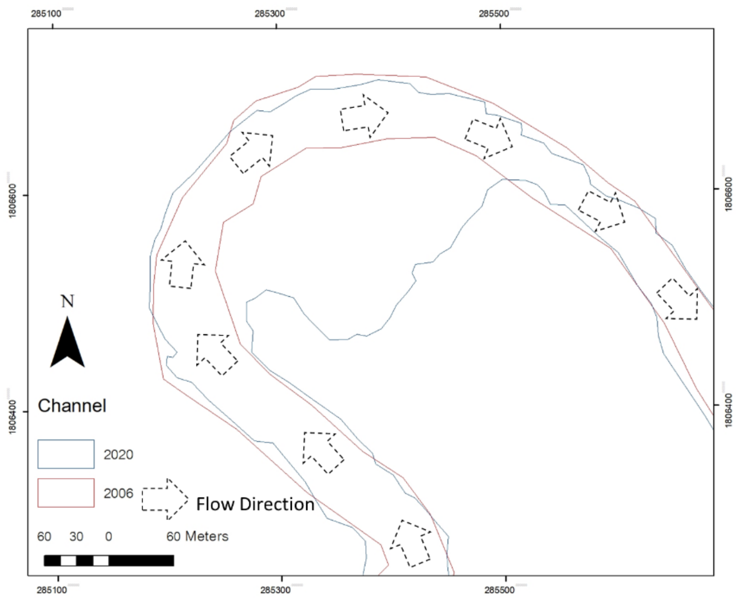

Figure 8. The boundary of channel in scope 6 in 2 different periods: A.D. 2006 and A.D. 2015. Significant change of widening rate is caused by sand mining.

The last scopes 9 and 10 have significant alteration in sinuosity index. Figure 9 shows the flow direction in 5 periods. It can be seen that the meander loop has translated to the west. The average migration rate in scopes 9 and 10 (station 61 to 85) increased from 0.22 m/ year in A.D. 1952 to 1992 to 0.62 m/year. Then, it increased to 0.95 m/year from A.D. 2006 to 2015. Finally, it decreased to 0.43 m/year. It may be concluded that the sand mining located in the upstream area of these scopes has influenced the migration rate of the meander loop in the first period of operation due to the increase in average migration rate of the meander loop in that period. However, it then decreased to 0.43 m/year, close to the average migration rate of the meander loop before sand mining operation.

In the scope 3 (bank protection zone), the average widening rate in this scope (station 23 to 27) reduced from -1.37 in period A.D. 2006 to 2015 (before bank protection installation) to -1.90 in period A.D. 2015 to 2020 (after the riverbank protection installation). The channel width in the protection zone has reduced after the riverbank protection was installed. It is similar to Li et al. (2007)’s study that the channel width decreased because bank protection reduced the degree of erosion. The average migration rate slightly rosed up from 0.79 m/year to 0.85 m/year.

