COMMUNITY-BASED RIVER CONSERVATION INITIATIVES AND THE USE OF DRONE TECHNOLOGY FOR MONITORING THE MAHAKAM SUB-WATERSHED ECOSYSTEM, EAST KALIMANTAN

(*INISIATIF KONSERVASI SUNGAI BERBASIS MASYARAKAT DAN PENGGUNAAN TEKNOLOGI DRONE UNTUK PEMANTAUAN EKOSISTEM SUB-DAS MAHAKAM, KALIMANTAN TIMUR*)

Arum Sekar Kedhaton[*], Sutriani[*], Fahma Mamlu'atul Mukarromah[*], Husnawati[*], Amalina Yusdianti[*], Prince Clinton Immanuel Christian Damanik[**]

[*]Universitas Mulawarman
Jl. Kuaro, Gunung Kelua, Samarinda Ulu, Kota Samarinda, Kalimantan Timur 75119
Email: arumsekar@fkip.unmul.ac.id

[**]Universitas Negeri Jakarta
Jl. R.Mangun Muka Raya, Rawamangun, Kec. Pulo Gadung, Kota Jakarta Timur, Daerah Khusus Ibukota Jakarta 13220

Received: May 6, 2026; Revised: July 14, 2026; Accepted: August 6, 2026

ABSTRACT

Tropical rivers play an essential role in maintaining biodiversity, providing ecosystem services, and supporting local livelihoods. However, river pollution caused by household waste, market waste, plastic packaging, disposable diapers, organic debris, detergent foam, and riparian degradation accompanied by localized sedimentation has become a major environmental challenge, particularly in Samarinda City, East Kalimantan. This study investigates community-based river conservation initiatives implemented by the Gerakan Memungut Sehelai Sampah Sungai Karang Mumus (GMSS–SKM) and explores the contribution of drone-assisted spatial observation to river conservation. The study employed a qualitative method combined with a spatial approach. Data were collected through in-depth interviews with the head of GMSS–SKM, field observations, documentation, literature review, and visual interpretation of drone aerial imagery. Data credibility was strengthened through source, method, and theory triangulation, while the findings were interpreted using a geographical perspective, particularly the regional-complex approach. The findings indicate that inorganic waste, particularly plastic packaging, disposable diapers, bottles, and food containers, predominated during the dry season, whereas the rainy season increased the accumulation of organic debris, wood fragments, mixed domestic waste, and sediment transported from upstream areas. Drone observations identified waste accumulation hotspots, degraded riparian vegetation, drainage outlets, localized sediment deposits, and river segments with limited ground accessibility. These spatial observations supported the prioritization of river clean-up, riparian greening, environmental education, and future river monitoring. The integration of community participation, local knowledge, and drone-assisted observation provides an effective decision-support approach for community-based river conservation.

Keywords: Community-Based Conservation; Karang Mumus River; Spatial Monitoring, River Pollution

ABSTRAK

Sungai tropis memainkan peran penting dalam menjaga keanekaragaman hayati, menyediakan jasa ekosistem, dan mendukung mata pencaharian masyarakat lokal. Namun, pencemaran sungai yang disebabkan oleh limbah rumah tangga, sampah pasar, kemasan plastik, popok sekali pakai, limbah organik, busa deterjen, serta degradasi daerah sempadan sungai yang disertai sedimentasi lokal

telah menjadi tantangan lingkungan yang serius, khususnya di Kota Samarinda, Kalimantan Timur. Penelitian ini mengkaji inisiatif konservasi sungai berbasis masyarakat yang dilaksanakan oleh Gerakan Memungut Sehelai Sampah Sungai Karang Mumus (GMSS–SKM) serta mengeksplorasi kontribusi observasi spasial berbantuan drone dalam upaya konservasi sungai. Penelitian menggunakan metode kualitatif yang dikombinasikan dengan pendekatan spasial. Data dikumpulkan melalui wawancara mendalam dengan ketua GMSS–SKM, observasi lapangan, dokumentasi, studi literatur, serta interpretasi visual citra udara drone. Kredibilitas data diperkuat melalui triangulasi sumber, metode, dan teori, sedangkan hasil penelitian diinterpretasikan menggunakan perspektif geografis, khususnya pendekatan kompleks wilayah. Hasil penelitian menunjukkan bahwa limbah anorganik, terutama kemasan plastik, popok sekali pakai, botol, dan wadah makanan, mendominasi pada musim kemarau. Sementara itu, pada musim hujan terjadi peningkatan akumulasi limbah organik, potongan kayu, sampah domestik campuran, serta sedimen yang terbawa dari wilayah hulu. Observasi drone berhasil mengidentifikasi titik-titik penumpukan sampah, degradasi vegetasi sempadan sungai, saluran drainase, endapan sedimen lokal, serta segmen sungai yang sulit dijangkau dari darat. Observasi spasial ini mendukung penentuan prioritas kegiatan pembersihan sungai, penghijauan sempadan, edukasi lingkungan, serta pemantauan sungai di masa mendatang. Integrasi partisipasi masyarakat, pengetahuan lokal, dan observasi berbantuan drone memberikan pendekatan pendukung pengambilan keputusan yang efektif dalam konservasi sungai berbasis masyarakat.

***Kata kunci**: Konservasi berbasis masyarakat; Sungai Karang Mumus; Monitoring spasial; Pencemaran Sungai*

INTRODUCTION

As Indonesia's second-longest river and the largest in East Kalimantan, the Mahakam River spans approximately 920 kilometers. This river serves as the backbone of life and ecology in the region, playing a crucial role in maintaining abundant biodiversity and supporting the livelihoods of local communities along its course (Arsita et al., 2024; Kedhaton & Hastuti, 2023; Kedhaton & Krismondo, 2024). This rich river ecosystem is vital, serving as the primary habitat for various endemic species, including rare aquatic mammals such as pesut, whose population is largely concentrated in the Mahakam River (Kreb et al., 2020; Mustika et al., 2022). Flowing through three main regencies/cities, West Kutai, Kutai Kartanegara, and Samarinda, the Mahakam River is not only fundamental for the local fishing sector but also supports various other human activities that depend heavily on its existence (Gani et al., 2021; Nala & Indriani, 2020). The presence of a healthy river ecosystem directly contributes to the provision of clean water, ensures food availability, facilitates transportation, and supports diverse aspects of livelihood for local communities.

