Hydrological and Hydraulic Analyses for a Proposed Bridge in Floridablanca, Pampanga

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***Abstract*: Several studies prove that hydraulic factors play a major part in bridge deterioration. Thus, the conduct of hydrological and hydraulic analyses are essential in ensuring the safety, stability, and long-term performance of bridge structures, particularly in flood-prone river systems. The study evaluated the hydrological conditions of a proposed bridge crossing the Porac River between Barangays Poblacion and Valdez in Floridablanca, Pampanga. Watershed characteristics were analyzed by topographic survey and Digital Elevation Model based watershed delineation using HEC-HMS. The Rainfall Intensity-Duration-Frequency of the Philippine Atmospheric, Geophysical and Astronomical Services Administration was used to perform the Rainfall frequency analysis with the 50-year rainfall. Peak design discharge obtained by rainfall-runoff simulation is 662.60 cu.m./s which is used as input for hydraulic modeling on HEC-RAS. The catchment area of watershed is 120.46 sq. km., longest flow path is 37.99 km and average basin slope is 8.26%. Hydraulic analysis showed a critical flow depth of 24.71 m for the design flood condition. The minimum bridge span of 23 meters was determined from the Design Guidelines, Criteria and Standards, and the proposed bridge will be able to span between existing riverbank slope protection structures. The hydrologic and hydraulic models combined showed that the proposed bridge size is sufficient to safely pass the design flood, and is a prudent, cost-effective, and resilient solution for the site. The findings of the study underscore the importance of a comprehensive hydrological and hydraulic evaluation in the development of sustainable and flood-resilient bridge infrastructure.**

***Keywords*: Hydrological Analysis, Hydraulic Analysis, HEC-HMS, HEC-RAS.**

1. Introduction

A bridge plays a pivotal role in transportation networks which enables the movement of goods, services, and people over various obstacles such as bodies of water, specifically rivers [1]. Archipelagos such as the Philippines significantly benefit from the construction of bridges since these may be utilized to connect different islands to facilitate trade and movement, improve tourism, ease administration, and ultimately, enhance the economy of the State as a whole. It is apparent that in all regions of the Philippines, roads and bridges stimulate socioeconomic development by promoting integration and seamless connectivity [2].

A riverine bridge is defined as a structure intended for people and road traffic in order for these to cross water currents located in the area of a riverbed, guaranteeing the effective transport and safety of the end-user [3]. As these bridges are generally exposed to water, the most critical hazards to which these bridges are exposed are hydrological, where the flood and foundation movement contributes to almost half of the failures compared to other causes of failure [3].

The benefits of constructing bridges come with consequent costs. Constructing one bridge costs a lot of millions, yet despite spending millions on these structures, many of the existing bridges do not have a longer lifespan [4]. This problem is attributable to different factors, among which are hydraulic factors.

Since 1990, hydraulic factors have become the primary causes that lead to bridge failure, which happens suddenly with damaging results [5]. Due to global climate change, it is anticipated that these kinds of failures will persist in the future [5]. These bridges are also susceptible to natural disasters such as typhoons, earthquakes, and floods, representing significant hazards and resulting in temporary or permanent disruptions to the economy and people's lives [2]. Thus, there is an imperative need for detailed hydrological and hydraulic investigation for proper design and construction [6].

Hydrologic analysis integrates rainfall records, watershed morphology, land cover, soil properties, and hydraulic modeling to estimate flood behavior. Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) is widely used to simulate the rainfall-runoff process, and Hydrologic Engineering Center - River Analysis System (HEC-RAS) is used to estimate the water-surface elevations, flow velocity, and flood extents [7]. These tools help with safe bridge design by identifying peak discharge, flood elevations and scour potential [7].

There are several rivers in the Philippines, among which is Porac River, which runs through the municipality of Floridablanca, which in turn is located in the province of Pampanga. Floridablanca is a first-class municipality in the Province of Pampanga within the Central Luzon Region of the Philippines [8]. It is located on the western part of the province along the mountain ranges of Zambales, bounded by nearby towns such as Lubao (South), Porac (North), Guagua (East), and Dinalupihan, Bataan (West) [8]. The proposed bridge will span across the Porac River, connecting two barangays in

Floridablanca: Poblacion (municipal center) and Valdez. It is proposed to be built at the encircled portion depicted below.



