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Cluster Based Classification of River Water Pollution Using K-Means for Policy Intervention and Environmental Justice in Central Java, Indonesia

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A B S T R A C T

The lack of technical parameters for water pollution clustering exacerbates the fragmentation of authority, weak supervision, and disharmony between regions, making it necessary to normalize classifications in technical regulations to ensure standardization and adequate ecology. This research aims to develop a policy design for classifying river water pollution in accordance with environmental justice theory. This type of research employs empirical legal research approach with a statistical focus on environmental regulations, utilizing case studies from several cities/districts in Indonesia and Central Java Province as samples for factual analysis. This research shows, first, that the issue of river pollution in Indonesia reveals a weak effectiveness of regulations and governance, thereby urging the implementation of an environmental justice framework based on polluter clustering according to regional typology characteristics. Second, the clustering results obtained using the K-Means method are divided into three clusters: Cluster 0, Cluster 1, and Cluster 2. Third, this research recommends the design of a river pollution classification policy based on environmental justice theory, which demands the normative standardization of pollution clusters in the Regulation of the Minister of Environment and Forestry, in order to create a formal legal instrument.

KEYWORDS: ***Classification; Environmental Justice; Policy; Pollution; Rivers.***

1. I N T R O D U C T I O N

The absence of technical standardization regarding the clustering of pollutant loads that enter or contaminate water sources in Indonesia results in a lack of certainty in

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determining ecological, social, and economic responsibility among the parties.[1] This means a scientific basis is needed to develop a targeted and effective strategy for managing water quality. The national pollution issue is rooted in five key factors: a division of authority that prioritizes administrative boundaries over ecosystems; weak human resources and institutional capacity; limited funding, coupled with potentially environmentally damaging regional levies; disharmony between upstream and downstream areas; and inadequate environmental oversight and law enforcement in the regions.[2] These five factors are interrelated and ultimately worsen the effectiveness of environmental management and protection.

The policy for controlling water source pollution in Indonesia has a legal basis in Law Number 32 of 2009 and its derivative regulations; however, the effectiveness of implementation remains weak due to the fragmentation of authority.[3] This means that a concept for regulating and calculating water source pollutants is needed in the design, which must be standardized into technical regulations. The urgency of standardizing the classification of water source pollutants through agency technical regulations is expected to make it an effective technical and legal instrument.[4] With a clustering approach, this not only ensures the existence of standardized measures for pollution but also strengthens the accountability of polluters by establishing a clear burden of responsibility for affected communities and promoting environmental sustainability.[5] Below are data related to the numerous polluted rivers on the island of Java, which require strategic legal and policy direction for pollution management, as this typically varies across regions. This means that

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[1] Muhammad Reza Cordova and others, 'Spatiotemporal Macro Debris and Microplastic Variations Linked to Domestic Waste and Textile Industry in the Supercritical Citarum River, Indonesia', *Marine Pollution Bulletin*, 175 (2022), 113338 https://doi.org/10.1016/j.marpolbul.2022.113338

[2] Lilik Sulistyowati and others, 'The Occurrence and Abundance of Microplastics in Surface Water of the Midstream and Downstream of the Cisadane River, Indonesia', *Chemosphere*, 291 (2022), 133071 https://doi.org/10.1016/j.chemosphere.2021.133071

[3] Dini Adyasari and others, 'Anthropogenic Impact on Indonesian Coastal Water and Ecosystems: Current Status and Future Opportunities', *Marine Pollution Bulletin*, 171 (2021), 112689 https://doi.org/10.1016/j.marpolbul.2021.112689

[4] Siti Mariyam, Adhi Putra Satria, and Markus Suryoutomo, 'The Making of Law in Indonesia: A Criticism and Evaluation of The Practise of Legislative Function in The House of Representatives', *LAW REFORM*, 16.2 (2020), 215–23 https://doi.org/10.14710/lr.v16i2.33773

[5] Wahyu Adi and others, 'Ecological Condition of Seagrass Meadows around Sea-Based Tin Mining Activities in the Waters of Bangka Belitung Islands, Indonesia', *Marine Pollution Bulletin*, 209 (2024), 117151 https://doi.org/10.1016/j.marpolbul.2024.117151

addressing pollution issues in water sources should not be generalized but also requires a typological study based on the geography of each region.

Table 1 Number of Regency/City According to Type of Environmental Pollution on the Island of Java

Province	2021	2024	Average
Jawa Tengah	1310	1366	1338
Jawa Barat	1217	1354	1285
Jawa Timur	1152	1101	1126
Banten	257	319	282
Yogyakarta	76	78	77
DKI Jakarta	78	74	76

Source: Central Statistics Agency of Republic Indonesia

Table 1 displays the number of villages/sub-districts impacted by environmental pollution on Java Island, emphasizing differences across provinces and changes from 2021 to 2024. The province with the highest number is Central Java, with an average of 1,338 villages/sub-districts, followed by West Java (1,285) and East Java (1,126). In contrast, Yogyakarta and DKI Jakarta have relatively low numbers, with an average of less than 80. In terms of trends, Central Java, West Java, and Banten experienced significant increases, while East Java and DKI Jakarta actually decreased, and Yogyakarta remained relatively stable. This pattern suggests that provinces with large areas, dense populations, and high industrial activity tend to experience greater pollution, while those with smaller areas exhibit more limited levels of pollution.

Therefore, the urgency of this research, *first,* lies in mapping water pollution issues in Indonesia using a direct approach to addressing the urgency and challenges in the field. *Second*, to provide recommendations for the classification and clustering of river water pollution in Indonesia. *Third,* this research aims to provide recommendations for policy design in classifying river water pollution in accordance with environmental justice principles. It is especially important that the regulatory concept and principles for water pollution clustering in the draft technical regulations include a scientifically based calculation pattern, as well as a division of authority with an ecological approach, in accordance with regional characteristics and typologies, as conceptualized in

environmental justice.[6]

Previous research by Mega et al. (2022) on plastic pollution in Indonesia revealed that rivers are the primary route for plastic waste to enter the ocean, with Indonesia being identified as one of the most significant global contributors.[7] This research highlights the importance of mapping the quantity and composition of plastic waste in major rivers, such as the Citarum and Musi, as well as those in the Jakarta area. However, most research only focuses on the amount of waste at river mouths without systematically classifying pollution sources at upstream and downstream points. The recommendation emerging from these findings is the need for a formal policy to classify river pollution sources, such as through technical regulations, to ensure spatial data-based management, clarify the burden of responsibility on polluters, and ensure the application of environmental justice principles,[8] namely, fair risk distribution, participation of affected communities, and recognition of the needs of vulnerable groups along Indonesia's river basins.

Previous research by Dini et al. (2021) highlighted that Indonesia's coastal ecosystems face severe pressure from anthropogenic activities, particularly domestic, industrial, and agricultural waste, as well as plastics. Water quality continues to decline despite regulations such as Government Regulation Number 22 of 2021 concerning seawater quality standards. A literature review reveals that most studies focus on estuaries and coastal areas, with research predominantly conducted in Java, particularly in Jakarta Bay. At the same time, sources of pollution from upstream rivers have not been systematically mapped.[9] This gap presents important recommendations regarding the need for a more technical and operational policy for classifying sources of river pollution through legal instruments, so as not only to measure the level of pollution but also to identify the source

[6] Rais Torodji and others, 'The Role of the Corporate Penalty System on Environmental Regulation', *Journal of Human Rights, Culture and Legal System*, 3.3 (2023), 600–624 https://doi.org/10.53955/jhcls.v3i3.179

[7] Mega Mutiara Sari and others, 'Plastic Pollution in the Surface Water in Jakarta, Indonesia', *Marine Pollution Bulletin*, 182 (2022), 114023 https://doi.org/10.1016/j.marpolbul.2022.114023

[8] Nicola Ulibarri, Omar Pérez Figueroa, and Anastasia Grant, 'Barriers and Opportunities to Incorporating Environmental Justice in the National Environmental Policy Act', *Environmental Impact Assessment Review*, 97 (2022), 106880 https://doi.org/10.1016/j.eiar.2022.106880

[9] Adyasari and others.

and determine the burden of responsibility of the perpetrator.[10]

Previous research by Mariana et al. (2025) on the water quality of the Citarum River emphasized the use of index methods such as the Overall Index of Pollution, Said-WQI, and Pollution Index to classify pollution status from 'good' to 'highly polluted.' The research results showed that the majority of measurement points were in the polluted category, reflecting the high pressure of domestic and industrial waste along the river. However, this research was still limited to the technical aspects of water quality measurement, without linking the classification to a formal policy framework or environmental justice considerations [11]. Therefore, it is recommended to formulate a policy for classifying river pollution sources that not only relies on water quality data but also incorporates the classification results into legal instruments.[12]

Thus, there is an urgent need to close the gap in technical parameters for classifying river water pollution in Indonesia, which leads to weak legal certainty in determining ecological, social, and economic responsibilities. [13] Although a legal basis has been established through Law Number 32 of 2009 and its derivative regulations, implementation is still hindered by the fragmentation of authority, weak institutional capacity, limited funding, disharmony between upstream and downstream stakeholders, and inadequate supervision. [14] Previous research on plastic pollution, anthropogenic pressures on coastal waters, and the classification of Citarum water quality using pollution indices has focused on technical aspects without integrating them into a policy framework that upholds the principles of environmental justice. Therefore, normative pollution

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[10] Amalia Calderón-Argelich and others, 'Tracing and Building up Environmental Justice Considerations in the Urban Ecosystem Service Literature: A Systematic Review', *Landscape and Urban Planning*, 214 (2021), 104130 https://doi.org/10.1016/j.landurbplan.2021.104130

[11] Septi Nur Wijayanti, Tanto Lailam, and Kelik Iswandi, 'Progressive Legal Approaches of the Constitutional Justice Reasoning on Judicial Review Cases: Challenges or Opportunities?', *Law Reform: Jurnal Pembaharuan Hukum*, 21.2 (2025), 219–40 https://doi.org/10.14710/lr.v21i2.66334.

