Techno-Science Research Journal 10(2) (2022) 17-22

Content list available at ITC

Techno-Science Research Journal

Journal Homepage: http://techno-srj.itc.edu.kh/

Techno-Science Research Journal

Twin Bridge Hydraulics Analysis using HEC-RAS Model

Norak Harn[1], Sytharith Pen[1*], Sokchhay Heng[1]

[1] *Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia, Russian Federation Blvd., P.O. Box 86, Phnom Penh, Cambodia*

Received: 13 February 2022; Accepted: 07 July 2022; Available online: December 2022

Abstract: *Bridges are high-cost and high-tech infrastructure which are essential to public transportation. However, it is subject to various environmental impacts. Especially, as it is built in the river, a detailed hydraulic study is essential before the construction of the bridge as it may cause a huge impact to the existing river conditions, livelihood near the river bank and river navigation. This study aims to quantify hydraulic responses at Prek Tamak bridge when another bridge is parallelly built next to it. To reach its aim, a 2D Mekong Hydraulic model at that area is constructed by using HEC-RAS model. Observed flood level played an important role in model calibration. Consequently, hydraulic analysis was developed to observe hydraulic condition near the Prek Tamak bridge before and after another bridge is built by considering on peak discharge observed between 2013 and 2017. The variation of velocity, shear stress and inundation area are assessed in this research. As a result, the flow's velocity and shear stress increase along the centerline and right bank of the river while decreasing near the left bank. In addition, inundation boundary extension ranged from 15m to 60m are spotted at upstream of the bridge. A detail slope stability analysis along the river bank need to be carried out prior to the construction.*

Keywords: Bridge hydraulics; Prek Tamak; HEC-RAS; Shear stress; River bank

1. INTRODUCTION

Constructing a bridge across a river is not solely a structural engineering task. It cannot be built with such a large opening that it spans all across the river at such a height that floodwater will never reach the deck. This is where bridge hydraulics study is critical. The length of span, and thereby the number of piers, is dictated by economics. Bridge pier constricted flow cross section and create backwater rise at upstream sections while also caused the decrement of longitudinal velocity at upstream [1]. Hence, prior to building a new bridge, it is necessary to demonstrate through calculation or modelling that the resulting backwater of its piers and/or abutments in the river will not cause, or greatly exacerbate, flooding of land and property upstream [2]. Depending on characteristics of the bridges, it could either reduce or increase peak flood flows upstream and downstream, or have no influence at all, implying that there is no easily foreseeable consequence and that hydraulic modeling is required for such river investigation [3].

Biswas [4] used 2-D mathematical modeling to conduct a case study on the effect of bridge pier on waterway construction. This study aimed to ensure the ease of flow through waterways located at the 111th km of the Surma river in Bangladesh. MIKE21C (Developed by DHI), a modeling system, was used to create a 2D morphological model. Additionally, 25 km in length of the river are covered in the study, specifically 12.5 km upstream of the bridge and 12.5 km downstream. Moreover, bathymetric cross sections with 50m intervals are used during model development. The flood events were chosen based on the frequency of occurrence of average floods and the worst-case scenario. After assessment, the resulting infographic depicts potential bank erosion and scour beyond expectations if the water ways become constrictive. River training work is also recommended if waterways need to be constrained. Atabay *et al*., [5] applied HEC-RAS to predict the level of backwater caused by constriction of bridge in waterways. The model was used to observe the effect of various factors on backwater level of single-opening semicircular arch, single-opening semielliptical arch and single-opening straight deck bridge. The results illustrate a considerably impact on backwater level by the variation of Froude number, discharge, coefficient of roughness and ratio of bridge opening.

* Corresponding author: Sytharith Pen

E-mail: sytharithpen@yahoo.com; Tel: +855-16 320 332

The general objective of this study is to analyze river hydraulic conditions under the impact of new bridge construction in the Mekong River at Prek Tamak area, Cambodia. More specifically, it aims to quantify hydraulic responses to the proposed new bridge under peak discharge observed between 2013 and 2017. Due to the lack of clear evidence, the observed flood mark is assumed to be the mark of 2013 historical flood for this analysis.

