

Review

A Holistic Review of Lake Rawapening Management Practices, Indonesia: Pillar-Based and Object-Based Management

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Abstract: Lake Rawapening, Semarang Regency, Indonesia, has incorporated a holistic plan in its management practices. However, despite successful target achievements, some limitations remain, and a review of its management plan is needed. This paper identifies and analyzes existing lake management strategies as a standard specifically in Lake Rawapening by exploring various literature, both legal frameworks and scholarly articles indexed in the Scopus database and Google Scholar about lake management in many countries. By using Publish or Perish with the keywords “lake management” OR “management of lake”, 1532 and 1990 works from the Scopus database and Google Scholar, respectively, have been reduced 37. The results show that there are two major types of lake management, namely pillar-based and object-based. The holistic review has resulted in nine points of pillar-based management, which consists of conceptual paradigms as the foundation, and 11 points of object-based management to restore or preserve the lake, which is in line with the form of programs and activities. Overall, Lake Rawapening management should be concerned with finance and technology when applying pillar-based management, and it should include more activities within programs on erosion-sedimentation control as well as monitoring of operational performance using information systems to ensure the implementation of activities within programs in applying object-based lake management.

Keywords: pillar-based lake management; object-based lake management; Lake Rawapening

1. Introduction

Lake ecosystems encompass the water body, riparian zone, and catchment and are composed of not only biogeophysical but also socioeconomic and institutional aspects. They also store and offer various ecosystem services, from provisioning to regulating, supporting (habitats for plants or animals), and cultural [1–3]. These varied ecological benefits have been increasingly utilized for socioeconomic purposes, especially provisioning and cultural services. Their intensive exploitation would, however, reduce the values of other ecosystem

services and lower the lake's resilience [4] to the threat of disasters called ecosystem disservices [5].

This threat is not direct and does not occur rapidly, but the impact is real and can be massive in scale [6]. Flood hazards due to channel overflow in the lower course, flash floods at slope breaks, and landslides in the upper course are among the indirect results of environmental degradation in the catchment area—i.e., a process or condition commonly associated with erosion–sedimentation dynamics that contribute to silting and, thus, reduce the lake's capacity to store water. Therefore, disaster threats in catchments can be referred to as environmental hazards, with the elements of threat originating from environmental stressors [3]. Lakes exposed to accelerating environmental hazards are considered national priorities, which, at least in Indonesia, are guaranteed damage control and recovery of their ecological functions in the national regulation scheme [7].

Lake Rawapening is one of the national-priority lakes in Central Java Province, Indonesia. It is a relatively large and shallow lake despite depth modifications [8], making it an interesting research object. Located in the tropics, Lake Rawapening has a warm water temperature that, in combination with nutrient supplies from the rivers emptying into it, promotes rapid growth and proliferation of (invasive) aquatic plants [9]. Consequently, there is a pressing need to address the likely consequences of these characteristics. On the one hand, the lake suffers environmental damage to part of its water body, riparian zone, and catchment, but on the other hand, it has a significant strategic value for the local communities. Through damage control and recovery measures designed for the sustainability of national priority lakes, it is expected that the lake will continue to give varied benefits [7].

The government's concern for lakes in Indonesia is manifested in the following conferences and supporting documents [10]. The 2009 Bali Agreement on Sustainable Lake Management in the first National Conference on Lakes was signed by nine ministers. Then, the second conference in 2011 in Semarang designed the Lake Recovery Movement (Germadan), which bases the Lake Recovery Action Plan for 15 lakes in Indonesia, including those with the Priority I status. Specifically for Lake Rawapening, five documents outline the management planning: Rawapening Area Management Planning issued by the Central Java Development Planning Agency and the Research Center for National Development Planning, Universitas Gadjah Mada (2000); Environmental Governance Planning Project for Lake Rawapening Catchment Area by the Semarang Regency Government (2000); Developing Action Plan for the Rawapening Area by the Central Java Development Planning Agency (2005); Germadan Rawapening by the Ministry of Environment (2011); and Designing Masterplan on Settlement Infrastructure Development in the Rawapening Area by Directorate General of Settlement Area Development, a subdivision of Directorate General of Human Settlements in the Ministry of Public Works and Housing (2018). However, the government had to dissolve Germadan due to major challenges in its development [8]. The most recent document consulted in current management practices is the Lake Rawapening Management Plan (2019).

The 2019 management plan was prepared to address problems arising from the degradation of function and carrying capacity of the catchment area, riparian zone, and water body. This document stimulates the participation of the community, business sector, and government based on the principles of integration and equity and is committed to implementing natural resources management in fair, effective, responsible, and sustainable manners [10]. It was also designed for a medium term of five years from 2019 to 2024, although some programs started in 2018.

There have been many previous studies on Lake Rawapening by both universities and government agencies [10], which can be broadly divided into two themes: potentials and problems/threats. The potential theme includes potentials originating in abiotic [11–15] and biotic components [16,17], while studies on problems or threats to the lake are concentrated on erosion–sedimentation [18–21], eutrophication [22,23], water hyacinth invasion [24,25], and other forms of degradation [26]. Abiotic and biotic components provide socioeconomic

opportunities to be used for the local people's livelihoods [27–34], which raise problems associated with massive agricultural fertilization [35] and the use of floating net cages for aquaculture [36]. The environmental complexity of the lake has been investigated from institutional, managerial, and political perspectives [6,8,37–42], making it one of the complex environmental commons (CEC) [43]. Studies that explicitly discuss the lake management plan from its aspects are still limited.

The plan documents describe recovery programs and activities in detail [10]. Hidayati et al. [42] performed an evaluation study of a recovery program aiming to control the water hyacinth population. There are only a few studies reviewing and assessing current management practices, even though the implemented programs are far from what were previously planned. Some projects are able to run until they reach the predefined targets, whereas some others are modified to adjust to the budget or even discontinued due to, among other reasons, the COVID-19 pandemic impact [44]. Based on the above reasons, a holistic review of the lake management plan becomes necessary.

