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MESOSCALE PERSPECTIVE OF ENVIRONMENTAL FLOW ASSESSMENT IN THE MIDDLE REACH OF SEKAMPUNG RIVER, INDONESIA

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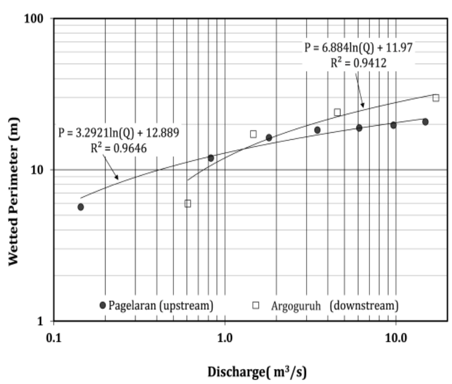
Graphical abstract



Abstract

Minimum environmental flow (E-flow) is a river discharge that is essential to maintain the environmental capacity along the river and support its ecological systems. A mesoscale approach is critical for a more focused understanding of river dynamics within the affected river reach. This paper discusses the mesoscale perspective of E-flow studied on the middle reach of a natural river, Sekampung in Indonesia. The wetted perimeter method was used to assess the minimum environmental flows at both the upstream and the downstream sides of the concerned reach of the river. An analytical approach was also used as a comparative method. The Average Reciprocal Distance (ARD) approach was used to obtain the E-flow at the specific site within the reach. Based on the mesoscale approach, a minimum E-flow of between 2.5 m^3/s and 3.6 m^3/s was obtained for the upstream and downstream boundaries, respectively. Using the ARD method, a minimum E-flow of 2.6 m^3/s must be provided at the new Sekampung Dam site. The water use and river dynamic nexus need to be further studied to make an integrated decision regarding the E-flow along the mesoscale boundaries.

Keywords: Environmental flow; mesoscale; natural river; average reciprocal distance; wetted perimeter method

1.0 INTRODUCTION

The concept of environmental flow (E-flow) has been extensively researched and is widely accepted as a fundamental aspect of improved river management practices. While there is considerable variation in the definitions of E-flow, a minimum E-flow is regarded as a crucial threshold for maintaining riverine ecosystems [1–5]. The E-flow represents the minimum water flow that is essential for the maintenance of environmental integrity and the preservation of the river's environmental carrying capacity, which is necessary to support the continued functioning of ecological systems within the riverine environment [6–10]. Uncertainty about how and what environmental flows should be provided, on the other hand, is the main issue [11]. Regarding to the effort of ensuring the availability of adequate river discharge along the downstream of dam, most country provide regulation to obligate river manager and all river stakeholder in ensuring that such amount of discharge has to be maintained. In the case of Indonesia, a policy decision has been made that requires the retention of a minimum of ninety-five percent of the dependable river discharge as a baseline level of E-flow [12]. The implementation of the regulation is impeded by the unavailability of sufficient hydrological data in most rivers in developing countries, including Indonesia. This represents a significant barrier to the application of desktop-type E-flow assessment methods.

It is important to be able to distinguish between the various methods of identifying the minimum E-flow, as there are several accepted approaches in the field. Reviews [13–16], four main categories of E-flow methods can be distinguished, namely: hydrological, hydraulic rating, habitat simulation, and holistic methods. Among those four, hydrological and habitat simulation are widely used to calculate minimum environmental flows in medium to small watersheds [8, 17, 18]. Each method has its own set of advantages and disadvantages, making it suitable for specific situations. Factors influencing method selection include the nature of the issue (such as abstraction, damming, or run-of-river schemes), management goals, available expertise, time and budget constraints, and the legislative context for flow considerations. Some approaches have been criticized for offering fixed minimum flow values that overlook the natural variability of river flows [19–21]. Thus, modifications are necessary to establish an environmental flow regime that preserves vital ecological functions [1, 5, 22]. Furthermore, the lack of discharge time-series data in Indonesia makes it difficult to apply traditional hydrological methods for environmental flows assessments. To effectively develop strategic river management, it is essential to accurately evaluate not just the volume but also the timing and duration of minimum flows and periods of flow cessation, ensuring adequate protection for aquatic ecosystems.

