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Diagnosing Fisheries Sustainability Challenges in Mrica Reservoir, Indonesia: An Application of the D(A)PSI(W)R(M) Framework

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ABSTRACT

In the context of climate change and food security, inland aquatic ecosystems support the livelihoods and resilience of small-scale fishing communities. However, these ecosystems face serious challenges related to water availability, ecological integrity, and environmental protection. In addition, Sudirman Reservoir in Banjarnegara, which supplies energy and supports fish biodiversity, faces ongoing sedimentation. This study examines aquatic resource management dynamics from a D(A)PSI(W)R(M) perspective. The framework conceptualizes causal links between human activities and environmental change, including pressures, observed states, and management responses. Semi-structured interviews were conducted in July 2025 with selected stakeholders from local government, community members, fish farmers, fishermen, fish sellers, and self-employed workers, and were supplemented with relevant literature. Data were analysed descriptively using the DAPSIR framework and its "butterfly model" representation. The results of the study revealed that the main threat to aquatic biodiversity is sedimentation, as all respondents stated that the impact of sedimentation is a decrease in fish numbers, which in turn leads to a decrease in the number of fish caught. The presence of sedimentation reduces the availability of usable areas for fishing activities due to the shallowing of inland waters. The situation is further worsened by water hyacinth covering the surface of the reservoir, limiting the range of movement available to fishermen, and accelerating habitat degradation. In response, management actions include flushing and dredging, while community initiatives include restrictions on fishing gear and local environmental conservation measures to protect fishing areas.

1. INTRODUCTION

Indonesia is an archipelagic country with extensive inland-water ecosystems; however, it faces serious challenges in managing these systems due to increasing anthropogenic pressures that often receive insufficient attention in planning and enforcement [1]. Inland waters play a crucial role in supporting food security and community well-being, particularly in addressing the challenges of climate change. Ecological roles they play include supplying clean water, habitats for biodiversity, and fisheries resources that are locally essential to communities. Moreover, in the light of the challenges of climate change, inland waters function as a buffer via carbon storage and micro temperature stabilization. A study [2] emphasized the significant role of freshwater ecosystems in supporting the food, tourism, and energy sectors, as well as their connections to local climate and socio-economic dynamics. However, inland waters also have their own set of environments that are fragmented and are subject to environmental degradation, particularly in reservoirs and lakes, which contribute to the decline in ecosystem services and socio-ecological vulnerability.

In this regard, a systematic approach to evaluating the pressures, impacts, and challenges of society for such changes is relevant, as proposed by the Drivers – Activities – Pressures – State – Impact – Welfare – Responses – Management or D(A)PSI(W)R(M) framework [3-5]. This model emphasizes the causal relationship between drivers, pressures, states, impacts, and responses, as well as ecosystem-based management. This framework has been widely adopted in water studies, as shown in the works of Faseyi et al. [6] in Ghana and El Behja et al. [7] in Morocco regarding the evaluation of environmental degradation and policies on conservation efficiency. The D(A)PSI(W)R(M) framework evolved from the classic DPSIR model used by research [8], which was itself an extension of Statistics Canada's Stress–Response (S-R) framework from 1979 [9], with the addition of Activities (A), Welfare (W), and Management (M) elements to enhance the diagnostic capabilities of social-ecological systems [3-5]. This approach allows for mapping the complexity of interactions between human activities (such as cage fish farming), environmental pressures (such as eutrophication), changes in ecosystem conditions, and policy and social responses.

One inland aquatic ecosystem with a typical potential for upstream-downstream conflict and multi-stakeholder interactions is the Mrica Reservoir in Banjarnegara. This reservoir is an inland aquatic ecosystem in the middle Serayu River that is experiencing habitat fragmentation and environmental degradation due to sedimentation [10, 11]. Several recent studies have shown differences in genetic variation in brek fish due to habitat fragmentation [12] and the invasive potential of flowerhorn in the reservoir [13, 14], amidst the dominance of tilapia and goby [14]. However, research on community responses and the efforts undertaken as a result of environmental degradation has not been conducted. Community and stakeholder responses to environmental change are crucial for considering the sustainability and acceptability of conservation strategies. The objectives of this study are to: (1) apply the D(A)PSI(W)R(M) framework to systematically diagnose the socio-ecological stress chain facing fishery resources in the Mrica Reservoir; (2) assess the pertinence and inadequacy of existing management measures; and (3) explore the potential and challenges of this region as an Other Effective Area-based Conservation Measures (OECM).

2. MATERIALS AND METHODS

2.1 Research Location

This research was conducted at the Mrica Reservoir in Banjarnegara, also known as the General Sudirman Reservoir. This reservoir is located in the Bawang and Wanadadi Districts, Banjarnegara Regency, Central Java (Figure 1). The construction of the Mrica Reservoir began in 1983 and began to be filled from April to October 1988. This reservoir has a watershed area of approximately 1,022 km², covering approximately 32% of the total area of the Serayu Watershed. The existence of the Mrica Reservoir has made a significant contribution to improving community welfare, both through the provision of electrical energy for the Java-Bali network, irrigation water supply for the Banjar Cahyana area of 7–11 m³/second, as well as the development of the fisheries, tourism, and flood control sectors in the downstream areas of the Serayu Watershed, especially in Banyumas and Cilacap Regencies [15].