2. METHODOLOGY

2.1. Study area

This study focuses on Prek Tamak bridge in Kandal province, Cambodia. This bridge crosses the Mekong River at Khsach Kandal district and connects National Road No.6 to No.8. The area of study extends to about 400m upstream and downstream of the bridge. It lies between latitudes 11° 44’ 50” and 11° 45’ 30” N, and longitudes 104° 59’ 50” and 105° 00’ 40” E.

2.2. Model selection

The ability to swiftly analyze multiple potential designs, reduce the likelihood of mathematical errors, and save time by avoiding arduous hand computations are all advantages of using software. There is several software available for the bridge hydraulics modelling but only two of those, which are HEC-RAS and SMS:SRH-2D, will be mentioned in this section because they are the most suitable in performing this kind of analysis. Hydrologic Engineering Center's River Analysis System (HEC-RAS), developed by Hydrologic Engineering Center, is a free and user-friendly software which supports networks of channels and is capable of modeling subcritical, supercritical, and mixed flow regime profiles. It has the abilities to model obstructions in the flow path such as bridge, dam, weir and culvert. Meanwhile, Sedimentation and River Hydraulics – Two-Dimensional model (SMS:SRH-2D) is a software which can be implemented for two-dimensional (2D) hydraulic, sediment, temperature, and vegetation model for river systems under development at the Bureau of Reclamation. It has a limited function as a free software. User need to buy the pro version to get access to its full feature. Considering that the feature of two software mentioned is almost the same, HEC-RAS is a better choice.

For the study, HEC-RAS will be used as modeling approach for bridge hydraulics study at Prek Tamak bridge. Moreover, it is providing a wide range of calculation and is used very often for various studies. The HEC-RAS model was found to perform well, with simulated results for both studies complying tightly with observed water level. Additionally, it is more convenient to edit model geometry with RAS mapper that is built-in in the model than to edit with other software. It also allows users to run multiple calculation plans which makes it easier in result comparison. Furthermore, HEC-RAS represents a powerful tool that can produce reliable findings when it comes to Manning's n-value estimation [6].

2.3. Overal study procedure

In this study, there are several stages of analysis procedures prior to getting the results. HEC-RAS model was used as a main tool in this analysis. Initially, river bathymetry was imported into the model to set up model geometry. It should be denoted that this river bathymetry data were measured by hydrographic survey for both below and above the water surface. Ground elevation below water surface was measured by using Acoustic Doppler Current Profiler (ADCP). Meanwhile, the elevation above water surface was measured by Differential Global Positioning System (DGPS). Perimeter of study area is sketched before computation points were generated for 2D stimulation. Subsequently, discharge data, which was recorded by Ministry of Water Resources and Meteorology (MOWRAM) at Chroy Chongva station, were brought in to the model to complete the model setup, and computation could begin. Soon after the initial results of parameters were obtained, the maximum water surface elevation was taken to compare with the observed flood mark of 2013. At this time, the model is calibrated and validated before the calculated data such as velocity, shear stress and water depth can be taken into Excel and ArcGIS to plot into graph and result map. For scenario development, one more bridge was added to the model’s geometry 20m upstream parallel to the existing bridge and then repeat the procedures above. After obtain the results from the two preceding processes, hydraulic analysis was carried out in order to plot the graph of variation and map of changes in percentage.

2.4. Scenario development

The calibrated HEC-RAS model can be used for evaluation of different scenarios. In this case, the model is used to assess the hydraulic responses of the river following the future construction of another bridge within the study area. The proposed bridge is assumed to have identical dimensions as the existing one and will be built 20m upstream.