2. Methods

This review looks into examples of lake management worldwide without strictly limiting the specific management criteria inputted into the literature screening. Its aim is to explore as comprehensively as possible. In summary, the order of the screening and selection of the reference material is shown in Figure 1. The sources of information used to access relevant scientific publications were Scopus and Google Scholar, with the keywords “lake management” OR “management of lake” for the search.

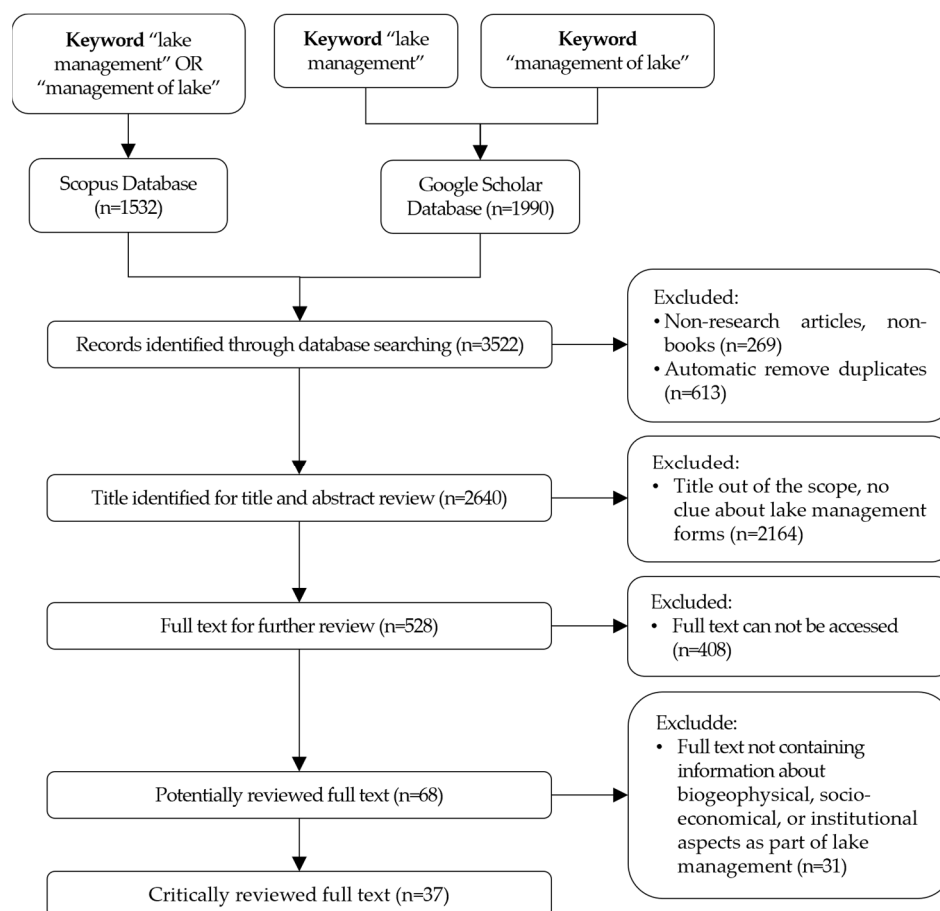


Figure 1. Flow chart of the selection of reviewed articles and books.

The Boolean operation “OR” on the Scopus search algorithm provides a wider scope in the Scopus database [45]. This study only used documents from English research journals

and books. Google Scholar is an alternative to a scientific journal database [46]. Data retrieval on Google Scholar has also been done with the support of Publish or Perish application [47]. Publish or Perish is open-source software that can be used to retrieve and analyze citations in a journal database [48]. Publish or Perish can be downloaded through the website <<https://harzing.com/resources/publish-or-perish>, (accessed on: 18 October 2022)>. The search results from Publish or Perish can be stored in format *.RIS [49]. RIS data can be imported into the reference manager application such as Zotero or Mendeley. Publish or Perish accommodates to retrieve data based on the keywords or titles [46]. Publish or Perish has a maximum data limit of 1000 articles from the Google Scholar database. Another limitation that Publish or Perish has is that there is no Boolean function in the search process such as the Scopus search algorithm. Based on this limitation, the search was completed twice. The first search for “lake management” returned 990 articles. The second search using the keyword “management of lake” returned 1000 articles.

This holistic review was conducted based on The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). PRISMA describes the process of determining articles relevant to this research [50]. The process of collecting literature data from Scopus and Google Scholar allows the possibility for duplication of articles [51]. The process of eliminating duplicate articles were done automatically using the Zotero reference manager application. The articles that were collected were then selected based on the title, abstract, and full paper access [52]. This study only includes research that focuses on a cluster of research goals. The cluster of research goals consists of catchment aspects, namely biogeophysical, socio-economical, and institutional aspects as part of the lake management forms. Figure 1 shows the PRISMA Protocol used in this study.

To gain a better understanding, the keywords containing aspects of biogeophysical, socio-economical, and institutional of the lake catchment were presented in a spreadsheet, separated into columns based on authors and year of the works referred to, and arranged in descending order as cluster points based on lake catchment aspects. The clusters of lake catchment aspects were then compared to detect similarity across columns. The clusters that were alike were positioned in the same row, and, if any, the repeated cluster points caused by nearly identical lake catchment aspects in one column were merged. Finally, a number of rows containing diverse lake management parameters were obtained as a synthesis result.

3. Overview of Lake Rawapening Environment: Abiotic, Biotic, and Cultural Components

According to local and provincial government regulations, Lake Rawapening is a local protection area and natural disaster-prone zone (Semarang Regency Regulation Number 6 of 2011) [53] and is an ecologically strategic region based on its function and carrying capacity (Central Java Regulation Number 6 of 2010) [54]. In a broader scope, it is part of the Jragung, Tuntang, Serang, Lusi, and Juwana River areas that compose the Jratunseluna watershed, a national strategic area according to Regulation of the Ministry of Public Works and Housing Number 04/PRT/M/2015 [55].