[12] Mariana Marselina, Nurul Aulia Rahmi, and Siti Ai Nurhayati, 'The Water Quality of the Upper Citarum: Applying the Overall Index of Pollution, Said-WQI, and Pollution Index Methods', *Heliyon*, 11.2 (2025), e41690 https://doi.org/10.1016/j.heliyon.2025.e41690

[13] Masfi Sya'fiatul Ummah, *Rules of Law and Laws of Ruling: On the Governace of Law*, *Sustainability (Switzerland)*, 2019, XI https://doi.org/10.4324/9781315607139

[14] Alberto Febbrajo, *Law, Legal Culture and Society*, *Law, Legal Culture and Society*, 2018 https://doi.org/10.4324/9781351040341

classification through cluster-based technical regulations is an urgent legal instrument to clarify the responsibilities of polluters, ensure equitable risk distribution, facilitate community participation, and recognize the vulnerability of affected groups based on regional typology and river ecosystem characteristics.[15]

2. RESEARCH METHODS

This research is empirical legal research based on the analysis of primary and secondary legal materials.[16] It can generate new concepts based on empirical facts from interviews and direct observations of river pollution problems in Indonesia, such as in Central Java, one of the metropolitan cities. The approach used in this research is by case, based on case data, which will be compared with environmental policy regulations in Indonesia, namely to answer whether there is a balance between facts and applicable laws, especially Law Number 32 of 2009 concerning Environmental Management and Control and Regional Regulation of Central Java Province Number 4 of 2023 concerning Environmental Protection and Management. This research employs the Environmental Justice Theory, as developed by Schlosberg (2007), which encompasses addressing environmental problems through distributive, procedural, and recognitional justice dimensions,[17] so that the policy output is in the form of technical guidelines for agencies in determining the burden of responsibility for polluters and ensuring fair and measurable protection of the community and the environment. The data collection technique used in this research is based on data and literature.[18] Data were obtained from routine observations at 156 sampling points spread across the main rivers of Central Java, divided into 3 to 12 monitoring points in each district/city, and supplemented with a literature study. Legal materials are obtained by collecting relevant laws and regulations, books, academic works, and international and national journals.[19] The analysis technique uses data cleaning, data aggregation, data

[15] Sudharto P. Hadi, Rizkiana S. Hamdani, and Ali Roziqin, 'A Sustainability Review on the Indonesian Job Creation Law', *Heliyon*, 9.2 (2023), e13431 https://doi.org/10.1016/j.heliyon.2023.e13431

[16] Andri Gunawan Wibisana, 'Menulis Di Jurnal Hukum: Gagasan, Struktur, Dan Gaya', *Jurnal Hukum & Pembangunan*, 49.2 (2019), 471 https://doi.org/10.21143/jhp.vol49.no2.2014

[17] David Schlosberg, 'Defining Environmental Justice', in *Defining Environmental Justice* (Oxford University PressOxford, 2007), pp. 3–10 https://doi.org/10.1093/acprof:oso/9780199286294.003.0001

[18] Susan S. Silbey, *Legal Culture and Legal Consciousness*, *International Encyclopedia of the Social & Behavioral Sciences: Second Edition*, Second Edi (Elsevier, 2015), XIII https://doi.org/10.1016/B978-0-08-097086-8.86067-5

[19] Terry Hutchinson, 'The Doctrinal Method: Incorporating Interdisciplinary Methods in Reforming the Law', *Erasmus Law Review*, 2016 https://doi.org/10.5553/ELR.000055

normalization, and feature engineering methods.

Data processing plays a fundamental role in formulating policies for classifying sources of river water pollution. Without accurate data processing, information on the type, volume, and distribution of pollutants will be difficult to understand comprehensively [20]. Raw data obtained from the field, such as water quality test results, industrial activity records, and community reports, must be processed systematically in order to provide a valid picture of environmental conditions. Thus, data processing is the main foundation for developing evidence-based policies [21].

Through appropriate data processing techniques, sources of pollution can be classified into specific categories, such as industrial, domestic, agricultural, and medical waste. This classification not only helps in mapping the problem but also in determining priorities for action. If the data is carefully processed, the resulting policies can be more effective in targeting the main sources of pollution that contribute significantly to the decline in river water quality. This process also prevents bias in decision-making.

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[20] Facundo Agustin and Patricia De Melin, 'Comparison of GRU and CNN Methods for Predicting the Exchange Rate of Argentine Peso (ARS) against US Dollar (USD)', *International Journal Artificial Intelligent and Informatics*, 2.1 (2024), 9–16 https://doi.org/10.33292/ijarlit.v2i1.31; Sanoun Mostafa, 'Comparison of CNN, CNN-GRU, and GRU Models for Prediction of Hryvnia (Ukraine) Exchange Rate against US Dollar', *International Journal Artificial Intelligent and Informatics*, 3.2 (2025), 67–73 https://doi.org/10.33292/ijarlit.v3i2.49; Boho Mokona and Ngezana Shipo, 'Comparative Analysis of LSTM and Grid Search Optimized LSTM for Stock Prediction: Case Study of Africa Energy Corp. (AFE.V)', *International Journal Artificial Intelligent and Informatics*, 2.1 (2025), 1–8 https://doi.org/10.33292/ijarlit.v2i1.30; Tomás López Aníbal and Rabiu Okanlawon, 'Stock Price Prediction of ReconAfrica (RECAF) Using Gated Recurrent Unit (GRU): Analysis and Implications for Investment Decisions', *International Journal Artificial Intelligent and Informatics*, 2.2 (2025), 41–46 https://doi.org/10.33292/ijarlit.v2i2.35.

[21] Indira Prabasari and others, 'Analysis of Cross Validation on Classification of Mangosteen Maturity Stages Using Support Vector Machine', *Emerging Information Science and Technology*, 5.1 (2024), 24–29 https://doi.org/10.18196/eist.v5i1.22359; Adinda Nurhayati Adriansyah and Slamet Riyadi, 'Classification of Duration in Global Terorism Using ResNet', *Emerging Information Science and Technology*, 5.2 (2024), 74–79 https://doi.org/10.18196/eist.v5i2.24756; Nafi Ananda Utama and others, 'Discrete Curvelet Transform Feature Extraction for Mangosteen Fruit Surface Damage Detection', *Emerging Information Science and Technology*, 5.1 (2024), 46–51 https://doi.org/10.18196/eist.v5i1.22602; Laila Indah Berlina, Ulfi Saidata Aesyi, and Kharisma Kharisma, 'Community Perspective Analysis of Yogyakarta Special Region Using K-Means Algorithm', *Emerging Information Science and Technology*, 5.2 (2024), 66–73 https://doi.org/10.33292/ijarlit.v2i1.30.

Data processing also enables the integration of various sources of information [22]. For example, water quality sensor data can be combined with satellite imagery data and regional administrative reports. This integration creates a more comprehensive understanding of the dynamics of water pollution in Indonesia. With this approach, policies are not based on a single dimension of data, but rather on multidimensional analysis that is better able to represent the actual conditions in the field.

From an environmental justice perspective, transparent and accountable data processing is crucial. Data that is processed and presented openly allows the public to understand the basis for the classification of polluters [23]. This strengthens the legitimacy of policies while also providing space for affected communities to demand their right to a clean and healthy environment. Thus, data processing is not merely technical in nature, but also has significant social and legal implications.

Ultimately, the success of policies for classifying sources of river water pollution is largely determined by the quality of the underlying data processing. Valid, integrated, and well-processed data can result in policies that are fair, targeted, and sustainable. Conversely, incorrectly processed data has the potential to result in biased policies that do

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[22] Apriliya Kurnianti, Pascal Pahlevi, and Inayah Mufidah, 'Recommendation System for Prospective Bride and Groom Using Cosine Similarity Algorithm', *Emerging Information Science and Technology*, 4.1 (2023), 8–15 https://doi.org/10.18196/eist.v4i1.18683; Aris Rakhmadi and Nila Dwi Rahmawati, 'Implementation of Simple Additive Weighting to Decide a Fund Proposal', *Emerging Information Science and Technology*, 4.2 (2023), 67–74 https://doi.org/10.18196/eist.v4i2.20741; Cahya Damarjati, Slamet Riyadi, and Ricki Irawan, 'Classification of Student Understanding on Covid-19 Booster Vaccine Using Machine Learning', *Emerging Information Science and Technology*, 3.2 (2022), 78–84 https://doi.org/10.18196/eist.v4i2.20741.

[23] Haris Setyawan, Laila Ma'rifatul Azizah, and Alvira Yusnia Pradani, 'Sentiment Analysis of Public Responses on Indonesia Government Using Naïve Bayes and Support Vector Machine', *Emerging Information Science and Technology*, 4.1 (2023), 1–7 https://doi.org/10.18196/eist.v4i1.18681; Radhitya Yunandri Hartanta and others, 'Analysis and Visualization of High School Student Achievement Data Using Decision Tree and Cross-Validation in Rapidminer', *Emerging Information Science and Technology*, 4.2 (2023), 62–66 https://doi.org/10.18196/eist.v4i2.20731; Faqihuddin Al Anshori and S Pidgeon, 'Prediction of Euro to US Dollar Exchange Rate Using CNN Method with Grid Optimization', *International Journal Artificial Intelligent and Informatics*, 3.2 (2025), 27–44 https://doi.org/10.33292/ijarlit.v3i2.45; Kovat Rai and Amit Vijayan, 'Performance Comparison of Long Short-Term Memory and Convolutional Neural Network for Prediction of Exchange Rate of Indian Rupee against US Dollar', *International Journal Artificial Intelligent and Informatics*, 3.1 (2025), 9–15 https://doi.org/10.33292/ijarlit.v3i1.41; Manuel Gabrielzinho and Giovana Moraes, 'Petrobras Stock Price Prediction Using Deep Learning Approach: Performance Comparison of CNN and CNN-GRU Methods', *International Journal Artificial Intelligent and Informatics*, 3.1 (2025), 30–36 https://doi.org/10.33292/ijarlit.v3i1.44.

not favor the affected communities. Therefore, improving data processing capacity needs to be prioritized in efforts to achieve environmental justice in Indonesia.

Given the wide variety of artificial intelligence (AI) methods available [24], clustering algorithms such as K-Means were chosen for their ability to efficiently group unlabeled data (unsupervised learning). This research uses the K-Means Clustering Method by applying the following algorithms: 1) Initialization, which randomly determines the number of clusters (k) and the initial value of the center of gravity; 2) Task, which classifies each data point into the nearest cluster based on Euclidean distance; 3) Update, which recalculates the centroid as the average of all points in the cluster; and 4) Iteration, which repeats steps 2-3 until convergence with the provisions (change in centroid < threshold). Meanwhile, the determination of the optimal number of clusters employs two methods: the elbow method and silhouette analysis. Thus, the formula for the minimized objective function is obtained:

$$J = \Sigma_{i=1}^{n} \Sigma_{i=1}^{k} w_{ij} ||x_i - \mu_i||^2$$

Description: J = Objective function (sum of squares in cluster), n = Number of data points, k = Number of clusters, w_{ij} = 1 if $x_i \in$ cluster j (0 otherwise), x_i = i-th data point, μ_j = jth cluster centroid

[24] Candra Juni Cahyo Kusuma and Khairunnisa Khairunnisa, 'Optimizing Bidirectional LSTM for Energy Consumption Prediction Using Chaotic Particle Swarm Optimization and Hyperparameter Tuning', *International Journal Artificial Intelligent and Informatics*, 2.2 (2024), 57–60 https://doi.org/10.33292/ijarlit.v2i2.37; Axia Flavia and Camila Mio, 'Performance Comparison of Standard LSTM and LSTM with Random Search Optimization for Spark New Zealand Limited Stock Price Prediction', *International Journal Artificial Intelligent and Informatics*, 3.2 (2025), 60–66 https://doi.org/10.33292/ijarlit.v3i2.48; Dušan Bohovic, 'Comparison of LSTM and GRU Methods for Predicting Gold Exchange Rate against US Dollar', *International Journal Artificial Intelligent and Informatics*, 3.1 (2025), 24–29 https://doi.org/10.33292/ijarlit.v3i1.43; Sutthipong Sanhatham, 'Stock Price Prediction of Thai Oil Public Company Limited (TOP.BK) Using LSTM Model with Grid Search Hyperparameter Optimization', *International Journal Artificial Intelligent and Informatics*, 2.1 (2024), 33–40 https://doi.org/10.33292/ijarlit.v2i1.34; Facundo Agustin and Patricia De Melin, 'Comparison of GRU and CNN Methods for Predicting the Exchange Rate of Argentine Peso (ARS) against US Dollar (USD)', *International Journal Artificial Intelligent and Informatics*, 2.1 (2024), 9–16 https://doi.org/10.33292/ijarlit.v2i1.31.