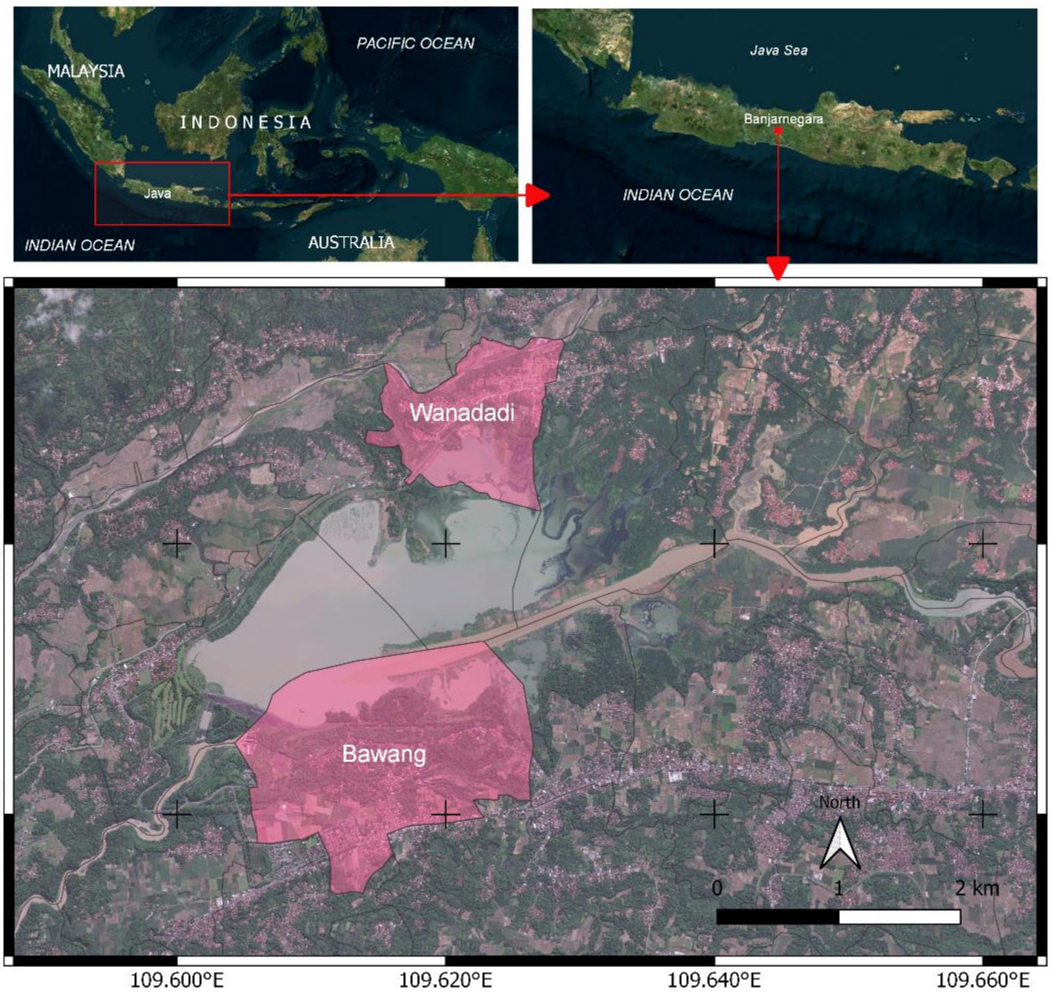

Figure 1. Research location map

2.2 Data collection

Data were collected through an inventory process that began with the collection of initial information through a secondary data-based study (desk study). This process was designed to recognize the condition of the Mrica Reservoit in the Serayu River and the key stakeholders who are involved in managing aquatic resources in the ecosystem. Based on the result if the desk study and field observation, key informants were identified for in-depth interviews. The interview process was further developed using a snowball sampling technique. The respondents who participated in the study included two local government representatives, two community leaders, three fish farmers, thirteen fishermen, one fish seller, and nine self-employed individuals. In total, this study consisted of thirty respondents (Table 1). Primary collection of data was through semi-structured methods such as interviews and discussions with stakeholders, and field observations. This research procedure and the data collection have been approved by the Ethics Clearance Council, National Research and Innovation, No. 095/KE.02/SK/05/2025.

Table 1. Information about respondents at the research site

Code	Identity	Location	Interview Date	Duration
G1	Government	Wanadadi	2 July 2025	1.5 hours
G2	Government	Wanadadi	2 July 2025	1.5 hours
LC1	Local community	Wanadadi	2 July 2025	1 hour and 40 minutes
LC2	Local community	Bawang	3 July 2025	2 hours
C1	Fish farmer	Wanadadi	2 July 2025	1 hour and 40 minutes
C2	Fish farmer	Bawang	3 July 2025	2 hours
C3	Fish farmer	Wanadadi	2 July 2025	1 hour and 40 minutes
F1	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F2	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F3	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F4	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F5	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F6	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F7	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F8	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F9	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F10	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F11	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F12	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
F13	Fisher	Wanadadi	2 July 2025	1 hour and 40 minutes
V1	Fish seller	Wanadadi	2 July 2025	1 hour
E1	Self-employed	Bawang	3 July 2025	2 hours
E2	Self-employed	Bawang	3 July 2025	2 hours
E3	Self-employed	Bawang	3 July 2025	2 hours
E4	Self-employed	Bawang	3 July 2025	2 hours
E5	Self-employed	Bawang	3 July 2025	2 hours
E6	Self-employed	Bawang	3 July 2025	2 hours
E7	Self-employed	Bawang	3 July 2025	2 hours
E8	Self-employed	Bawang	3 July 2025	2 hours
E9	Self-employed	Bawang	3 July 2025	2 hours

2.3 Data analysis

The research data analysis process began with identifying fragmented study areas, followed by mapping key stakeholders based on existing literature. Primary data collection was then conducted through field observation and semi-structured interviews based on the D(A)PSI(W)R(M) framework [16]. In-depth interviews were documented in field notes and/or recorded (where possible) for verbatim transcription to preserve the integrity of the information. All field notes, transcripts, and supporting documents were then compiled as a data corpus that was further analyzed using the Butterfly model to map the interrelationships between elements in the system (Figure 2).