The study area covers the entire catchment of Lake Rawapening (Figure 2), which administratively extends across four regencies/cities: Semarang, Magelang, Temanggung Regency, and Salatiga City. Geographically, it lies from 110°17'30" to 110°30'15" E and from 7°11'15" to 7°26'15" S. The lake itself is 15.3 km² and the catchment area is 260.3 km². As seen from the toponymy, the word Rawapening combines the word ‘rawa’, which translates to marsh or swamp, and ‘pening’, which means clear or transparent [8]. Rawapening has a unique ecosystem with quite complex problems for its relatively small area [39]. This condition indicates less balanced interactions between the three components that make up the ecosystem, i.e., abiotic, biotic, and cultural. Such imbalances trigger environmental or ecological disasters.

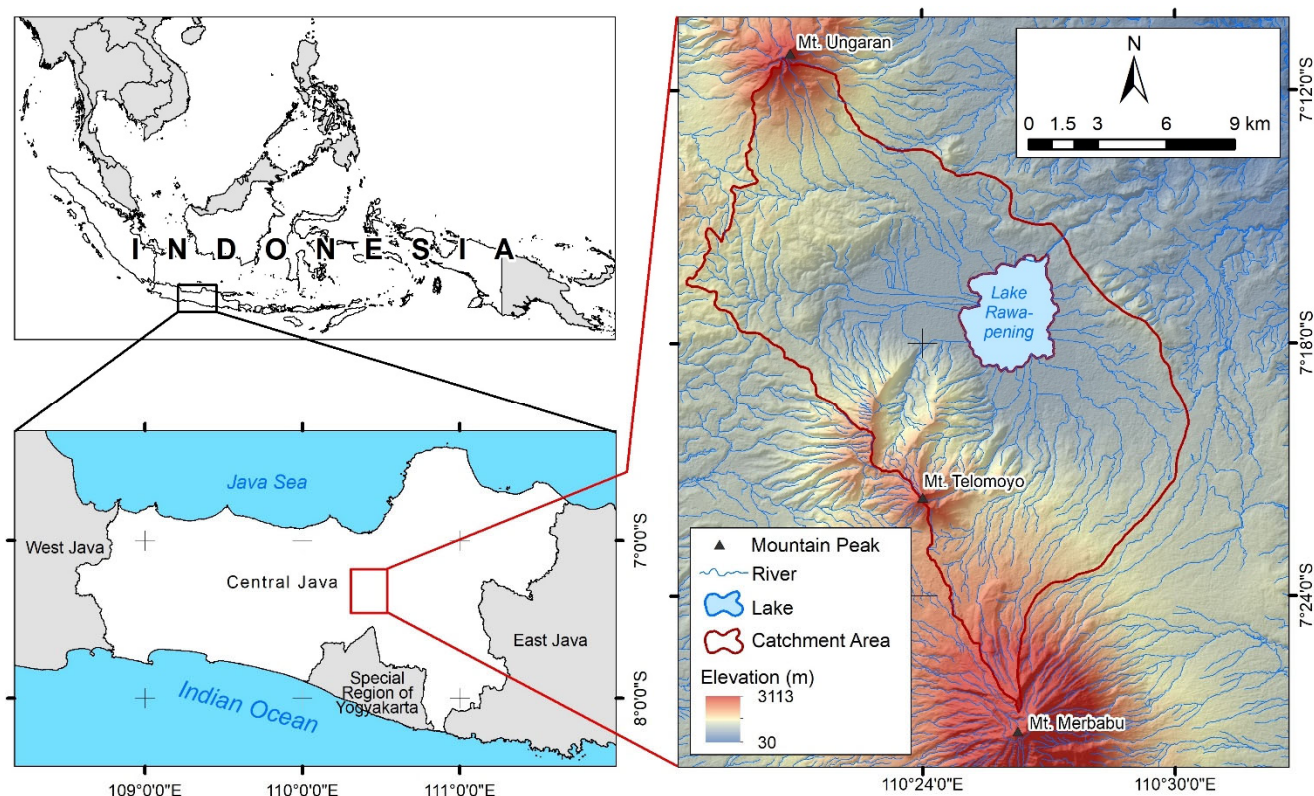


Figure 2. Location of the study area.

3.1. Abiotic Component

Abiotic characteristics can be explained by topographical conditions and land characteristics. The Lake Rawapening catchment is formed of a series of mountains and hills: Mt. Ungaran, Mt. Telomoyo, Mt. Merbabu, and Kali Getas Hills. The elevation of the complex is in the range of 480–2800 masl, with Mt. Merbabu as the highest point. This topography shapes the slope conditions of the catchment, which are mainly of the class 0–8% and 15–25%. Slopes with an average steepness of >40% are found in mountain and hill ridges, comprising 11% of the study area. This condition created a tectonic lake in the middle area. The maximum depth of the lake is 18 m, while the western area of the lake is 2–4.7 m in depth [56]. Geologically, the west side of the lake is composed of Kaligetas Formation (consists of breccia and lahar), the east is of Payung Formation (consists of lahar, claystone, breccia, and tuff) and Kerek Formation (consists of claystone, siltstone, calcareous sandstone, sandy limestone, and volcanic materials), and the area around the lake is mostly alluvium. Based on the soil texture analysis, the upstream of the catchment has clay-rich soils [57]. In the downstream part of the catchment, the alluvium forms alluvial soil. Furthermore, there is peat soil formed by organic material decomposition near the lake basin and under the water body, which becomes local people's livelihood. The climate condition in Lake Rawapening, based on Meteorological, Climatological, and Geophysical Agency (BMKG) data, had moderate rainfall (Figure 3). The year 2010 had the highest rainfall, up to 3459.6 mm, while the year 2018 had the lowest rainfall, with about 936 mm [58]. Compared to class I and II water quality standards in Government Regulation of the Republic of Indonesia Number 82 of 2021, Lake Rawapening had a heavily polluted quality status. This water quality is based on several parameters with the following values: TSS 140.9–242.1 mg/L, total P 0.1–0.2 mg/L, BOD 3.8–5.0 mg/L, COD 22.1–29.2 mg/L, H₂S 0.005–0.01 mg/L, Cd 0.01–0.02 mg/L, Pb 0.02–0.04 mg/L, and total coliform 5500–6800 MPN/100 mL [14].