3. RESULTS AND DISCUSSION

The Issue of River Water Pollution in Indonesia: Urgency and Challenges

Environmental pollution and/or damage control policies are implemented to preserve environmental functions. Environmental pollution refers to the introduction of living organisms, substances, energy, or pollutants that are present in a specific resource and considered harmful to the environment.[25] Furthermore, regarding the size limits or levels of living creatures, substances, energy, or components that exist or must exist and/or pollutant elements whose presence is tolerated in a particular resource, as environmental elements, they must not exceed the threshold of 'environmental quality standards.'[26] Waste is a material or compound produced from chemical and/or industrial production processes, such as the use of hazardous and toxic products that generate hazardous and toxic waste, as well as the result of community activities or industrialization.[27] This means that waste must be managed effectively, even in the planning process, such as through environmental impact analysis, which must include a study of production waste results and ensure compliance with environmental quality standards.[28]

Environmental quality standards for liquids include water, wastewater, and seawater. Article 20 of the Environmental Law explains that water quality standards are a measure of the tolerable levels of a substance in water. Wastewater quality standards are measures of the tolerable levels of pollutants in water. In contrast, seawater quality standards are a measure of the tolerable levels of a pollutant in the water. Technically, water quality standards are regulated in Regulation of the Minister of Environment Number 7 of 2014

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[25] Linwei Du and others, 'Assessing and Predicting the Illegal Dumping Risks in Relation to Road Characteristics', *Waste Management*, 169 (2023), 332–41 https://doi.org/10.1016/j.wasman.2023.07.031

[26] Yun Arifatul Fatimah and others, 'Industry 4.0 Based Sustainable Circular Economy Approach for Smart Waste Management System to Achieve Sustainable Development Goals: A Case Study of Indonesia', *Journal of Cleaner Production*, 269 (2020), 122263 https://doi.org/10.1016/j.jclepro.2020.122263

[27] Andi Cudai Nur and Andi Irwan Nur, 'Enhancing Hazardous Waste Management Through the "SIPENGOLAH LIMBAH B3" Innovation', *International Journal of Public Administration in the Digital Age*, 12.1 (2025), 1–19 https://doi.org/10.4018/IJPADA.368716

[28] Bernadette C. Hohl and others, 'Community Identified Characteristics Related to Illegal Dumping; a Mixed Methods Study to Inform Prevention', *Journal of Environmental Management*, 346 (2023), 118930 https://doi.org/10.1016/j.jenvman.2023.118930

concerning Environmental Losses due to Pollution and/or Environmental Damage.[29]

Government Regulation Number 20 of 2001 concerning Water Quality Management and Water Pollution Control. [30] Classification and criteria for water quality are differentiated based on its intended use, such as drinking water, agricultural water, and water for fisheries, among others. Article 8, paragraph (1), stipulates the classification of water quality into four classes: class one, water suitable for consumption; class two, water for water recreation infrastructure/facilities, freshwater fish farming, animal husbandry, and irrigation of land crops; class three, water for freshwater fish farming, animal husbandry, and irrigation of land crops; and class four, water for irrigation of land crops. However, several applicable laws and regulations have not been fully effective in addressing the problem of water pollution in Indonesia.[31]

The challenges of environmental pollution and water resource management in Indonesia are primarily caused by, first, the division of authority, which is still oriented towards a territorial administrative approach rather than an ecosystem-based approach;[32] second, the weakness of human resources and institutional management capacity at both the central and regional levels; third, the lack of funding accompanied by a narrow understanding among regions that they are free to issue regulations for various levies within the framework of local revenue, even in ways that have the potential to damage the environment;[33] fourth, the unclear relationship between the upper (upstream) areas as conservation areas and the lower (downstream) areas that enjoy the impacts of the good

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[29] Mariana Marselina, Fachriah Wibowo, and Arini Mushfiroh, 'Water Quality Index Assessment Methods for Surface Water: A Case Study of the Citarum River in Indonesia', *Heliyon*, 8.7 (2022), e09848 https://doi.org/10.1016/j.heliyon.2022.e09848

[30] Ario Damar and others, 'The Eutrophication States of the Indonesian Sea Large Marine Ecosystem: Jakarta Bay, 2001–2013', *Deep Sea Research Part II: Topical Studies in Oceanography*, 163 (2019), 72–86 https://doi.org/10.1016/j.dsr2.2019.05.012

[31] Patrik John Gustav Henriksson and others, 'Indonesian Aquaculture Futures – Evaluating Environmental and Socioeconomic Potentials and Limitations', *Journal of Cleaner Production*, 162 (2017), 1482–90 https://doi.org/10.1016/j.jclepro.2017.06.133

[32] Zhaoguang Liao and Luan Xiao, 'Government Environmental Regulation, Media Attention, and Corporate Green Innovation', *International Review of Economics & Finance*, 97 (2025), 103751 https://doi.org/10.1016/j.iref.2024.103751

[33] Ambrose Theobald Kessy, 'Decentralization and Administrative Discretion in Tanzania: An Analysis of Administrative Discretion on Human Resources, Finance and Service Delivery', *Social Sciences & Humanities Open*, 8.1 (2023), 100684 https://doi.org/10.1016/j.ssaho.2023.100684

and bad environment above them; fifth, weak government supervision of the implementation of government affairs in the regions and regional legal products that hurt the environment, which ultimately results in weak enforcement of environmental law in the regions.[34]

The urgency of using an environmental justice framework for analyzing policies for clustering river pollution lies in its ability to transcend the limitations of mere technocracy and establish social justice as the foundation of environmental management.[35] A perspective is needed that ensures that pollution burdens are mapped fairly and no longer borne disproportionately by the poor, fishermen, or indigenous communities. It also ensures public participation and information transparency, preventing policies from being merely elitist and bureaucratic. It also encourages recognition of the vulnerabilities and specific needs of vulnerable groups that have been overlooked.[36]

Furthermore, this research sampled Central Java Province because, as one of Indonesia's economic centers, it experiences annual degradation of water quality standards. Metropolitan areas in Central Java, such as Semarang, Surakarta, and Tegal, are significant contributors to pollution due to the concentration of textile, food, and chemical industries. Agricultural intensification, characterized by the excessive use of fertilizers and pesticides, also exacerbates the decline in surface water quality. A suboptimal waste management system and weak enforcement of environmental laws aimed at protecting the environment exacerbate this phenomenon. Public health and the health of river ecosystems are at risk due to this water pollution.

Classification of River Water Pollution in Indonesia

The classification of river pollution clusters using the K-Means method aims to provide

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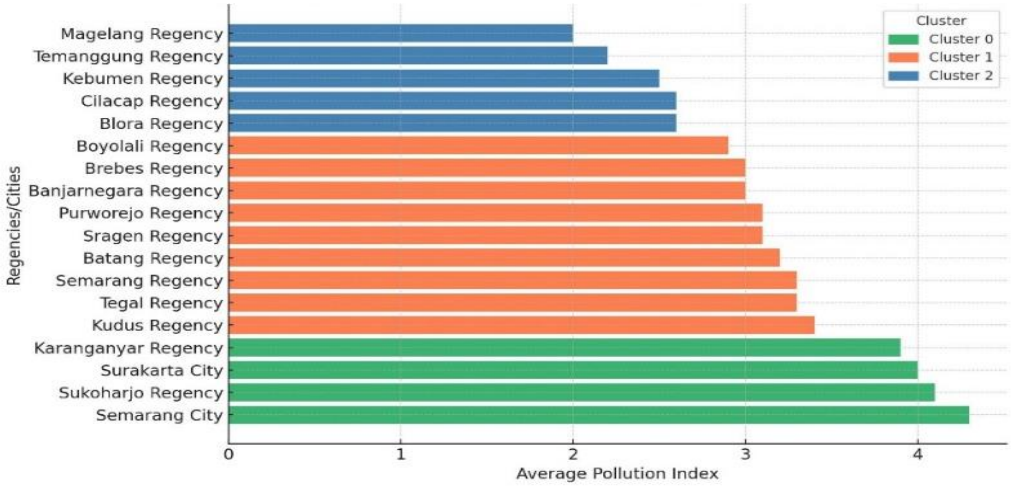
[34] Rajeev K. Goel and others, 'Different Forms of Decentralization and Their Impact on Government Performance: Micro-Level Evidence from 113 Countries', *Economic Modelling*, 62 (2017), 171–83 https://doi.org/10.1016/j.econmod.2016.12.010

[35] Nilam Firmandayu and Ayman Alameen Mohammed Abdalrhman, 'Spatial Policy Regarding Carbon Trading for Climate Change Mitigation in Indonesia: Environmental Justice Perspective', *Journal of Law, Environmental and Justice*, 3.1 (2025), 1–29 https://doi.org/10.62264/jlej.v3i1.113

[36] Jens Newig and others, 'Does Stakeholder Participation Improve Environmental Governance? Evidence from a Meta-Analysis of 305 Case Studies', *Global Environmental Change*, 82 (2023), 102705 https://doi.org/10.1016/j.gloenvcha.2023.102705

guidelines for calculating the quantity of pollutant entry into rivers, which are then categorized into specific clusters.[37] This research focused on 18 regencies/cities in Central Java that had complete river water quality monitoring data for the period from 2019 to 2023. The research area encompassed all regencies/cities in Central Java, covering an area of approximately 32,800 km² and a population of around 36 million. Data were obtained from routine monitoring at 156 sampling points spread across the main rivers in Central Java. Each regency/city was represented by 3 to 12 monitoring points, depending on the number and characteristics of rivers in the region. This research sampled 20 regencies/cities in Central Java Province and obtained the results as shown in Figure 1.