However, the Mahakam River ecosystem, particularly in the Karang Mumus sub-watershed, faces various serious threats to its sustainability (Azzahra et al., 2025). Water pollution, especially due to domestic and industrial waste, is a real environmental problem in Indonesia that also affects river ecosystems (Husamah et al., 2023). Poor waste management, including the direct disposal of household and industrial waste into waters, causes water and soil pollution, ecosystem damage, and increased contaminant concentrations (Aboyitungiye et al., 2021). Uncontrolled waste disposal also contributes to river shallowing (Pusmiati et al., 2025) and, if it consists of plastic waste, significantly damages the river ecosystem network (Sakti et al., 2023). This pervasive contamination severely compromises water quality, rendering it unsuitable for human consumption and agricultural use, while simultaneously endangering aquatic flora and fauna.

Facing these complex environmental challenges, the role of local communities becomes central to river conservation efforts (Thornton et al., 2020). Locally led management approaches that integrate traditional ecological knowledge have proven more effective in achieving positive outcomes for human well-being and environmental integrity (Novick et al.,

2022; Szałkiewicz et al., 2020). For instance, local communities, such as the Karang Mumus River Clean Community, are empowered to make autonomous decisions that address their needs and interests, ultimately improving living standards through sustainable resource utilization (de Jong & Kuipers, 2020; Herawati et al., 2024). Community concern for the condition of the Karang Mumus River has become the starting point for action to begin repairing, following up on, and protecting the river from pollution caused by waste, which is a long-term effect of community social activities (Priambudi & Utami, 2020).

The Karang Mumus River Clean Community not only conducts river clean-up activities as a routine activity, but is also active in carrying out various educational programs aimed at the wider community. As a community with a formal legal basis, they have a bargaining position that facilitates cooperation and partnerships with many parties to support the development of programs and obtain project funding from many stakeholders, including the government, sponsors, and companies (Suharko & Kusumadewi, 2019). The educational activities were reinforced by providing information that was easy for the younger generation to understand, using a hands-on approach and encouraging behavioral change in order to preserve a sustainable river ecosystem. Such initiatives are crucial for promoting a sense of shared responsibility and collective action among residents, fostering sustainable practices that directly mitigate pollution at its source.

To monitor the condition of the Karang Mumus River ecosystem, it needs to be supported by the use of drones. The role of local communities has limitations in real-time monitoring of river conditions. The use of drone technology presents a potential for effective technological integration to reach wider monitoring areas. Not all coverage areas can be monitored via waste transport boats. The limitations of human resources and the vastness of the river area pose challenges in identifying locations of waste accumulation and polluted areas. This research aims to explore community-based initiatives in river conservation, focusing on river cleaning and preservation activities by the Karang Mumus River Clean Community. This research will also discuss the utilization of drone technology to monitor the physical quality of the river and ecosystem conditions, thereby supporting more effective river management decisions.

METHOD

This research employs a qualitative method combined with a spatial approach to thoroughly investigate community-based river conservation efforts and environmental monitoring. The qualitative component focused on understanding the intricacies of community initiatives in river ecosystem conservation. This was primarily achieved through in-depth interviews conducted with the head of the Gerakan Memungut Sehelai Sampah Sungai Karang Mumus (GMSS-SKM) community in Samarinda City. These interviews aimed to capture nuanced perspectives, local knowledge, and the practical challenges and successes encountered in their conservation work.

Data sources for this study comprised both primary and secondary data. Primary data were gathered directly from the community interviews. Field notes were taken to document the physical conditions of the river, waste accumulation hotspots, and the spatial characteristics of the surrounding environment. Secondary data consisted of scientific literature, government reports, river conservation documents, and previous assessments related to river pollution and the use of drone-based environmental monitoring in Indonesia. These secondary sources served to contextualize the findings and support cross-verification. To ensure the robustness and credibility of the findings, data validity was rigorously ensured through triangulation, encompassing source triangulation (comparing information from different individuals or documents), theory triangulation (interpreting data through multiple theoretical lenses), and method triangulation (using different data collection methods to cross-verify findings).

Spatial techniques were utilized to analyze the aerial photographs monitoring the physical quality of the river. Aerial photographs were captured using drones. These photographs, captured using advanced drone technology, were instrumental in monitoring the physical quality of the Karang Mumus River. Drones provided a high-resolution, efficient, and comprehensive view of river conditions, including the identification of waste accumulation hotspots and polluted areas that are often difficult to access or monitor through traditional means (Chiang & Juang, 2023; Gutsa et al., 2024). The collected spatial data allowed for a detailed assessment of environmental elements. Finally, the findings derived from both qualitative interviews and spatial analysis were integrated and analyzed using a geographical approach, specifically the regional complex approach. This approach facilitated a holistic understanding of the complex interrelationships between environmental elements, such as pollution levels and ecosystem health, and the social conditions and community actions within the Sungai Karang Mumus watershed (Azzahra et al., 2025).

RESULT AND DISCUSSION

Community-Based Initiatives in Mahakam River, Karang Mumus Sub-Watershed Conservation

Community-based initiatives led by Gerakan Memungut Sehelai Sampah Sungai Karang Mumus (GMSS–SKM) have become an important component of river conservation efforts in Samarinda by complementing formal river-management programs through continuous public participation, environmental education, and multi-stakeholder collaboration. Established in 2012 in response to the worsening condition of the Karang Mumus River, the organization has maintained regular river-cleaning campaigns, environmental awareness activities, and community outreach involving residents, students, universities, civil society organizations, and local government institutions. Rather than functioning solely as a volunteer movement, GMSS–SKM has gradually developed into a collaborative platform that connects local communities with governmental stakeholders in addressing river pollution. Recent studies emphasize that long-term institutional continuity, stakeholder engagement, and cross-sector collaboration are among the principal indicators of successful community-based environmental governance because they strengthen collective action and increase the resilience of local conservation initiatives.

The contribution of GMSS–SKM has also been reinforced through collaboration with governmental agencies and institutional partners. Since receiving formal recognition from the Samarinda City Government, the organization has participated in various collaborative activities, including community river clean-up campaigns, environmental education through Sekolah Sungai Karang Mumus (SeSuKaMu), tree-planting activities along riparian corridors, public awareness campaigns, and educational outreach involving schools and universities. These activities have generally been supported through institutional partnerships, community-service programs conducted by universities, logistical assistance from local government agencies, volunteer participation, and collaboration with environmental organizations rather than relying exclusively on dedicated project funding. Such collaborative arrangements are increasingly recognized as an effective governance model because they combine governmental capacity with local ecological knowledge and community participation to improve environmental management outcomes.