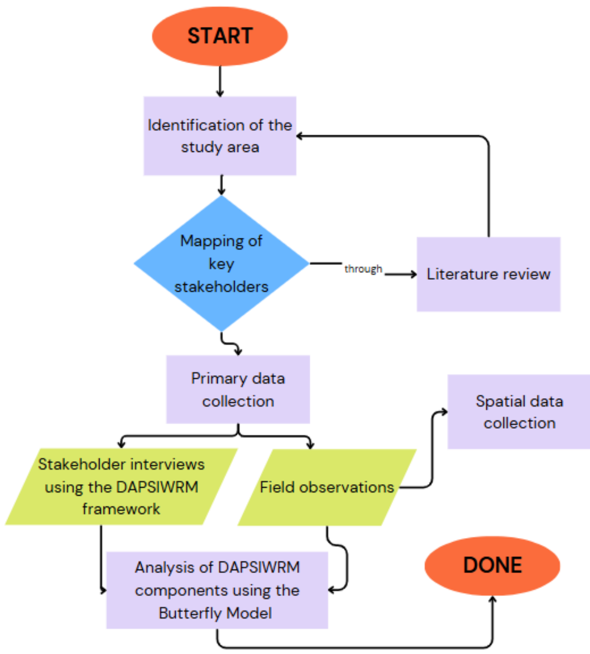

Figure 2. Research data analysis

A qualitative approach with an inductive strategy was used in this study, in which categories and patterns of analysis were constructed from field data. The analysis process was carried out through the following stages of thematic analysis: (1) repeatedly reading notes/transcripts to understand the context;

(2) performing open coding on relevant statements; (3) grouping codes into themes that represent the components of D(A)PSI(W)R(M); and (4) compiling interpretations of the relationships between themes. The coding process was carried out systematically, so that themes and concepts developed gradually from raw data to more general patterns.

Furthermore, the identification of "keywords" and "frequency" was obtained from the results of grouping codes that appeared repeatedly in stakeholder interview notes. The percentage of occurrence of each coded statement was calculated to identify the dominant issues in each component of D(A)PSI(W)R(M). The simple quantification was not intended as a statistical analysis, but rather as a tool to clarify the intensity of respondent attention to certain issues.

3. RESULTS

Based on Figure 3, the composition of respondents in this study was dominated by fishermen, who accounted for 43%, indicating that most of the information was obtained from the main actors involved in the utilization of inland fishery resources. The second largest group was entrepreneurs or self-employed workers, accounting for 30%, followed by fish farmers at 10%. Meanwhile, respondents from the government and local community each accounted for 7%, and fish sellers accounted for 3%. This composition illustrates the diversity of the respondents' backgrounds, with a predominance of groups that are directly dependent on fisheries and water activities, making it relevant to describe the social and economic conditions at the research site.