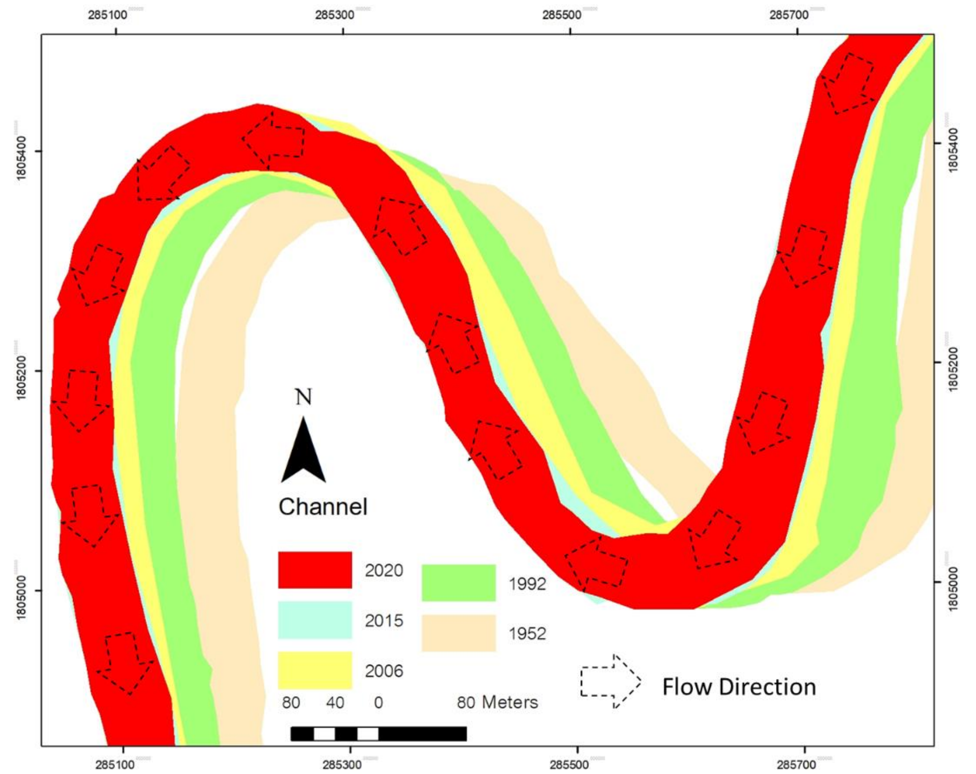

Figure 9. The boundary of channel in scopes 9 and 10 in 5 different periods:1952, 1992, 2006, 2015 and 2020. The Chi River here shows translation to the west.

Conclusion and recommendation

The artificial elements analysis in this paper shows the effect to alter the geomorphic index of the Chi River. At least three areas show significant geomorphic index alteration: scopes 5, 6, and 9 to 10. First, scope 5 had a neck cut-off from A.D. 1952 to 1992 that influenced the migration rate as 6.41 m/year. Second, scope 6 is the sand mining zone that has operated after A.D. 2006. Sand mining has influenced geomorphological changes and downstream areas. It can be seen that from the migration rate and widening rate of this scope. The widening rate of scope 6 dramatically increased from -0.15 to 16.98 m/year after the sand mining has operated. The migration rate dramatically rosed up from 0.37 to -9.05 m/year after the sand mining has operated. It can be seen that sand mining changes not only the rate of migration, but also migration direction. However, sand mining does not change the planform of the channel. It is different from the previous study that the sand mining has changed the channel planform (Collins and Dunne, 1990, Sear and Archer, 1998). For scope 9 to 10 (downstream area), the average migration rate of the meander loop moderately increased in the first period of the sand mining operation. However, the migration rate decreased in the period A.D. 2015 to 2020 that almost close to the average migration rate before sand mining operation. For scope 3 (bank protection zone), no significant geomorphic index alteration was shown. The bank protection influenced only channel width that reduced the widening rate from -1.37 to -1.90 m/year. The erosional and depositional patterns of this study area suggest the sand mining and the bank protection have alerted the degree of erosion and deposition significantly. In order to provide recommendation for future prediction in bank erosion and protection, the artificial elements analysis is recommended.

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References

Biedenharn, D. S., Thorne, C. R., and Watson, C. C. 2000. Recent morphological evolution of the Lower Mississippi River. Geomorphology 34(3-4): 227-249.

Bierman, P., and Montgomery, D. 2014. Hillslope. Key Concepts in Geomorphology: 145-178.

Chen, D., and Liu, M. One-and two-dimensional modeling of deep gravel mining in the Rio Salado. pp. 1-9.

Collins, B., and Dunne, T. 1990. Fluvial geomorphology and river-gravel mining: a guide for planners, case studies included. California Department of Conservation, Division of Mines and Geology.

Duţu, L. T., Provansal, M., Le Coz, J., and Duţu, F. 2014. Contrasted sediment processes and morphological adjustments in three successive cutoff meanders of the Danube delta. Geomorphology 204: 154-164.

