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Hydrological Data Integration for Environmental Risk Assessment

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Abstract:
This study presents a systematic literature review aimed at integrating hydrological data into environmental risk assessment. The literature sources were obtained from Scopus, DOAJ, and Google Scholar, focusing on publications from the last 10 years. The discussed literature emphasizes the crucial role of hydrological data integration in enhancing the accuracy and quality of environmental risk assessments. The study details various proposed approaches, including a risk-based eco-hydrological approach, spatial geo-statistical techniques, the development of the meta-scientific-modeling (MSM) framework, automated assessment of local sensor networks, and the creation of web-based software platforms. The research findings illustrate the active efforts of researchers to find more effective and comprehensive ways of utilizing hydrological data in environmental risk evaluation. Each proposed approach has its strengths and limitations, with specific considerations related to data complexity, computational requirements, and analytical skills. In addition to highlighting the necessity of coordinated and integrated techniques to enhance future risk assessments, this study lays the groundwork for a thorough knowledge of the function that hydrological data integration plays in the context of environmental risk assessment.

Keywords: Hydrological Data; Environmental Risk Assessment; Data Integration.

1. Introduction

Hydrological data, encompassing rainfall, river flow, and groundwater levels, provides insights into water movement within an environment. Environmental risk assessment (ERA) systematically evaluates risks to ecosystems and human health from human activities. Integrating hydrological data into ERA offers a comprehensive understanding of environmental impacts by linking water dynamics with potential risks (Kaikkonen et al., 2021). This synergy enables deeper analysis of risks like floods or water quality degradation, supporting effective mitigation strategies and sustainable risk management for safeguarding ecosystems and human health. The relevance of hydrological data in understanding the water dynamics in the environment is crucial for identifying, analyzing, and detailing water-related processes that impact ecosystems (Brauman, 2015). Hydrological data provides critical information on the behavior of water flow, the hydrological cycle, and the interaction of water with other environmental elements (Cui et al., 2019). In this context, hydrological data enables a deeper understanding of changes in rainfall patterns, river flow, and groundwater distribution. This information is highly beneficial for designing sustainable water management strategies, mitigating flood risks, and comprehending the impacts of climate change on water resources. Additionally, hydrological data supports modeling and simulation to forecast future hydrological patterns, essential for spatial planning and overall environmental sustainability (Fatichi et al., 2016). By leveraging hydrological data, we can establish a robust knowledge foundation for the wise protection, management, and utilization of water resources.

Environmental risk assessment is a scientific methodology dedicated to identifying and assessing the potential of an activity or substance to pose a threat to the environment and living organisms. This practice involves recognizing hazards and risk factors, conducting an analysis and evaluation of the associated risks, and implementing suitable measures to control these risks (Larramendy & Liwszyc, 2023). In the context of marine environments, risk assessment focuses on characterizing both the exposure and effects of pollutants, considering future scenarios of global change (Marigómez, 2024). Moreover, environmental risk assessment extends its scope to include risks arising from natural events and technological sources, incorporating risk management techniques (Hiola & Badjuka, 2021). The ecological and economic risk assessment system

takes into account the distribution of challenges and hazards in the workplace, facilitating the transition from uncertainty to anticipated outcomes. This process involves the implementation of effective measures and mechanisms for controlling potential environmental costs (Mandala et al., 2022).
The fusion of hydrological data with environmental risk assessment represents a burgeoning area of study. Numerous abstracts provided delve into the amalgamation of hydrological data with environmental factors to gauge risks. A risk assessment procedure for hydrological disasters that incorporates threshold rainfall, as well as environmental and social criteria (Magalhães et al., 2023). Guan et al. devise a water-quality prediction and pollution-risk early-warning system employing hydrological and water quality data to bolster water environmental protection efforts (Guan et al., 2022). Hristopulos et al. (Hristopulos et al., 2020) underscore the significance of spatial and space-time methodologies in analyzing environmental data and mitigating environmental risks, encompassing hydrological events. Virkki et al. (Virkki et al., 2022) offer a global evaluation of environmental flows utilizing hydrological data to safeguard riverine ecosystems. Zhu et al. (Zhu et al., 2023) present an Environmental Vulnerability Analysis Model that integrates multi-source remote sensing data with hydrological information to assess short-term flood vulnerability. These articles collectively signify an increasing acknowledgment of the importance of incorporating hydrological data into environmental risk assessment for diverse applications. The accuracy of risk assessment can be improved through the incorporation of hydrological data (Girsang et al., 2021).
Much of the research has focused on developing domain-specific methods and applications of hydrological data and has not fully described the integration of such data in the broader context of ERA. This creates a knowledge gap in understanding how hydrological data integration can specifically support and enrich the ERA process for environmental risk management. Utilizing a systematic literature review approach, this research aims to bridge this gap by providing a more holistic understanding of how hydrological data integration can be effectively applied in the context of ERA. Focusing the analysis on the cause-and-effect relationship between hydrological factors and environmental impacts, this research seeks to offer deeper and more applicable insights to improve the accuracy and effectiveness of environmental risk assessment and management.