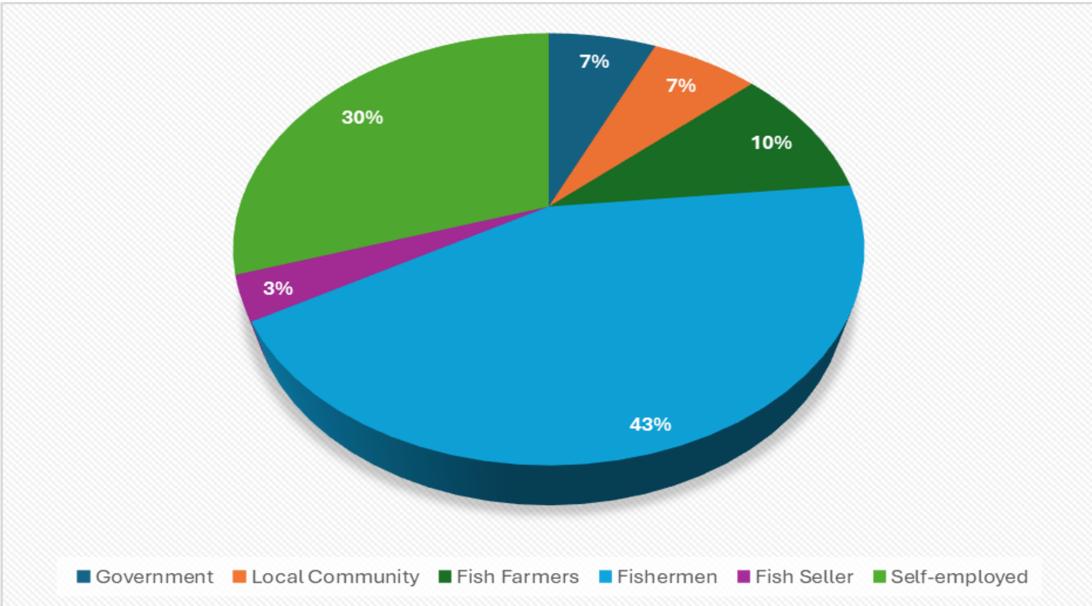

Figure 3. Composition of selected respondents

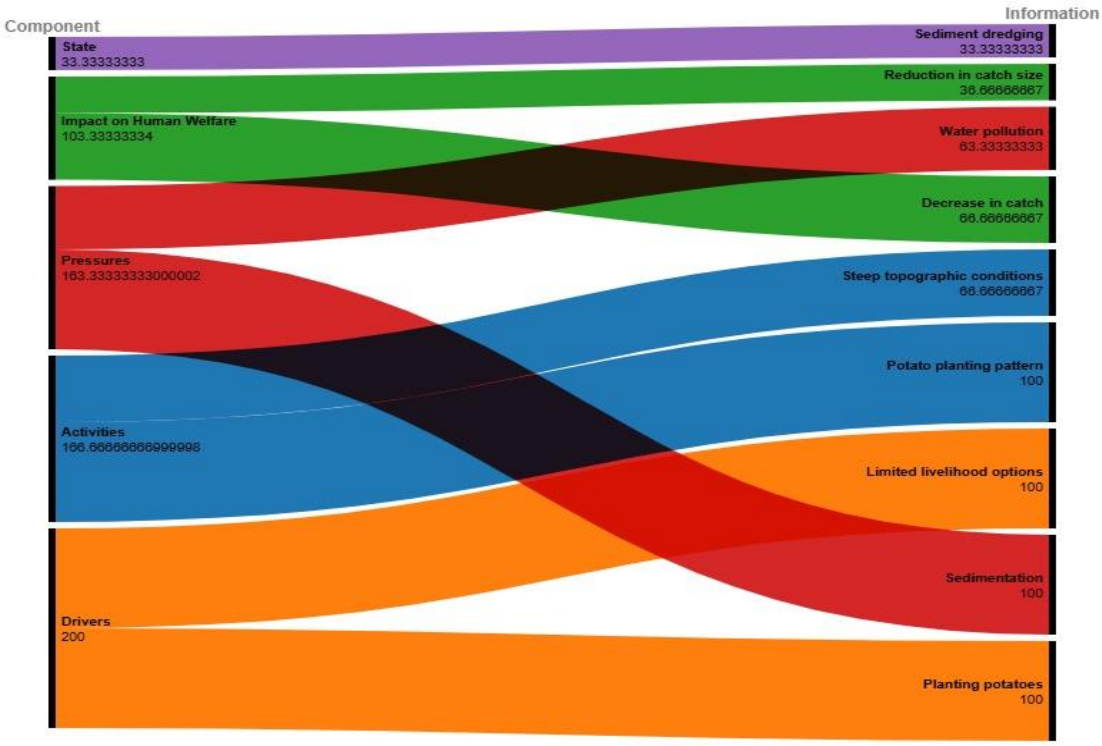

Figure 4. DAPSIR component relationships with respondent frequency and keywords

In general, complex socio-ecological interactions occur in the Mrica Reservoir - Serayu River, which are best explained within the framework of DPSIR development. The expanded DPSIR framework, D(A)PSI(W)R(M), is used to map problems arising from imbalances between components in the river ecosystem. Anthropogenic changes in the upstream area, lack of alternative livelihoods, market demand, and the economic value of agricultural commodities act as drivers of pressure on inland water ecosystems, including soil erosion, sedimentation, eutrophication, and reservoir siltation.

Based on research in 2019 showed that the Mrica Reservoir had accumulated 122.073 million m³ of sediment, with a sedimentation rate of 4.069 million m³ per year. This condition indicates that the reservoir will likely not be able to survive its 50-year design life [17]. The Mrica Reservoir itself is located in the middle reaches of the Serayu River. The vastness of the Serayu River Basin creates a wide variety of activities that impact the condition of this watershed. According to the ecosystem approach, a watershed can be divided into three parts: upstream, midstream, and downstream [18]. Consequently, everything that occurs in the upstream area will impact downstream areas through the hydrological cycle. This also applies to the Serayu Watershed.

Furthermore, the relationship between components in the DAPSIR framework based on respondent frequency and keywords that appear, visualized in the form of a flow chart, is presented in Figure 4. The figure shows that the main drivers are potato cultivation activities and limited livelihood options for the community related to potato cultivation patterns in steep topography, which in turn cause environmental pressures such as sedimentation and water pollution. This pressure affects the state of the water system, as reflected in management responses such as sediment dredging. These changes in environmental conditions then have an impact on human welfare, particularly a decline in the quantity and size of fish catches, which ultimately contributes to fishermen's income. The thickness of the lines in each relationship indicates the frequency of respondents, which indicates that sedimentation and water pollution are the most dominant pressures, while declining catches and limited livelihoods are the most significant socioeconomic impacts.

3.1 Drivers

Socioeconomic conditions in the watershed area strongly affect the sustainability of the watershed resources. Research [19] shows that four districts, Wonosobo, Banjarnegara, Purbalingga, and Banyumas, have more than 2,400 people per square kilometer. The dominant sector in theeconomy is agricultural. Both high population density and dependence on the agricultural sector are indicators of regional vulnerability. Thus, the Serayu watershed area covered by the mentioned four regencies is categorized as having a very high level of vulnerability. The factor that most influences this vulnerability is the relationship between the population and the land, characterized by high population density and the dominance of the agricultural sector in the economic structure. To illustrate this, in the Dieng area (which is part of the upper Serayu sub-watershed), steeply sloping land is still used for agriculture.

One of the main activities in the agricultural sector is the cultivation of potatoes, whose production continues to increase year after year. This is due to the high market demand, which encourages farmers to cultivate potatoes. It is in line with 100% of respondents who said that the cultivation of potatoes in the upstream area is very dependent on relatively stable market demand and a higher selling price compared to other horticultural commodities, whose price movements tend to be volatile. In addition, potatoes are considered to give better economic returns because of their shorter harvest period. In contrast, crops such as corn can only be harvested once every year because they depend on seasonal patterns and calculations of profit and loss. Meanwhile, potato cultivation allows farmers to reap their produce up to three times per year, which makes it more economically profitable. Farmers also understand that soil fertility is no longer as it used to be around 1985. In the past, less fertilizer was used because soil fertility was sufficient to support crop growth. When other crops required much water, potatoes needed less but could still thrive and give high yields. However, nowadays, if not given a lot of fertilizer, potato crops will not produce [20].

Furthermore, research [20] reveals that the implementation of potato monoculture farming, which focuses on increasing crop yields, also has a broader impact on the community. The significance of the Dieng region, located upstream of the Serayu River Basin, cannot be overstated because of its importance in the conservation of the environment of the downstream region. In the event of environmental degradation of the upstream region, it is bound to have an effect on the regions downstream. Indeed, the critical nature of land condition has resulted in considerable soil erosion, especially during the rainy seasons. It is during this period that the soil sediment reaches the river systems and eventually oozes into various points, of which the Mrica Reservoir is one.

The community is, in essence, aware that potato farming is a contributing factor to increased erosion and sedimentation culminating in the Serayu River Basin. However, 100% of the respondents opined that due to limited livelihood opportunities in the upstream area, the community is still dependent on potato farming because it is the only source of livelihood. This is a classic dilemma of needing to choose between economic needs and the need for conservation. Indeed, the awareness of the community towards the environment is a significant factor. The awareness of the community towards the environment is established. However, the said awareness does not significantly contribute to behavioral change. The community is aware of the impact on the environment. However, the change to more environmentally friendly activities is motivated by the presentation of concrete evidence of the effectiveness of alternative activities. In this respect, education, in the conventional sense, is not fundamentally what is needed. What is required in the given scenario is not conventional education but an evidence-based approach that is capable of illustrating the benefits of alternative activities and motivates the community to change voluntarism [21].