Although the present study did not quantify changes in waste volume or water-quality parameters before and after program implementation, qualitative evidence obtained from interviews, field observations, and community documentation demonstrates several observable outcomes. Informants consistently reported that regular clean-up activities reduced the accumulation of visible floating waste in targeted river sections immediately after community

interventions, while repeated environmental campaigns encouraged greater public participation in subsequent conservation activities and strengthened awareness regarding household waste management. Furthermore, the continued implementation of SeSuKaMu, sustained volunteer involvement over more than a decade, and expanding collaboration with governmental and non-governmental institutions represent qualitative indicators of program effectiveness. In qualitative environmental research, institutional sustainability, repeated stakeholder participation, and observable behavioural change are considered appropriate indicators for evaluating community-based conservation initiatives when longitudinal quantitative monitoring is unavailable (Conrad & Hilchey, 2011; Fraisl et al., 2022).

The findings of this study are further supported by recent evidence describing the environmental condition of the Karang Mumus and Mahakam river systems. Previous investigations have shown that the Karang Mumus River continues to experience significant environmental pressures associated with domestic waste inputs, sedimentation, deteriorating water quality, and elevated concentrations of BOD, COD, TSS, and microbiological contaminants (Pramaningsih et al., 2023; Puspa et al., 2023). In response, the Samarinda City Government has introduced complementary river-management measures, including mechanical waste collection using trash-skimmer boats in strategic sections of the river, demonstrating that community participation remains essential to complement government-led waste management efforts rather than replace them (Setiawan et al., 2025). Consequently, the activities implemented by GMSS–SKM should be understood as preventive upstream interventions that contribute to reducing visible waste accumulation, strengthening environmental awareness, and supporting early identification of pollution hotspots before waste is transported downstream into the Mahakam River.

The integration of community participation with drone-assisted environmental monitoring represents the principal contribution of this study. Community observations provide contextual information regarding pollution sources and local environmental behaviour, whereas drone-based monitoring enables rapid identification of waste hotspots, riparian degradation, and areas requiring priority intervention. Although quantitative evaluation of waste reduction remains beyond the scope of the present qualitative research, combining participatory environmental governance with spatial monitoring offers an adaptive framework for urban river conservation. Future studies should integrate qualitative community participation with systematic measurements of waste volume, water-quality parameters, and longitudinal assessments of environmental behaviour to provide a more comprehensive evaluation of conservation effectiveness.

Field observations showed that the composition and distribution of waste in the Karang Mumus River varied according to seasonal hydrological conditions. During the dry season, visible waste was dominated by plastic packaging, disposable diapers, plastic bottles, food containers, and mixed household waste that accumulated near densely populated settlements, traditional markets, bridges, and low-flow riverbanks. During the rainy season, increased runoff transported larger quantities of organic debris, leaves, branches, sediment, and mixed domestic waste from upstream areas, resulting in waste accumulation around river bends, drainage outlets, and floodgates. Although this qualitative study did not quantify waste composition by weight or percentage, these observations are consistent with studies of Indonesian urban rivers reporting that floating litter is generally dominated by plastic-based household waste, whereas rainfall substantially increases the transport of organic material and mixed debris downstream (Sousa et al., 2025). Furthermore, spatial analysis by Kedhaton & Krismondo, (2024) identified approximately 2 km² of settlement areas encroaching upon protected riparian buffers in Samarinda, indicating persistent anthropogenic pressure that contributes to recurring waste inputs into the Karang Mumus River.

Manual clean-up remains the primary conservation approach implemented by GMSS–SKM because it enables volunteers to remove floating waste and debris from river sections that are difficult to access using mechanical equipment. During field observations, volunteers used small boats, hand nets, sacks, hooks, and personal protective equipment to collect floating litter from the river surface and adjacent riverbanks. Interviews with community members indicated that these activities consistently reduced visible waste accumulation immediately after each clean-up event and improved the visual condition of targeted river sections. However, the present study did not systematically record the weight or volume of collected waste, the number of volunteers, or the frequency of clean-up events, making quantitative evaluation of program effectiveness beyond the scope of this research. Consequently, the effectiveness of the program is interpreted qualitatively based on direct observations, interviews, and community documentation rather than numerical indicators.

Despite its contribution, manual clean-up has several operational limitations. Its implementation depends heavily on volunteer availability, weather conditions, river discharge, and accessibility of polluted river sections. In addition, manually operated clean-up activities are unable to detect submerged waste, dispersed debris, or pollution sources located upstream before waste reaches downstream segments. The broader environmental context also indicates that waste removal alone cannot fully address river degradation. Previous studies in the Samarinda watershed reported that Fe, BOD, and COD concentrations exceeded Indonesian water-quality standards, suggesting that domestic wastewater and other pollutant sources continue to degrade river health beyond the visible accumulation of solid waste (Hansen et al., 2017; Kedhaton & Krismondo, 2024). These findings indicate that periodic clean-up activities should be complemented by pollution prevention measures targeting upstream sources.

The findings of this study suggest that future conservation efforts should integrate community participation with drone-assisted environmental monitoring and broader waste-management strategies. Drone imagery can rapidly identify waste hotspots, riparian degradation, sediment accumulation, and inaccessible river sections, thereby improving the spatial targeting of community clean-up activities. At the same time, strengthening household waste segregation, waste-bank programs, environmental education through Sekolah Sungai Karang Mumus (SeSuKaMu), and routine municipal waste collection would reduce waste inputs at the source. To enable quantitative evaluation in future studies, GMSS–SKM could adopt standardized monitoring indicators, including the approximate weight or volume of collected waste, number of collection sacks, cleaned river length, activity duration, volunteer participation, GPS coordinates of clean-up locations, and before–after drone imagery. Integrating these indicators with community-based monitoring would provide stronger evidence for evaluating conservation effectiveness and support adaptive river management in urban watersheds.

The scope of the GMSS–SKM clean-up program strategically covers critical river sections, ranging from easily accessible populated residential zones, where the impact of human activities is most acute, to more challenging, hard-to-reach areas that often serve as accumulation points for waste. The effectiveness and reach of these initiatives are profoundly shaped by the enthusiastic participation of diverse stakeholder groups. Key participants include residents, whose intimate knowledge of the river's dynamics, current patterns, and historical pollution hotspots is invaluable (Okamoto et al., 2023). Alongside these experienced community members, organized volunteers and university students contribute significantly, bringing not only additional labor but also fresh perspectives and an opportunity for experiential learning regarding environmental stewardship (Delamontano et al., 2025; Demssie et al., 2022). Analogous community efforts in Indonesia have consistently demonstrated that increased public involvement can lead to substantial reductions in waste reaching landfills and water

bodies, sometimes up to 33% (Kristanto et al., 2021; Zahra et al., 2024). The sustained engagement of these multi-sectoral participants is thus fundamental for the successful execution and continuity of river conservation endeavors, fostering a broader sense of collective responsibility (Mahadiansar et al., 2023; Zulkifli et al., 2025).