Source: Complied by the author

Figure 1 Clustering of Districts/Cities Based on Average River Pollution Index (2019-2023)

Figure 1 shows the clustering results in districts/cities based on the average River Pollution Index from 2019 to 2023. The results are divided into three clusters: Cluster 0 (green) contains areas with the highest levels of pollution, namely the cities of Semarang, Sukoharjo, Surakarta, and Karanganyar; Cluster 1 (orange) has moderate levels of pollution, including Kudus, Tegal, Semarang, Batang, Sragen, Purworejo, Banjarnegara, Brebes, and Boyolali; and Cluster 2 (blue) shows relatively lower levels of pollution,

[37] Abiodun M. Ikotun and others, 'K-Means Clustering Algorithms: A Comprehensive Review, Variants Analysis, and Advances in the Era of Big Data', *Information Sciences*, 622 (2023), 178–210 https://doi.org/10.1016/j.ins.2022.11.139

namely Blora, Cilacap, Kebumen, Temanggung, and Magelang. Urban and industrial areas, such as Semarang, Surakarta, and Sukoharjo, have higher levels of river pollution compared to mountainous or agricultural areas, like Magelang and Temanggung. This confirms that urbanization and industrialization are the primary factors contributing to increased river pollution,[38] a more complete explanation of the clusters is in Table 2 to 4 below:

Table 2 Characteristics of Cluster 0

Indicator	Value/Description
Water Pollution Index Average	4.02 (heavily polluted)
Water Pollution Index Range	3,66 - 4,31
Temporal Variability	Relatively stable with an increasing trend of 2.1% per year
Characteristics of The Region	1) Urbanization rate >75%; 2) Population density >1,500 person/km²; 3) Intensive industrial activity

Source: Complied by the author

Based on Table 2, the results of K-Means clustering with k = 3 form three clusters with the following characteristics. *First,* Cluster 0: High Pollution Zone. Cluster 0 consists of four urban and suburban areas in Semarang City, Sukoharjo Regency, Surakarta City, and Karanganyar Regency, with the characteristics listed in Table 1. Table 1 presents the characteristics of Cluster 0, which has an average Water Pollution Index of 4.02, categorized as 'heavily polluted,' with a range of 3.66–4.31 and an increasing trend of 2.1% per year. Areas in this cluster exhibit a high level of urbanization (>75%), a population density exceeding 1,500 people/km², and intensive industrial activity. Semarang City has the highest Water Pollution Index value (4.31), mainly influenced by organic pollution from domestic waste and the food processing industry.[39] Large rivers, such as the Semarang River and the Banger River, have experienced significant declines in water

[38] David Colozza, Yi-Chen Wang, and Mauricio Avendano, 'Does Urbanisation Lead to Unhealthy Diets? Longitudinal Evidence from Indonesia', *Health & Place*, 83 (2023), 103091 https://doi.org/10.1016/j.healthplace.2023.103091

[39] Himadri Soni, Rajiv Kant Yadav, and Suresh Kumar Patra, 'Global Impact of Urbanization on Ecosystems: A Comprehensive Bibliometric Analysis', *Natural Hazards Research*, 5.1 (2025), 21–35 https://doi.org/10.1016/j.nhres.2024.04.001

quality. Meanwhile, Sukoharjo and Karanganyar Regencies, despite their status as regencies, exhibit a similar pattern, with pollution being a dominant issue due to their proximity to Surakarta and the development of industrial areas, particularly in the textile, food, and household sectors, as well as waste generation from densely populated settlements.[40] A temporal analysis for the period 2019-2023 revealed different pollution dynamics in each cluster. Cluster 0 exhibited a consistent upward trend of 2.1% per year, with the highest spike occurring during the 2020-2021 period, coinciding with the pandemic. This increase is strongly suspected to be related to increased domestic waste from workplaces and household activities.[41]

Table 3 Characteristics of Cluster 1

Indicator	Value/Description
Water Pollution Index Average	3.23 (moderately polluted)
Water Pollution Index Range	2,95 - 3,58
Temporal Variability	Fluctuating with a downward trend of 1.8% per year
Characteristics of The Region	Urbanization rate 45-70%

Source: Complied by the author

Second, Cluster 1: Medium Pollution Zone, Cluster 1 comprises nine regencies with semi-urban characteristics in Kudus, Tegal, Semarang, Batang, Sragen, Purworejo, Banjarnegara, Brebes, and Boyolali, as outlined in Table 3. Table 2 shows the characteristics of Cluster 1, which has an average Water Pollution Index of 3.23, falling within the moderate pollution category, with a range of 2.95–3.58 and a decreasing trend of 1.8% per year. The areas in this cluster have a medium urbanization rate (45–70%) and a diverse economic structure, including industry, agriculture, and services. The primary sources of river water pollution include agricultural runoff, small- to medium-scale

[40] Liton Chandra Voumik and Tasnim Sultana, 'Impact of Urbanization, Industrialization, Electrification and Renewable Energy on the Environment in BRICS: Fresh Evidence from Novel CS-ARDL Model', *Heliyon*, 8.11 (2022), e11457 https://doi.org/10.1016/j.heliyon.2022.e11457

[41] Duc Hong Vo, Anh The Vo, and Chi Minh Ho, 'Urbanization and Renewable Energy Consumption in the Emerging ASEAN Markets: A Comparison between Short and Long-Run Effects', *Heliyon*, 10.9 (2024), e30243 https://doi.org/10.1016/j.heliyon.2024.e30243

industrial waste, and domestic waste.[42] However, the downward trend in the water pollution index indicates the effectiveness of pollution control programs, particularly through the construction of communal wastewater disposal installations and improved waste management programs, which are starting to have a positive impact on improving river water quality.[43] Cluster 1 experienced a downward trend of 1.3% per year on average, although there was variation between regions. Boyolali Regency recorded the most significant decline (-3.2% per year) thanks to the implementation of a comprehensive river revitalization program.

Table 4 Characteristics of Cluster 2

Indicator	Value/Description
Water Pollution Index average	2.51 (lightly polluted)
Water Pollution Index Range	2,01 - 2,84
Temporal Variability	Stable with a downward trend of 0.8% per year
Characteristics of The Region	Urbanization rate <45%

Source: Complied by the author

Third, Cluster 2: Low Pollution Zone. This cluster comprises five regencies with rural characteristics in Blora, Cilacap, Kebumen, Temanggung, and Magelang, as outlined in Table 4. Table 4 presents the characteristics of Cluster 2, which has an average Water Pollution Index of 2.51, falling within the lightly polluted category, with a range of 2.01–2.84 and a stable downward trend of 0.8% per year. This region is generally dominated by rural areas with low urbanization rates (<45%), such as Blora, Cilacap, Kebumen, Temanggung, and Magelang. The geographical conditions, characterized by hilly topography and relatively fast river flows, support the natural purification process, thereby controlling pollution.[44] The main pollution load comes from agricultural activities, but is still within the tolerance limits of the river ecosystem, which indicates that the

[42] Andhika Putra Pratama, Muhammad Halley Yudhistira, and Eric Koomen, 'Highway Expansion and Urban Sprawl in the Jakarta Metropolitan Area', *Land Use Policy*, 112 (2022), 105856 https://doi.org/10.1016/j.landusepol.2021.105856

[43] Fatimah and others.

[44] Tonni Agustiono Kurniawan and others, 'Unlocking Synergies between Waste Management and Climate Change Mitigation to Accelerate Decarbonization through Circular-Economy Digitalization in Indonesia', *Sustainable Production and Consumption*, 46 (2024), 522–42 https://doi.org/10.1016/j.spc.2024.03.011

environmental carrying capacity in this cluster is relatively well maintained.[45]

Based on these three classifications, it also determined the spatial patterns that strongly correlate with urban hierarchies and economic corridors in Central Java. Cluster 0 is concentrated in the Semarang and Surakarta corridors, specifically the Kedungsepur metropolitan area, indicating that river pollution is closely related to urbanization and industrialization patterns in key economic growth centers.[46] Cluster 1 is a transition zone around the urban center and along major transportation routes (such as the Pantura road and national roads), reflecting the spillover effects of economic activity from the urban core to the suburbs. Meanwhile, Cluster 2 is spread across rural areas, particularly in mountainous areas (Dieng, Merapi, and Merbabu), that's geographic isolation and limited infrastructure act as protective factors against pollution. These findings confirm the spatial dependence of water pollution on regional development dynamics, with pollution intensity decreasing from the urban center to the rural periphery.[47] Cluster 2 exhibits high stability with minimal fluctuations, marked by a mild downward trend of 0.8% per year. This reflects environmental sustainability, characterized by limited pollution pressure, supported by geographic characteristics and human activities that have minimal adverse impacts.[48]

The characteristics of the research dataset consist of 90 observations (18 districts × 5 years) with Water Pollution Index values varying between 2.01 and 4.31. Descriptive statistics show an average Water Pollution Index of 3.12 (±0.67), indicating an overall 'moderately polluted' condition.[49] The data distribution exhibits a relatively normal

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[45] Aulia Ulfah Farahdiba and others, 'The Present and Proposed Sustainable Food Waste Treatment Technology in Indonesia: A Review', *Environmental Technology & Innovation*, 32 (2023), 103256 https://doi.org/10.1016/j.eti.2023.103256

[46] La Pande Jurumai and others, 'Impact of Population Growth and Housing Development on the Riverine Environment: Identifying Environmental Threat and Solution in the Wanggu River, Indonesia', *Ecological Modelling*, 486 (2023), 110540 https://doi.org/10.1016/j.ecolmodel.2023.110540

[47] Yulianto Suteja and others, 'Spatial and Temporal Trends of Microplastic Contamination in Surface Sediment of Benoa Bay: An Urban Estuary in Bali-Indonesia', *Marine Pollution Bulletin*, 202 (2024), 116357 https://doi.org/10.1016/j.marpolbul.2024.116357

[48] Kiki Nidya Stephanie and Rukuh Setiadi, 'Morphological Analysis of River Characteristics in Musi Rawas Utara Regency', *Pembangunan Wilayah Kota*, 20.3 (2024), 10 https://doi.org/https://doi.org/10.14710/vol%viss%ipp256-270

[49] Marselina, Wibowo, and Mushfiroh.

pattern with a slight positive skew (0.23), suggesting the presence of several regions with exceptionally high pollution levels. The coefficient of variation of 21.4% indicates significant heterogeneity between regions, justifying the use of a clustering approach.[50]

Meanwhile, the determination of the optimal number of clusters was analyzed using the elbow method, which showed a fairly drastic decrease in Within-Cluster Sum of Squares values from cluster 1 to cluster 2 (from 5.98 to 2.51), followed by a more moderate decrease to cluster 3 (0.89). The determination of the optimal number of clusters clearly identified the elbow point at k = 3, where the addition of further clusters resulted in only a marginal decrease in Within-Cluster Sum of Squares. The results of the silhouette analysis supported this finding, with the highest silhouette score (0.71) at k = 3, indicating satisfactory clustering quality with clear separation between clusters and high cohesion within the clusters. The individual silhouette scores for each data point ranged from 0.42 to 0.89, indicating no significant misclassification.