3.2 Activities

The Mrica Reservoir is part of the Serayu River and thus inseparable from the impacts brought by the activities of the community in its upstream area. Unsustainable agricultural practices in the Dieang Plateau, especially in the intensive horticulture sector, are contributing to pressures for the sustainable functioning of the Serayu Watershed ecosystem. Land degradation in the upstream areas contributes to increased sedimentation in the downstream area, including that of Mrica Reservoir [22].

Information covering 100% of the respondents revealed that the reason for the reservoir's silting was the activities related to agriculture upstream, especially the cultivation of potatoes in the Dieng area, resulting in soil erosion. Increasing erosion rates and increased chemical use have negatively impacted the soil. Mountainous forest areas have been completely converted to potato fields. Bare hillsides are now filled with potato crops. Erosion-resistant tree stands are minimal, if not virtually non-existent [20].

Most of the sediment deposited in Mrica Reservoir comes from the Serayu River Watershed, which is very vulnerable to erosion. It is confirmed by 66.67% of respondents who said that high-level erosion is affected by steep topography and also intense agricultural activities. The dominance of agricultural land use further increases the potential for erosion, given that agricultural practices in this region are generally intensive and lack extensive application of land conservation principles [23].

3.3 Pressures

The pressure that occurs at Mrica Reservoir comes under endogenic managed pressures. From the information given, it was evident that 100% of respondents noted that the main problem that occurs at Mrica Reservoir is sedimentation, which causes a great amount of silting of the water. The effect of this silting of water causes a reduction of water volume, thus affecting the physical condition of the water directly, especially because of agricultural activities upstream of the river that do not follow any conservation measures, leading to erosion of the land, resulting in sedimentation of water flowing through it. In addition to sedimentation pressure, the trophic status of the reservoir has also been reported to be eutrophic to hypereutrophic [24], indicating high nutrient loads and water productivity that have the potential to exacerbate water quality degradation.

Moreover, one person talked about sedimentation deposits, which are estimated at 80-85%. This effect of sediment has resulted in the silting up of the reservoir. For example, the reservoir area around Bawang Subdistrict now only has around 15-20% of its original capacity. As a result of this silting, the number and types of fish have declined dramatically. The community began to notice significant silting in 2015, whereas in 2012, conditions were still relatively good. The initial depth of the reservoir was estimated to be 150 meters, but currently it is likely only around 4–5 meters. In addition, 63.33% of respondents mentioned that factors affecting fish catches in Wanadadi Subdistrict include river and reservoir water pollution, as well as severe sedimentation in the reservoir. It is estimated that the volume of water remaining in the reservoir is currently only about 10% of its original capacity.

3.4 State change

The D(A)PSI(W)R(M) framework uses the term State change (rather than State) because its primary focus is on changes caused by human activities. State change in this context refers to natural (ecological) systems undergoing change due to one or more pressures. This includes physicochemical variables (such as sediment type, dissolved oxygen levels, organic matter, and so on) as well as biological health at all levels of organization from cellular systems, individuals, populations, communities, to ecosystems.

In addition to siltation, 33.33% of respondents mentioned that sediment dredging activities carried out to reduce sedimentation actually worsened water quality, as indicated by increased turbidity levels. These increased turbidity levels put additional pressure on aquatic ecosystems. On the other hand, the lush and widespread growth of water hyacinth in the reservoir area requires utilization efforts [25]. This plant grows quickly and easily, covering most of the reservoir's surface. One respondent also mentioned that the growth of water hyacinth covering the reservoir's surface makes it difficult for fishermen to carry out their fishing activities.

Time series data on silting in 2005 indicated that the average annual sediment inflow into the reservoir was 4,210,000 m³, bringing the total sediment inflow into the Mrica reservoir to 71,730,000 m³, meaning that 48% of the reservoir's volume is currently filled with sediment [26]. It should be noted that although the Serayu River is a major contributor of sediment to the reservoir, these measurements represent sediment from a single river segment and therefore do not fully reflect the overall sediment dynamics across the entire watershed. Other data states that since its inception in 1989 to 2008, the Mrica Reservoir experienced sediment accumulation of approximately 83,791,000 m³ from its initial storage capacity of 148,287,000 m³, meaning that approximately 56.51% of the reservoir volume has been filled with mud deposits. Furthermore, the volume of sediment accumulated in the reservoir as of October 2018 reached 122.073 million m³ or 82.22% of the total reservoir volume [23]. Based on research [27], over the past few years, the level of sedimentation originating from the upstream segment of Wonosobo Regency in the reservoir has shown worrying conditions, as shown in Table 2.

Table 2. Suspended sediment load entering Mrica Reservoir via the Serayu River from the Wonosobo Regency segment

Year	Mrica Reservoir Sediment (m³/year)	Suspended Sediment from Serayu River (m³/year)	Contribution of Suspended Sediment from the Serayu River in Wonosobo to the Total Sediment in the Mrica Reservoir (%)
2016	6,839,330.00	4,433,494	64.82%
2017	8,190,072.06	4,058,604	49.56%
2018	5,623,806.24	2,232,645	39.70%
2019	6,830,332.94	2,889,591	42.31%
2020	6,428,998.49	2,676,834	41.64%
2021	10,302,911.98	6,588,680	63.95%
2022	10,837,956.37	4,165,389	38.43%
2023	7,996,680.53	3,450,948	43.15%

Source: Study [27].

3.5 Impact on human welfare

One respondent mentioned that sedimentation has caused fishermen who make their living in the reservoir to experience a decline in income. Another impact of this silting is the growth of water hyacinth, which covers almost the entire surface of the reservoir, making it difficult for fishermen to carry out their fishing activities. In addition, fish species have begun to decline, as evidenced by the disappearance of fish that were once characteristic of the Serayu River.