This paper presents a discussion of the mesoscale viewpoint of E-flow, with a particular focus on the middle reach of a natural river. The mesoscale approach is a widely utilized methodology in climatology. It is employed to represent the intermediate area, which constitutes a portion of the macroscale riverine system. Newson and Newson [24] proposed that the mesoscale approach to the river can be illustrated by varying the width of the main channel along the designated reach of the river. The concept of mesoscale has gained prominence in the context of river management, where the majority of challenges are now regional in nature, rather than site-specific (microscale) issues. This shift has led to a greater emphasis on integrated approaches to management [25]. Conversely, Wahono et al and also Frissell et al [15, 26] suggested that a macroscale approach to basin-scale river management is primarily concerned with a more comprehensive perspective, encompassing the identification of shared challenges across a broader regional context, such as river catchment.

The middle reach of Sekampung River has currently become the most strategic part of the Sekampung River, as the Sekampung Dam has been constructed within this area [23]. This dam serves as a regulating dam to ensure water management at the Argoguruh barrage. The barrage is the downstream boundary of the mesoscale reach and situated on the downstream side of the river's reach. The construction of the Sekampung Dam has resulted in the creation of the Sekampung Reservoir. In order to ensure the effective and efficient operation of this reservoir, it is necessary to implement an appropriate operational rule. This operational procedure must consider environmental flow rates while also meeting various downstream discharges requirements of the dam. Given the strategic importance of this central section, an analysis of environmental flow rates is required, not only to meet specific points along the river but also to consider the broader environmental flow within the meso-scale scope.

2.0 METHODOLOGY

2.1. Area of Study

The Sekampung River is situated within the Indonesian province of Lampung, and is designated as a strategic river basin. The river has a catchment area of 796 square kilometers and a total length of 256 kilometers. The river serves as a principal water source for the irrigation of a considerable area of land, amounting to over 50,000 acres, as well as fulfilling various other water requirements within the river basin. The typical cross-section of a river can be described as having a main channel width of approximately 30 meters and a floodplain length of approximately 250 meters [23].

The Sekampung River has a very strategic role for the people of Lampung Province, located in the southern part of Sumatra Island. This role is mainly due to the availability of water throughout the year, as well as its location connecting the western part of Lampung Province to the eastern part of the region. The river originates from the mountain upon which the Bukit Barisan Selatan National Park is located. The river flows to the East Coast of Sumatera. The annual precipitation within the river basin is recorded at a range of 1,600 to 2,500 millimeters. The highest annual precipitation levels were observed in the upstream reach of the river [12,23].

2.2. Research Approach

Traditional wetted perimeter method was used by [27] to investigate a minimum environmental flow is categorized into hydraulic rating type. The wetted perimeter method is basically based on wetted perimeter–discharge relationship which is a basic tool for evaluating a minimum environmental flow. The method is mainly based on cross section profile of the river. However, it could not be used to provide the seasonal variations of the environmental flows [21, 28]. The procedure is to derive the relationship between wetted perimeter length and its corresponding water levels within the concerned channel cross-sections. The average river cross-section on the studied section was calculated using the arithmetic mean of the wet perimeter length of several locations reviewed. Since the minimum environmental flow is the main concern, therefore the first inflection point is then considered as the minimum environmental flow. An analytical approach done by [12] was also used to define a minimum environmental flow, which then will be compared with the environmental flow values provided by the inflection point of the wetted perimeter-discharge graphs.

As the comparison approach against the P-Q method, time series discharge data on both upstream and downstream sites was collected from local water resources institution. The data was then analysed using magnitude-frequency approach based on the method introduced by [12]. The method is basically based on Lane's balance equations:

$$SD^1 B^{\frac{2}{3}} :: Q^{\frac{5}{3}} i^{\frac{5}{3}} \tag{1}$$

in case of mean bed material diameter (D), river width (B) and river gradient (i) are assumed to be constant, then sediment rate (S) will be proportional to discharge and its frequency of occurrence (F).

$$S :: F_i Q^{\frac{5}{3}} \tag{2}$$

Using the equation (2), a minimum discharge for both upstream and downstream of the concerned river reach were determined. The values were then provided based on the climb part of the graph as relation between equation (2) and the discharge (Q). The beginning part of the climbing graph, near the initiation of motion point, is the targeted point.

