

Research Article

# Spatial Analysis for Prioritizing Flood Inundation Mitigation Using the Topographic Wetness Index: A Case Study of Pangkal Pinang City

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## ABSTRACT

Flooding is a recurring environmental challenge in Pangkal Pinang City, influenced by both natural topographic conditions and increasingly intensive land use changes. This study aims to assess spatial flood risk using the Topographic Wetness Index (TWI) as a hydrological indicator derived from Digital Elevation Model (DEM) data. Through slope and flow accumulation analysis, TWI values were calculated and classified using the equal interval method into five classes: very low, low, medium, high, and very high. The results show that the majority of the area falls into the very low and low categories, indicating good drainage conditions. However, localized zones of high and very high TWI values were identified in Bukit Intan, Gabek, and Rangkui sub-districts. In Bukit Intan, high flood susceptibility is linked to large-scale land clearing for industrial areas, residential expansion, and fish ponds. In Gabek, extensive deforestation for new settlements contributes to increasing flood risks. Meanwhile, in Rangkui, the accumulation of water is exacerbated by the density of existing built-up areas and insufficient drainage infrastructure. These findings highlight the relevance of TWI as a spatial analysis tool to support urban flood mitigation planning, especially in areas undergoing rapid land conversion. The study emphasizes the need to integrate topographic analysis into urban development policies to ensure flood-resilient growth.

**Keywords:** Topographic Wetness Index; Flood Risk; Spatial Analysis; Pangkal Pinang

## 1. INTRODUCTION

Flooding is one of the deadliest and most costly natural disasters worldwide, with its frequency increasing due to a combination of extreme rainfall and other contributing factors such as storm surges (Fang et al. 2021; Harrigan et al. 2023). The interaction between Indonesia's abundant rainfall and its physical environmental conditions contributes to the frequent occurrence of floods across the country (Fitra et al. 2024). Studies have also shown that the impacts of this disaster can be exacerbated by human activities, such as urbanization and unsustainable land management, which reduce the capacity of ecosystems to absorb water and regulate river flow (Gao et al. 2020; Jiang et al. 2022). According to data from the National Disaster Management Agency (BNPB), Indonesia experienced 8,143 flood events between 2014 and 2023 (BNPB, 2024). Flooding is a complex hydrological phenomenon significantly influenced by soil characteristics, particularly soil moisture and texture. Flood events are shaped by multiple interrelated factors, including topography, hydrometeorology, geology, soil properties, and human activities (Afsari et al. 2022; Safiah Yusmah et al. 2020; Yamamoto, et al. 2021).

Topographic factors play a crucial role in flood dynamics (Aziza et al. 2021). Slope and landform shape can influence the flow and accumulation of water during rainfall events (Al Fauzi 2022). For instance, steep slopes can cause rapid runoff, thereby increasing the likelihood of flash floods, whereas flatter areas may experience prolonged flooding due to slower drainage (Amaliah & Syabandi 2023; Basri et al. 2022). Additionally, the configuration of river networks and their capacity to convey runoff are critical factors in determining flood severity (Basri et al. 2022; Gabriels et al. 2020). The Topographic Wetness Index (TWI) is a crucial metric in hydrology that quantifies how topography influences the accumulation and movement of water across the landscape (Fatah et al. 2022; Khumaeroh & Sari 2024; Wardana 2024). TWI serves as a fundamental tool in hydrology, providing insights into the interaction between topography and hydrological processes. This method enables the cartographic representation of the spatial distribution of hydrological conditions (Fitra et al. 2024).

The utilization of Digital Elevation Model (DEM) data in assessing the Topographic Wetness Index (TWI) is a vital aspect of hydrological modeling and landscape analysis. TWI is essential for understanding how water moves across the

landscape, particularly in predicting areas vulnerable to flooding (Gao et al. 2021; Maina et al. 2022). Conducting TWI analysis using high-resolution DEM enhances the spatial accuracy of flood risk assessment, thereby enabling more precise decision-making in flood management and mitigation strategies (Astagneau et al. 2021; Jafarzadegan et al. 2021). The results of TWI analysis can provide valuable information on flood potential, which can be utilized to raise awareness for disaster preparedness as part of disaster risk reduction efforts (Vignesh et al. 2021).