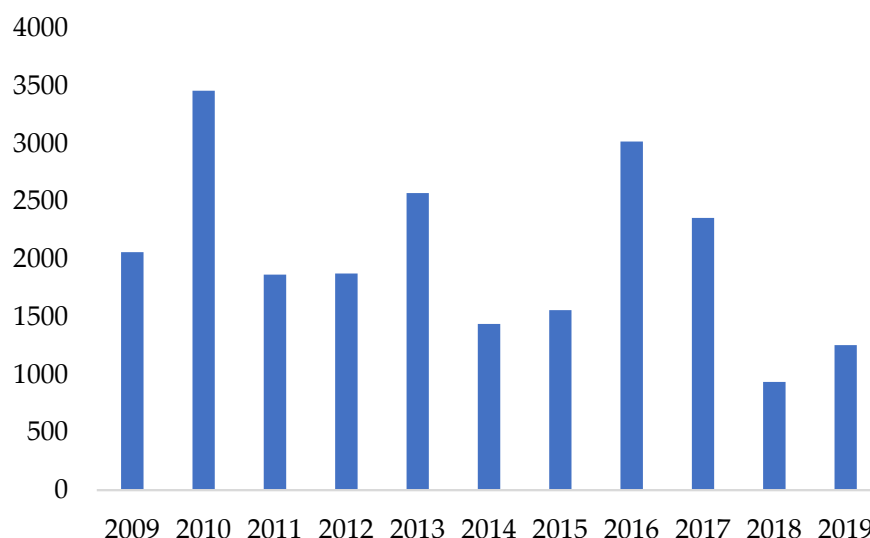


Figure 3. Annual total precipitation (mm) in Lake Rawapening catchment area from 2009–2019 [58], data processed.

3.2. Biotic Component

The Lake Rawapening water body has an area of $\pm 15 \text{ km}^2$ and is the habitat of various freshwater fish species, including tilapia, grass carp, snakehead murrel, catfish, spotted barb, marble goby, and *Mozambique tilapia* [16]. It is also home to *Eichhornia crassipes* (common water hyacinth) that grows very well to a point of eutrophication [6,22]. Previous studies indicate a mesotrophic status, but the total nitrogen content and water brightness of less than 2 m suggest a eutrophic condition. It is evident from the predominance of *Aulacoseira granulata* and *Melosira varians* [59].

The Lake Rawapening catchment consists of several sub-catchments: Rengas, Panjang, Torong, Galeh, Legi, Parat, Sragen, Ringis, and Kedungringin. Relative to other land uses, plantations have the largest area, about 40.5% of the total catchment in 2017 (Table 1, Figure 4). The area becomes the habitat of woody perennials such as jackfruit (*Artocarpus integra* MERR), breadfruit (*Artocarpus communis* FORST), mango (*Mangifera indica*), coconut (*Cocos nucifera*), bamboo (*Bambusa* sp.), mahogany (*Swietenia macrophylla*), banyan (*Ficus benjamina*), Moluccan albizia (*Paraserianthes falcata*), and durian (*Durio zibethinus* MURR) [60].

Table 1. Land use area and percentage within Lake Rawapening catchment.

Land Use Type	Area (ha)	Percentage (%)
Lake	6.39	0.02
Building	3.22	0.01
Grassland	203.98	0.78
Plantation	10,535.08	40.47
Settlement	5016.24	19.27
Irrigated rice field	3459.75	13.29
Non irrigated rice field	3128.39	12.02
Shrub	682.56	2.62
Non irrigated cropland	2994.43	11.50
Total	26,030	100

[61], data processed.