Fig. 1. Vicinity map



Fig. 2. Study area

2. Statement of the Problem

Considering that hydraulic factors have become the major causes of bridge deterioration, the following problems are sought to be addressed by the study:

a. Why should hydrological and hydraulic analyses be conducted for the proposed bridge?
b. What are the results of the hydrological and hydraulic analyses conducted for the proposed bridge?

3. Related Literature

Acknowledging its critically important purpose as the foundation of the economy, a driver of social activities, and a facilitator of increasing levels of interconnection among various regions, islands, cities, and provinces, the Philippines has placed a significant emphasis on infrastructure development in recent years [2].

The benefits of erecting bridges are widely accepted across the globe. However, as many factors affect the lifespan of these bridges, various studies have been adopted to extend the said lifespan through the effective management of controllable factors. An imperative aspect in carrying out a hydrological evaluation is analyzing and predicting the behavior of the river that crosses the bridge. In this regard, various types of hydraulic simulations can be carried out using models in HEC RAS, MIKE 11, FLO 2D, TELEMAC 2D, among others [3]. Even at present, the debate about which type of model to use persists, since often the performance of the software depends closely on the availability and precision of the input data necessary for modeling [3].

In their study of the Bajo Grau Bridge in Arequipa, Peru, Vigil and Booker (2023) proposed and implemented an extensive hydrological vulnerability framework [3]. Researchers discovered that the acquisition of topological and hydrometrical data is crucial to the investigation [3]. They conducted a topographical assessment of the bridge and the streambed, thereafter compiling a series of annual peak flow rates, which were adjusted with empirical and theoretical distribution functions for a probability analysis [3]. The system was simulated with HEC-RAS following the completion of the hydrological study [3].

Meanwhile, Ario et. al. (2022) conducted an investigation of bridge collapse phenomena due to heavy rain floods wherein they utilized structural, hydraulic, and hydrological analysis to identify the design elements that can help increase the resistivity of bridge structures in small rivers against floods with effective methods [9]. They conducted a field survey of the washed out Misasa railway bridge, which is located in Japan, and evaluated the conditions that caused the failure based on hydrological, hydraulic, and structural analyses at the time of the flood, based on a field survey of the affected bridge [9]. They believed that these analyses will help obtain design elements for small and medium bridge structures and countermeasures in the future [9].

According to Akay and Koçyiğit (2020), a hydrologic evaluation method was integrated into a safety-inspection framework for river bridges in Turkey, utilizing diverse hydrologic indicators including morphometric parameters, land cover and usage, precipitation characteristics, flood history, and the existence of retention structures to analyze hydrologic dynamics and flash flood risk within the bridge watershed [10]. The methodology suggested by Akay and Koçyiğit involved conducting a hydrologic assessment of the watersheds by aggregating the scores of several variables and categorizing the bridge watershed based on its vulnerability to flash floods [10]. Akay and Koçyiğit utilized a hydrologic evaluation methodology on 10 river bridges located in the Western Black Sea Basin of Turkey, which frequently experienced intense flash floods [10]. The chosen indicators positively demonstrated the flood potential and hydrologic characteristics of the watersheds through a comparison of the assessed bridge grades [10]. Ultimately, they determined that hydrologic evaluation could empower engineers to implement essential measures to mitigate the impacts of floods on river bridges during both the design and operational phases [10].

Meanwhile, Gedamu & Nagappa (2020), to determine the size of the openings of their proposed bridge, conducted hydrological analysis of the rivers, streams and flood paths which intersect with the proposed bridge, to estimate their different return floods magnitudes [4]. They conducted the

following activities throughout their study: analysis and interpretation of different topographic maps, soils map, satellite imagery and DEM (Digital Elevation Model) [4]. They also collected data and analyzed such data on un-gauged rivers and streams, conducted estimation of flood magnitudes by applying different rainfall-runoff models, and sizing of bridges [4]. Likewise, they provided designs type, size, and location of bridge and assessed scour potential at bridge locations [4]. In their study, Gedamu & Nagappa stated that the flood magnitudes at the bridge site are the function of geomorphology, geology, rainfall; soil and land use or land cover within the catchments of the rivers and streams crossing the road [4].

4. Methodology

The primary objective of the study is to conduct a hydrological analysis for a proposed bridge in Floridablanca, Pampanga, to support safe and resilient bridge design. The proponent utilized hydrologic and hydraulic modeling techniques to quantify the runoff, peak discharge, flood elevation, and hydraulic conditions that will impact the proposed bridge.

Methodology includes topographic survey, watershed analysis, rainfall frequency analysis, rainfall-runoff simulation and hydraulic modelling using industry standard software.