This case study was conducted in Pangkalpinang City, located in the Bangka Belitung Islands Province, which experiences periodic flood inundation. According to a study on flood vulnerability in Pangkalpinang City, spatial analysis using overlay methods and the Analytic Hierarchy Process (AHP) revealed that most areas exhibit moderate to high flood vulnerability, with land use being the dominant factor contributing approximately 40% to this vulnerability (Fitriansyah et al. 2024). The primary objective of this study is to evaluate the effectiveness and reliability of the Topographic Wetness Index (TWI) in assessing flood vulnerability levels. Additionally, the study aims to identify priority areas for flood management in Pangkalpinang City. Flood hazard mapping is a crucial geographical application for managing environmental disasters, especially in tropical regions where flood risks are exacerbated by climatic factors and human activities (Vignesh et al. 2021). The expected outcomes of the TWI analysis are intended to serve as a basis for stakeholder decision-making and proactive actions during flood events in Pangkalpinang City.

## 2. RESEARCH METHOD

This study was conducted using a quantitative approach with data analysis employing the Topographic Wetness Index (TWI) method. High TWI values indicate areas prone to water accumulation due to supportive topography, suggesting a higher potential for flooding. The relationship between TWI and flood risk has been demonstrated in various scientific studies linking topography with hydrological response (Halabisky et al. 2023; Larson et al. 2022). This method utilizes raster data derived from DEM, which is then converted into slope information through spatial analysis tools. Subsequently, flow accumulation is analyzed using Watershed Delineation Tools (WDT) (Miardini & Saragih 2019). High flow accumulation values indicate greater volumes of water accumulated in the respective cells (Vignesh et al. 2021). Beven and Kirby (1979), as cited in Hojati & Mokarram (2016), proposed the primary formula used in the calculation of TWI as follows:

$$TWI: \ln (\alpha / \tan \beta)$$

Where:

$\alpha$ : Flow accumulation

$\beta$ : Slope steepness

The application of the Topographic Wetness Index (TWI) in urban flood risk analysis is highly significant. TWI enables the assessment of how urban topography influences water movement and accumulation, which is crucial for predicting flood scenarios. Studies have shown that urban catchment areas with varying topographic indices, including TWI, exhibit different drainage and flooding behaviors due to their unique hydrological connectivity patterns (Fatone et al. 2021; Zhou et al. 2022). The role of Digital Elevation Model (DEM) in calculating the Topographic Wetness Index (TWI) cannot be underestimated, as the accuracy of DEM directly affects the TWI results. High-resolution DEM provides more detailed terrain information, enabling more precise assessments of hydrological processes. Studies indicate that low-resolution DEMs inadequately represent flood inundation areas, underscoring the importance of high-resolution data in both TWI calculations and urban flood modeling (Almagro et al. 2021; Jafarzadegan et al. 2021; Weber et al. 2021).

In this approach, the range of TWI values is divided into five equal-sized intervals between the minimum and maximum values in the dataset. The method ensures that each class spans an equal range of TWI values, regardless of how many data points fall within each interval (Ma'rifah et al. 2024). The method used for classification of TWI as follows:

$$\text{Class Interval} = \frac{\text{Maximum Value} - \text{Minimum Value}}{\text{Number of Classes}}$$

Where:

The number of classes are set by 5.

## 3. RESULTS AND DISCUSSION

### 3.1 Topography Wetness Index

The results of the Topographic Wetness Index (TWI) analysis reveal a significant spatial distribution of flood-prone areas in several parts of Pangkal Pinang City, particularly in Bukit Intan, Gabek, and Rangkui sub-districts. The TWI map indicates that areas with high TWI values, which represent zones with greater potential for water accumulation due to favorable topographic conditions are predominantly located in regions that have experienced substantial land cover changes. In Bukit Intan, the high flood risk is primarily attributed to extensive land clearing for industrial zones, residential developments, and fish pond construction. These activities have significantly reduced natural vegetation cover and diminished the land's ability to absorb rainfall, leading to increased surface runoff (Khoirunisa 2023).