3. RESULTS AND DISCUSSION

In this section, the value of manning’s coefficient obtained from model calibration is illustrated. Following that, the variation of flow’s velocity, shear stress and inundation area due to the effect of waterway constriction caused by bridge’s pier are shown and discussed. The location of key components which will be mentioned in the following parts are depicted in Fig. 1.

3.1. Calibration of model

After the implementation of model using a range of input parameters, a suitable manning coefficient for Mekong hydraulic model at Prek Tamak bridge has been found with value of n equal to 0.042 for channel and 0.012 for bridge's pier. The result obtained by using this calibrated parameter, yielded the water surface elevation closest to the area of observed flood mark is 6.52 m amsl, which is approximately 5% lower than the recorded flood mark. It is considered as acceptable for the chosen hydraulic model. Additionally, the overall aim of the study is to observe the variation of hydraulic condition in the river, therefore this small error will not have significant impact on the desired result. However, close attention should be given to Manning's n roughness calibration when different hydraulic models are applied since Bopulomytis et al. [7] detected that selection of the same Manning's n roughness coefficients for different hydraulic models causes an error in the flow simulation process.

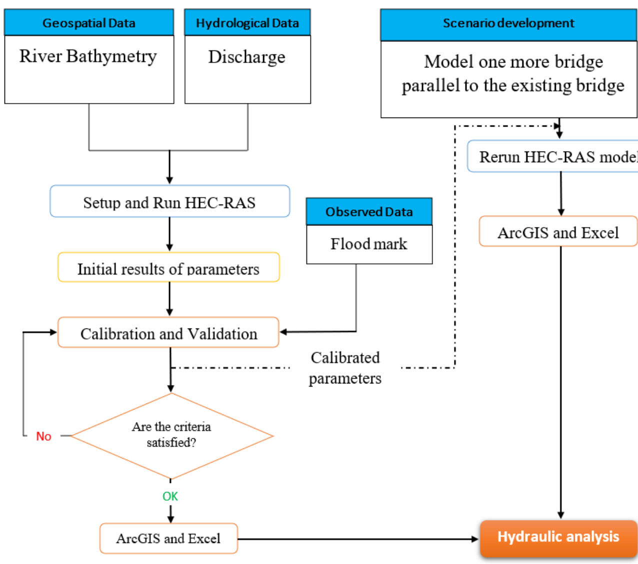

Fig. 1. Overall study flowchart

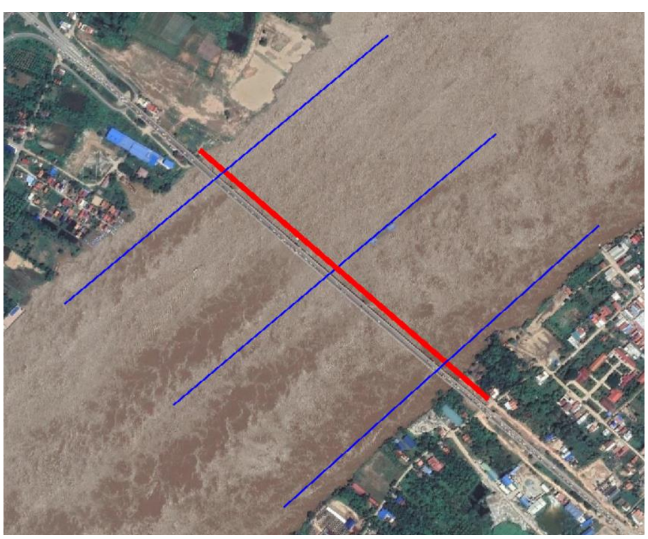

Fig. 1. Location of key component of the study

3.2. Impact of bridge's piers on flow's velocity

The presence of proposed bridge, impacted the flow's velocity which is an important parameter which influence many more parameters of the river (Fig. 2).

The differences in flow velocity along the centerline of the study area are graphically represented in Fig. 2. Overall, the variation is significant in between the bridge pier due to the constriction of water way. The constriction causes a loss of energy as the flow contracts, crosses through the bridge, and thereafter, most importantly, re-expands back to the full channel width [2]. The most significant changes were observed approximately 20 meters upstream of the proposed bridge, where the velocity increased from 2.7 m/s to 2.8 m/s. In the meantime, it has risen by 0.54% on average.