One fisherman also mentioned that not only fishing activities have been affected, but aquaculture has also been impacted by sedimentation deposits. The high level of silt has caused a decline in pond production. This condition has led to a decrease in the number of fish species found, mainly due to the disruption of the nekton habitat under the surface covered by water hyacinth. Fish populations have also declined due to a combination of siltation, pollution, and habitat degradation. This decline in fish populations has led to a decrease in catches for both fishermen and anglers. This has had a direct impact on fishermen's incomes, further worsening their socio-economic conditions.

Furthermore, 66.67% of respondents stated that a few years ago, people could still easily catch large quantities of large fish in the reservoir. However, this situation has now changed drastically. Fish can still be found, but their numbers have greatly decreased and their quality is not as good as it was five years ago. This reservoir is still the major source of livelihood among most members within the community, especially fishermen, within Wanadadi District. The community, particularly fishermen, is starting to become worried that their sources of livelihood are about to be taken away from them due to the deteriorating environmental conditions.

The current condition, on one side, shows that it is getting harder and harder to catch fish. Fish are still recorded to be present, but the numbers have decreased considerably compared to five years ago. It signals a big decline in the population of fish. This decline straightforwardly threatens the livelihood of the fishermen because they rely on the catch every day. As one of the respondents said, "Fish are currently sold poorly, and snakehead fish, which used to be the best-selling fish, can hardly get it now." Business is currently slow, unlike in previous years. Profits range from around IDR 50,000 to 200,000 per day, depending on the availability of fish.

In addition, 36.67% of respondents pointed out that there were additional sources of income from fishing activities. In 2010, fishing alone would sustain a family. However, things have changed, and currently, people fish for hobby purposes only, as they do not even catch enough fish to take home.

3.6 Responses and management measures

The management process in the context of the D(A)PSI(W)R(M) model is significantly controlled by the governance context in which policies, regulations, administration, and economic and technological instruments are included. Response, in this research context, is defined as management actions that are carried out to manage drivers, activities, pressures, and impacts in relation to human well-being and environmental conditions. Through this definition, the management response in the context of the D(A)PSI(W)R(M) model does not just respond to change but can be made to address change in various stages of the process [28, 29].

The demonstration of the response to avoid drivers can be shown in the development of dairy goat farming as an alternative to potato farming in the upstream region. This is done to create alternatives to land use pressure, thus slowing down the rate of land erosion caused by intensive farming practices. By incorporating the farming of livestock with the cultivation of pasture crops and hardwood trees like calliandra, indigofera, moringa, and katuk, not only is the livelihood diversification of the people demonstrated, but also the land conservation response as a means of live vegetation rehabilitation.

The response to controlling activities is by implementing the Social Forestry Program with an agroforestry approach. This system allows communities to keep farming while maintaining vegetation cover through planting trees [30]. Tree planting activities carried out by Perum Jasa Tirta I together with PT PLN Indonesia Power in the Serayu watershed are one of the concrete examples of erosion control and improvement of land cover quality (Figure 5). This response is strengthened by support from regional policies through the 2025-2045 RPJPD of Wonosobo Regency, which confirms the direction of development based on environmental sustainability and integrated watershed management.

Figure 5. PT Indonesia Power Mrica energy forest plant conservation area

Responses to mitigate the impacts of reservoir siltation on the fisheries sector are carried out through community-based management. The fisherman and angler groups have started to protect the reservoirs by controlling the fishing gear, fish size, and even the establishment of core zones or no-take zones. Another measure is the restocking of fish species, including Bonylip barb and Java barb, to preserve the ecological balance, while introduced species are controlled [31]. However, measures to address the effects of reservoir siltation face a few challenges due to the need for a more comprehensive conservation approach for the restoration of non-cultivated local fish species.

Responses to mitigate pressures and improve state change were carried out primarily by PT Indonesia Power through dredging and flushing sediment in the Mrica Reservoir, as well as the construction of a sabo dam in the upstream area [17]. Although these activities were able to control some of the sedimentation, the rate of sedimentation was higher than the control capacity, resulting in the reservoir's lifespan being shorter than originally planned [32]. The involvement of Perum Jasa Tirta I equally outlines a significant component of this management response that entails technical planning, monitoring of water quality, dredging of rivers, as well as empowerment of the community [33]. Based on the results derived from the process and the management response generally, it is evident that key outcomes of the management response have been focused on addressing different aspects of management response activities and that the success of such an outcome significantly depends on synergy developed between the upstream watershed area and conservation efforts. The results of the D(A)PSI(W)R(M) mapping are presented in Figure 6.