A. Topographic Survey

Topographic surveying is the detailed measurement and representation of the physical features of an area of land, including both natural and man-made elements [11].

B. Watershed Analysis

Shaikh and Birajdar (2015) defined a watershed as an area of land that drains into a common water body, such as a stream, river or lake [12]. A watershed can also be known as a basin or a catchment area [12]. The watershed in the proposed bridge was delineated using HEC-HMS which is often used to simulate rainfall–runoff processes. A Digital Elevation Model (DEM) was used to determine the different watershed characteristics such as: watershed (catchment) area, length of main watercourse (longest path), length of main watercourse from the center of area, average basin slope.

C. Rainfall Frequency Analysis

Rainfall or precipitation frequency analysis is a cornerstone of hydrometeorology [13]. It is used to quantify how often extreme rainfall events of different magnitudes are expected to occur in a specific area [13]. As for its benefits, these analyses guide engineers, planners, and water resource managers in designing high-risk infrastructure like dams to withstand heavy rainfall events and reduce flood risk [13].

D. Rainfall-runoff Simulation

Rainfall-runoff simulation was performed using the HEC-HMS. The model components include:

1) Basin Model

Basin Models constitute a fundamental element of a project [14]. Their primary function is to transform atmospheric conditions into streamflow at designated sites within the watershed [14]. Hydrologic components are employed to segment the watershed into manageable sections [14]. The research segmented the watershed into hydrologically uniform sub-basins.

2) Meteorologic Model

The principle of meteorological models is to prepare meteorologic boundary conditions for subbasins [15]. Design storm hyetographs corresponding to return periods were assigned in the study.

3) Transform Method

The SCS Unit Hydrograph converted excess rainfall into runoff hydrographs. Lag time was estimated using Modified Snyder's Lag Equation.

$$L_g = 0.6865 * C_t * \left[\frac{L * L_{ca}}{\sqrt{s}}\right]^{0.38}$$

where:
Lg - lag time, hour
Ct - lag time coefficient
L - length of main watercourse (longest path), km
Lca - length of main watercourse from the center of area, km
S - basin slope

E. Hydraulic Modeling

Hydraulic modeling was performed using HEC-RAS. The design discharge generated by HEC-HMS served as upstream boundary condition in HEC-RAS.

F. Design Consideration

The following criteria has been used for the bridge design based on DGCS:

1) Bridge Length

Desirable minimum bridge span length can be estimated using the design standard by the Ministry of Construction in Japan.

$$L = 20 + 0.005Q$$

where:
L - minimum span length, m
Q - design discharge from HEC-HMS, m^3/s

2) Freeboard Clearance

Vertical clearance from the Design Flood Level (DFL) obtained from HEC-RAS or the Maximum Flood Level (MFL) and the lowest member of bridge superstructure shall not be less than:

a. 1.50 meters for rivers carrying debris
b. 1.00 meters for other bridges

Table 1
Catchment area characteristics

Catchment Area, sq. km.	Longest Path, km.	Length of main watercourse from the center of area, km.	Average Basin Slope
120.46	37.98805	26.04272	0.08262

5. Result and Discussion

A. *Topographic Survey*

Topographic Survey was conducted to gather data on the riverbed and its banks. These data were then processed to create cross-sections of the river which are essential to hydraulic analysis.

B. *Watershed Analysis*

Figure 4 shows the delineated catchment area performed using HEC-HMS. It identified an area of 120.46 sq. km, longest flow path of 37.99 km, and 26.04 km as the length of the main watercourse from the center of area. These lengths affect the travel time of runoff from the upstream to the outlet. Also, the delineated catchment identified an average basin slope of 0.0826 (8.26%) indicating a moderately sloping watershed.

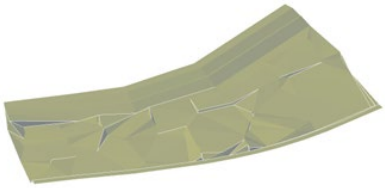


Fig. 3. 3D Perspective (AutoCAD 3D) of Porac river (Poblacion-Valdez section)