Mesoscale of Sekampung River, particularly on its middle reach, was chosen as the study area. The chosen river reach is considered as the important part since on this river reach, most community activities are connected to the river environment. The discharge data utilized for the E-flow analysis were collated from the discharge measurement stations situated at Pagelaran and Argoguruh, representing the upstream and downstream sites, respectively. The measurement was conducted by the river basin authority of the Sekampung River. To obtain a seasonal pattern of the river in its natural state, river discharge data from 3,070 days over a ten-year period (2011-2020) were selected. Field measurements were performed to determine the cross section of the river at both upstream and downstream sites and the wetted perimeter of the concerned river sites as well. Measurements were also conducted to record a long sections profile of the mesoscale reach. Mesoscale of the river reach was the main concern since the reach has a prominent role to provide water resources support for number of purposes, mainly for irrigation, along the Sekampung River [12, 15].

In order to ascertain the quantity of environmental flow within the section situated between the upper and lower boundaries of the study area, the Average Reciprocal Distance (ARD) approach was employed. The ARD is the median of the inverse distances from the focal site to both upstream and downstream sites within the concerned river reach. The ARD employs a weighted inverse distance calculation, wherein the distances are weighted inversely in relation to one another. The ARD formula employed in the present study is as follows [29, 30]:

$$EF_x = \frac{\sum_{i=1}^{n}\left(\frac{EF_i}{D_i}\right)}{\sum_{i=1}^{n}\left(\frac{1}{D_i}\right)} \tag{3}$$

where *Di* is the distance between the concerned site with other boundaries sites, and the *i*th nearest defined EF sites. *EFx* is the estimated value of the missing *EF, EFi* is the value of EF at i-th nearest boundary sites, and n is the number of the nearest boundary sites. The research area in which this work was conducted is situated on the middle reach of the Sekampung River, as illustrated in Figure 1.

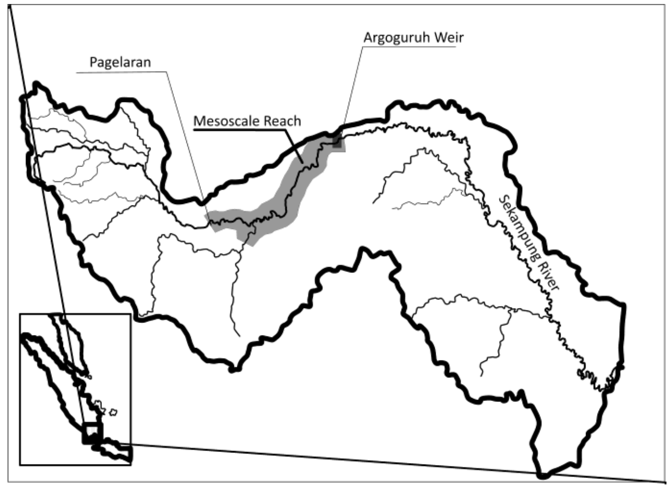


Figure 1 Mesoscale of Middle Reach Sekampung River

3.0 RESULTS AND DISCUSSION

The middle reaches of a river play an important role in the development and management of water resources in a river basin. Water resources are fundamental resources that support people's lives and economic activities, and sustainable development of these resources is paramount. In most regions, the middle reaches of rivers are critical areas where water management challenges and priorities must be managed comprehensibly. It is crucial to examine the significance of the river middle reach in the context of water resources development, emphasizing its distinctive characteristics, pivotal considerations, and the implications for effective water resources management.

The middle reach of a river often represents a transitional region between the upstream and downstream areas, where the dynamics of water quantity, quality, and competing uses become particularly multifactorial and complex [31]. This region is typically characterized by a higher population density, extensive agricultural activities, and growing industrial and urban water demands. The middle reach is where the impacts of upstream water use, such as irrigation and hydropower, become more pronounced, while the downstream water requirements for domestic, industrial, and environmental needs also take precedence [32]. Accordingly, the middle reach of the river is regarded as a crucial area for the management of both fluctuating water requirements and the evolving dynamics of water user needs and available water sources.