Overall, the correlation analysis revealed three main groups of factors that determine the clustering patterns of water pollution in Central Java. Demographic factors showed the strongest correlation, with population density (r = 0.84) and urbanization rate (r = 0.79) being closely correlated with high pollution, while population growth (r = 0.61) also exerted significant pressure.[51] Economic factors also play a significant role, particularly the contribution of industry to Gross Regional Domestic Product (r = 0.73) and the number of medium- to large-sized industries (r = 0.68), which are the primary drivers of the formation of high-pollution clusters. An intriguing phenomenon is the correlation between per capita income (r = 0.52), which reveals a paradox: more prosperous areas tend to experience higher pollution, possibly due to the increased intensity of economic activity.[52] Geographic factors provide a protective effect, with elevation (r = -0.45) and slope (r = -0.41) favoring natural purification processes, and distance from the city center (r = -0.62) inversely related to pollution levels. These findings reinforce research that water pollution patterns are systemic, influenced by complex interactions between

[50] Marselina, Rahmi, and Nurhayati.
[51] Mochamad Lutfi Firmansyah, Intan Nurul Rizki, and Nisar Ullah, 'Recent Advances in Urban Mining Technology: A Focus on Electronic Waste Recycling Potential in Indonesia', *Cleaner Waste Systems*, 10 (2025), 100239 https://doi.org/10.1016/j.clwas.2025.100239
[52] Fatimah and others.

anthropogenic pressures and natural environmental characteristics.[53] Thus, the findings of cluster analysis provide a scientific basis for developing quality management strategies that incorporate authority-sharing patterns, using an ecological approach tailored to regional characteristics and typology.

Policy Design for The Classification of River Water Pollution based on Environmental Justice

Policies related to the utilization and prevention of pollution and/or destruction of natural resources have been regulated in Law Number 32 of 2009 concerning Environmental Protection and Management.[54] Then, it is regulated more strictly through the implementation of regulations, including Government Regulation Number 20 of 2001 concerning Water Quality Management and Water Pollution Control,[55] Government Regulation Number 19 of 1999 concerning Control of Marine Pollution and/or Destruction,[56] and Government Regulation Number 74 of 2001 concerning Management of Hazardous and Toxic Materials.[57] In the technical context, the utilization and/or control of water pollution in an area must be based on special implementing regulations.

To provide a sharp analysis of law enforcement regarding water source pollution, this research uses the Environmental Justice Theory framework by Schlosberg (2007) in line with his work 'Defining Environmental Justice.[58] The environmental justice framework used refers to three main dimensions, namely distributive justice, procedural justice, and

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[53] Farahdiba and others.

[54] Rizky Aulia Rahman, Benedict White, and Chunbo Ma, 'The Effect of Growth, Deforestation, Forest Fires, and Volcanoes on Indonesian Regional Air Quality', *Journal of Cleaner Production*, 457 (2024), 142311 https://doi.org/10.1016/j.jclepro.2024.142311

[55] Zainal Arifin and others, 'Indonesian Policy and Researches toward 70% Reduction of Marine Plastic Pollution by 2025', *Marine Policy*, 155 (2023), 105692 https://doi.org/10.1016/j.marpol.2023.105692

[56] Prieskarinda Lestari and Yulinah Trihadiningrum, 'The Impact of Improper Solid Waste Management to Plastic Pollution in Indonesian Coast and Marine Environment', *Marine Pollution Bulletin*, 149 (2019), 110505 https://doi.org/10.1016/j.marpolbul.2019.110505

[57] Matsuyama Akito and others, 'Reevaluation of Minamata Bay, 25 Years after the Dredging of Mercury-Polluted Sediments', *Marine Pollution Bulletin*, 89.1–2 (2014), 112–20 https://doi.org/10.1016/j.marpolbul.2014.10.019

[58] Schlosberg.

recognitional justice.[59] As a form of recommendation, this discussion attempts to provide a legal framework by normalizing the classification of water source pollution in the form of relevant ministerial regulations as a guideline for agencies in determining the burden of responsibility of parties towards affected communities and/or the environment, as follows:

First, at the very least, the affirmation of the river pollution can be standardized in a Ministerial Regulation from the Ministry of Environment and Forestry as the leading sector. Therefore, environmental management and handling, including water utilization and pollution control, are delegated to relevant government agencies,[60] Therefore, the ministerial regulation is one of the effective and technical legal products to contain the basis for calculating water pollution using the K-Means clustering method.[61] This ministerial regulation aims to provide guidelines for Central and/or Regional Environmental Agencies in determining the level of environmental pollution, whether it is included in Cluster 0, Cluster 1, or Cluster 2, along with calculating the costs of ecological and economic losses that must be borne by parties who have carried out acts of destruction and/or pollution of river and/or water areas in Indonesia.

The policy direction for cluster 0 requires intensive intervention, including the implementation of a real-time monitoring system with an early warning system, the construction of centralized wastewater treatment plants equipped with state-of-the-art technology, the introduction of economic instruments such as pollution levies for industry, and the relocation of waste-intensive industries to integrated areas. In cluster 1, a more moderate approach can be implemented through developing waste management plants with appropriate technology, fostering small and medium-sized industries in waste management, implementing sustainable agricultural systems to reduce runoff, and strengthening local institutional capacity. Meanwhile, for cluster 2, policies should focus on programs for conserving river ecosystems, providing economic incentives for

[59] Hanne Svarstad and Tor A. Benjaminsen, 'Reading Radical Environmental Justice through a Political Ecology Lens', *Geoforum*, 108 (2020), 1–11 https://doi.org/10.1016/j.geoforum.2019.11.007

[60] Charles Simabura and others, 'Ministerial Authority in Formulating Regulations Related to Presidential Lawmaking Doctrine', *Constitutional Review*, 9.2 (2023), 299–301 https://doi.org/https://doi.org/10.31078/consrev924

[61] Fitriani Ahlan Sjarif, 'Delegated Legislation Making Models in Indonesia within 1999-2012', *Pandecta Research Law Journal*, 18.1 (2023), 133–49 https://doi.org/10.15294/pandecta.v18i1.44476

environmental conservation, preventive monitoring, and capacity building to maintain sustainable development. The establishment of river basin organizations or cross-district/city coordination forums is an urgent need to ensure policy synergy and optimize holistic water resource management. This cluster-based approach enables more efficient resource allocation while ensuring effective policy implementation tailored to the characteristics of each region.[62]

Second, it is urgent to internalize the relevant ministerial regulations at every regional environmental agency, including both provincial and city/district levels. This recommendation is motivated by the delegation of environmental management authority from the central Ministry of Environment and Forestry to each provincial and/or district/city environmental agency.[63] This aims to ensure policy effectiveness and efficiency through the principle of decentralization. An optimistic perspective believes that decentralization of environmental management will have a positive impact on the environment.[64] Decentralization policies can prevent the oversimplification of natural, ecological, social, and environmental issues. This is because the relationship between humans and nature is a factor in the failure of environmental policy implementation, the loss of biodiversity, and the social wisdom that supports it.[65]

Meanwhile, each regional agency certainly has different system needs in each region/city. The basis of regional autonomy is laid out in Law Number 23 of 2014 concerning Regional Government, which stipulates that holders of autonomous power are required to carry out activities in the environmental sector in a decentralized manner. This decentralization policy direction is the basis for granting broad autonomy to regional

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[62] Afzal Husain Khan, 'Current Solid Waste Management Strategies and Energy Recovery in Developing Countries - State of Art Review', *Chemosphere*, 291.3 (2022), 1333 https://doi.org/https://doi.org/10.1016/j.chemosphere.2021.133088

[63] Ulrik B.U. Roehl, 'Automated Decision-Making and Good Administration: Views from inside the Government Machinery', *Government Information Quarterly*, 40.4 (2023), 101864 https://doi.org/10.1016/j.giq.2023.101864

[64] Nurfaika Ishak, Rahmad Ramadhan Hasibuan, and Tri Suhendra Arbani, 'Bureaucratic and Political Collaboration Towards a Good Governance System', *Bestuur*, 8.1 (2020) https://doi.org/10.20961/bestuur.42922

[65] Anirban Goutam Mukherjee, 'A Review on Modern and Smart Technologies for Efficient Waste Disposal and Management', *Journal of Environmental Management*, 297.1 (2021), 113347 https://doi.org/https://doi.org/10.1016/j.jenvman.2021.113347

governments to regulate and manage their own households, including the environmental sector. Article 63, paragraphs (2) and (3), of Law 32 of 2009 have also given technical authority to district/city regional governments. Meanwhile, the central government is more focused on formulating macro policies and establishing norms, standards, criteria, and procedures.[66]

Third, regarding the concept of regulation and principles of water pollution clustering in the draft Ministerial Regulation, namely, strengthening the pattern of division of authority with an ecological approach in accordance with the characteristics and typology of the region, as per the concept in the Environmental Justice Theory.[67] The granting of regional autonomy for environmental management should not be uniform across all regions. The format for granting environmental autonomy should take into account regional typology based on the potential of their natural and human resources. Government Regulation Number 20 of 2001 concerning Water Quality Management and Water Pollution Control. This government regulation explains that water quality management and water pollution control are carried out using an ecosystem approach. This means that granting authority to regions within administrative boundaries should not ignore environmental interests in a comprehensive and integrated manner.[68] It is essential to comprehend the regional autonomy framework thoroughly, so that the interests of one region do not harm those of other regions or vice versa. There must be cooperation between certain regions that benefit from the favorable environmental conditions of other regions.[69]

Schlosberg's (2007) analysis of environmental justice theory regarding river pollution clustering policies is based on three dimensions, including the distributive justice dimension, which emphasizes the importance of fairness in the distribution of environmental burdens and benefits. In the context of river pollution classification, the

[66] Roanne van Voorst, 'Formal and Informal Flood Governance in Jakarta, Indonesia', *Habitat International*, 52 (2016), 5–10 https://doi.org/https://doi.org/10.1016/j.habitatint.2015.08.023
[67] Svarstad and Benjaminsen.
[68] Hohl and others.
[69] Goel and others.

distribution of pollution burdens must be mapped not only ecologically but also socially.[70] Poor communities living along riverbanks, fishermen, and indigenous communities often bear the brunt of pollution, despite their relatively small contribution to it. Therefore, classification policies should not stop at technical assessments of water quality but should be linked to the distribution of risk to specific social groups. This will guarantee the use of classification results to hold polluters accountable and offer genuine protection to affected communities.[71]

The procedural justice dimension emphasizes public participation in the decision-making process. River pollution classification policies formulated solely by technical institutions have the potential to overlook the empirical experiences of residents who are in direct contact with rivers daily. This means that fair procedural mechanisms must ensure data transparency, open access to information, and space for participation for affected communities in determining parameters, locations, and follow-up actions based on classification results. By involving the public, classification becomes not merely a bureaucratic product but a democratic instrument that strengthens policy legitimacy and increases public trust.[72]

Meanwhile, the recognitional justice dimension demands recognition of the needs and identities of vulnerable groups. In river pollution classification policies, this means taking into account the differences in experiences and vulnerabilities between social groups, such as women who use river water more frequently for domestic purposes. These children are more susceptible to pollution-related diseases, as are indigenous communities with cultural ties to rivers.[73] Without this recognition, policies that appear technically neutral can remain biased and discriminatory. Therefore, the design of river pollution classification policies based on environmental justice must integrate these three