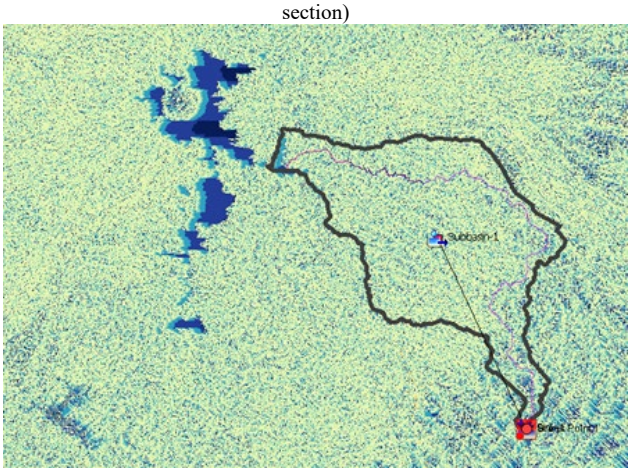


Fig. 4. Delineated catchment area

C. *Rainfall Frequency Analysis*

In the study, design rainfall was estimated using Rainfall Intensity Duration Frequency (RIDF) data prepared by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) in Iba as the synoptic station. A 50-year return period is established based on the design storm frequencies considered for bridge infrastructure projects as per the Design Guidelines, Criteria, and Standards (DGCS 2015 volume III) of the Department of Public Works and Highways (DPWH).

D. *Rainfall-Runoff Simulation*

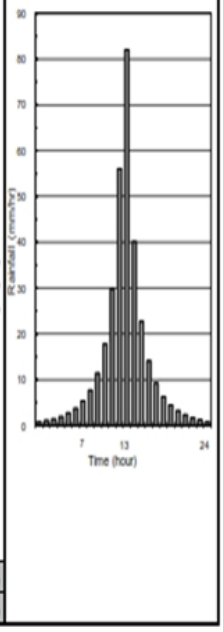
Using the identified catchment characteristics, the lag time was estimated to be approximately 10.61 hours (636.61 minutes). Moreover, the PAG-ASA RIDF was also used to calculate the frequency of rainfall. The result of this was used in the simulation to obtain the design peak discharge of the catchment. The watershed had a peak discharge of 662.60 cubic meters per second, according to the simulation.

E. *Hydraulic Modeling*

The hydraulic behavior of the river was determined using HEC-RAS using the simulated peak design discharge of 662.60 cubic meter per second and survey data. In the hydraulic model, the critical flow depth was computed as 24.71 m.

Table 2
Rainfall data

Time (hour)	Total Rain (adjusted by fa) (mm/hr)	Loss (mm/hr)	Excess Rain (mm/hr)	Excess Rain (%) to total	Design Hyetograph (Excess Rain, Basin Rainfall)
1	0.73	0.00	0.73	0.22%	
2	1.06	0.00	1.06	0.32%	
3	1.41	0.00	1.41	0.43%	
4	1.90	0.00	1.90	0.58%	
5	2.71	0.00	2.71	0.83%	
6	3.74	0.00	3.74	1.14%	
7	5.32	0.00	5.32	1.63%	
8	7.63	0.00	7.63	2.33%	
9	11.36	0.00	11.36	3.47%	
10	17.72	0.00	17.72	5.41%	
11	29.78	0.00	29.78	9.10%	
12	56.01	0.00	56.01	17.11%	
13	82.09	0.00	82.09	25.08%	
14	40.11	0.00	40.11	12.25%	
15	22.70	0.00	22.70	6.93%	
16	14.09	0.00	14.09	4.30%	
17	9.23	0.00	9.23	2.82%	
18	6.27	0.00	6.27	1.92%	
19	4.42	0.00	4.42	1.35%	
20	3.17	0.00	3.17	0.97%	
21	2.27	0.00	2.27	0.69%	
22	1.67	0.00	1.67	0.51%	
23	1.22	0.00	1.22	0.37%	
24	0.74	0.00	0.74	0.23%	
Total	327.35	0.00	327.35	100.0%	
Max.	82.09	0.00	82.09	25.08%	



HEC-HMS Input Data

Table 3
Lag time computation

Catchment Area (sq.km)	Length (km)	Slope S	Lca (km)	Ct	Lg (hr)	Lg (min)
120.46	37.9881	0.08262	26.04272	0.7	10.6100899	636.605

Table 4
Design discharge

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
Subbasin-1	120.5	662.6	1 January 2000, 2...	150.11
Sink-1	120.5	662.6	1 January 2000, 2...	150.11