2. Methods

Investigating the incorporation of hydrological data in environmental risk assessment is the goal of this study. This study employs a methodical approach to literature review. The study's main goal is to perform a thorough review of literature that has been published in the last ten years (2013–2024) from reputable academic sources as Google Scholar, DOAJ, and Scopus. The research procedure is as shown in Figure 1.

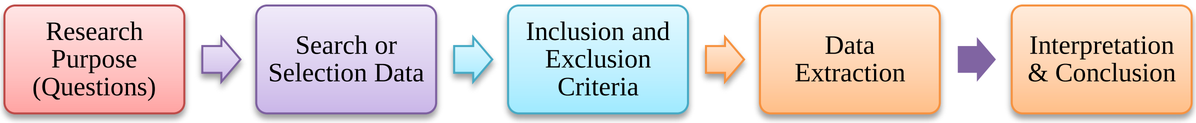

Figure 1: Research Procedure

This research is aimed at providing a comprehensive understanding of how hydrological data can contribute to environmental risk assessment. Data were selected by searching journal indexing databases with keywords such as “hydrological data integration” and “environmental risk assessment”. This stage concentrated on literature published in the last 10 years to ensure relevance and freshness of the information accessed. In the data selection stage, we applied data inclusion and exclusion criteria that must be met by each selected data, namely the research focus on the integration of hydrological data in environmental risk assessment, Indonesian and English papers. Conversely, literature that is not related to the research focus or does not meet the established methodological quality standards will be excluded. The data selection and extraction process will be conducted by carefully selecting studies that meet the inclusion criteria and extracting relevant data, including the conceptual framework of hydrological data integration, the types of data and research variables studied, and key findings from each. Finally, synthesizing and interpreting the findings to formulate the most appropriate conclusions, as well as finding gaps in the research results to be the most appropriate topics for future research that significantly contribute to the understanding of hydrological data integration.

3. Result and Discussions

3.1. Efforts in Integrating Hydrological Data for Environmental Risk Assessment

Several studies have explored endeavors in integrating hydrological data into the evaluation of environmental risks. One strategy entails the formulation of a risk-based ecohydrological approach that takes into account ecosystem values, flow alteration, and broader ecosystem requirements (Mcgregor et al., 2018). Another methodology encompasses the application of spatial and space-time geostatistical techniques for modeling and predicting the relationship between the magnitude and probability of hydrological events (Hristopulos et al., 2020). Additionally, the development of a Meta-Scientific-Modeling (MSM) framework, characterized by sustainability and user-friendliness, addresses the challenges associated with accessing heterogeneous data sources and integrating diverse models (Salas et al., 2020). Moreover, a proposed method involves the automatic assessment of local sensor networks utilizing globally available MODIS images to gauge the reliability and efficiency of the data. Lastly, the development of an online software platform makes it easier to integrate field data on groundwater vulnerability and assess the danger of groundwater pollution, enabling the swift incorporation of new information into risk modeling frameworks (Sege et al., 2018). Several studies have delved into the incorporation of hydrological data into environmental risk assessment. Research has identified various approaches to integrate hydrological data into environmental risk assessment, each with strengths and weaknesses. These approaches collectively reflect ongoing efforts to optimize the use of hydrological data for evaluating environmental risks.