In Gabek, high TWI values are observed in areas that have undergone major deforestation for the establishment of new residential zones. The absence of sufficient drainage infrastructure in these rapidly urbanized zones further exacerbates flood vulnerability (Khoirunisa 2023). Meanwhile, in Rangkui, flood-prone zones are concentrated in long-established residential areas, suggesting that inadequate urban drainage systems continue to limit the area's capacity to handle heavy rainfall events. This indicates that even older urbanized areas remain susceptible to flooding without proper water management infrastructure (Ma'rufah et al. 2024). These findings emphasize the critical role of topographic analysis in urban planning, particularly for identifying priority areas for flood mitigation interventions. The use of TWI proves to be a valuable geospatial tool in assessing flood risk, offering essential insights that can inform climate adaptation strategies and disaster risk governance in urban environments.

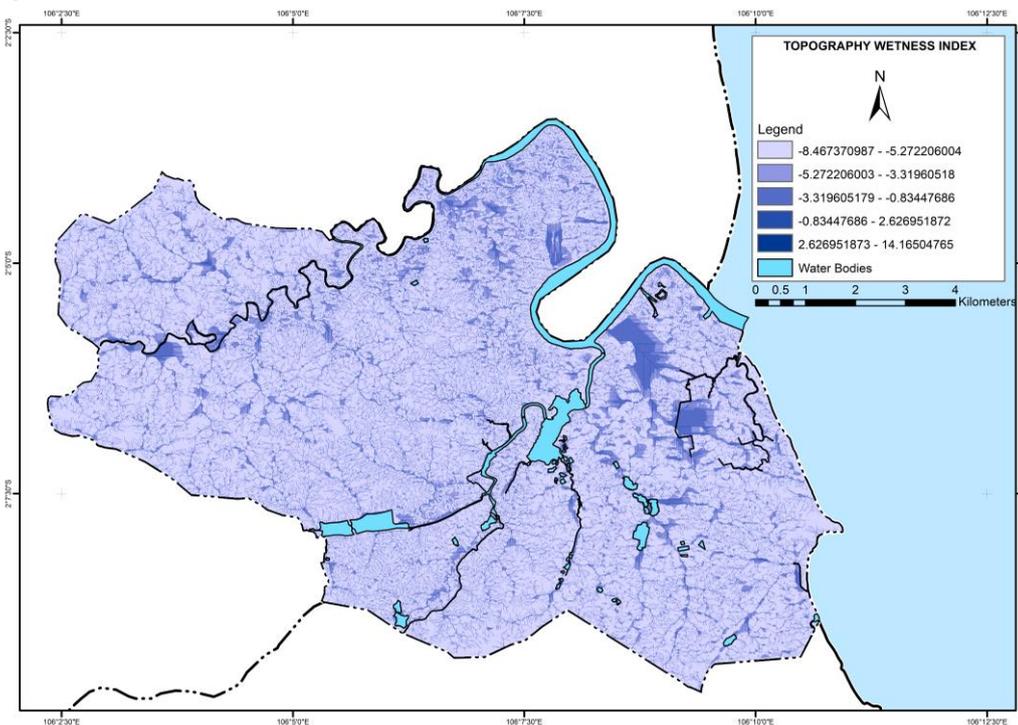


Figure 1. Topography Wetness Index in Pangkal Pinang

### 3.2 Topography Wetness Index Interpretation

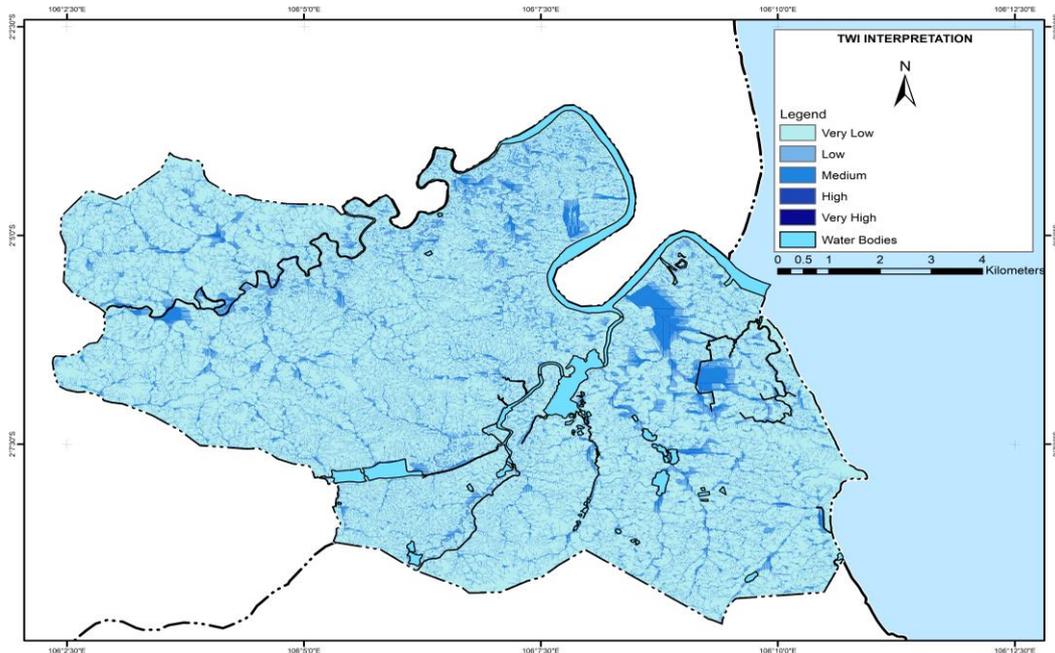
In this study, the classification of the Topographic Wetness Index (TWI) was conducted using the class interval method, which divides the entire range of TWI values into five equal classes: very low, low, medium, high, and very high. This method enables a straightforward interpretation of flood susceptibility levels based on the accumulation and flow potential of surface water. The resulting TWI classification provides a spatial understanding of flood risk distribution in Pangkal Pinang City. Areas classified under "very low" and "low" categories are generally characterized by higher elevation or steeper slopes, which support rapid surface runoff and limited water retention. On the other hand, areas in the "medium" to "very high" categories are predominantly found in lower-lying, flatter regions, where water tends to accumulate due to limited drainage capacity and topographic convergence. These classifications serve as a foundation for identifying priority zones for flood risk mitigation and urban drainage improvement (Ma'rufah et al. 2024).