[70] Willy Naresta Hanum, Tran Thi Dieu Ha, and Nilam Firmandayu, 'Eliminating Ecological Damage in Geothermal Energy Extraction: Fulfillment of Ecological Rights by Proposing Permits Standardization', *Journal of Law, Environmental and Justice*, 2.2 (2024), 205–28 https://doi.org/10.62264/jlej.v2i2.105

[71] Margot Hurlbert and Jeremy Rayner, 'Reconciling Power, Relations, and Processes: The Role of Recognition in the Achievement of Energy Justice for Aboriginal People', *Applied Energy*, 228 (2018), 1320–27 https://doi.org/10.1016/j.apenergy.2018.06.054

[72] S.E. Walker and others, 'Defining and Conceptualizing Equity and Justice in Climate Adaptation', *Global Environmental Change*, 87 (2024), 102885 https://doi.org/10.1016/j.gloenvcha.2024.102885

[73] Christoph Kubitza and others, 'Land Property Rights, Agricultural Intensification, and Deforestation in Indonesia', *Ecological Economics*, 147 (2018), 312–21 https://doi.org/10.1016/j.ecolecon.2018.01.021

dimensions: distributive, procedural, and recognition, to create legal and administrative instruments that are not only formally legitimate but also socially and ecologically just.[74]

Fourth, regarding permits for wastewater utilization and wastewater discharge, both fall under the authority of the regent/mayor, and their issuance must be based on the results of an environmental impact analysis conducted by the local environmental agency. From an administrative law perspective, regional permits must be regulated in regional regulations; however, in reality, this has not been widely implemented by districts/cities in Indonesia. In fact, regional regulations regarding water classification and quality standards have not yet been established. Currently, regional regulations are primarily economic in nature, aimed explicitly at collecting levies as permitted by Article 24 of the Government Regulation.[75]

This also relates to the application of administrative sanctions as a preventative measure to control water pollution. The authority to impose these sanctions rests with the relevant regent/mayor, who has issued permits for the use of water sources and waste disposal permits. Administrative sanctions are imposed under Article 48, which can take the form of written warnings, temporary suspension, and revocation of business and/or activity permits. Specifically, marine water pollution control is regulated in Government Regulation Number 19 of 1999 concerning the Control of Marine Pollution and/or Damage. [76] This regulation emphasizes that marine pollution/damage control encompasses marine quality protection, the prevention and mitigation of marine pollution/damage, marine quality restoration, the issuance of dumping permits, supervision, and compensation. Therefore, recommendations to improve the systematic oversight process by regional governments are urgent, so they must recognize that regional budget allocations are related to environmental supervision and control. Therefore, recommendations specifically focus on standardizing rules in regional regulations and enhancing the transparency of the licensing process at both regional and

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[74] Schlosberg.

[75] I Wayan Koko Suryawan and Chun-Hung Lee, 'Citizens' Willingness to Pay for Adaptive Municipal Solid Waste Management Services in Jakarta, Indonesia', *Sustainable Cities and Society*, 97 (2023), 104765 https://doi.org/https://doi.org/10.1016/j.scs.2023.104765

[76] Carya Maharja and others, 'Multiple Negative Impacts of Marine Plastic Pollution on Tropical Coastal Ecosystem Services, and Human Health and Well-Being', *Ocean & Coastal Management*, 258 (2024), 107423 https://doi.org/10.1016/j.ocecoaman.2024.107423

local levels.

Fifth, regarding supervision directed at parties who have and/or do not have permits for water utilization and/or water source pollution control, regional governments must strengthen an integrated monitoring system between the central government, regional governments, and the community. Furthermore, the government needs to enhance the capabilities of its human resources and institutional capacity, as well as develop funding and cooperation between regions, particularly between upstream and downstream areas.[77] Thus, the policy of controlling water source pollution in Indonesia has a legal basis in Law Number 32 of 2009 and its derivative regulations. However, the effectiveness of implementation remains weak due to the fragmentation of authority, limited oversight, and a lack of technical regulations at the regional level. Therefore, the environmental justice framework by Schlosberg encompasses distributive, procedural, and recognitional justice dimensions that need to be integrated into policy design, particularly through the normative integration of cluster-based river pollution classification into the Regulation of the Minister of Environment and Forestry. This approach ensures that the distribution of pollution burdens is mapped fairly, affected communities are involved in the decision-making process, and the needs of vulnerable groups are recognized, so that pollution classification does not stop at a mere technical assessment but also functions as a legitimate, effective, and equitable regulatory instrument for the community and the sustainability of river ecosystems.

4. CONCLUSION

The absence of technical parameters related to the clustering of pollutant loads renders the calculation of ecological, social, and economic responsibility uncertain, thereby weakening the effectiveness of environmental law enforcement. This research indicates, *first*, that the issue of river pollution in Indonesia is characterized by weak regulatory and governance effectiveness, primarily due to fragmented authority, limited capacity, and minimal law enforcement. This finding further supports the implementation of an environmental justice framework based on polluter clustering, aiming to ensure fair,

[77] Bima Suprayoga, Hartiwiningsih, and Muhammad Rustamaji, 'Reconstruction of State Economic Losses in Criminal Acts of Corruption in Indonesia', *Revista de Gestão Social e Ambiental*, 17.4 (2023), e03453 https://doi.org/10.24857/rgsa.v17n4-024

participatory, and sustainable water management. *Second,* an example of river pollution classification in Central Java using the K-Means method is divided into three clusters, namely Cluster 0 (Semarang City, Sukoharjo, Surakarta, and Karanganyar), Cluster 1 (Kudus, Tegal, Semarang, Batang, Sragen, Purworejo, Banjarnegara, Brebes, and Boyolali), and Cluster 2 (Blora, Cilacap, Kebumen, Temanggung, and Magelang). *Third,* the design of a river pollution classification policy based on Schlosberg's Environmental Justice Theory (2007) demands the normalization of pollution clusters in the Regulation of the Minister of Environment and Forestry so that the distribution of environmental burdens is fair, community participation is guaranteed, vulnerable groups are recognized, and legal instruments are created that are legitimate, effective, and just for the sustainability of the ecosystem.

5. CONFLICTING INTEREST STATEMENT

The authors state that there is no conflict of interest in the publication of this article.

R E F E R E N C E S

Adi, Wahyu, Agus Hartoko, Pujiono W. Purnomo, Okto Supratman, Delianis Pringgenies, and Udhi E. Hernawan, 'Ecological Condition of Seagrass Meadows around Sea-Based Tin Mining Activities in the Waters of Bangka Belitung Islands, Indonesia', *Marine Pollution Bulletin*, 209 (2024), 117151 https://doi.org/10.1016/j.marpolbul.2024.117151

Adriansyah, Adinda Nurhayati, and Slamet Riyadi, 'Classification of Duration in Global Terorism Using ResNet', Emerging Information Science and Technology, 5.2 (2024), 74–79 https://doi.org/10.18196/eist.v5i2.24756

Adyasari, Dini, Mochamad Adhiraga Pratama, Novi Andriany Teguh, Aninditia Sabdaningsih, Mariska Astrid Kusumaningtyas, and Natasha Dimova, 'Anthropogenic Impact on Indonesian Coastal Water and Ecosystems: Current Status and Future Opportunities', *Marine Pollution Bulletin*, 171 (2021), 112689 https://doi.org/10.1016/j.marpolbul.2021.112689

Agustin, Facundo, and Patricia De Melin, 'Comparison of GRU and CNN Methods for Predicting the Exchange Rate of Argentine Peso (ARS) against US Dollar (USD)', International Journal Artificial Intelligent and Informatics, 2.1 (2024), 9–16 https://doi.org/10.33292/ijarlit.v2i1.31

Akito, Matsuyama, Yano Shinichiro, Hisano Akihiro, Kindaichi Michiaki, Sonoda Ikuko, Tada Akihide, and others, 'Reevaluation of Minamata Bay, 25 Years after the Dredging of Mercury-Polluted Sediments', *Marine Pollution Bulletin*, 89.1–2 (2014), 112–20 https://doi.org/10.1016/j.marpolbul.2014.10.019

Al Anshori, Faqihuddin, and S Pidgeon, 'Prediction of Euro to US Dollar Exchange Rate Using CNN Method with Grid Optimization', International Journal Artificial Intelligent and Informatics, 3.2 (2025), 27–44 https://doi.org/10.33292/ijarlit.v3i2.45

Aníbal, Tomás López, and Rabiu Okanlawon, 'Stock Price Prediction of ReconAfrica (RECAF) Using Gated Recurrent Unit (GRU): Analysis and Implications for Investment Decisions', International Journal Artificial Intelligent and Informatics, 2.2 (2025), 41–46 https://doi.org/10.33292/ijarlit.v2i2.35

Arifin, Zainal, Dede Falahudin, Hiroaki Saito, Tuti Hendrawati Mintarsih, Muhammad Hafizt, and Yulianto Suteja, 'Indonesian Policy and Researches toward 70% Reduction of Marine Plastic Pollution by 2025', *Marine Policy*, 155 (2023), 105692 https://doi.org/10.1016/j.marpol.2023.105692

Berlina, Laila Indah, Ulfi Saidata Aesyi, and Kharisma Kharisma, 'Community Perspective Analysis of Yogyakarta Special Region Using K-Means Algorithm', Emerging Information Science and Technology, 5.2 (2024), 66–73 https://doi.org/10.18196/eist.v5i2.24729

Bohovic, Dušan, 'Comparison of LSTM and GRU Methods for Predicting Gold Exchange Rate against US Dollar', International Journal Artificial Intelligent and Informatics, 3.1 (2025), 24–29 https://doi.org/10.33292/ijarlit.v3i1.43

Calderón-Argelich, Amalia, Stefania Benetti, Isabelle Anguelovski, James J.T. Connolly, Johannes Langemeyer, and Francesc Baró, 'Tracing and Building up Environmental Justice Considerations in the Urban Ecosystem Service Literature: A Systematic Review', *Landscape and Urban Planning*, 214 (2021), 104130 https://doi.org/10.1016/j.landurbplan.2021.104130

Chandra Voumik, Liton, and Tasnim Sultana, 'Impact of Urbanization, Industrialization, Electrification and Renewable Energy on the Environment in BRICS: Fresh Evidence from Novel CS-ARDL Model', *Heliyon*, 8.11 (2022), e11457 https://doi.org/10.1016/j.heliyon.2022.e11457

Colozza, David, Yi-Chen Wang, and Mauricio Avendano, 'Does Urbanisation Lead to

Unhealthy Diets? Longitudinal Evidence from Indonesia', *Health & Place*, 83 (2023), 103091 https://doi.org/10.1016/j.healthplace.2023.103091

Cordova, Muhammad Reza, Intan Suci Nurhati, Akihiro Shiomoto, Katsumori Hatanaka, Ramadhona Saville, and Etty Riani, 'Spatiotemporal Macro Debris and Microplastic Variations Linked to Domestic Waste and Textile Industry in the Supercritical Citarum River, Indonesia', *Marine Pollution Bulletin*, 175 (2022), 113338 https://doi.org/10.1016/j.marpolbul.2022.113338