Figure 1. Manual Waste Collection Process
Source: Author'(s) own work, (2025)

Consistent implementation of cleanup activities by the GMSS–SKM community typically yields an observable reduction of waste, transforming visibly polluted sections of the river into cleaner, more aesthetically pleasing environments. This immediate visual improvement is often a precursor to more profound positive changes in the river's physical condition. By removing solid waste, these initiatives directly contribute to alleviating blockages, improving water flow, and reducing the leaching of harmful substances into the aquatic ecosystem (Gunawan & Santoso, 2021). Studies on the Karang Mumus River highlight existing pollution concerns such as high biochemical oxygen demand, chemical oxygen demand, total suspended solids, and the presence of heavy metals and coliform bacteria, indicating a clear need for intervention (Nugroho et al., 2025; Pramaningsih et al., 2023; Puspa et al., 2023). Community-led cleanups, by reducing the pollutant load, are instrumental in potentially mitigating these issues and improving overall water quality parameters (Azzahra et al., 2025; Basuki et al., 2024). Such sustained efforts also play a crucial role in raising environmental awareness among riparian communities, fostering pro-environmental behaviors, and contributing to the long-term ecological health and sustainability of the Mahakam River basin (Zunariyah et al., 2025).

Beyond river clean-up activities, GMSS–SKM conducts environmental education through Sekolah Sungai Karang Mumus (SeSuKaMu), an informal community-based learning initiative designed to strengthen public understanding of river conservation. The program primarily targets students, university volunteers, youth organizations, community groups, and residents living along the Karang Mumus River. Learning activities combine classroom discussion with direct field experience through river walks, waste identification, observation of pollution sources, participatory clean-up activities, and discussions on riparian ecosystems and household waste management. This experiential learning approach enables participants to

connect environmental concepts with the ecological conditions of the river and the consequences of everyday waste-disposal practices. Recent studies have shown that field-based environmental education encourages deeper environmental understanding and promotes active participation because learning is directly linked to local environmental issues and community action (Zeng et al., 2023).

Figure 2. The GMSS–SKM community, together with volunteers, collects waste along the Karang Mumus River
Source: Author'(s) own work, (2025)

The present study did not administer pre- and post-program knowledge tests, behavioural surveys, or longitudinal evaluations of SeSuKaMu participants. Therefore, behavioural change cannot be claimed as a quantitatively measured outcome. Instead, qualitative evidence obtained from interviews, participant observation, and community documentation indicates that SeSuKaMu has contributed to strengthening environmental awareness and encouraging continued participation in river-conservation activities. Several informants described that participants became more willing to join subsequent clean-up events, discuss household waste management within their neighbourhoods, and disseminate environmental messages through schools, youth organizations, and community activities. Although these observations cannot be interpreted as statistically verified behavioural change, they represent qualitative indicators of increased environmental engagement that are widely accepted in community-based environmental research (Fraisl et al., 2022; Pratiwi et al., 2023). Future implementation should strengthen program evaluation by documenting participant attendance, participant profiles, activity frequency, repeated participation, and simple pre- and post-activity assessments to complement qualitative findings with measurable indicators.

GMSS–SKM also conducts riparian greening activities as a complementary conservation strategy to improve riverbank conditions and increase public involvement in river restoration. Tree planting was undertaken collaboratively with volunteers, local communities, educational institutions, and government partners during environmental campaigns. Because this qualitative study did not record the number of seedlings planted, species composition, planting locations, survival rates, or maintenance frequency, the greening program is interpreted as a community conservation initiative rather than a quantitatively evaluated ecological restoration program. Nevertheless, previous studies consistently demonstrate that riparian vegetation contributes to reducing riverbank erosion, improving slope stability, filtering surface runoff,

enhancing habitat quality, and increasing ecological resilience in urban river systems (Huang et al., 2024; Lima et al., 2024; Sousa et al., 2025). These ecological functions support the relevance of integrating community-led greening with broader watershed management despite the absence of quantitative restoration measurements in the present study.

The findings suggest that the principal contribution of SeSuKaMu lies in fostering continuous community engagement rather than producing immediately measurable behavioural outcomes. Together with river clean-up and riparian greening activities, the program has strengthened collaboration among local communities, universities, volunteers, and government agencies while maintaining public attention toward river conservation. Although the present research did not quantify participant numbers, behavioural changes, or tree survival rates, the sustained implementation of these activities over more than a decade, supported by repeated community participation and institutional collaboration, indicates the continuity of community-based environmental stewardship. Future conservation programs would benefit from integrating educational activities with systematic monitoring indicators, including participant attendance records, repeated volunteer participation, environmental knowledge assessments, georeferenced tree inventories, seedling survival monitoring, and drone-based documentation of riparian vegetation. Such integration would provide stronger evidence for evaluating both educational outcomes and ecological restoration performance while maintaining the participatory character of community-based river conservation.

Use of Drone Technology for Monitoring River Physical Quality and Ecosystem Conditions

Drone observations were employed in this study to complement field observations and interviews by providing a broader spatial perspective of environmental conditions along the Karang Mumus River. The aerial survey was conducted using a DJI Mavic Air 2S equipped with a 20 MP camera incorporating a 1-inch CMOS sensor (22 mm equivalent focal length; f/2.8 aperture), flown at an operational altitude of approximately 50–100 m above ground level (AGL). The flight path was designed to cover river segments characterized by dense settlements, bridges, drainage outlets, riparian vegetation, and locations frequently used for community-based clean-up activities. Unlike studies employing UAV photogrammetry for quantitative terrain modelling or automated image classification, the drone in this study functioned primarily as a qualitative spatial observation tool that enabled rapid visual assessment of river conditions across multiple river segments. Consistent with the qualitative design of this study, aerial photographs were visually interpreted in ArcGIS Pro to identify environmental features relevant to river conservation, including waste accumulation hotspots, riparian vegetation conditions, drainage outlets, localized sediment deposition, and river segments with limited accessibility. The interpretation results were subsequently verified through direct field observations, semi-structured interviews, and community documentation to ensure consistency between aerial observations and actual environmental conditions. No orthomosaic generation, digital surface modelling, object-based image classification, or quantitative photogrammetric processing was performed.

Drone imagery was interpreted visually and subsequently verified through direct field observations, semi-structured interviews, and community documentation. The interpretation focused on environmental features directly relevant to river conservation, including visible floating waste, waste accumulation along riverbanks, drainage outlets, riparian vegetation condition, exposed riverbanks, shallow sediment deposits, and areas with limited accessibility from ground level. The combination of aerial observation and ground verification enabled cross-validation of observed environmental conditions and reduced the possibility of interpreting aerial imagery without contextual understanding obtained from local communities.

Unlike quantitative remote sensing studies, this research did not estimate the volume of waste, sediment thickness, erosion rate, or river morphological change from drone imagery. Instead, aerial observations were used to identify qualitative spatial patterns of waste accumulation, riparian degradation, and localized sediment deposition and determine river segments requiring priority intervention based on field evidence.