Table 1. Classification for Topography Wetness Index in Pangkal Pinang

TWI Classification	Area (Ha)
Very Low	7056.75
Low	2290.53
Medium	563.16
High	57.23
Very High	0.43

The classification table of the Topographic Wetness Index (TWI) in Pangkal Pinang presents a detailed distribution of flood susceptibility based on five categories: very low, low, medium, high, and very high. According to the analysis, the majority of the area falls under the "very low" TWI class, covering approximately 7056.75 hectares. This suggests that a

significant portion of the city's landscape consists of elevated or well-drained areas with minimal potential for water accumulation (Ullah et al. 2024). The “low” category encompasses 2290.53 hectares, indicating areas with moderate slopes that still allow for relatively efficient drainage. Meanwhile, the “medium” class, with a coverage of 563.16 hectares, represents transitional zones where moderate water retention may occur, especially in areas with flat terrain or partial land cover alteration (Mukhtar et al. 2024). Notably, the “high” and “very high” classes, though covering only 57.23 hectares and 0.43 hectares respectively, are critical as they represent locations with the highest flood vulnerability due to topographic convergence and potential water stagnation (Mukhtar et al. 2024). These high-risk zones are particularly important for targeted intervention, as they are often found in lowland areas with dense land use changes, such as settlements or deforested lands. The relatively small extent of the high and very high classes emphasizes the importance of micro-scale flood mitigation strategies in localized, yet high-impact areas. This distribution pattern highlights the pressing need for land use control and effective urban drainage planning in specific zones, especially where development activities intersect with flood-prone topography.