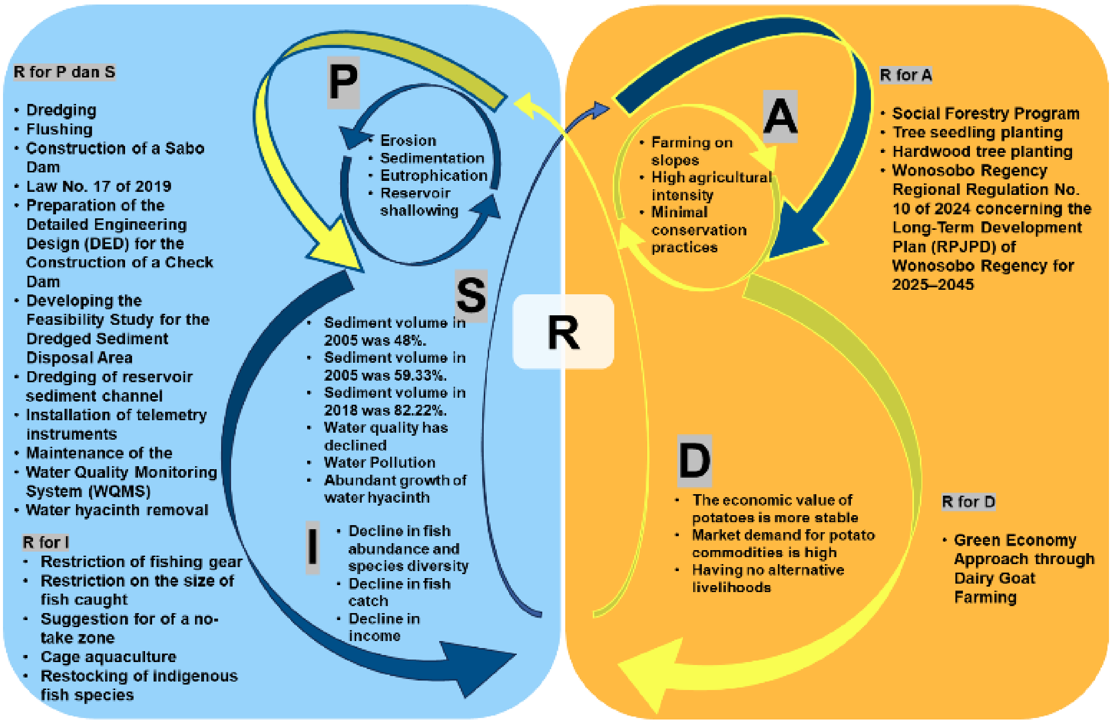

Figure 6. DAPSIR framework for inland fisheries in Mrica Reservoir

4. DISCUSSION

D(A)PSI(W)R(M) can facilitate such an understanding by the separation of activities and pressures. As the above results indicates, the implementation of the D(A)PSI(W)R(M) framework with regard to the Mrica Reservoir implies the complex interaction of human activities upstream with the deterioration of the water system. As a result of such activities, intensive land use upstream of the Serayu River results in soil erosion, which negatively affects the quality of the water used for fishing activities. Such a condition has significant negative implications for the aquatic system as well as the welfare of the fishermen. A similar condition was also identified with regard to Inle Reservoir in Myanmar [34]. Such a condition resulted from the transformation of the land for the sake of intensive agriculture.

The effect of sedimentation in the Mrica Reservoir is seen in the reduction of the water depth. The estimates remain at only 10-20% of the initial volume of the reservoir. Consequently, the reservoir is not able to hold the water that falls during the rains. This reduces the aquatic ecosystem. This phenomenon is similar to what is taking place in Lake Kyoga, Uganda. Land-use changes resulting from increased agricultural activities have caused sedimentation in the lake. This change has drastically contributed to the reduction in the rate of production of fish resources in the lake [35]. It is also evident that the degradation of the aquatic resource could result from changes taking place outside the area.

Alterations in the physical condition of these bodies of water brought about by siltation, as identified by increased turbidity and pollution, are contributing factors to the change of habitat quality. As observed in Mrica Reservoir, the growth of water hyacinths reflects the eutrophic conditions, which constrain the movements of fishermen to the potential fishing areas. From the perspective of the welfare of the people involved, the silting of Mrica Reservoir impacts the catch of fish as well as the earning of the fishermen. As identified by research [2], increased anthropogenic forces as well as siltation are responsible for the growth of aquatic weeds, causing a decline in biodiversity as seen in Lake Malomba, Malawi.

The mitigation activities observed in the Mrica Reservoir are related to the application of community-based management practices, including the implementation of local fish restocking, fish protection zones, and fishing gear management by local fishing groups. The Banjarnegara Regency Agricultural, Fisheries, and Food Security Office has practiced local fish restocking activities by distributing a total of 188,000 Bonylip barb and 97,000 Java barb fingerlings from 2022 to 2024 (Figure 7). Several existing fish protection zones where fish reproduction is allowed are indentified in Figure 8. This activity was observed to have fostered community awareness on the need for the maintenance of a balanced ecosystem. To apply the adaptive management approach according to the principle of co-management in fishery management, the local community is to contribute to the management of the fishery resource. A study on ancient tank systems, specifically in Sri Lanka, was able to sustain the fishery resources by installing sedimentation dams and fish conservation zones [36].

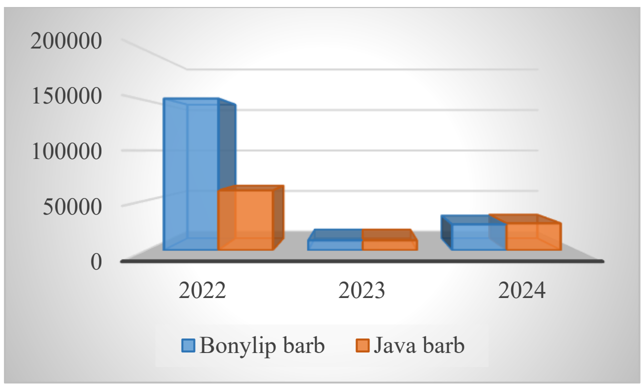

Figure 7. Restocking of local fish in Mrica Reservoir during 2022-2024

Figure 8. Several potential fish protection areas in Mrica Reservoir

In addition, Table A1 offers an integrated evaluation of them management responses at Mrica Reservoir, Serayu River. This integrated assessment was conducted using the D(A)PSI(W)R(M) model, which identifies the effectiveness different interventions carried out through different activities, impact, changes, drives, and pressures. Table A1 indicates that responses oriented towards the upper parts of the reservoir, which include actions like diversification of livelihoods and agroforestry, have higher effectiveness when carried out in the long term, thus generating synergies. Similarly, interventions oriented towards the lower parts of the reservoir, which include dredging, have temporary effects. For the most part, the effectiveness of these responses is confined to a shorter period. However, it is crucial to understand that effective management of the reservoir depends on the synergy between different interventions. The level of effectiveness depends on the rate of synergy that can be achieved. In a similar sense, responses oriented towards policies have a profound effect on the implementation of actions. Policy-based responses can help in aligning actions collectively to ensure maximum effectiveness. An integrated approach, therefore, requires combining the processes of fisheries management with ecological restoration.

When linked to the concept of OECM, the criteria for an area to be considered a potential OECM area after the area is declared outside the protected area are that the area is regulated and managed. The existence of PT Indonesia Power as the legitimate manager of the Mrica Reservoir is very important in managing threats to biodiversity, in this case, sedimentation that occurs in the area (Figure 9). In addition, the ability to manage potential new threats, such as the presence of water hyacinth, has also been carried out through periodic monitoring activities with the involvement of academic and community reports.