3.2. Impacts of Hydrological Data Integration on Environmental Risk Assessment Accuracy

The incorporation of hydrological data significantly influences the precision and reliability of environmental risk assessment (Jayaprathiga et al., 2022). Inaccurate data can lead to flawed decision-making, heightened risks to the environment or human well-being, wastage of resources, and a decline in credibility. In regions with limited data availability, particularly where spatial and temporal resolutions are either unavailable or of low quality, the dependability of simulations is compromised, resulting in increased flow simulations (Teodosiu et al., 2015). To uphold data validity and reliability, it is imperative to implement quality control and quality assurance procedures (Aryal, n.d.). Employing collaborative modeling that integrates various aspects of environmental processes provides a comprehensive approach, enhancing the precision of monitoring water quantity and quality, as well as water resource management. The establishment and execution of methodologies for quantitatively assessing environmental impact and associated risks contribute to swift and enhanced decision-making processes. Leveraging sensor networks and high-resolution data can deepen the comprehension of environmental phenomena, thereby supporting decision-making processes.

3.3. Significant Variances in Hydrological Data Integration Approaches Based on Geographic or Environmental Contexts

Hydrological data integration approaches exhibit significant variations contingent upon the geographical or environmental context. In the face of climate change and the heightened dynamics of the hydrological cycle, there arises a necessity for innovative integrated methodologies that amalgamate spatially distributed flow models and datasets. This integration encompasses various data sources, including in situ observations, high-resolution hydro-meteorology, and satellite data (Pujol et al., 2022). Spatial statistics and geo-statistics methods, including space-time techniques, find common application in addressing environmental and hydrological issues, facilitating the quantification of spatial variation, generation of interpolated maps, simulation of scenarios, and optimization of sampling designs (Hristopulos et al., 2020). The intersection of remote sensing, resource management, environmental monitoring, and GPS (global positioning system) becomes an essential field in groundwater hydrology, resource management, and emergency response (Thakur et al., 2017). To enhance the precision and efficiency of velocity measurement in river discharge, a proposed three-dimensional hydrodynamic model coupled with data assimilation proves instrumental (Sun et al., 2022). Watershed simulation software, exemplified by the UBC watershed model, presents a dependable and flexible tool for parameter selection and testing, catering to operational requirements (Fotakis et al., 2014).

Figure 2: Overview of keywords or variables about the research focus (2013-2024)

Figure 2 illustrates the chronological development of research efforts from 2013 to 2024, focusing on the diverse exploration of hydrological data integration in environmental risk assessment and health-related interventions. This visual representation encompasses innovative approaches introduced during each specific period, showcasing the evolution of methodologies and interventions. The figure reflects dynamic interactions between advancements in hydrological data integration and an increasing emphasis on interdisciplinary research, contributing to a comprehensive understanding of environmental complexities and health outcomes. The presented timeline in Figure 1 serves as a roadmap, highlighting significant milestones and thematic shifts in research focus, ultimately underscoring the necessity for innovative methodologies and collaborative efforts across various domains.

4. Conclusion

In summary, the literature review underscores the substantial influence of integrating hydrological data in improving the precision and quality of environmental risk assessments. These studies illuminate the potential repercussions of inaccurate data, such as disruptions in decision-making processes and heightened environmental risks. Proposed remedies, like collaborative modeling and quantitative assessment methodologies, make notable contributions to achieving a more thorough and precise comprehension of environmental impacts, thereby facilitating effective decision-making. The interdisciplinary character of environmental risk assessment is stressed, emphasizing that hydrological data integration is indispensable not only for technical precision but also for ethical, cultural, and psychological dimensions, as delineated in the studies. This all-encompassing approach aligns with recent advancements in environmental research and management.

Despite the valuable insights offered by the literature, certain gaps require careful consideration. Firstly, additional research is imperative to examine and validate the efficacy of the proposed approaches in diverse geographical and environmental settings. This validation is critical for ensuring the dependability and broad applicability of these methods. Secondly, technical challenges linked to hydrological data integration, such as spatial and temporal resolution limitations, necessitate innovative strategies and advanced technological solutions. Moreover, there is still ample room to delve deeper into the repercussions of hydrological data integration on mitigating environmental risks, especially within the context of ongoing climate change. Further exploration in this area will yield profound insights into the role of the hydrological sector in promoting environmental sustainability. Undertaking these research topics in the future can significantly contribute to the advancement of hydrological data integration methodologies and enrich our comprehension of intricate environmental risks.

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