**Figure 2.** Interpretation for Topography Wetness Index in Pangkal Pinang

### 3.3 Topography Wetness Index Interpretation on Settlement Area

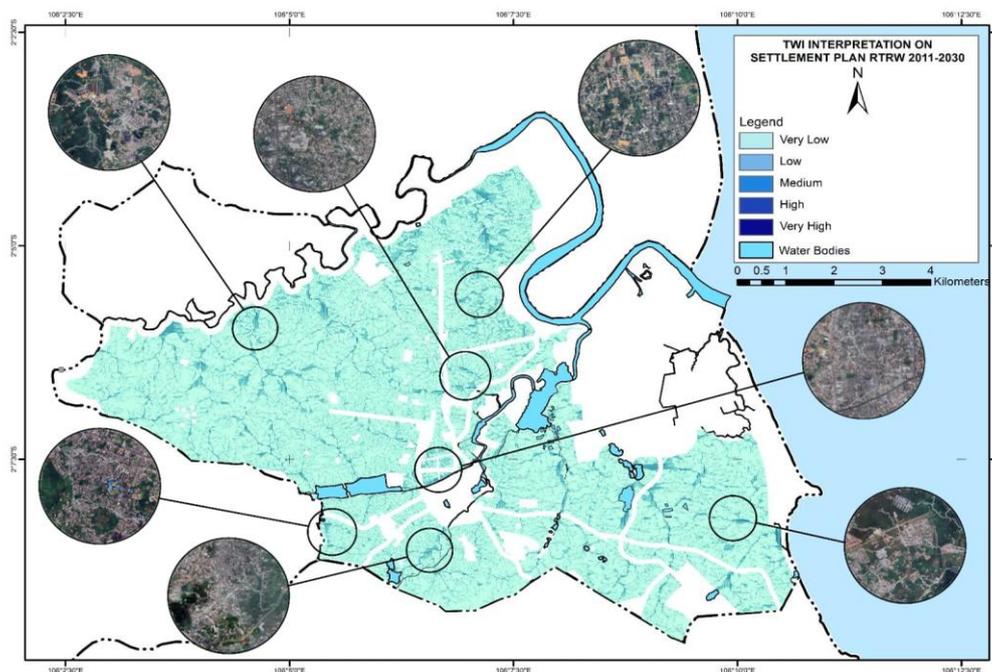
The interpretation of the Topography Wetness Index (TWI) as applied to settlement areas, serving as a critical indicator for assessing soil moisture potential and the risk of flooding or waterlogging. This analysis offers valuable insights into the spatial distribution of wetness conditions across residential zones, which is essential for informed urban planning and flood risk mitigation. By mapping the varying degrees of wetness through TWI values, vulnerable areas prone to water accumulation can be identified, thereby guiding effective drainage management and sustainable development strategies to minimize flood impacts in settlements.

**Table 2.** Classification for Topography Wetness Index in Pangkal Pinang’s Settlement

TWI Classification on Settlement	Area (Ha)
Very Low	4116.21
Low	1263.51
Medium	234.88
High	28.42
Very High	0.12

The classification of flood vulnerability in settlement areas, based on Table 2, reveals that while most residential zones fall under very low and low Topography Wetness Index (TWI) categories with 4116.21 hectares and 1263.51 hectares respectively, indicating generally well-drained conditions. The areas with medium, high, and very high TWI values that have area from 234.88 hectares, 28.42 hectares, and 0.12 hectares are predominantly concentrated in the subdistricts of

Bukit Intan, Gabek, and Rangkui. In Bukit Intan, the high susceptibility to flooding is largely attributed to extensive land clearing activities for industrial development, residential expansion, and the creation of fish ponds, which drastically alter the natural hydrological processes and increase surface runoff. Gabek faces similar challenges, where widespread deforestation for new settlements has compromised the land's ability to absorb water, thus elevating its flood risk. Meanwhile, in Rangkui, the dense existing built-up areas combined with inadequate drainage infrastructure exacerbate water accumulation during heavy rainfall events. These localized conditions emphasize the effectiveness and relevance of the Topography Wetness Index as a spatial analysis tool to identify flood-prone settlements, especially in regions undergoing rapid land use conversion. The study underscores the necessity for urban planning policies that integrate topographic and hydrological analyses to promote flood-resilient growth, prioritize the improvement of drainage systems, and mitigate flood risks in these vulnerable subdistricts.