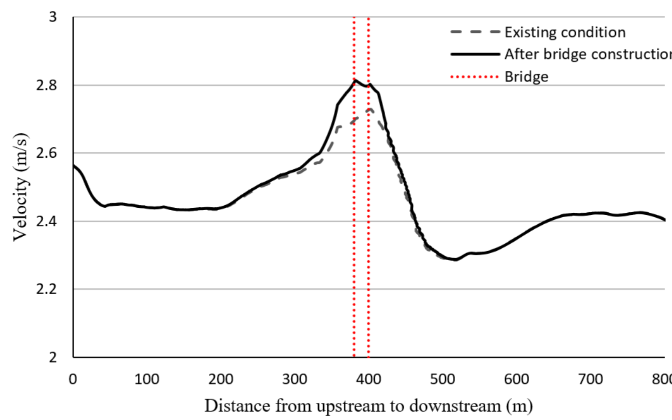

Fig. 2. Velocity variation along the center line

Fig. 3 depicts the velocity difference near the left bank, where it is increased by 0.14 m/s near the bridge's pier but reduced by 1.22% on average. The greatest drop was observed 25 meters upstream of the proposed bridge, where the velocity decreased by 0.2 m/s. It seems to oppose to the law of mass conservation which the velocity generally increase after the waterway is constricted. It is due to present of secondary flow which induced by meandering of the river and lateral variation of bed topology [8]. Additionally, the near-boundary secondary flow invariably shifts to a higher velocity location [9]. The bed topology and flow's velocity near the left bank is significantly lower than the inner flow line cause the flow to move toward the inner flow line after obstructed by the bridge's pier.

The velocity increased significantly close the bridge's pier near the right bank (Fig. 4). It appears to increase from 1.42 m/s to 1.6 m/s. Meanwhile, it increased by 0.66 percent on average along the riverbank. Even though, it is also considered as boundary layer flow as the left bank, it does not expose to the same condition. The velocity near the right bank is not decreased due to the reason that it has only slightly bed topology different as compared to the inner flowline. Moreover, the bridge's pier is located at a greater distant to the river bank than in the case at left bank.