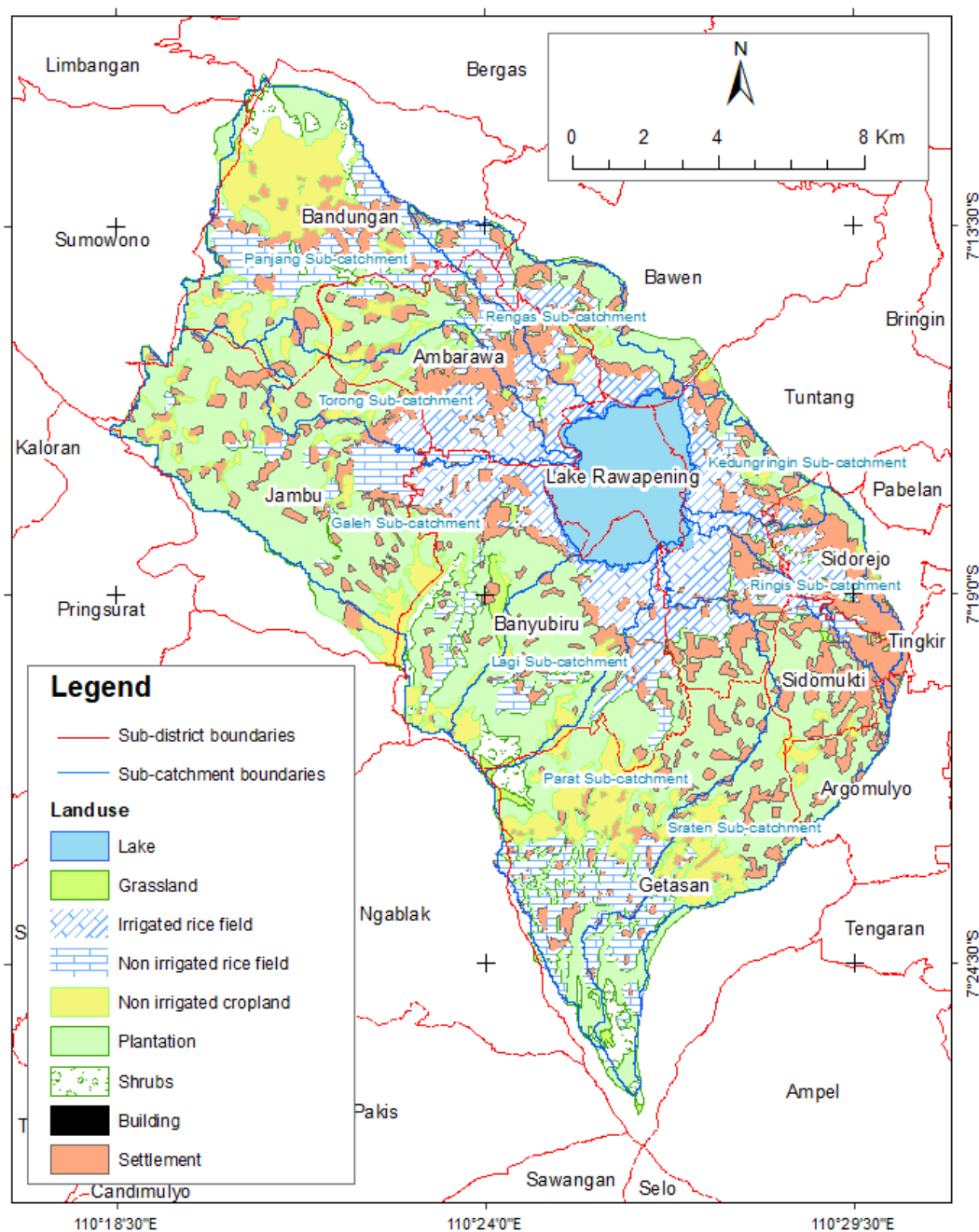


Figure 4. Distribution of land uses in Lake Rawapening catchment [61], data processed.

3.3. Cultural Component

Most of the Lake Rawapening catchment is located in Semarang Regency, which consists of eight subdistricts. The four largest subdistricts within the catchment area are Pringapus (78.35 km², population of 56,452), Getasan (65.80 km², 50,625), Tuntang (55.63 km², 65,008), and Sumowono (54.41 km², 30,625). Farming is the main source of livelihood, and 513,987 people work in this sector. Semarang Regency has 95,020.67 ha of agricultural land with a productivity of up to 5.73 tonnes/ha. In addition, it has fairly large horticultural production, and the main commodities are cabbage, mustard greens, large chilies, cayenne pepper, and green onions. The regency produces 26,414 tonnes of chili, 37,079.9 tonnes of cabbage, 11,256.2 tonnes of green onion, and 33,738.9 tonnes of mustard greens [62]. The livelihoods of residents in the Lake Rawapening Watershed, apart from those working in the agricultural sector as farmers, are water hyacinth seekers, peat miners,

capture fishermen, aquaculture fishermen (with floating net cages), traders, and tourism activists [31].

4. Overview of Lake Rawapening Management

Indonesia is a unitary state in the form of a republic with a presidential government [63]. This system is also manifested in the issuance of Presidential Regulation Number 60 of 2021 on Lake Rawapening's management [7]. Even though the regulation has no stronger statutory position than the 1945 Constitution, acts of government regulations in-lieu-of acts, and government regulations, its content does not contradict the three pieces of legislation above it [64].

According to the 2019 management plan for Lake Rawapening, its improved version of the formatting management policy and strategy system have become the Lake Recovery Movement (Germadan) and Lake Recovery Action Plan. The adopted plans or strategies have changed depending on the dynamics of the government system. In the New Order (1966–1998), they employed a top-down policy approach that tended to be centralized. Then, in the Reformation era, decentralization started, and regions were given the authority to manage the lake. However, the established system was bitter about events and challenges. One of its main focuses was utilizing and eventually turning riparian zones into open-access or public goods, leading to unsustainable lake management practices [8]. For this reason, the lake management authority was returned to the central government. Putting Lake Rawapening on the list of national priority lakes also forced central agencies or institutions to take over the formatting management policy and strategy system [7]. However, this has not entirely changed it back to employing the top-down approach [65,66] because the authority of the central government has only extended to the formation of policy changes as far as policy-making goes, while implementation still requires public participation to stimulate and promote community engagement [66].

The 2019 Lake Rawapening Management Plan document compiled in the presidential government system implicitly mandates that the president has executive power as the implementer of the written regulation of the legislative council. In this policy role, the president is assisted by several ministers acting as the steering committee, and the responsibility for lake recovery strategy is shared between the regional policy teams (the National Priority Lake Recovery Team at the regional level) and the national policy teams (the National Priority Lake Recovery Team at the central level). The specific recovery team for monitoring and surveillance operations of the lake has been working by intelligence service actions in terms of management. It was demonstrated as a change of the deformation mechanisms of the regional policy team, which is aligned to the Fundamental Decree Revision 2018 of the Central Java Government [67].

This review takes the 2019 management plan as an example of a lake management framework that sets the benchmark for implementation by stakeholders. To identify the ideal framework(s), previous relevant studies have been screened and investigated. From 37 published works, many points of information were obtained to formulate an overview of lake management, which is broadly divided into pillar-based and object-based.