Figure 3. Map of the Karang Mumus River Area
Source: Author'(s) own work, (2025)

The drone survey demonstrated several practical advantages for community-based river conservation. First, aerial imagery enabled rapid identification of waste accumulation hotspots located near bridges, densely populated riverbanks, drainage outlets, and low-flow river sections where floating waste tended to concentrate. Second, the aerial perspective facilitated observation of riparian vegetation gaps, exposed riverbanks, and localized sediment accumulation that were difficult to evaluate comprehensively through ground observation alone. Third, comparison between drone imagery and interview findings confirmed that locations identified by community members as problematic generally corresponded with visually degraded river segments observed from the air. These findings indicate that drone observation substantially improved spatial understanding of river conditions by integrating community knowledge with visual environmental evidence. Rather than replacing conventional field surveys, drone observation strengthened qualitative environmental assessment by

expanding spatial coverage while maintaining direct verification through field observation and interviews.

The integration of qualitative drone observation with community participation provides practical support for river management in the Karang Mumus watershed. Information obtained from aerial imagery assisted in identifying priority locations for community clean-up activities, riparian greening, environmental education, and future water-quality monitoring. Consequently, drone observation served not as a stand-alone analytical method but as a decision-support tool that enhanced spatial planning for community-based conservation.

The Karang Mumus River is a tributary that flows through Samarinda City in East Kalimantan. With a stream length of 34.7 kilometers, it forms part of the Mahakam River system. The Karang Mumus River functions as a water transportation route for communities within the watershed (DAS) area. Additionally, it is used for various activities such as washing, bathing, and other industrial uses. These multiple human activities create complex environmental pressures that necessitate accurate and timely monitoring.

Drone provides more detailed descriptions, supported by satellite imagery as an initial overview of the study area. The drone images show that the Karang Mumus River in Samarinda has become a critical point for household waste disposal and domestic wastewater originating from densely populated settlements along the riverbanks. Market waste, plastics, and household garbage accumulate in several segments, worsening the water's turbidity and overall condition. Drone cameras not only detect floating debris but also detergent foam on the water surface, which serves as a visual indicator of surface pollution.

Drone technology enhances sustainable river management by providing crucial, near-real-time, high-resolution data that fills spatial and temporal gaps in monitoring water quality and quantity. Through detailed aerial imagery and photogrammetry, drones support timely decision-making for diverse environmental management needs, ranging from water quality assessment and sedimentation mapping to the detection of pollution hotspots, morphological changes, and flood-prone zones (Acharya et al., 2021; Sibanda et al., 2021). This capability supports timely decision-making for river health assessment, urban waterway management, and detailed riverbed mapping for flood and ecosystem monitoring (Manfreda et al., 2024; Peko et al., 2024).

According to Sanyata (Sanyata, 2010), penalties for residents who dispose of waste into the river remain relatively light, causing waste dumping in the Karang Mumus River to continue. Along the river, a trash-skimmer boat has been introduced as a solution to clean the waste along the Karang Mumus channel. This boat can collect waste from the estuary along a 4.1 km route, with paths and holding capacity adjusted to existing conditions (Setiawan et al., 2025). However, this solution has not been fully optimal, as significant waste is still present in the river today.

In addition to waste monitoring, drones can also be used to analyze riparian vegetation conditions along the riverbanks, which play an important role in preventing erosion and maintaining water quality. Drone imagery enables assessments of vegetation health and land-cover levels near the river (Song et al., 2024) to support decision-making for future river-ecosystem conservation and restoration efforts (Medeiros et al., 2025). Currently, the Karang Mumus River has undergone changes along its watershed area, where parts of the riverbanks have become very gentle in slope. Drone visuals indicate that this phenomenon is influenced by improper land use and the lack of vegetation in the watershed, resulting in erosion that causes sediment to enter the river and reduce its carrying capacity.

The findings of this study support our initial assumption that drones can serve as an effective tool to identify various types of waste discarded in open areas of illegal dumping sites. The morphological results are closely related to potential flow disturbances; sediment

deposition can narrow the channel, alter flow velocity, accelerate sedimentation, and lead to water-quality degradation (Setiawan et al., 2025) going forward, the combination of drone-based monitoring and laboratory analysis will be ideal for sustainable water-quality management of the Karang Mumus River.

Technical and operational challenges persist, including adverse weather conditions (e.g., wind, rain, solar irradiance) that compromise flight capability and data quality (Gao et al., 2021; Slingsby et al., 2023). Limited flight duration and range also constrain widespread application (Acharya et al., 2021; Dille et al., 2025). Addressing these requires advanced camera calibration and rigorous data quality assessment (Lane et al., 2020). Despite these hurdles, drones offer significant opportunities for sustainable, long-term river monitoring and integration into broader environmental observation systems. Advancements in automation, digital twin systems, and autonomous flight promise enhanced efficiency and consistency in long-term monitoring (Hamzah et al., 2024; Kim et al., 2024). Integrating drone technology with traditional methods, remote sensing, citizen science, and AI can revolutionize monitoring, fostering comprehensive river management within wider observation frameworks (Lane et al., 2020; Manfreda et al., 2024).

Community-based environmental monitoring has been successfully implemented in several tropical regions through citizen-science initiatives that engage local residents in collecting environmental observations, documenting pollution sources using smartphones, and collaborating with universities and environmental agencies to support conservation planning (Fraisl et al., 2022). Similarly, UAV-assisted monitoring has increasingly been adopted to improve ecosystem mapping and support participatory environmental management by integrating local ecological knowledge with spatial information. These examples demonstrate that technology transfer and capacity-building programs can strengthen the effectiveness of community-based conservation when accompanied by continuous institutional support. The present findings demonstrate that GMSS–SKM already maintains regular community participation, environmental education through SeSuKaMu, and collaborative river clean-up activities. These existing institutional and social capacities provide a strong foundation for introducing citizen-science monitoring, drone-based spatial observation, and technology-transfer programs in future river-conservation initiatives.

CONSLUSION

Community-based river conservation efforts and the use of drone technology demonstrate significant potential for enhancing the effectiveness of river ecosystem management, particularly in tropical regions such as the Mahakam River. The river clean-up activities carried out by GMSS–SKM have proven effective in reducing solid waste loads, improving the physical condition of the river, and increasing community environmental awareness through education and direct involvement. This participatory approach not only produces short-term ecological benefits but also fosters a sense of collective responsibility that is crucial for the sustainability of conservation programs. Drone technology provides precise spatial and temporal data, enabling faster, more accurate, and more sustainable monitoring of water quality and quantity. This technology supports the identification of pollution hotspots, mapping of river morphological changes, and evidence-based decision-making. Although it faces technical challenges such as limited flight duration and sensitivity to weather conditions, advances in automation, sensors, and digital modeling systems continue to expand its potential for long-term monitoring.