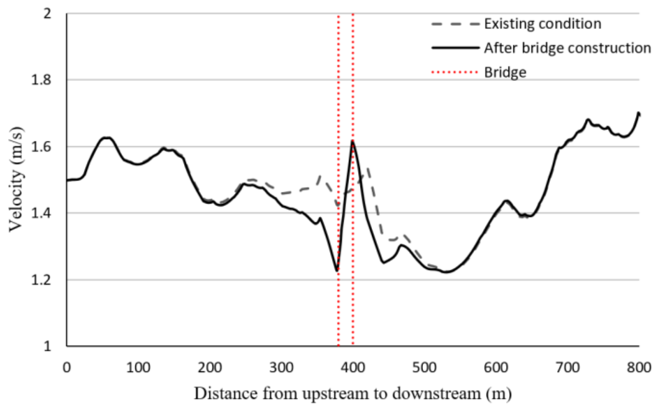

Fig. 4. Velocity variation near the left bank

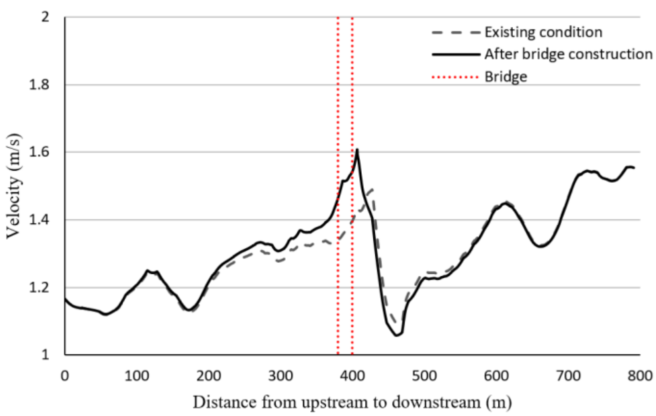

Fig. 5. Velocity variation near the right bank

3.3. Impact of bridge's piers on shear stress

Having strong correlation with velocity, shear stress in the study area is also affected by the new bridge's piers. The increment of a shear stress can erode the river bed if it exceeds the resistance strength of the material. In addition, near the river bank, it can result in deformation and/or sliding based on the internal resistance of the slope material and the friction with the slope. On the other hand, if it fall below the significance threshold required to transport a specific particle, the particles will become trapped behind other particles at the channel's bed and cause deposition [10].

Along the centerline, the shear stress increased by 0.97% on average (Fig. 5). At 43 meters upstream from the proposed bridge, the shear stress increases from 27.49 N/m^2 to 28.96 N/m^2 which is the highest change caused by the present of another bridge's pier.

Near the left bank, the shear stress is decreased by 2.53% on average (Fig. 6). The highest drop take place at 374 meters from upstream of the study area where the shear stress lowered from 11.1 N/m^2 to 8.6 N/m^2.

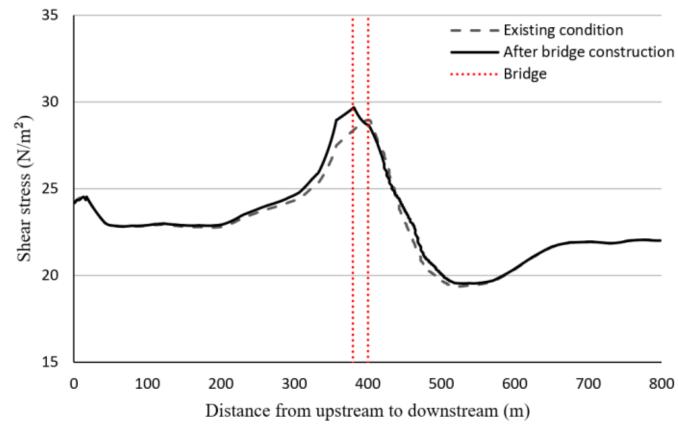

Fig. 6. Shear stress variation along the center line

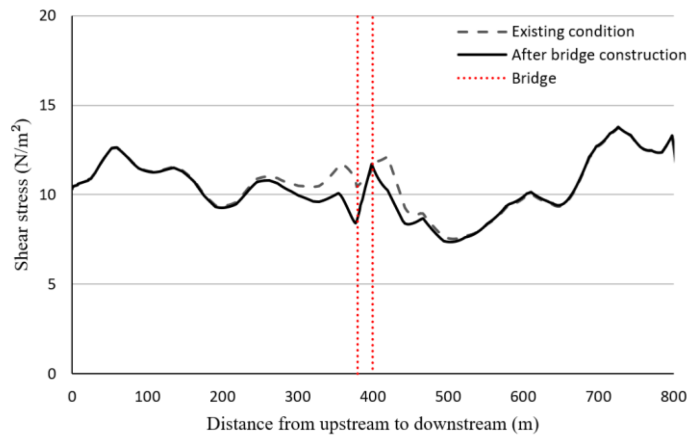

Fig. 7. Shear stress variation near the left bank

Near the right bank, the shear stress is increased by 0.62% on average (Fig. 7). The highest rise take place at 386 meters from upstream of the study area where the shear stress goes up from 9.37 N/m^2 to 11.06 N/m^2.It can be seen that the trend of change of shear stress follow the trend of velocity. The increment near the right bank indicates the risk of river bank collapse after the construction of the new bridge. This issue must be taken into account and detail slope stability must be conducted prior to the construction.