Pillars and objects in lake management are the only ones to be reviewed as they play crucial roles in overall lake management. Correct pillars for lake management will determine the correctness of the Lake Rawapening management framework according to the current best lake management theories, basically adopted from Nakamura and Rast [1]. Correct objects, meanwhile, will determine the consistency and the compliance of the practices implemented for Lake Rawapening management with the supposed practices that are needed according to the goal of the lake management, that are in line with the current best concepts in lake management. The objects are related to lake catchment aspects, namely biogeophysical, socio-economical, or institutional, which become parts of lake management practices and the 'embryo' of the points of object-based management.

4.1. Pillar-Based Lake Management

Pillar-based lake management is a term used to describe the conceptual paradigm of lake management or parameters in lake management. In Nakamura and Rast's work [1], the pillars are developed as *indicator*, while in Chidammodzi and Muhandiki's [68], the *indicators* become more detailed, and, therefore, the pillars are called *categories*. According to ILEC [69], the word *indicators* is used to help the public and decision-makers to understand *parameters* in lake management, especially in water quality. In this study, the word *parameters* is selected as our concern, not only as the pillars or indicators but also as the objects that can be related to *parameters*, one of which is the water quality.

As presented in the left column in Table 2 or Appendix A, there are nine points or pillars of paradigm synthesized from 15 publications from 1989 to 2022: *finance*; *planning, designs, management scenarios, and actions*; *institutions*; *power and authorities*; *policies and rules*; *participations*; *good governance*; *information and sciences*; and *technology*. *Finance* illustrates the significance of funding in implementing lake management to create a system of resource management and guarantee sustainability [70,71]. It is imperative that involved parties perform thorough *planning, designs, and management scenarios* before realizing plans into actions. *Institutions* refer to actors, organizations, institutions, and coordination platforms responsible for lake management [71]. The *power and authorities* pillar signifies the roles of both, which are not necessarily absolute, considering that Indonesia is a democratic country [64]. This means that adaptability to achieve balance and address limitations in power and authorities is necessary, especially when issues in lake management occur across regional or even national political boundaries. *Policies and rules* are instruments that accommodate power and authorities within the legal framework [71]. *Participations* also play a crucial part in lake management as it requires the role of a wide range of parties, including the private sector, community, and local or informal institutions [71–73]. *Good governance* is the conceptual paradigm expected to exist in fair and transparent lake management and to empower the community or open up opportunities for the region to take action. *Information and sciences* contribute to forming or presenting knowledge in lake management. Lastly, *technology* determines whether and to what extent the management plan can be executed mechanically, especially for activities that require quick actualization.

Table 2. Synthesis of pillar-based lake management.

Conceptual Pillars	[74]	[75]	[69]	[76]	[77]	[78]	[43]	[1]	[68]	[70]	[79]	[80]	[81]	[82]	[83]
Finance	✓	✓	✓	✓	✓	-	-	✓	✓	✓	-	✓	✓	-	-
Planning, designs, management scenarios, and actions	-	✓	-	-	-	✓	✓	-	-	-	-	-	-	-	-
Institutions	✓	-	✓	✓	-	-	-	✓	✓	✓	-	-	-	✓	-
Power, authorities	✓	-	-	-	-	-	✓	-	-	✓	-	✓	-	-	-
Policies, rules	✓	✓	✓	✓	-	-	✓	✓	✓		-	-	-	-	-
Participations	✓	-	✓	✓	-	✓	✓	✓	✓	✓	✓	-	-	-	✓
Good governance	-	-	-	-	-	✓	✓	-	-	✓	-	✓	-	-	-
Information, sciences	-	-	✓	✓	-	✓	-	✓	✓	-	-	-	-	-	-
Technology	-	-	✓	-	-	-	-	✓	✓	✓	-	-	✓	-	-

This review examines if the legal frameworks for Lake Rawapening management, namely the 2019 Memorandum of Understanding (MoU) [84] (Table 3) and Presidential Regulation Number 60 of 2021 [7] (Table 4), have accommodated the nine pillars of the conceptual lake management paradigm. Table 2 shows that the MoU incorporates the nine pillars, although not in a similar level of significance across the eight chapters. *Institutions*, *power and authorities*, *policies and rules*, *participations*, and *good governance* are the most

significantly accommodated pillars in the MoU. On the contrary, *finance; planning, designs, management scenarios, and actions; information and sciences; and technology* are less discussed. Table 3 shows that nearly all of the 21 articles in the presidential regulation accommodate all nine pillars. However, relative to the others, *finance* and *technology* are less considered. In conclusion, the MoU and the presidential regulation have not substantially taken account of *finance* and *technology*. Technology can help perform tasks efficiently, but this can only be achieved if funding (*finance*) is available.

Table 3. Overview of pillar-based Lake Rawapening management within the Memorandum of Understanding between the Ministry of Public Works and Housing, Ministry of Environment and Forestry, Ministry of Agrarian and Spatial Planning/National Land Agency, National Disaster Management Agency, Government of Central Java Province, and Government of Semarang Regency in 2019 on the Recovery of Lake Rawapening and Tuntang River Watershed in Central Java Province.

Chapter and Verse	Finance	Planning, Designs, Management Scenarios, and Actions	Institutions	Power, Authorities	Policies, Rules	Participations	Good Governance	Information, Sciences	Technology
1 (1)	-	✓	✓	-	✓	✓	✓	-	-
1 (2)	-	-	✓	-	-	✓	✓	-	-
2 (1)	-	-	-	-	-	-	-	✓	-
2 (2)	✓	✓	✓	-	✓	✓	✓	✓	-
3 (1)	-	-	-	-	✓	-	-	-	-
3 (2)	-	-	✓	✓	-	-	-	-	-
3 (3)	✓	-	✓	-	✓	-	-	-	-
4 (1)	-	-	-	-	✓	✓	-	-	-
4 (2)	-	-	-	-	-	✓	✓	-	-
4 (3)	-	-	✓	✓	✓	-	-	-	-
5	✓	-	✓	-	✓	-	-	-	-
6	-	-	-	✓	✓	✓	-	-	-
7	-	-	✓	-	✓	-	✓	✓	✓
8	-	-	-	✓	-	-	-	-	-

4.2. Object-Based Lake Management

Object-based lake management is a term used to indicate objects to be addressed in lake restoration. As presented in Table 5 or Appendix B (left column), there are eleven object-based lake management strategies identified and synthesized from 31 publications from 1987 to 2022. They include management, restoration, and monitoring of lake basins; water bodies; water quality and quantity; riparian/littoral zones; catchments/watersheds; habitats; erosion–sedimentation processes by controlling fertilizers as the source of nutrients in eutrophication; cultural components (harmonized human–nature interaction); operational performance of the programs; climatic factors; and management based on economic empowerment.