Table 5
HEC-RAS Summary Output table

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Reach1	200	PF 1	662.60	20.80	25.83		26.01	0.000766	1.87	353.90	93.95	0.31
Reach1	180	PF 1	662.60	20.76	25.82		26.00	0.000736	1.86	355.61	91.85	0.30
Reach1	160	PF 1	662.60	20.74	25.77		25.98	0.000873	2.00	330.49	87.13	0.33
Reach1	140	PF 1	662.60	20.77	25.63		25.94	0.001642	2.47	267.83	81.91	0.44
Reach1	120	PF 1	662.60	20.71	25.49		25.90	0.002364	2.81	235.88	77.38	0.51
Reach1	100	PF 1	662.60	20.58	24.77	24.71	25.76	0.009293	4.39	150.95	70.80	0.96
Reach1	80	PF 1	662.60	20.30	25.05		25.51	0.002495	3.03	218.50	67.49	0.54
Reach1	60	PF 1	662.60	20.81	24.65		25.42	0.005235	3.87	171.43	63.97	0.75
Reach1	40	PF 1	662.60	20.82	24.62		25.30	0.004169	3.65	181.47	62.79	0.69
Reach1	20	PF 1	662.60	20.25	24.19	23.92	25.16	0.006914	4.37	151.62	57.99	0.86
Reach1	0	PF 1	662.60	20.43	23.76	23.76	24.98	0.009428	4.89	135.55	56.18	1.00

F. Design Consideration

Based on the hydraulic analysis, the proposed bridge's minimum design span was determined to be 23 meters. Furthermore, the soffit of this bridge was found to be at least 25.71 meters above the surface.

$$L_{span} = 20 + 0.005Q = 20 + 0.005(662.60) \approx 23.313$$
$$= \mathbf{23\ meters}$$

$$h_{minimum} = flow\ depth_{critical} + 1.0\ \text{(other bridges)}$$
$$= 24.71 + 1.0 = \mathbf{25.71\ meters}$$

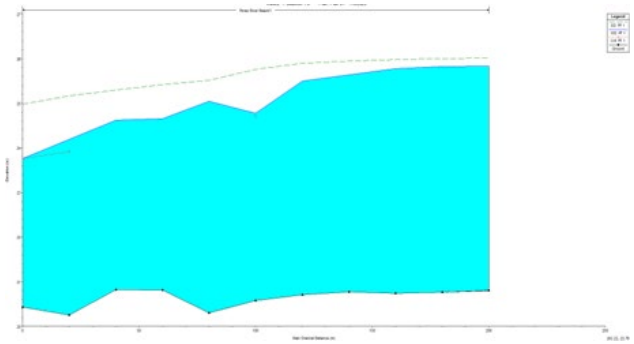


Fig. 5. Profile plot

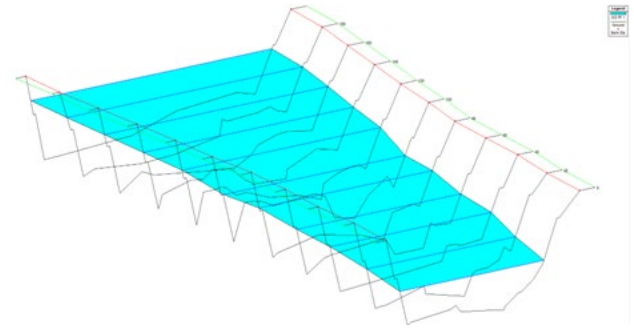


Fig. 6. 3D Perspective (HEC-RAS) of Porac river (Poblacion-Valdez Section)

6. Conclusion

The site for the proposed bridge crossing along Porac River at Brgy. Poblacion- Valdez, Floridablanca, Pampanga is suitable for bridge construction based on computed watershed characteristics and hydraulic conditions from the hydrological and hydraulic analyses. The parameters used to simulate the rainfall-runoff using HEC-HMS were catchment area of 120.46 sq. km., basin slope, the longest flow path and watershed geometry. The model used the 50-year return period rainfall data of the PAG-ASA in the hydraulic analysis and calculated the lag time to generate a design discharge of 662.60 cu.m/sec.

The HEC-RAS simulation indicated that the critical flow depth of the river section is approximately 24.71 m for the design flood condition. The generated water surface profile and the three-dimensional hydraulic model clearly described the flow behaviour in the study reach, which made it possible to assess the proposed bridge alignment and confirm that the structure could safely accommodate the design flood without substantially obstructing river flow.

The hydraulic analysis and the selected bridge design criteria showed that the minimum required bridge span was about 23 m. This span satisfies hydraulic requirements and reduces interference to the river channel. The proposed bridge can also be designed to span between the existing slope protection structures on both sides of the river without further encroachment into the channel and without compromising the integrity of the existing riverbank protection works. This configuration provides increased hydraulic efficiency, reduced potential for scour around the abutments, and reduced construction impacts to the river.