**Figure 3.** Interpretation for Topography Wetness Index in Pangkal Pinang's Settlement Plan RTRW 2011-2030

#### 4. CONCLUSION

The Topographic Wetness Index (TWI) analysis effectively highlights the spatial distribution of flood-prone areas in Pangkal Pinang City, with varying degrees of susceptibility classified using the equal interval method. The largest portion of land falls within the very low and low categories, indicating that much of the city benefits from topographic conditions that facilitate rapid drainage and minimal water accumulation. However, the presence of medium, high, and very high classes, although covering smaller areas, is of particular concern. These zones are located in low-lying, relatively flat regions and are often associated with areas experiencing rapid land use changes such as settlements, industrial developments, and deforestation for new settlement. Therefore, the results underline the importance of integrating TWI-based spatial analysis into urban planning and disaster risk reduction strategies. Urban zones such as Bukit Intan, Gabek, and Rangkui require immediate attention, as they exhibit concentrated high TWI values due to unregulated land development and insufficient drainage infrastructure. The application of TWI provides a cost-effective and data-driven approach to identifying critical areas for flood mitigation efforts. Future development in Pangkal Pinang should adopt a more precautionary framework by considering TWI findings in zoning regulations, infrastructure design, and land conversion policies. These measures are crucial for enhancing the city's resilience against recurring flood events and for ensuring that urban expansion does not compromise the natural hydrological balance.