Damar, Ario, Karl-J. Hesse, Franciscus Colijn, and Yon Vitner, 'The Eutrophication States of the Indonesian Sea Large Marine Ecosystem: Jakarta Bay, 2001–2013', *Deep Sea Research Part II: Topical Studies in Oceanography*, 163 (2019), 72–86 https://doi.org/10.1016/j.dsr2.2019.05.012

Damarjati, Cahya, Slamet Riyadi, and Ricki Irawan, 'Classification of Student Understanding on Covid-19 Booster Vaccine Using Machine Learning', Emerging Information Science and Technology, 3.2 (2022), 78–84 https://doi.org/10.18196/eist.v3i2.18680

Du, Linwei, Jian Zuo, John Vanzo, Ruidong Chang, and George Zillante, 'Assessing and Predicting the Illegal Dumping Risks in Relation to Road Characteristics', *Waste Management*, 169 (2023), 332–41 https://doi.org/10.1016/j.wasman.2023.07.031

Farahdiba, Aulia Ulfah, I.D.A.A. Warmadewanthi, Yunus Fransiscus, Elsa Rosyidah, Joni Hermana, and Adhi Yuniarto, 'The Present and Proposed Sustainable Food Waste Treatment Technology in Indonesia: A Review', *Environmental Technology & Innovation*, 32 (2023), 103256 https://doi.org/10.1016/j.eti.2023.103256

Fatimah, Yun Arifatul, Kannan Govindan, Rochiyati Murniningsih, and Agus Setiawan, 'Industry 4.0 Based Sustainable Circular Economy Approach for Smart Waste Management System to Achieve Sustainable Development Goals: A Case Study of Indonesia', *Journal of Cleaner Production*, 269 (2020), 122263 https://doi.org/10.1016/j.jclepro.2020.122263

Febbrajo, Alberto, *Law, Legal Culture and Society*, *Law, Legal Culture and Society*, 2018 https://doi.org/10.4324/9781351040341

Firmandayu, Nilam, and Ayman Alameen Mohammed Abdalrhman, 'Spatial Policy Regarding Carbon Trading for Climate Change Mitigation in Indonesia: Environmental Justice Perspective', *Journal of Law, Environmental and Justice*, 3.1

(2025), 1–29 https://doi.org/10.62264/jlej.v3i1.113

Firmansyah, Mochamad Lutfi, Intan Nurul Rizki, and Nisar Ullah, 'Recent Advances in Urban Mining Technology: A Focus on Electronic Waste Recycling Potential in Indonesia', *Cleaner Waste Systems*, 10 (2025), 100239 https://doi.org/10.1016/j.clwas.2025.100239

Flavia, Axia, and Camila Mio, 'Performance Comparison of Standard LSTM and LSTM with Random Search Optimization for Spark New Zealand Limited Stock Price Prediction', International Journal Artificial Intelligent and Informatics, 3.2 (2025), 60–66 https://doi.org/10.33292/ijarlit.v3i2.48

Gabrielzinho, Manuel, and Giovana Moraes, 'Petrobras Stock Price Prediction Using Deep Learning Approach: Performance Comparison of CNN and CNN-GRU Methods', International Journal Artificial Intelligent and Informatics, 3.1 (2025), 30–36 https://doi.org/10.33292/ijarlit.v3i1.44

Goel, Rajeev K., Ummad Mazhar, Michael A. Nelson, and Rati Ram, 'Different Forms of Decentralization and Their Impact on Government Performance: Micro-Level Evidence from 113 Countries', *Economic Modelling*, 62 (2017), 171–83 https://doi.org/10.1016/j.econmod.2016.12.010

Govender, P., and V. Sivakumar, 'Application of K-Means and Hierarchical Clustering Techniques for Analysis of Air Pollution: A Review (1980–2019)', *Atmospheric Pollution Research*, 11.1 (2020), 40–56 https://doi.org/10.1016/j.apr.2019.09.009

Hadi, Sudharto P., Rizkiana S. Hamdani, and Ali Roziqin, 'A Sustainability Review on the Indonesian Job Creation Law', *Heliyon*, 9.2 (2023), e13431 https://doi.org/10.1016/j.heliyon.2023.e13431

Hanum, Willy Naresta, Tran Thi Dieu Ha, and Nilam Firmandayu, 'Eliminating Ecological Damage in Geothermal Energy Extraction: Fulfillment of Ecological Rights by Proposing Permits Standardization', *Journal of Law, Environmental and Justice*, 2.2 (2024), 205–28 https://doi.org/10.62264/jlej.v2i2.105

Hartanta, Radhitya Yunandri, Asroni Asroni, Slamet Riyadi, and Jeckson Jeckson, 'Analysis and Visualization of High School Student Achievement Data Using Decision Tree and Cross-Validation in Rapidminer', Emerging Information Science and Technology, 4.2 (2023), 62–66 https://doi.org/10.18196/eist.v4i2.20731

Henriksson, Patrik John Gustav, Nhuong Tran, Chadag Vishnumurthy Mohan, Chin Yee Chan, U-Primo Rodriguez, Sharon Suri, and others, 'Indonesian Aquaculture Futures – Evaluating Environmental and Socioeconomic Potentials and Limitations', *Journal of Cleaner Production*, 162 (2017), 1482–90 https://doi.org/10.1016/j.jclepro.2017.06.133

Hohl, Bernadette C., Michelle C. Kondo, Laney A. Rupp, Richard C. Sadler, Catherine H. Gong, Kai Le, and others, 'Community Identified Characteristics Related to Illegal Dumping; a Mixed Methods Study to Inform Prevention', *Journal of Environmental Management*, 346 (2023), 118930 https://doi.org/10.1016/j.jenvman.2023.118930

Hurlbert, Margot, and Jeremy Rayner, 'Reconciling Power, Relations, and Processes: The Role of Recognition in the Achievement of Energy Justice for Aboriginal People', *Applied Energy*, 228 (2018), 1320–27 https://doi.org/10.1016/j.apenergy.2018.06.054

Hutchinson, Terry, 'The Doctrinal Method: Incorporating Interdisciplinary Methods in Reforming the Law', *Erasmus Law Review*, 2016 https://doi.org/10.5553/ELR.000055

Ikotun, Abiodun M., Absalom E. Ezugwu, Laith Abualigah, Belal Abuhaija, and Jia Heming, 'K-Means Clustering Algorithms: A Comprehensive Review, Variants Analysis, and Advances in the Era of Big Data', *Information Sciences*, 622 (2023), 178–210 https://doi.org/10.1016/j.ins.2022.11.139

Jurumai, La Pande, Afri Ahyarky Abidin, Endang Triningsih Soetrisno, and Dwiprayogo Wibowo, 'Impact of Population Growth and Housing Development on the Riverine Environment: Identifying Environmental Threat and Solution in the Wanggu River, Indonesia', *Ecological Modelling*, 486 (2023), 110540 https://doi.org/10.1016/j.ecolmodel.2023.110540

Kessy, Ambrose Theobald, 'Decentralization and Administrative Discretion in Tanzania: An Analysis of Administrative Discretion on Human Resources, Finance and Service Delivery', *Social Sciences & Humanities Open*, 8.1 (2023), 100684 https://doi.org/10.1016/j.ssaho.2023.100684

Khan, Afzal Husain, 'Current Solid Waste Management Strategies and Energy Recovery in Developing Countries - State of Art Review', *Chemosphere*, 291.3 (2022), 1333 https://doi.org/https://doi.org/10.1016/j.chemosphere.2021.133088

Kubitza, Christoph, Vijesh V. Krishna, Kira Urban, Zulkifli Alamsyah, and Matin Qaim, 'Land Property Rights, Agricultural Intensification, and Deforestation in Indonesia',

Ecological Economics, 147 (2018), 312–21 https://doi.org/10.1016/j.ecolecon.2018.01.021

Kurnianti, Apriliya, Pascal Pahlevi, and Inayah Mufidah, 'Recommendation System for Prospective Bride and Groom Using Cosine Similarity Algorithm', Emerging Information Science and Technology, 4.1 (2023), 8–15 https://doi.org/10.18196/eist.v4i1.18683

Kurniawan, Tonni Agustiono, Christia Meidiana, Hui Hwang Goh, Dongdong Zhang, Mohd Hafiz Dzarfan Othman, Faissal Aziz, and others, 'Unlocking Synergies between Waste Management and Climate Change Mitigation to Accelerate Decarbonization through Circular-Economy Digitalization in Indonesia', *Sustainable Production and Consumption*, 46 (2024), 522–42 https://doi.org/10.1016/j.spc.2024.03.011

Kusuma, Candra Juni Cahyo, and Khairunnisa Khairunnisa, 'Optimizing Bidirectional LSTM for Energy Consumption Prediction Using Chaotic Particle Swarm Optimization and Hyperparameter Tuning', International Journal Artificial Intelligent and Informatics, 2.2 (2024), 57–60 https://doi.org/10.33292/ijarlit.v2i2.37

Lestari, Prieskarinda, and Yulinah Trihadiningrum, 'The Impact of Improper Solid Waste Management to Plastic Pollution in Indonesian Coast and Marine Environment', *Marine Pollution Bulletin*, 149 (2019), 110505 https://doi.org/10.1016/j.marpolbul.2019.110505

Liao, Zhaoguang, and Luan Xiao, 'Government Environmental Regulation, Media Attention, and Corporate Green Innovation', *International Review of Economics & Finance*, 97 (2025), 103751 https://doi.org/10.1016/j.iref.2024.103751

Maharja, Carya, Radisti A. Praptiwi, Sainal Sainal, Prawesti Wulandari, Matthew Ashley, Kayleigh J. Wyles, and others, 'Multiple Negative Impacts of Marine Plastic Pollution on Tropical Coastal Ecosystem Services, and Human Health and Well-Being', *Ocean & Coastal Management*, 258 (2024), 107423 https://doi.org/10.1016/j.ocecoaman.2024.107423

Mariyam, Siti, Adhi Putra Satria, and Markus Suryoutomo, 'The Making of Law in Indonesia: A Criticism and Evaluation of The Practise of Legislative Function in The House of Representatives', *LAW REFORM*, 16.2 (2020), 215–23 https://doi.org/10.14710/lr.v16i2.33773

Marselina, Mariana, Nurul Aulia Rahmi, and Siti Ai Nurhayati, 'The Water Quality of the

Upper Citarum: Applying the Overall Index of Pollution, Said-WQI, and Pollution Index Methods', *Heliyon*, 11.2 (2025), e41690 https://doi.org/10.1016/j.heliyon.2025.e41690

Marselina, Mariana, Fachriah Wibowo, and Arini Mushfiroh, 'Water Quality Index Assessment Methods for Surface Water: A Case Study of the Citarum River in Indonesia', *Heliyon*, 8.7 (2022), e09848 https://doi.org/10.1016/j.heliyon.2022.e09848

Mokona, Boho, and Ngezana Shipo, 'Comparative Analysis of LSTM and Grid Search Optimized LSTM for Stock Prediction: Case Study of Africa Energy Corp. (AFE.V)', International Journal Artificial Intelligent and Informatics, 2.1 (2025), 1–8 https://doi.org/10.33292/ijarlit.v2i1.30