With regard to the longitudinal slope of the Sekampung stream, it has been established that the upstream section of the river exhibits a slope of approximately 0.0024, or 0.24%, while the middle section of the river displays a slope range of 0.0009 to 0.001, or 0.09% to 0.1%. This information is illustrated in Figure 2. A square mark in Figure 2 indicates a river reach with the most typical characteristics, which was selected as the mesoscale boundaries for this study.

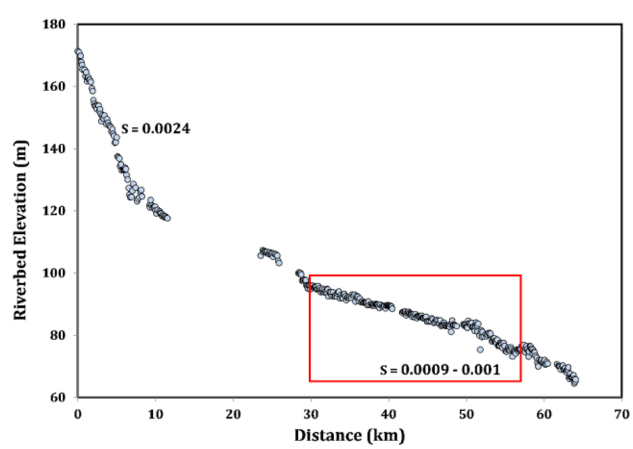


Figure 2 Longitudinal profile of Sekampung River

This area, a relatively mild slope, is primarily used for agricultural activities. The river corridor in this reach is mainly occupied by rice farms and seasonal farms cultivating crops such as corn, beans, and vegetables.

In order to ensure the sustainability of the riverine ecosystem, it is imperative that a comprehensive stream management policy be implemented to ensure the continuous existence of water along the river reach, thus enabling the continuity of various community activities. Besides, the river reach has its main function as the conveyance river carrying water released from the Batutegi reservoir, as an upstream part, to the Argoguruh weir as the regulator structure at the downstream part of the reach. As the Argoguruh barrage supports more than forty thousand acres irrigation area, ensuring the existence of required water for irrigation is very important.

In accordance with the wetted perimeter methodology, a wetted perimeter of 22 meters in length has been delineated for the downstream site of the river reach situated at Argoguruh. The value was found to correspond to a minimum environmental flow of 3.6 m³/s, which is evidenced by its inflection point on the wetted perimeter-discharge graph [15, 33, 34]. Furthermore, it can be stated that there is a 95% probability of a river flow of 4.5 m³/s, which represents the minimum discharge that must be considered in Argoguruh as a downstream site of the river reach. Meanwhile, at the upstream boundary of the specified reach, a minimum E-flow of 2.8 m³/s is observed at Pagelaran. Furthermore, the minimum environmental flow was determined based on the inflection point on the wetted perimeter-discharge (P-Q) graph. The 2.8 m³/s discharge on the Pagelaran corresponds with 17.49 m length of the wetted perimeter. Comparison between P-Q graph of upstream and downstream site is presented in Figure 3.

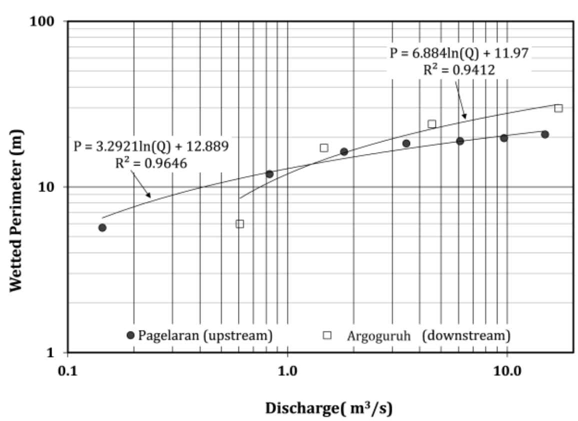


Figure 3 Wetted perimeter on mesoscale of Sekampung River

Concerning the graph on Figure 3, it can be seen that there is similar type of logarithmic data of both P-Q graphs. Upstream site, which is sited at Pagelaran, provides the P-Q trend that can be described as:

$$P = 3.2921Ln(Q) + 12.889 \tag{4}$$

with the correlation coefficient (R^2) of 0.965

Meanwhile, for the downstream site, which is located at the Argoguruh, the P-Q graph of its site can be described as:

$$P = 6.884Ln(Q) + 11.97 \tag{5}$$

with the correlation coefficient (R^2) of 0.9412

The inflection point of those two data is just about shifting to the greater value (to the right side) as the observation site also shifting from the upstream to the downstream side. The phenomenon is obvious since the discharge of the river is also increased to downstream direction. What must be concerned is how the environmental condition along the concerned reach will be able to be supported by the managed river discharge.