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## REFERENCES

- Afsari, Rasoul, Saman Nadizadeh Shorabeh, Mostafa Kouhnavard, Mehdi Homaei, and Jamal Jokar Arsanjani. 2022. "A Spatial Decision Support Approach for Flood Vulnerability Analysis in Urban Areas: A Case Study of Tehran." *ISPRS International Journal of Geo-Information* 11(7).
- Almagro, André, Paulo Tarso Sanches de Oliveira, Antônio A. M. Neto, Tirthankar Roy, and P. A. Troch. 2021. "CABra: A Novel Large-Sample Dataset for Brazilian Catchments." *Hydrology and Earth System Sciences* 25(6):3105–35.
- Amaliah, Rizki, and Muh. A. Syabandi. 2023. "Analysis of Flood Susceptibility Using Frequency Ratio Method in Paremang Watershed." *Iop Conference Series Earth and Environmental Science* 1277(1):12017.
- Astagneau, Paul C., Guillaume Thirel, Olivier Delaigue, Joseph H. A. Guillaume, Juraj Párajka, Claudia Brauer, Alberto Viglione, Wouter Buytaert, and Keith Beven. 2021. "Technical Note: Hydrology Modelling R Packages – A Unified Analysis of Models and Practicalities From a User Perspective." *Hydrology and Earth System Sciences* 25(7):3937–73.
- Aziza, Sitty Nur, Lili Somantri, and Iwan Setiawan. 2021. "Analisis Pemetaan Tingkat Rawan Banjir Di Kecamatan Bontang Barat Kota Bontang Berbasis Sistem Informasi Geografis." *Jurnal Pendidikan Geografis Undiksha* 9(2):109–20.
- Basri, Hairul, Syakur Syakur, Azmeri Azmeri, and Eldina Fatimah. 2022. "Floods and Their Problems: Land Uses and Soil Types Perspectives." *Iop Conference Series Earth and Environmental Science* 951(1):12111.
- Fang, Jiayi, Thomas Wahl, Jian Fang, Xun Sun, Feng Kong, and Min Liu. 2021. "Compound Flood Potential From Storm Surge and Heavy Precipitation in Coastal China: Dependence, Drivers, and Impacts." *Hydrology and Earth System Sciences* 25(8):4403–16.
- Fatah, Kaiwan K., Yaseen T. Mustafa, and Imaddadin O. Hassan. 2022. "Flood Susceptibility Mapping Using an Analytic Hierarchy Process Model Based on Remote Sensing and GIS Approaches in Akre District, Kurdistan Region, Iraq." *Iraqi Geological Journal* 55(2C):121–49.
- Fatone, Francesco, Bartosz Szeląg, Adam Kiczko, Dariusz Majerek, Monika Majewska, Jakub Drewnowski, and Grzegorz Lagód. 2021. "Advanced Sensitivity Analysis of the Impact of the Temporal Distribution and Intensity of Rainfall on Hydrograph Parameters in Urban Catchments." *Hydrology and Earth System Sciences* 25(10):5493–5516.
- Al Fauzi, Rahmat. 2022. "Analisis Tingkat Kerawanan Banjir Kota Bogor Menggunakan Metode Overlay dan Scoring Berbasis Sistem Informasi Geografis." *Geomedia* 20(2):96–107.
- Fitra, Joni, Semangat Marudut Tua Debataraja, and Lismawaty. 2024. "Identification of Flood Vulnerability Using the Topographic Wetness Index Method in Pantai Labu Baru Village, Deli Serdang, North Sumatera" edited by M. R. Radiansyah, T. M. Wardiny, R. Noviyanti, E. N. Kusumaningrum, L. Warlina, Isfarudi, D. Nursantika, A. Fauziyiah, M. Permana, D. N. Hakiki, and W. Hidayat. *E3S Web of Conferences* 483:01014.
- Fitriansyah, Hadi, Fahri Setiawan, Muhammad Yusuf Caesar, and Haya Aqilah Maulidya. 2024. "Analisis Sebaran Kerawanan Banjir Menggunakan Metode Spatial Multi-Criteria Evaluation (SMCE) Di Kota Pangkalpinang." *Journal of Education, Humaniora and Social Sciences (JEHSS)* 7(2):797–809.
- Gabriels, Karen, Patrick Willems, and Jos V Orshoven. 2020. "A Data-Driven Analysis, and Its Limitations, of the Spatial Flood Archive of Flanders, Belgium to Assess the Impact of Soil Sealing on Flood Volume and Extent." *Plos One* 15(10):e0239583.
- Gao, Chao, Martijn J. Booij, and Yue-Ping Xu. 2020. "Assessment of Extreme Flows and Uncertainty Under Climate Change: Disentangling the Uncertainty Contribution of Representative Concentration Pathways, Global Climate Models and Internal Climate Variability." *Hydrology and Earth System Sciences* 24(6):3251–69.
- Gao, Yuan, Lili Yao, Ni-Bin Chang, and Dingbao Wang. 2021. "Diagnosis Toward Predicting Mean Annual Runoff in Ungauged Basins." *Hydrology and Earth System Sciences* 25(2):945–56.
- Halabisky, Meghan, Dan Miller, Anthony J. Stewart, Amy Yahnke, Daniel Lorigan, Tate Brasel, and L. M. Moskal. 2023. "The Wetland Intrinsic Potential Tool: Mapping Wetland Intrinsic Potential Through Machine Learning of Multi-Scale Remote Sensing Proxies of Wetland Indicators." *Hydrology and Earth System Sciences* 27(20):3687–99.
- Harrigan, Shaun, Ervin Zsótér, Hannah Cloke, Peter Salamon, and Christel Prudhomme. 2023. "Daily Ensemble River Discharge Reforecasts and Real-Time Forecasts From the Operational Global Flood Awareness System." *Hydrology and Earth System Sciences* 27(1):1–19.