Management, restoration, or monitoring of lake basins, hydrology, and water bodies in general means that the lake basin management is centered on water management. *Management and monitoring of water quantity* specifically aims to control the amount of water resources to ensure the fulfillment of various water demands, while *management and monitoring of water quality* prioritizes water quality control, including anticipating and treating waste input. *Management of riparian or littoral zones* is focused on protecting the land abutting the lake from physical development (buildings), which begins with conducting surveys, followed by regulating its use for agriculture and allocating some spawning areas for local fauna. *Management of catchments, watersheds, or habitats* has a broader scope than riparian zones (as it includes the upper, middle, and lower course), is focused on ecosystems or habitats of flora and fauna, and aims to overcome interruptive and destructive stressors with or without modifications.

Table 4. Overview of the pillar-based Lake Rawapening management within Presidential Regulation of the Republic of Indonesia Number 60 of 2021 on National Priority Lakes Recovery.

Chapter and Verse	Finance	Planning, Designs, Management Scenarios, and Actions	Institutions	Power, Authorities	Policies, Rules	Participations	Good Governance	Information, Sciences	Technology
1	-	-	-	-	-	-	-	✓	-
2	-	-	✓	-	✓	✓	✓	-	-
3 (1)	-	-	-	-	-	-	-	✓	-
3 (2)	-	✓	-	-	-	-	-	✓	-
4	-	-	-	-	✓	-	-	-	-
5	✓	✓	✓	-	-	✓	✓	✓	✓
6 (1)	-	-	✓	-	-	-	-	-	-
6 (2)	-	-	-	-	✓	-	-	-	-
7 (1)	-	-	✓	-	-	✓	✓	-	-
7 (2)	✓	✓	✓	-	-	-	✓	-	-
7 (3)	-	-	-	-	-	✓	✓	-	-
8	-	-	-	✓	-	-	-	-	-
9 (1)	-	-	✓	✓	✓	-	-	-	-
9 (2)	-	-	✓	✓	-	✓	✓	-	-
10 (1)	✓	✓	✓	✓	✓	-	✓	-	-
10 (2)	-	-	-	-	-	✓	✓	-	-
11	-	✓	✓	✓	-	-	-	-	-
12 (1)	✓	✓	✓	-	✓	-	✓	-	-
12 (2)	-	-	-	✓	-	-	-	-	-
12 (3)	-	-	-	-	-	✓	✓	-	-
13 (1)	-	-	✓	✓	✓	-	-	-	-
13 (2)	-	-	✓	-	-	✓	✓	-	-
14 (1)	-	-	-	✓	-	-	-	-	-
14 (2)	-	-	-	-	✓	-	-	-	-
15	-	-	-	✓	-	-	-	-	-
16 (1)	-	-	-	✓	✓	-	-	-	-
16 (2)	-	-	-	-	✓	✓	-	✓	-
17 (1)	-	-	✓	✓	-	✓	✓	-	-
17 (2)	-	-	-	-	-	✓	✓	✓	-
18 (1)	-	-	✓	-	-	-	✓	-	-
18 (2)	-	-	✓	-	-	-	✓	-	-
18 (3)	-	-	✓	-	-	-	✓	-	-
18 (4)	-	-	✓	-	-	-	✓	-	-
18 (5)	-	-	✓	-	-	-	✓	-	-
19	✓	-	-	-	-	-	-	-	-
20	-	-	-	-	✓	-	-	-	-
21	-	-	-	✓	-	-	✓	✓	-

Table 5. Synthesis of object-based lake management.

Identified Management Strategies		[85]	[86]	[87]	[75]	[88]	[89]	[90]	[77]	[78]	[91]	[92]	[93]	[94]	[70]	[95]	[96]	[79]	[97]	[80]	[98]	[99]	[100]	[101]	[81]	[102]	[103]	[82]	[83]	[104]	[105]	[106]
1.	Management, restoration, or monitoring of lake basins, hydrology, and water bodies in general	✓		✓	✓	-	-	✓	✓	✓	-	-	✓	-	✓	-	-	-	✓	-	✓	-	✓	-	-	-	-	-	-	✓	✓	✓
2.	Management and monitoring of water quantity	-	✓	✓	✓	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	-	✓	-	✓	-	-	-	✓	-	✓	-
3.	Management and monitoring of water quality	✓	✓	-	✓	-	-	✓	-	-	-	✓	-	-	-	✓	-	-	-	-	-	-	-	-	✓	-	-	-	✓	-	✓	✓
4.	Management of riparian or littoral zones	-	✓	-	✓	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	-	-	-	-	✓	-	✓	-
5.	Management of catchments, watersheds, or habitats	-	✓	✓	✓	-	-	-	-	-	-	-	-	-	✓	-	✓	✓	✓	-	-	-	✓	-	-	-	-	-	-	-	-	-
6.	Management of erosion–sedimentation and regulating the use of fertilizers (sources of nutrients, P and N) that cause eutrophication	-	✓	✓	✓	✓	-	-	-	-	✓	✓	✓	-	-	-	-	-	-	-	✓	✓	✓	-	-	-	✓	-	✓	-	✓	-
7.	Management and preservation of biodiversity by controlling invasive biotic components (afforestation, reforestation) and biological manipulation	-	✓	✓	✓	✓	✓	-	-	-	✓	✓	-	✓	-	-	✓	-	✓	-	✓	-	-	✓	-	✓	-	-	✓	-	-	✓
8.	Management of cultural components: harmonizing human–nature interaction through legal permits and sustainable cultivation	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-	-	✓	-	-	✓	-	✓	-

Table 5. Cont.