RECOMMENDATION

Based on the findings of this study, the following recommendations are proposed to improve the effectiveness, sustainability, and scalability of community-based river conservation initiatives, particularly through the integration of local participation, drone-assisted monitoring, and collaborative environmental governance:

1. Strengthen community-based river conservation through regular clean-up activities, environmental education, and broader public participation.
2. Integrate drone technology into routine monitoring to identify waste accumulation, riparian degradation, sedimentation, and changes in river morphology.
3. Combine drone-based spatial data with field observation and laboratory water-quality analysis to improve the accuracy of river ecosystem assessment.
4. Develop collaborative governance among community organizations, local government, universities, and technology providers to support sustainable, participatory, and data-driven river management.

ACKNOWLEDGEMENT

The author would like to thank the local community, Gerakan Memungut Sehelai Sampah Sungai Karang Mumus (GMSS-SKM) for their participation in this research.

REFERENCES

Aboyitungiye, J. B., Suryanto, S., & Gravitiani, E. (2021). River pollution and human health risks: Assessment in the locality areas proximity of Bengawan Solo river, Surakarta, Indonesia. *Indonesian Journal of Environmental Management and Sustainability*, *5*(1). https://doi.org/10.26554/ijems.2021.5.1.13-20

Acharya, B. S., Bhandari, M., Bandini, F., Pizarro, A., Perks, M., Joshi, D. R., Wang, S., Dogwiler, T., Ray, R. L., Kharel, G., & Sharma, S. (2021). Unmanned Aerial Vehicles in Hydrology and Water Management: Applications, Challenges, and Perspectives. *Water Resources Research*, *57*(11). https://doi.org/10.1029/2021wr029925

Arsita, E. D., Asikin, D., & Titisari, E. Y. (2024). Tingkat Keberlanjutan Sosial-Ekonomi Desa Pela Kalimantan Timur Berdasarkan Sustainable Development Goals (SDGs). *Arsitektura*, *22*(1), 13. https://doi.org/10.20961/arst.v22i1.78781

Azzahra, M. R., Adhyasta, S. A., Utami, A. N., & Putri, D. H. (2025). Dampak Aktivitas Masyarakat Terhadap Kondisi Sosial-Ekonomi Lingkungan di Bantaran Sungai Karang Mumus (Studi Kasus: RT. 32, Kampung Baru Permai Kota Samarinda). *JURNAL SOSIAL EKONOMI DAN HUMANIORA*, *11*(2), 170–176. https://doi.org/10.29303/jseh.v11i2.765

Basuki, T. M., Indrawati, D. R., Nugroho, H. Y. S. H., Pramono, I. B., Setiawan, O., Nugroho, N. P., Nada, F. M. H., Nandini, R., Savitri, E., Adi, R. N., Purwanto, P., & Sartohadi, J. (2024). Water Pollution of Some Major Rivers in Indonesia: The Status, Institution, Regulation, and Recommendation for Its Mitigation. *Polish Journal of Environmental Studies*, *33*(4), 3515–3530. https://doi.org/10.15244/pjoes/178532

Chiang, C.-H., & Juang, J. (2023). Application of UAVs and Image Processing for Riverbank Inspection. *Machines*, *11*(9), 876. https://doi.org/10.3390/machines11090876

Conrad, C. C., & Hilchey, K. G. (2011). A review of citizen science and community-based environmental monitoring: Issues and opportunities. *Environmental Monitoring and Assessment*, *176*(1–4), 273–291. https://doi.org/10.1007/s10661-010-1582-5

de Jong, E. B. P., & Kuipers, K. (2020). Perceptions of Change: Adopting the Concept of Livelihood Styles for a More Inclusive Approach to 'Building with Nature.' *Sustainability*, *12*(23), 10011. https://doi.org/10.3390/su122310011

Delamontano, E., Endyana, C., Winoto, Y., & Novianti, E. (2025). *The Impact of a River*

Cleanup Program on Youth's Pro-Environmental Behavior through Educational Tourism. https://doi.org/10.21203/rs.3.rs-7695179/v1

Demssie, Y., Biemans, H. J. A., Wesselink, R., & Mulder, M. (2022). Fostering students' systems thinking competence for sustainability by using multiple real-world learning approaches. *Environmental Education Research*, *29*(2), 261–286. https://doi.org/10.1080/13504622.2022.2141692

Dille, M., Vespignani, M., Bruce, J., & Wong, U. (2025). Advancing river flow monitoring with small uncrewed aircraft and simulation-driven development. *Frontiers in Remote Sensing*, *6*. https://doi.org/10.3389/frsen.2025.1520963

Fraisl, D., Hager, G., Bedessem, B., Gold, M., Hsing, P. Y., Danielsen, F., Hitchcock, C. B., Hulbert, J. M., Piera, J., Spiers, H., Thiel, M., Haklay, M., & Fritz, S. (2022). Citizen science in environmental and ecological sciences. *Nature Reviews Methods Primers*, *2*, 64. https://doi.org/10.1038/s43586-022-00144-4

Gani, I., Gaffar, E. U. A., Muliati, M., & Auliansyah, A. (2021). Sustainable Livelihood Framework Approach of Communities in Agricultural Sector of Middle Mahakam River, East. *Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi Dan Pembangunan*, *22*(2), 139–152. https://doi.org/10.23917/jep.v22i2.15569

Gao, M., Hugenholtz, C. H., Fox, T. A., Kucharczyk, M., Barchyn, T. E., & Nesbit, P. R. (2021). Weather constraints on global drone flyability. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-91325-w

Gunawan, L. E., & Santoso, I. B. (2021). The relevancy of law enforcement toward water quality in Kali Buntung's downstream area. *E3S Web of Conferences*, *325*, 3010. https://doi.org/10.1051/e3sconf/202132503010

Gutsa, T., Trois, C., de Vries, R., & Mani, T. (2024). Wasted shores: Using drones to monitor the spatio-temporal evolution of debris accumulation hotspots on South Africa's Umgeni River. *The Science of The Total Environment*, *955*, 176791. https://doi.org/10.1016/j.scitotenv.2024.176791

Hamzah, A., Aqlan, F., & Baidya, S. (2024). Drone-based digital twins for water quality monitoring: A systematic review. In *Digital twins and applications.* (Vol. 1, Issue 2, pp. 131–160). https://doi.org/10.1049/dgt2.12021

Hansen, Oktaviani, L. W., & Susanti, E. W. (2017). Kualitas Air Sungai Mahakam terhadap Kesehatan Masyarakat di Kelurahan Loa Duri Ulu Kecamatan Loa Janan Kutai Kartanegara Samarinda. *Jurnal Sangkareang Mataram*, *3*(4), 17–19.