3.4. Impact on on inundation boundary

The construction of this proposed bridge causes no significant change to depth of the river. However, the backwater effect caused by the waterway constriction of bridge pier will result in extension of inundation boundary. Its extension varies across upstream side of the study area in range from approximately 15 m to 60 m as shown in Fig. 9. It should be denoted that this is just the extension cause by the peak flow observed between 2013 and 2017. As the climate change is getting worse, higher discharge can be expected in the future [11] which result in a larger extension. It is becoming more vital as the need for buildings that were constructed on floodplains of the river that, by definition, are already at risk to flooding. Moreover, to some extent, at locations where there is bridge and huge flood, a study is needed to address the amount of the flood caused by the bridge and to compare with other factors. If the investigation illustrates the bridge to be at fault, therefore it might be a sign to construct a new structure. Hence, if the bridge is obstacle to flow and is the main reason of the flooding that happened, comprehension of bridge hydraulics might be able to aid in design improvement works that will overcome the issue.

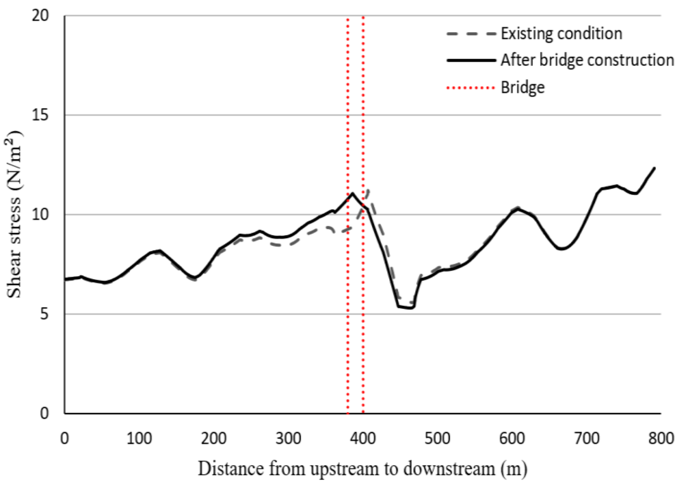

Fig. 8. Shear stress variation near the right bank

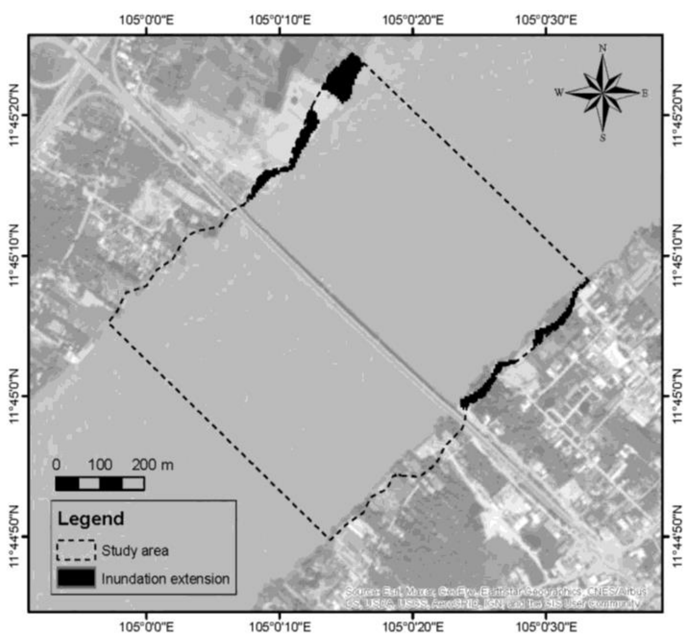

Fig. 9. Extension of inundation boundary

4. CONCLUSIONS

The overall aim of this study is to evaluate Mekong river's hydraulic responses in the event that a new bridge is built. With the use of the HEC-RAS model, the hydraulic responses after building another bridge on the Prek Tamak bridge have been successfully quantified. Two objectives of this study, which consist of the construction of 2D Mekong hydraulic model at Prek Tamak and the assessment of hydraulics responses, were both achieved. After the analysis, conclusion can be made that the addition of another bridge has a substantial impact on the river as the flow velocity increased up to 3.7% along the centerline. At the left bank, velocity and shear stress are both dropped. Meanwhile, it increased near the right bank and under each span of the bridges. Consequently, these changes will have an influence on erosion and deposition patterns in the river. Last but not least, minimal inundation boundary extension has been observed on the upstream side. Even though it does not indicate a considerable extension in this study, it cannot be overlooked. A minor alteration by the bridge could endanger human life and property in the surrounding area. In addition, it can be seen from the result that the bridge only impact hydraulic condition of the river in a very minimal area (only 200m to upstream and downstream of the bridge in this case). Therefore, excluding the extension of inundation boundary, only short profile of river