Environmental analysis using an analytical approach called water-sediment method (equation 2) was also used to analyze environmental for both upstream and downstream site of the mesoscale boundaries. The results indicate that the estimated minimum E-flow at Argoguruh is 3.6 m³/s. Meanwhile, at the upstream boundary, the relation between water and sediment method was utilized to determine an environmental flow rate of 2.5 m³/s.

Based on the ARD formula (Equation 3), the environmental discharge at the site of a new dam called Sekampung Dam was calculated. The main building of the dam is located 5.2 km away from the upper boundary of the river section considered in this research. Meanwhile, the distance from Argoguruh as the lower boundary of the studied river reaches is 47.3 km. Considering the distance and EF at Pagelaran and Argoguruh as the upper and lower reach's limits, respectively, the EF at the new dam site, based on ARD formula, is about 2.6 m³/s. This value must be considered for a minimum E-flow on the operating rules of the proposed reservoir management. Minimum environmental discharge is particularly important during the dry season and at the end of the rice growing season in the Sekampung irrigation area. During this period, water is released from the reservoir at the minimum capacity. It is therefore essential to ensure that the minimum E-flow is conveyed downstream of the dam in order to maintain the river's carrying capacity in a sustainable manner and to support the long-term ecological sustainability and biodiversity of the downstream section of the affected river reach.

4.0 CONCLUSION

As a conclusion, it is clearly described that, mesoscale perspective must be considered to provide reliable E-Flow in the concerned, particularly, middle river reach. The E-flow ideally should be increasing along the downstream direction of the river since water's discharge of the river will also increase. However, interaction between water use and river dynamics within the mesoscale region must be carefully studied in order to have an integrated decision for both the water user and the river environment. As presented in this paper that E-flow at middle reach of the Sekampung river increases for about 40% (about 1.0 m³/s) at the downstream site compared to the upstream one. The environmental flow was in the range of 2.5 to 3.6 m³/s within the studied mesoscale river's reach. It is necessary to ensure the environmentally sound development of water resources along the concerned river reach. Using ARD approach, it was provided EF of 2.6 m^3/s must be provided at the new Sekampung Dam site, 5.2 km away from the upstream boundary site. The implementation of water resource management policies with a meso-scale approach in river basins in an integrated manner requires identification of water resources and needs, preparation of management plans involving the participation of various stakeholders, and implementation of regulations and education programs to support sustainability. In addition, periodic monitoring and evaluation are also needed to adjust policies, with an ecosystem-based approach through environmental restoration and conservation. A further challenge is how this tool could also be useful for preparation due to unpredictable climate change.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

References

[1] Acreman MC, Dunbar MJ, Acreman M. 2024. Defining environmental river flow requirements : a review. *Hydrology and Earth System Sciences Discussions*, https://hal.archives-ouvertes.fr/hal-00304968 (accessed October 20, 2024).

[2] Dunbar M, Alfredsen K, Harby A. 2024. Hydraulic-habitat modelling for setting environmental river flow needs for salmonids. *Wiley Online Library*, https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2400.2011.00825.x (accessed October 20, 2024).

[3] Boodoo KS, McClain ME, Vélez Upegui JJ, Ocampo López, Olga Lucia. 2014. Impacts of implementation of Colombian environmental flow methodologies on the flow regime and hydropower production of the Chinchiná River, Colombia. *Ecohydrology Hydrobiology*, 14(4): 267–284, DOI: 10.1016/j.ecohyd.2014.07.001.

[4] Acreman M, Dunbar MJ. 2024. Defining environmental river flow requirements-a review. *Hydrology and Earth System Sciences*, 8(5): 861–876.

[5] Wei Q, Xue L, Liao S, Liu Y. 2024. Ecohydrological indicators and environmental flow assessment in the middle and lower reaches of the Huai River, China. *Science of the Total Environment*, 940: 173639, DOI: 10.1016/j.scitotenv.2024.173639.