Mostafa, Sanoun, 'Comparison of CNN, CNN-GRU, and GRU Models for Prediction of Hryvnia (Ukraine) Exchange Rate against US Dollar', International Journal Artificial Intelligent and Informatics, 3.2 (2025), 67–73 https://doi.org/10.33292/ijarlit.v3i2.49

Mukherjee, Anirban Goutam, 'A Review on Modern and Smart Technologies for Efficient Waste Disposal and Management', *Journal of Environmental Management*, 297.1 (2021), 113347 https://doi.org/https://doi.org/10.1016/j.jenvman.2021.113347

Newig, Jens, Nicolas W. Jager, Edward Challies, and Elisa Kochskämper, 'Does Stakeholder Participation Improve Environmental Governance? Evidence from a Meta-Analysis of 305 Case Studies', *Global Environmental Change*, 82 (2023), 102705 https://doi.org/10.1016/j.gloenvcha.2023.102705

Nur, Andi Cudai, and Andi Irwan Nur, 'Enhancing Hazardous Waste Management Through the "SIPENGOLAH LIMBAH B3" Innovation', *International Journal of Public Administration in the Digital Age*, 12.1 (2025), 1–19 https://doi.org/10.4018/IJPADA.368716

Nurfaika Ishak, Rahmad Ramadhan Hasibuan, and Tri Suhendra Arbani, 'Bureaucratic and Political Collaboration Towards a Good Governance System', *Bestuur*, 8.1 (2020) https://doi.org/10.20961/bestuur.42922

Prabasari, Indira, Afrizal Zuhri, Slamet Riyadi, Tony K Hariadi, and Nafi Ananda Utama, 'Analysis of Cross Validation on Classification of Mangosteen Maturity Stages Using Support Vector Machine', Emerging Information Science and Technology, 5.1 (2024), 24–29 https://doi.org/10.18196/eist.v5i1.22359

Pratama, Andhika Putra, Muhammad Halley Yudhistira, and Eric Koomen, 'Highway Expansion and Urban Sprawl in the Jakarta Metropolitan Area', *Land Use Policy*, 112 (2022), 105856 https://doi.org/10.1016/j.landusepol.2021.105856

Rahman, Rizky Aulia, Benedict White, and Chunbo Ma, 'The Effect of Growth, Deforestation, Forest Fires, and Volcanoes on Indonesian Regional Air Quality', *Journal of Cleaner Production*, 457 (2024), 142311 https://doi.org/10.1016/j.jclepro.2024.142311

Rai, Kovat, and Amit Vijayan, 'Performance Comparison of Long Short-Term Memory and Convolutional Neural Network for Prediction of Exchange Rate of Indian Rupee against US Dollar', International Journal Artificial Intelligent and Informatics, 3.1 (2025), 9–15 https://doi.org/10.33292/ijarlit.v3i1.41

Rakhmadi, Aris, and Nila Dwi Rahmawati, 'Implementation of Simple Additive Weighting to Decide a Fund Proposal', Emerging Information Science and Technology, 4.2 (2023), 67–74 https://doi.org/10.18196/eist.v4i2.20741

Roehl, Ulrik B.U., 'Automated Decision-Making and Good Administration: Views from inside the Government Machinery', *Government Information Quarterly*, 40.4 (2023), 101864 https://doi.org/10.1016/j.giq.2023.101864

Sanhatham, Sutthipong, 'Stock Price Prediction of Thai Oil Public Company Limited (TOP.BK) Using LSTM Model with Grid Search Hyperparameter Optimization', International Journal Artificial Intelligent and Informatics, 2.1 (2024), 33–40 https://doi.org/10.33292/ijarlit.v2i1.34

Sari, Mega Mutiara, Pertiwi Andarani, Suprihanto Notodarmojo, Regil Kentaurus Harryes, Minh Ngoc Nguyen, Kuriko Yokota, and others, 'Plastic Pollution in the Surface Water in Jakarta, Indonesia', *Marine Pollution Bulletin*, 182 (2022), 114023 https://doi.org/10.1016/j.marpolbul.2022.114023

Schlosberg, David, 'Defining Environmental Justice', in *Defining Environmental Justice* (Oxford University PressOxford, 2007), pp. 3–10 https://doi.org/10.1093/acprof:oso/9780199286294.003.0001

Setyawan, Haris, Laila Ma'rifatul Azizah, and Alvira Yusnia Pradani, 'Sentiment Analysis of Public Responses on Indonesia Government Using Naïve Bayes and Support Vector Machine', Emerging Information Science and Technology, 4.1 (2023), 1–7 https://doi.org/10.18196/eist.v4i1.18681

Siems, Mathias M., 'The Taxonomy Of Interdisciplinary Legal Research: Finding The Way Out Of The Desert', *Journal of Commonwealth Law and Legal Education*, 7.1 (2009), 5–17 https://doi.org/10.1080/14760400903195090

Silbey, Susan S., *Legal Culture and Legal Consciousness*, *International Encyclopedia of the Social & Behavioral Sciences: Second Edition*, Second Edi (Elsevier, 2015), XIII https://doi.org/10.1016/B978-0-08-097086-8.86067-5

Simabura, Charles, Satya Arinanto, Maria Farida Indrati, Saldi Isra, and Fitra Arsil, 'Ministerial Authority in Formulating Regulations Related to Presidential Lawmaking Doctrine', *Constitutional Review*, 9.2 (2023), 299–301 https://doi.org/https://doi.org/10.31078/consrev924

Sjarif, Fitriani Ahlan, 'Delegated Legislation Making Models in Indonesia within 1999-2012', *Pandecta Research Law Journal*, 18.1 (2023), 133–49 https://doi.org/10.15294/pandecta.v18i1.44476

Soni, Himadri, Rajiv Kant Yadav, and Suresh Kumar Patra, 'Global Impact of Urbanization on Ecosystems: A Comprehensive Bibliometric Analysis', *Natural Hazards Research*, 5.1 (2025), 21–35 https://doi.org/10.1016/j.nhres.2024.04.001

Stephanie, Kiki Nidya, and Rukuh Setiadi, 'Morphological Analysis of River Characteristics in Musi Rawas Utara Regency', *Pembangunan Wilayah Kota*, 20.3 (2024), 10 https://doi.org/https://doi.org/10.14710/vol%viss%ipp256-270

Sulistyowati, Lilik, Nurhasanah, Etty Riani, and Muhammad Reza Cordova, 'The Occurrence and Abundance of Microplastics in Surface Water of the Midstream and Downstream of the Cisadane River, Indonesia', *Chemosphere*, 291 (2022), 133071 https://doi.org/10.1016/j.chemosphere.2021.133071

Suprayoga, Bima, Hartiwiningsih, and Muhammad Rustamaji, 'Reconstruction of State Economic Losses in Criminal Acts of Corruption in Indonesia', *Revista de Gestão Social e Ambiental*, 17.4 (2023), e03453 https://doi.org/10.24857/rgsa.v17n4-024

Suryawan, I Wayan Koko, and Chun-Hung Lee, 'Citizens' Willingness to Pay for Adaptive Municipal Solid Waste Management Services in Jakarta, Indonesia', *Sustainable Cities and Society*, 97 (2023), 104765 https://doi.org/https://doi.org/10.1016/j.scs.2023.104765

Suteja, Yulianto, Anna Ida Sunaryo Purwiyanto, Triyoni Purbonegoro, and Muhammad Reza Cordova, 'Spatial and Temporal Trends of Microplastic Contamination in

Surface Sediment of Benoa Bay: An Urban Estuary in Bali-Indonesia', *Marine Pollution Bulletin*, 202 (2024), 116357 https://doi.org/10.1016/j.marpolbul.2024.116357

Svarstad, Hanne, and Tor A. Benjaminsen, 'Reading Radical Environmental Justice through a Political Ecology Lens', *Geoforum*, 108 (2020), 1–11 https://doi.org/10.1016/j.geoforum.2019.11.007

Torodji, Rais, Hartiwiningsih Hartiwiningsih, I Gusti Ayu Ketut Rachmi Handayani, and Muhammad Nur, 'The Role of the Corporate Penalty System on Environmental Regulation', *Journal of Human Rights, Culture and Legal System*, 3.3 (2023), 600–624 https://doi.org/10.53955/jhcls.v3i3.179

Uittenbroek, Caroline J., Heleen L. P. Mees, Dries L. T. Hegger, and Peter P. J. Driessen, 'The Design of Public Participation: Who Participates, When and How? Insights in Climate Adaptation Planning from the Netherlands', *Journal of Environmental Planning and Management*, 62.14 (2019), 2532–33 https://doi.org/10.1080/09640568.2019.1569503

Ulibarri, Nicola, Omar Pérez Figueroa, and Anastasia Grant, 'Barriers and Opportunities to Incorporating Environmental Justice in the National Environmental Policy Act', *Environmental Impact Assessment Review*, 97 (2022), 106880 https://doi.org/10.1016/j.eiar.2022.106880

Ummah, Masfi Sya'fiatul, *Rules of Law and Laws of Ruling: On the Governace of Law*, *Sustainability (Switzerland)*, 2019, XI https://doi.org/10.4324/9781315607139

Utama, Nafi Ananda, Wahyu Indah Triyani, Slamet Riyadi, and Cahya Damarjati, 'Discrete Curvelet Transform Feature Extraction for Mangosteen Fruit Surface Damage Detection', Emerging Information Science and Technology, 5.1 (2024), 46–51 https://doi.org/10.18196/eist.v5i1.22602

Vo, Duc Hong, Anh The Vo, and Chi Minh Ho, 'Urbanization and Renewable Energy Consumption in the Emerging ASEAN Markets: A Comparison between Short and Long-Run Effects', *Heliyon*, 10.9 (2024), e30243 https://doi.org/10.1016/j.heliyon.2024.e30243

Voorst, Roanne van, 'Formal and Informal Flood Governance in Jakarta, Indonesia', *Habitat International*, 52 (2016), 5–10 https://doi.org/https://doi.org/10.1016/j.habitatint.2015.08.023

Walker, S.E., E.A. Smith, N. Bennett, E. Bannister, A. Narayana, T. Nuckols, and others, 'Defining and Conceptualizing Equity and Justice in Climate Adaptation', *Global Environmental Change*, 87 (2024), 102885 https://doi.org/10.1016/j.gloenvcha.2024.102885

Wibisana, Andri Gunawan, 'Menulis Di Jurnal Hukum: Gagasan, Struktur, Dan Gaya', *Jurnal Hukum & Pembangunan*, 49.2 (2019), 471 https://doi.org/10.21143/jhp.vol49.no2.2014

Wijayanti, Septi Nur, Tanto Lailam, and Kelik Iswandi, 'Progressive Legal Approaches of the Constitutional Justice Reasoning on Judicial Review Cases: Challenges or Opportunities?', Law Reform: Jurnal Pembaharuan Hukum, 21.2 (2025), 219–40 https://doi.org/10.14710/lr.v21i2.66334