is needed to do the assessment of changes in hydraulic condition. Additionally, this study also provides some important parameters for hydraulic structure design as well as other related studies. Moreover, it offers a better perspective in decision making for new bridge development. Bridge designer can use this analysis to better design the bridge for sustainable development. Nevertheless, this analysis is just a preliminary study. In project implementation, it is required to have detail study within the most updated and extreme case scenario. In addition, the study only focus and discuss to the local effect without any implication to outside the model boundary.

REFERENCES

[1] Ghobadian, R., Basiri, M., & Seydi Tabar, Z. (2018). Interaction between channel junction and bridge pier on flow characteristics. Alexandria Engineering Journal, 57(4), 2787–2795.

[2] Springer, J., & Zhou, K. (2003). Bridge hydraulics. In Bridge Engineering: Substructure Design. https://doi.org/10.1061/(asce)0733-9429(2001)127:7(632)

[3] Trueheart, M. E., Dewoolkar, M. M., Rizzo, D. M., Huston, D., & Bomblies, A. (2020). Simulating hydraulic interdependence between bridges along a river corridor under transient flood conditions. *Science of the Total Environment*, *699*, 134046. https://doi.org/10.1016/j.scitotenv.2019.134046

[4] Biswas, S. K. (2010). Effect of bridge pier on waterways constriction : a case study using 2-D mathematical modeling. *Joint Conference on Advances in Bridge*

Engineering-II, 369–376.
[5] Atabay, S., Haji Amou Assar, K., Hashemi, M., & Dib, M. (2018). Prediction of the backwater level due to bridge constriction in waterways. *Water and Environment Journal*, *32*(1), 94–103.
[6] Ardıçlıoğlu, M., & Kuriqi, A. (2019). Calibration of channel roughness in intermittent rivers using HEC-RAS model: case of Sarimsakli creek, Turkey. *SN Applied Sciences*, *1*(9), 1–9.
[7] Boulomytis, V. T. G., Zuffo, A. C., Dalfré Filho, J. G., & Imteaz, M. A. (2017). Estimation and calibration of Manning's roughness coefficients for ungauged watersheds on coastal floodplains. *International Journal of River Basin Management*, *15*(2), 199–206. https://doi.org/10.1080/15715124.2017.1298605
[8] Wang, Z. Q., & Cheng, N. S. (2005). Secondary flows over artificial bed strips. *Advances in Water Resources*, *28*(5), 441–450.
[9] Yang, S. Q., Tan, S. K., & Wang, X. K. (2012). Mechanism of secondary currents in open channel flows. *Journal of Geophysical Research F: Earth Surface*, *117*(4), 1–13.
[10] Charlton, R. (2007). Fundamentals of fluvial geomorphology. In *Fundamentals of Fluvial Geomorphology*.
[11] Horton, A. J., Triet, N. V. K., Hoang, L. P., Heng, S., Hok, P., Chung, S., Koponen, J., & Kummu, M. (2022). The Cambodian Mekong floodplain under future development plans and climate change. *Natural Hazards and Earth System Sciences*, *22*(3), 967–983. https://doi.org/10.5194/nhess-22-967-2022