Herawati, H., Setyowati, A., Kausar, L. I. E., Keman, S., & Devy, S. R. (2024). Understanding river culture to approach health promotion in river management in Banjarmasin, South Kalimantan, Indonesia. *Healthcare in Low-Resource Settings*. https://doi.org/10.4081/hls.2024.13032

Huang, L., Chen, X., Yuan, Z., Ye, C., & Liang, Y. (2024). Determining the relationship between urban river water quality and landscape patterns based on XGBoost and SHAP analysis. *Environmental Management*. https://doi.org/10.1007/s00267-024-02017-w

Husamah, H., Rahardjanto, A., Hadi, S., Lestari, N., & BK, M. K. U. (2023). Spirituality-based environmental literacy among prospective biology teacher in Indonesia: Analysis based on gender, accreditation, and semester-level aspects. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *9*(3), 418–432. https://doi.org/10.22219/jpbi.v9i3.29500

Kedhaton, A. S., & Hastuti. (2023). *The Existence of Settlement and The Geography of Mahakam Estuary*. *25*(2), 109–121. https://doi.org/10.55981/jmb.2023.2066

Kedhaton, A. S., & Krismondo, A. (2024). Monitoring Penataan Permukiman Tepian Sungai Mahakam Di Kota Samarinda: Studi Kasus Daerah Sempadan Sungai Kecamatan Loa Janan Ilir, Palaran Dan Samarinda Seberang. *Jurnal Riset Inossa : Media Hasil Riset*

Pemerintahan, Ekonomi Dan Sumber Daya Alam, *5*(02), 39–51. https://doi.org/10.54902/jri.v5i02.141

Kim, S., Lee, C. W., Park, H.-J., Hwang, J. E., Park, H. Bin, Yoon, Y.-J., & Kim, Y. J. (2024). UAV telephotography elucidates floristic variability and beta diversity of island cliffs under grazing interventions. *Scientific Reports*, *14*(1). https://doi.org/10.1038/s41598-024-66446-7

Kreb, D., Lhota, S., Porter, L., Redman, A., Susanti, I., & Lazecký, M. (2020). Long-Term Population and Distribution Dynamics of an Endangered Irrawaddy Dolphin Population in Balikpapan Bay, Indonesia in Response to Coastal Development. *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.533197

Kristanto, G. A., Pratama, M. A., Nandhita, P. A. C., Kemala, D., Munif, A., & Ahmad, D. A. (2021). The Citarum River as our front yard: A case of community engagement in Bintang Alam, Indonesia. *IOP Conference Series Earth and Environmental Science*, *716*(1), 12003. https://doi.org/10.1088/1755-1315/716/1/012003

Lane, S. N., Gentile, A., & Goldenschue, L. (2020). Combining UAV-Based SfM-MVS Photogrammetry with Conventional Monitoring to Set Environmental Flows: Modifying Dam Flushing Flows to Improve Alpine Stream Habitat. *Remote Sensing*, *12*(23), 3868. https://doi.org/10.3390/rs12233868

Lima, A. F., Ferreira, G. F., & Pires, A. (2024). Prioritizing Urban River Restoration Management Practices : A Cross-Evaluation Using the Criticality Index for Watershed Restoration (CIWR) and Opportunity Layers. *Land*, *13*(13), 1–30. https://doi.org/10.3390/land13122244

Mahadiansar, M., Alfiandri, A., & Marliani, M. (2023). PESTEL Analysis of Blue Economy Development Policy in Indonesia. *BIO Web of Conferences*, *70*, 5005. https://doi.org/10.1051/bioconf/20237005005

Manfreda, S., Miglino, D., Saddi, K. C., Jomaa, S., Eltner, A., Perks, M., Peña-Haro, S., Bogaard, T., van Emmerik, T., Mariani, S., Maddock, I., Tauro, F., Grimaldi, S., Zeng, Y., Gonçalves, G., Strelnikova, D., Bussettini, M., Marchetti, G., Lastoria, B., … Rode, M. (2024). Advancing river monitoring using image-based techniques: challenges and opportunities. *Hydrological Sciences Journal*, *69*(6), 657–677. https://doi.org/10.1080/02626667.2024.2333846

Medeiros, B. M., Cândido, B., Jimenez, P. A., Avanzi, J. C., & Silva, M. L. (2025). UAV-Based Soil Water Erosion Monitoring: Current Status and Trends. In *Drones* (Vol. 9, Issue 4). https://doi.org/10.3390/drones9040305

Mustika, P. L. K., High, K. K., Putra, M. I. H., Sahri, A., Ratha, I. M. J., Prinanda, M. O., Agung, F., Purnomo, F. S., & Kreb, D. (2022). When and Where Did They Strand? The Spatio-Temporal Hotspot Patterns of Cetacean Stranding Events in Indonesia. *Oceans*, *3*(4), 509–526. https://doi.org/10.3390/oceans3040034

Nala, I. W. L., & Indriani, N. (2020). Pengembangan Ekowisata Sungai Berbasis Masyarakat di Desa Pela Kutai Kartanegara, Kalimantan Timur. *Journal of Tourism and Creativity*, *4*(2), 85. https://doi.org/10.19184/jtc.v4i2.14579

Novick, B., Crouch, J., Ahmad, A., Rodiansyah, Muflihati, M., Kartikawati, S. M., Sudaryanti, Sagita, N., & Miller, A. E. (2022). Understanding the interactions between human well-being and environmental outcomes through a community-led integrated landscape initiative in Indonesia. *Environmental Development*, *45*, 100791. https://doi.org/10.1016/j.envdev.2022.100791

Nugroho, H., Hardi, E. H., Hamdani, H., Duma, K., Masruhim, M. A., Harihanto, H., & Pagoray, H. (2025). Investigating Water Qualities of Karang Mumus River: Is It Secure to be Used by Populations? In *Advances in engineering research/Advances in Engineering*

Research (pp. 500–512). Atlantis Press. https://doi.org/10.2991/978-94-6463-732-8_45

Okamoto, M., Osawa, T., Prasetyawan, W., & Binawan, A. (2023). Local Governance of Peatland Restoration in Riau, Indonesia. In *Global environmental studies*. https://doi.org/10.1007/978-981-99-0902-5

Peko, M., Milić, D. C., & Vidaković, I. (2024). Unmanned Aerial Vehicle Mapping of River Flow for Water Resources Management. In *Lecture notes in networks and systems* (pp. 154–163). Springer International Publishing. https://doi.org/10.1007/978-3-031-51494-4_14