References

[1] Manalastas, M. V., Carbungco, J. V. M., Dayrit, C. N. O., Lugtu, R. J. L., Manalang, J. M. Q., Manalo, V. P. B., Mandap, G., Cayanan, F., & Zoleta, J. C. R. (2025). Proposed Design Replacement of Del Carmen-Paguiruan Bridge in Brgy. Del Carmen, Floridablanca, Pampanga. International Journal of Scientific Research and Engineering Development, 8(3), 2987-3018. https://doi.org/10.5281/zenodo.15698597

[2] Adarne, M.J & Henry, M. (2024). Regional Impacts of Natural Disasters on Road Bridges in the Philippines. Bridge Maintenance, Safety, Management, Digitalization and Sustainability - Proceedings of the 12th International Conference on Bridge Maintenance, Safety and Management. DOI: 10.1201/9781003483755-359

[3] Vigil, A.J. & Booker, J. (2023). Hydrological Vulnerability Assessment of Riverine Bridges: The Bajo Grau Bridge Case Study. MDPI Open Access Journals. https://doi.org/10.3390/w15050846

[4] Gedamu, B. H., & Nagappa, V. (2020). Hydrological Analysis for the Proposed Bridge at South Wollo Ethiopia. International Journal of Scientific & Technology Research, 9(09), 66-71.

[5] Xiong, W., Cai, C. S., Zhang, R., Shi, H., & Xu, C. (2023). Review of Hydraulic Bridge Failures: Historical Statistic Analysis, Failure Modes, and Prediction Methods. Journal of Bridge Engineering, 28(4). https://doi.org/10.1061/JBENF2.BEENG-5763

[6] Department of Public Works and Highways (2015). Design Guidelines, Criteria and Standards, Philippine Government, Manila.

[7] Francine Kaye O. Tolentino, Allan Paul B. David, Karla Sue D. Galang, Eriane O. Laxamana, Mark Louis L. Pangilinan, Euvilaine R. Ranara, Aaron S. Malonzo, & John Vincent G. Tongol. (2023). Peak Discharge Determination using HEC-HMS for Flood Analysis: A Case of San Simon, Pampanga. International Journal of Progressive Research in Science and Engineering, 4(6), 411–422. Retrieved from https://journal.ijprse.com/index.php/ijprse/article/view/931

[8] Official Website of Municipality of Floridablanca, Province of Pampanga. (2025, August 11). Municipal profile. https://www.floridablanca.gov.ph/about-us/municipal-profile/

[9] Ario, I., Yamashita, T., Tsubaki, R., Kawamura, S., Uchida, T., Watanabe, G., and Fujiwara, A. (2022). Investigation of Bridge Collapse Phenomena due to Heavy Rain Floods: Structural, Hydraulic, and Hydrological Analysis. American Society of Civil Engineers. DOI: 10.1061/(ASCE)BE. 1943-5592.0001905.

[10] Akay, H. & Koçyigit, M. (2020). Hydrologic Assessment Approach for River Bridges in Western Black Sea Basin, Turkey. Journal of Performance of Constructed Facilities. DOI:10.1061/(ASCE) CF.1943-5509.0001372

[11] Okwuenu, C., Igbokwe, E., & Anyadiegwu, P. (2024). Topographic Survey of Comprehensive Secondary School Nawfia, Anambra State. International Journal of Research Publication and Reviews. https://www.researchgate.net/publication/378588753_Topographic_Survey_of_Comprehensive_Secondary_School_Nawfia_Anambra_State

[12] Shaikh, M. & Birajdar, F. (2015). Analysis of Watershed Characteristics Using Remote Sensing and GIS Techniques. International Journal of Innovative Research in Science, Engineering and Technology. DOI: 10.15680/IJIRSET.2015.0404023

[13] RTI International. (n.d). Precipitation Frequency Analysis. https://www.rti.org/water-resources-tools/precipitation-frequency-analysis.

[14] US Army Corps of Engineers Hydrologic Engineering Center. (n.d). HEC-HMS Users Manual - Basin Models. https://www.hec.usace.army.mil/confluence/hmsdocs/hmsum/4.12/watershed-physical-description/basin-models

[15] US Army Corps of Engineers Hydrologic Engineering Center. (n.d). HEC-HMS Users Manual - Meteorologic Models. https://www.hec.usace.army.mil/confluence/hmsdocs/hmsum/4.12/meteorology-description/meteorologic-models