Fuller, I. C., Large, A. R., and Milan, D. J. 2003. Quantifying channel development and sediment transfer following chute cutoff in a wandering gravel-bed river. Geomorphology 54(3-4): 307-323.

Gurnell, A., Downward, S., and Jones, R. 1994. Channel planform change on the River Dee meanders, 1876–1992.

Regulated rivers: research management 9(4): 187-204.

Hooke, J. 1995. River channel adjustment to meander cutoffs on the River Bollin and River Dane, northwest England. Geomorphology 14(3): 235-253.

Hooke, J. M. 2007. Complexity, self-organisation and variation in behaviour in meandering rivers. Geomorphology 91(3): 236-258.

Kuntiyawichai, K., Schultz, B., Uhlenbrook, S., and Suryadi, F. Delineation of flood hazards and risk mapping in the Chi River Basin, Thailand. pp. 298-313.

Lagasse, P., Zevenbergen, L., Spitz, W., and Thorne, C. R. 2004. Methodology for predicting channel migration.

Lai, X., Yin, D., Finlayson, B. L., Wei, T., Li, M., Yuan, W., Yang, S., Dai, Z., Gao, S., and Chen, Z. 2017. Will river erosion below the Three Gorges Dam stop in the middle Yangtze? Journal of Hydrology 554: 24-31.

Langbein, W. B., and Leopold, L. B. 1964. Quasi-equilibrium states in channel morphology. American Journal of Science 262(6): 782-794.

Leopold, L. B., and Wolman, M. G. 1957. River channel patterns: Braided, meandering, and straight. Professional Paper. Washington, D.C.: U. S. G. P. Office. [in English]

Li, D., Lu, X. X., Chen, L., and Wasson, R. 2019. Downstream geomorphic impact of the Three Gorges Dam: With special reference to the channel bars in the Middle Yangtze River. Earth Surface Processes Landforms 44(13): 2660-2670.

Li, L., Lu, X. X., and Chen, Z. 2007. River channel change during the last 50 years in the middle Yangtze River, the Jianli reach. Geomorphology 85: 185-196.

Makaske, B., Maathuis, B. H., Padovani, C. R., Stolker, C., Mosselman, E., and Jongman, R. H. 2012. Upstream and downstream controls of recent avulsions on the Taquari megafan, Pantanal, south-western Brazil. Earth Surface Processes Landforms 37(12): 1313-1326.

Mueller, J. E. 1968. An introduction to the hydraulic and topographic sinuosity indexes. Annals of the association of american geographers 58(2): 371-385.

Petts, G. E., and Gurnell, A. M. 2005. Dams and geomorphology: research progress and future directions. Geomorphology 71(1-2): 27-47.

Phillips, J. D. 2009. Changes, perturbations, and responses in geomorphic systems. Progress in Physical Geography: Earth and Environment 33(1): 17-30.

Rinaldi, M., Wyżga, B., and Surian, N. 2005. Sediment mining in alluvial channels: physical effects and management perspectives. River research applications 21(7): 805-828.

Sear, D., and Archer, D. 1998. The effects of gravel extraction on the stability of gravel-bed rivers: A case study from the Wooler Water, Northumberland, UK. Gravel bed rivers in the environment 415: 432.

Williams, G. P., and Wolman, M. G. 1984. Downstream effects of dams on alluvial rivers. US Government Printing Office.

Zawiejska, J., Wyżga, B., and Radecki-Pawlik, A. 2015. Variation in surface bed material along a mountain river modified by gravel extraction and channelization, the Czarny Dunajec, Polish Carpathians. Geomorphology 231: 353-366.

Zhou, M., Xia, J., Lu, J., Deng, S., and Lin, F. 2017. Morphological adjustments in a meandering reach of the middle Yangtze River caused by severe human activities. Geomorphology 285: 325-332.