Pramaningsih, V., Yuliawati, R., Sukisman, S., Hansen, H., Suhelmi, R., & Daramusseng, A. (2023). Indek Kualitas Air dan Dampak terhadap Kesehatan Masyarakat Sekitar Sungai Karang Mumus, Samarinda. *JURNAL KESEHATAN LINGKUNGAN INDONESIA*, *22*(3), 313–319. https://doi.org/10.14710/jkli.22.3.313-319

Pratiwi, J. R., Ramadani, B. M. F., & Tambunan, E. A. (2023). Community Perception In Domestic Wastewater Treatment To Reduce River Pollution: A Study In Rw 09 Kotalama Village, Kedungkandang Subdistrict, Malang City. *E3S Web of Conferences*, *445*, 1026. https://doi.org/10.1051/e3sconf/202344501026

Priambudi, H., & Utami, T. (2020). Upaya Komunitas Peduli Sungai Dalam Pelaksanaan Konservasi Sungai di Kabupaten Sukoharjo. *Journal of Development and Social Change*, *3*(2), 36–43.

Pusmiati, P., Nurhidayah, M., Mubarak, T., Diana, Y., & Kelana, A. H. (2025). Hubungan Tingkat Pengetahuan Dengan Perilaku Pengelolaan Sampah Di Kampung Yaturaharja Arso X. *SCIENCE Jurnal Inovasi Pendidikan Matematika Dan IPA*, *5*(2), 493–500. https://doi.org/10.51878/science.v5i2.4875

Puspa, R. A., Pramaningsih, V., & Daramusseng, A. (2023). Analisis Status Mutu Air Sungai Karang Mumus Segmen Jembatan S. Parman Dan Jembatan Perniagaan Kota Samarinda. *ECOTROPHIC Jurnal Ilmu Lingkungan (Journal of Environmental Science)*, *17*(1), 137. https://doi.org/10.24843/ejes.2023.v17.i01.p10

Sakti, A. D., Sembiring, E., Rohayani, P., Fauzan, K. N., Anggraini, T. S., Santoso, C., Patricia, V. A., Ihsan, K. T. N., Ramadan, A. H., Arjasakusuma, S., & Candra, D. S. (2023). Identification of illegally dumped plastic waste in a highly polluted river in Indonesia using Sentinel-2 satellite imagery. *Scientific Reports*, *13*(1), 5039. https://doi.org/10.1038/s41598-023-32087-5

Sanyata, S. (2010). Teknik dan srategi konseling kelompok. *Paradigma*, *5*(9), 105–120.

Setiawan, F., Basuki, T. M., Santosa, B. H., Pramono, I. B., Chulafak, G. A., Rahmadya, A., & Nada, F. M. H. (2025). Developing algorithms for estimating total suspended solids (TSS) using unmanned aerial vehicle: A case study in the Upper Citarum River, Indonesia . *Journal of Degraded and Mining Lands Management*, *12*(2 SE-Research Article), 7379–7388. https://doi.org/10.15243/jdmlm.2025.122.7379

Sibanda, M., Mutanga, O., Chimonyo, V. G. P., Clulow, A., Shoko, C., Mazvimavi, D., Dube, T., & Mabhaudhi, T. (2021). Application of Drone Technologies in Surface Water Resources Monitoring and Assessment: A Systematic Review of Progress, Challenges, and Opportunities in the Global South. In *Drones* (Vol. 5, Issue 3, p. 84). Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/drones5030084

Slingsby, J., Scott, B. E., Kregting, L., McIlvenny, J., Wilson, J., & Williamson, B. J. (2023). A Review of Unmanned Aerial Vehicles Usage as an Environmental Survey Tool within Tidal Stream Environments. In *Journal of Marine Science and Engineering* (Vol. 11, Issue 12, p. 2298). Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/jmse11122298

Song, F., Zhang, W., Yuan, T., Ji, Z., Cao, Z., Xu, B., Lu, L., & Zou, S. (2024). UAV

Quantitative Remote Sensing of Riparian Zone Vegetation for River and Lake Health Assessment: A Review. In *Remote Sensing* (Vol. 16, Issue 19). https://doi.org/10.3390/rs16193560

Sousa, M. C., Martins, R., Eduardo, N., Maria, S., & Feio, J. (2025). Ecosystem services of urban rivers : a systematic review. *Aquatic Sciences*, *87*(1), 1–13. https://doi.org/10.1007/s00027-024-01138-y

Suharko, & Kusumadewi, C. D. M. (2019). Organisasi Masyarak Sipil dan Restorasi Sungai : Studi pada Gerakan Memungut Sehelai Sampah di Sungai Karang Mumus di Kota Samarinda. *Sosiologi Reflektif*, *14*(1), 81–104.

Szałkiewicz, E., Sucholas, J., & Grygoruk, M. (2020). Feeding the Future with the Past: Incorporating Local Ecological Knowledge in River Restoration. *Resources*, *9*(4), 47. https://doi.org/10.3390/resources9040047

Thornton, S. A., Setiana, E., Yoyo, K., Dudin, Yulintine, Y., Harrison, M. E., Page, S., & Upton, C. (2020). Towards biocultural approaches to peatland conservation: The case for fish and livelihoods in Indonesia. *Environmental Science \& Policy*, *114*, 341–351. https://doi.org/10.1016/j.envsci.2020.08.018

Zahra, S. C., Anggrainy, A. D., Mohd-Zaki, Z., & Bagastyo, A. Y. (2024). *Food waste reduction strategies in composting and recycling centers based on material flow analysis*. https://doi.org/10.22034/gjesm.2024.10.SI.11

Zeng, D., Chen, B., Wang, J., Innes, J. L., Lu, J., Guo, F., Yan, Y., & Wang, G. (2023). Evolving environmental awareness and shifts in management priorities: a socioeconomic lens on the min river basin, China. *Frontiers in Environmental Science*, *11*. https://doi.org/10.3389/fenvs.2023.1257089

Zulkifli, S., Jayanegara, A., Noorachmat, B. P., Fahmi, M. R., & Tandio, T. (2025). Sustainability Analysis of Environmental Waste Alleviation through Bioconversion using Black Soldier Fly Larvae: A Case Study in Depok City, Indonesia. *Jurnal Pengelolaan Sumberdaya Alam Dan Lingkungan (Journal of Natural Resources and Environmental Management)*, *15*(1), 19. https://doi.org/10.29244/jpsl.15.1.19

Zunariyah, S., Sunesti, Y., & Demartoto, A. (2025). Social transformation of winongo river bank people in managing domestic waste. *E3S Web of Conferences*, *605*, 3034. https://doi.org/10.1051/e3sconf/202560503034