[6] Beilfuss R, Brown C. 2010. Assessing environmental flow requirements and trade-offs for the lower Zambezi river and delta, Mozambique. *International Journal River Basin Management*, 8(2): 127–138, DOI: 10.1080/15715121003714837.

[7] King JM, Tharme RE and de Villiers MS. *Environmental Flow Assessments for Rivers : Manual for the Building Block Methodology*, 2010. Cape Town, Republic of South Africa. Water Research Commission, 64.

[8] Mehmood K, Tischbein B, Mahmood R, Borgemeister C, Flörke M, Akhtar F. 2024. Analysing and evaluating environmental flows through hydrological methods in the regulated Indus River Basin. *Ecohydrology*, 17(4): 1–19, DOI: 10.1002/eco.2624.

[9] King J, Brown C, Sabet H. A. 2003. Scenario-Based Holistic Approach to Environmental Flow Assessments for Rivers. *River Research and Applications*, 19(5-6): 619–639. DOI: 10.1002/rra.709.

[10] Khwairakpam E. 2024. Environmental Flow Estimation in Nambul River, Northeast India Through PHABSIM. *Egyptian Journal of Aquatic Biology and Fisheries*, 28(1): 209–221, DOI: 10.21608/ejabf.2024.337353.

[11] Schlüter M, Khasankhanova G, Talskikh V, Taryannikova R, Agaltseva N, Joldasova I, Ibragimov R, Abdullaev U. 2013. Enhancing resilience to water flow uncertainty by integrating environmental flows into water management in the Amudarya River, Central Asia. *Global and Planetary Change*, 110(A): 114–129, DOI: 10.1016/j.gloplacha.2013.05.007.

[12] Wahono E.P, Legono D, Istiarto, Yulistiyanto, B. 2014. Environmental Flow Assessment Using Water-Sediment Approach at the Sekampung River , Indonesia. *Open Journal of Modern Hydrology*, 4(4): 164–172, DOI: 10.4236/ojmh.2014.44016.

[13] Dunbar MJ, Alfredsen K, Harby A. 2012. Hydraulic-habitat modelling for setting environmental river flow needs for salmonids. *Fisheries Management and Ecology,* 19(6): 500–517, DOI: 10.1111/j.1365-2400.2011.00825.x

[14] Poff NLR, Tharme RE, Arthington AH. *Evolution of Environmental Flows Assessment Science, Principles, and Methodologies*. Water for the Environment: From Policy and Science to Implementation and Management, 2017. Singapore. Academic Press, 203-236, ISBN 9780128039076, DOI: 10.1016/B978-0-12-803907-6.00011-5.

[15] Wahono EP, Chrisandini, Legono D. 2021. Environmental flow assessment of Kayan River: Managing sustainability indicator of hydropower project. *IOP Conference Series: Earth and Environmental Science*, 930: 012073, DOI: 10.1088/1755-1315/930/1/012073.

[16] Zhang J, Xu L, Yu B, Li X. 2014. Environmentally feasible potential for hydropower development regarding environmental constraints. *Energy Policy*, 73: 552–562, DOI: 10.1016/j.enpol.2014.04.040.

[17] Belmar O, Velasco J, Martinez-Capel F. 2011. Hydrological Classification of Natural Flow Regimes to Support Environmental Flow Assessments in Intensively Regulated Mediterranean Rivers, Segura River Basin (Spain). *Journal of Environmental Management,* 47(5): 992–1004, DOI: 10.1007/s00267-011-9661-0.

[18] Mahmood R, Jia S, Lv A, Naeem, Shahid. 2024. Environmental flow assessment, evaluation, and suggestions for dying riverine ecosystem of the transboundary Amudarya River, Central Asia. *Ecological Indicators*, 158: 111419, DOI: 10.1016/j.ecolind.2023.111419.

[19] Mahdi S, Manizheh J, Bithin D. 2023. Evaluating Minimum Environmental Flow Requirements in Rivers: A Combined Decision-Tree Approach Integrating Hydrological, Physical Habitat, and Water Quality Indexes. *Journal of Sustainable Water in the Built Environment*, 9: 4023006, DOI: 10.1016/j.ecolind.2023.111419.