- Hojati, Majid, and Marzieh Mokarram. 2016. "Determination of a Topographic Wetness Index Using High Resolution Digital Elevation Models." *European Journal of Geography* 7(4):41–52.
- Jafarzadegan, Keighobad, Peyman Abbaszadeh, and Hamid Moradkhani. 2021. "Sequential Data Assimilation for Real-Time Probabilistic Flood Inundation Mapping." *Hydrology and Earth System Sciences* 25(9):4995–5011.
- Jiang, Shijie, Emanuele Bevacqua, and Jakob Zscheischler. 2022. "River Flooding Mechanisms and Their Changes in Europe Revealed by Explainable Machine Learning." *Hydrology and Earth System Sciences* 26(24):6339–59.
- Khoirunisa, Risty. 2023. "Urban Flood And Its Correlation With Built-Up Area In Semarang, Indonesia." *Smart City* 3(2).
- Khumaeroh, Dinda N. F., and Dewi N. Sari. 2024. "Application of Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) in Flood Hazard Analysis in the Rawa Pening Sub-Watershed, Indonesia." *Iop Conference Series Earth and Environmental Science* 1314(1):12114.
- Larson, Johannes, William Lidberg, Anneli Ågren, and Hjalmar Laudon. 2022. "Predicting Soil Moisture Conditions Across a Heterogeneous Boreal Catchment Using Terrain Indices." *Hydrology and Earth System Sciences* 26(19):4837–51.
- Ma'rufah, Wahyuni, Ridwan Ridwan, and Muhammad Amin. 2024. "Deteksi Kerawanan Banjir Genangan Menggunakan Topographic Wetness Index (TWI) Di Sub Das Way Katibung." *Jurnal Agricultural Biosystem Engineering* 3(2):238.
- Maina, Fadji Z., Haruko Wainwright, P. J. Denny-Frank, and Erica R. Siirila-Woodburn. 2022. "On the Similarity of Hillslope Hydrologic Function: A Clustering Approach Based on Groundwater Changes." *Hydrology and Earth System Sciences* 26(14):3805–23.
- Miardini, Arina, and Grace Serepina Saragih. 2019. "Penentuan Prioritas Penanganan Banjir Genangan Berdasarkan Tingkat Kerawanan Menggunakan Topographic Wetness Index Studi Kasus Di DAS Solo." *Jurnal Ilmu Lingkungan* 17(1):113.
- Mukhtar, Muhammad Ahsan, Donghui Shangguan, Yongjian Ding, Muhammad Naveed Anjum, Abhishek Banerjee, Asim Qayyum Butt, Nilesh yadav, Da Li, Qin Yang, Amjad Ali Khan, Ali Muhammad, and Bei Bei He. 2024. "Integrated Flood Risk Assessment in Hunza-Nagar, Pakistan: Unifying Big Climate Data Analytics and Multi-Criteria Decision-Making with GIS." *Frontiers in Environmental Science* 12.
- Safiah Yusmah, M. Y., L. J. Bracken, Z. Sahdan, H. Norhaslina, M. D. Melasutra, A. Ghaffarianhoseini, S. Sumiliana, and A. S. Shereen Farisha. 2020. "Understanding Urban Flood Vulnerability and Resilience: A Case Study of Kuantan, Pahang, Malaysia." *Natural Hazards* 101(2):551–71.
- Ullah, Niamat, Aqil Tariq, Said Qasim, Sanauallah Panezai, Md. Galal Uddin, M. Abdullah-Al-Wadud, and Sajid Ullah. 2024. "Geospatial Analysis and AHP for Flood Risk Mapping in Quetta, Pakistan: A Tool for Disaster Management and Mitigation." *Applied Water Science* 14(11):236.
- Vignesh, K. S., I. Anandakumar, Rajeev Ranjan, and Debashree Borah. 2021. "Flood Vulnerability Assessment Using an Integrated Approach of Multi-Criteria Decision-Making Model and Geospatial Techniques." *Modeling Earth Systems and Environment* 7(2):767–81.
- Wardana, K. 2024. "Land Use Change Analysis and Remote Sensing-Based Spatial Evaluation in Kendal District, Indonesia in 2015 and 2020." *Iop Conference Series Earth and Environmental Science* 1357(1):12010.
- Weber, Michael, Franziska Koch, Matthias Bernhardt, and Karsten Schulz. 2021. "The Evaluation of the Potential of Global Data Products for Snow Hydrological Modelling in Ungauged High-Alpine Catchments." *Hydrology and Earth System Sciences* 25(5):2869–94.
- Yamamoto, Kodai, Takahiro Sayama, and Apip. 2021. "Impact of Climate Change on Flood Inundation in a Tropical River Basin in Indonesia." *Progress in Earth and Planetary Science* 8(1).
- Zhou, Leocadia, Dumisani S. Kori, Melusi Sibanda, and Kenneth Nhundu. 2022. "An Analysis of the Differences in Vulnerability to Climate Change: A Review of Rural and Urban Areas in South Africa." *Climate* 10(8):118.