Figure 9. PT Indonesia Power's efforts to mitigate threats in the Mrica Reservoir

Furthermore, the next criterion is how to achieve a sustainable and effective contribution to in-situ biodiversity conservation. In this context, threats, both existing and anticipated, can be effectively addressed by preventing, significantly reducing, or eliminating them, and by restoring damaged ecosystems. Several efforts, such as dredging and flushing, are being implemented to mitigate existing threats. This is supported by mechanisms, such as policy and regulatory frameworks, that are implemented to recognize and respond to existing and/or new threats to biodiversity.

Thus, good management of inland fisheries involves not only technical innovations and adaptations at lake/reservoir levels but also complete reforms at upstream levels. Land usage changes, soil conservation processes, and community contributions to watershed management are vital components. Studies at Lake Kyoga, Uganda [35], and in Malawi [2] highlight that cross-sectoral engagement is vital for sustaining fisheries resources. Therefore, consistent application of the D(A)PSI(W)R(M) framework, with upstream–downstream integration, is a promising approach for addressing the ecological and social complexities of the Mrica Reservoir and other inland water systems.

5. CONCLUSIONS

The link between upstream human activities through intensive agricultural activities on steep land and minimal conservation practices, followed by environmental problems in the Sudirman Reservoir, which is the middle area of the Serayu River, in the form of sedimentation, eutrophication, and siltation. These impacts result in a decline in water quality, excessive growth of water hyacinth, and a decrease in catches that impact fishermen's incomes. Technical interventions through dredging, Sabo dam construction, fishing gear management, and social forestry programs and green economy approaches are carried out as mitigation efforts. In addition, the management, in this case, PT Indonesia Power, has indirectly implemented OECM criteria to address threats to the sustainability of existing biodiversity.

An integrated strategy combining technical interventions, land conservation, and community economic empowerment is needed. In upstream areas, focus on land rehabilitation through hardwood tree planting, conservation agriculture practices, and income diversification. In reservoir areas, sediment management must be accompanied by continuous water quality monitoring, restrictions on intensive cultivation, and restocking of native fish in preservation areas to maintain ecosystem balance. Integration of cross-sectoral programs with support from regional policies is key to long-term success.

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APPENDIX

Table A1. Evaluation of management responses within the D(A)PSI(W)R(M) framework in the Mrica Reservoir, Serayu River

Response Orientation	Targeted D(A)PSI(W)R(M) Element	Main Management Measures	Key Actors	Effectiveness	Synergy Assessment	Main Objectives and Implications
Avoid Drivers	Drivers	Livelihood diversification through dairy goat farming, combined with planting of fodder and perennial trees	Department of Food, Agriculture, and Fisheries; Upstream communities	High (long-term) – relatively cost-effective, preventive, reduces erosion at the source while strengthening local economic resilience	Strongly synergistic with downstream sediment control and reservoir management by reducing sediment inflow	Reducing dependence on commodities with a high risk of erosion; suppressing the rate of land degradation from upstream, while strengthening the economic resilience of communities
Regulate Activities	Activities	Agroforestry under the Social Forestry Program, allowing potato cultivation while maintaining tree cover	Department of Environment; PT Indonesia Power	Moderate–High – medium cost, gradual impact; effectiveness depends on farmer compliance	Synergistic with driver-avoidance strategies through vegetation-based erosion control	Control intensive agricultural practices, increase vegetation cover, and reduce soil erosion vulnerability.

Response Orientation	Targeted D(A)PSI(W)R(M) Element	Main Management Measures	Key Actors	Effectiveness	Synergy Assessment	Main Objectives and Implications
Regulate Activities (Policy)	Governance / Response	Long-term regional development policy (RPJPD Wonosobo 2025–2045), emphasizing environmentally based development	Local Government	Indirect but essential – provides institutional stability and policy continuity	Enabling synergy across all management responses through legal and planning coherence	Ensuring the sustainability of watershed management institutionally and across sectors in the long term
Mitigate Pressures & Restore State	Pressures & State Change	Routine dredging and flushing of reservoir sediments	PT Indonesia Power	Low–Moderate cost-effectiveness – high operational cost, rapid but temporary benefits; does not address root causes	Weak synergy if implemented alone; effectiveness increases when combined with shown upstream erosion control	Control reservoir sedimentation, maintain reservoir capacity, slow down the decline in reservoir age
Mitigate Pressures (Technical Measures)	Pressures	Construction of sabo dams and check dams; river channel dredging	Perum Jasa Tirta I; Serayu - Opak River Basin Center	Moderate – less costly than reservoir dredging but still largely reactive	Partial synergy with upstream land rehabilitation as intermediate sediment traps	Maintaining the hydrological function and quality of the Serayu River Basin aquatic ecosystem
Mitigate Impacts	Impacts on Human Welfare	Restrictions on fishing gears and fish size; establishment of core/no-take zones	Department of Fisheries; Fisher groups	High socio-ecological effectiveness, low cost, community-based enforcement	Highly synergistic with dredging by protecting fish stocks and ensuring ecological benefits persist	Maintaining the sustainability of fish resources and the stability of fishermen's income
Mitigate Impacts (Fisheries)	Impacts & State	Restocking of native fish species (e.g., Osteochilus vittatus, Barbonymus gonionotus); prohibition of non-native cultured species	Department of Fisheries; Fisher groups	Moderate–High, contingent on habitat quality	Aligned with sediment and water quality management efforts	Protecting the balance of the ecosystem and preventing the dominance of introduced species
Restore State (Long-term)	State Change	Recovery of native, non-cultured fish populations using upstream tributaries as broodstock sources	Multi-stakeholder collaboration	Potentially high, but requires time and cross-sector coordination	Strong synergy across upstream–downstream ecological restoration measures	Sustainable restoration of local fish populations of ecological and cultural value
Social Adaptation	Human Welfare	Livelihood adaptation and occupational shifts among fishers	Fishing communities	Low as an ecological solution, but socially important	Weak synergy if not accompanied by ecosystem restoration	Reducing socio-economic vulnerability due to declining catches