[20] Liu X, Song H, Ren Y, Yu M, Liu Y, Wang D, Xia F, Tang C, Tian L, Dong W, He J, Fu T. 2024. Ecological environmental flow estimation for rivers with complicated hydraulic conditions. *Water Science and Technology*, 89(2): 357–367. DOI: 10.2166/wst.2023.412.

[21] Liu S, Zhang Q, Xie Y, Xu P, Du H. 2023. Evaluation of Minimum and Suitable Ecological Flows of an Inland Basin in China Considering Hydrological Variation. *Water (Switzerland)*, 15(4): 1–19, DOI:10.3390/w15040649.

[22] García-Barreras E, Martínez-Fernández V, García de Jalón D. 2023. Long-term Macrobentos Responses to Environmental Flows and Water Quality improvement along River Jarama. *Ecohydrology & Hydrobiology*, 23(2): 304–315, DOI: 10.1016/j.ecohyd.2022.12.009.

[23] Wahono EP, Djausal A, Mariyanto, Winarno DJ. 2003. *River Maintenance Plan For Sekampung River*. 58.Lampung. GGWRM

[24] Newson MD, Newson CL. 2000. Geomorphology, ecology and river channel habitat: mesoscale approaches to basin-scale challenges. *Progress in Physical Geography*, 24(2): 95–17, DOI: 10.1191/030913300760564724.

[25] Farò D, Baumgartner K, Vezza P, Zolezzi G. 2022. A novel unsupervised method for assessing mesoscale river habitat structure and suitability from 2D hydraulic models in gravel-bed rivers. *Ecohydrology*, 15(7): 1–18, DOI: 10.1002/eco.2452.

[26] Frissell CA, Liss WJ, Warren CE, Hurley, MD. A. 1986. Hierarchical Framework for Stream Habitat Classification : Viewing Streams in a Watershed Context. *Environmental Management*, 10(2): 199-214.

[27] Gippel CJ, Stewardson MJ. 1998. Use of Wetted Perimeter in defining Minimum Environmental Flows. *Regulated Rivers: Research and Management*, 14: 53–67.

[28] Liu C, Zhao C, Xia J, Sun C, Wang R, Liu T, 2011. An instream ecological flow method for data-scarce regulated rivers. *Journal of Hydrology*, 398: 17–25, DOI: 10.1016/j.jhydrol.2010.11.026.

[29] Sattari MT, Rezazadeh-Joudi A, Kusiak A. 2017. Assessment of different methods for estimation of missing data in precipitation studies. *Hydrology Research*, 48(4): 1032–1044, DOI: 10.2166/nh.2016.364.

[30] Kabo F. 2022. Overcoming the liability of distance? An exploratory study of the associations between social networks, sense of community and spatial colocation". J*ournal of Corporate Real Estate*, 24(4): 273–289, DOI: 10.1108/JCRE-10-2020-0055.

[31] Torabi Haghighi A, Fazel N, Hekmatzadeh AA, Klöve, Björn. 2018. Analysis of Effective Environmental Flow Release Strategies for Lake Urmia Restoration. *Water Resources Management*, 32(11): 3595–3609, DOI: 10.1007/s11269-018-2008-3.

[32] Wang D, Jia Y, Niu C, Yan X, Hao C. 2024. A multiple criteria decision-making approach for water allocation of environmental flows considering the value trade-offs - A case study of Fen River in China. *Science of the Total Environment*, 912: 169588, DOI: 10.1016/j.scitotenv.2023.169588

[33] Meng, C. F., Song, X. Y., Liu, X. Y., Zhao, W. J., Wang, Y., Ye, B.X., Guo, S. X. 2022. The Minimum Environmental Flow of Polluted Rivers in Areas Lacking Ecological Data–a Case Study of a Heavily Polluted River in the Upper Hai River, China. *Applied Ecology and Environmental Research*, 20(6): 5023–5041. DOI: 10.15666/aeer/2006_50235041.

[34] Vietz GJ, Lintern A, Webb JA. 2018. River Bank Erosion and the Influence of Environmental Flow Management. *Environmental Management*, 61,(3): 454–468, DOI: 10.1007/s00267-017-0857-9