Identified Management Strategies		[85]	[86]	[87]	[75]	[88]	[89]	[90]	[77]	[78]	[91]	[92]	[93]	[94]	[70]	[95]	[96]	[79]	[97]	[80]	[98]	[99]	[100]	[101]	[81]	[102]	[103]	[82]	[83]	[104]	[105]	[106]
9.	Monitoring of operational performance of existing programs	-	-	-	-	-	-	√	-	-	-	-	-	-	-	-	-	-	-	-	-	-	√	-	-	-	-	-	-	-	-	-
10.	Monitoring of weather, climate, and other physical conditions	-	-	-	√	-	-	-	-	-	√	-	-	√	-	-	-	-	-	-	-	-	-	-	-	-	-	-	√	-	-	-
11.	Economic empowerment-based management (supporting livelihoods dependent on fisheries and other ecosystem services, alleviating poverty, optimizing business opportunities)	-	-	-	√	-	-	-	-	-	√	-	√	√	√	-	√	√	-	√	-	-	-	√	-	-	-	√	√	-	-	-

Management of erosion–sedimentation is a specific action intended to prevent and control this process, one of which is regulating the use of fertilizers (sources of nutrients, P and N) that cause eutrophication. It can be implemented through sediment removal, combat nutrient, combat eutrophication [93], controlled sedimentation [98], reducing sediment loading by preventing resuspension, and reducing sediment loading by reducing deposition [99]. Compared to the Lake Rawapening Management Plan (2019), erosion–sedimentation can also be controlled through dam and gully plug conservation, agroforestry, cropland management, plantation intensification, procurement and planting of seeds, reforestation, and environmental pollution control [10]. After *management of erosion–sedimentation*, the strategy of *management and preservation of biodiversity* can be explained as focusing on biotic components and including the control of invasive ones (afforestation, reforestation) and biological manipulation. *Management of cultural components* engages humans to achieve a harmonized human–nature interaction through legal permits and sustainable cultivation practices. *Monitoring of operational performance of existing programs* uses measurable instruments, such as information systems, for the implementation of lake management programs and activities. *Monitoring of weather, climate, and other physical conditions* aims to minimize damages to abiotic components outside the land ecosystems using sensors or instruments for direct measurements. Lastly, *economic empowerment-based management* is designed to empower local communities to be economically productive while preserving the lake’s ecological functions by, for instance, maintaining ecosystem services for livelihoods depending on fishery and other relevant sectors, alleviating poverty, and opening up business opportunities.

This review evaluates if the current Lake Rawapening management programs and activities belong to one or more object-based management types synthesized from the screened publications. Table 6 shows that the identified eight programs are subdivided into 57 activities, which include all 11 object-based management strategies to varying degrees. Strategies six (*management of erosion–sedimentation*) and nine (*monitoring of operational performance of existing programs*) are the least considered and implemented in Lake Rawapening management. Only one activity explicitly supports the objectives of Strategy six, i.e., optimizing and turning agricultural waste into organic fertilizers, which is part of the recovery program of Lake Rawapening catchment through the development of environmentally friendly farming practices. Also, only one activity explicitly follows Strategy nine, i.e., monitoring and evaluating Lake Rawapening management, which is incorporated in the program of monitoring, evaluation, and information system development.

Table 6. Number of activities within the identified programs according to object-based lake management strategies.

Program * and Number of Activities	Management, Restoration, or Monitoring of Lake Basins, Hydrology, and Water Bodies in General	Management and Monitoring of Water Quantity	Management and Monitoring of Water Quality	Management of Riparian or Littoral Zones	Management of Catchments, Watersheds, or Habitats	Management of Erosion–Sedimentation and Regulating the Use of Fertilizers (Sources of Nutrients, P and N) That Cause Eutrophication	Management and Preservation of Biodiversity by Controlling Invasive Biotic Components (Afforestation, Reforestation) and Biological Manipulation	Management of Cultural Components: Harmonizing Human–Nature Interaction through Legal Permits and Sustainable Cultivation	Monitoring of Operational Performance of Existing Programs	Monitoring of Weather, Climate, and Other Physical Conditions	Economic Empowerment-Based Management (Supporting Livelihoods Dependent on Fisheries and Other Ecosystem Services, Alleviating Poverty, Optimizing Business Opportunities)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Spatial planning of the lake area (3)	1	-	-	-	1	-	-	1	-	-	-
Lake’s water preservation (13)	10	-	-	1	-	-	1	-	-	-	1
Lake’s riparian preservation (3)	-	-	-	3	-	-	-	-	-	-	-
Lake catchment preservation (31)	-	-	7	-	7 + 3 *	1	2 + 2 *	8 + 2 *	-	1	1 + 2 *
Water resources utilization (3)	-	2	-	-	-	-	-	-	-	1	-
Development of monitoring, evaluation, and information system for lake management (4)	-	-	-	-	-	-	-	2	1	1	-
Increasing community roles and participation (13)	-	-	-	-	1 + 1 *	-	-	3 + 1 *	-	-	8 + 1 *
Development of institutional capacity and coordination (3)	-	-	-	-	-	-	-	-	-	-	3

* These programs consist of activities that can be included in more than one object-based lake management types.

Although the object-based management points that have been matched with activities in the Lake Rawapening management program show gaps in some strategies, they have some alignment in quality. Strategy one is in line with the activities of the lake's water body preservation in the form of zoning water bodies, dredging lakes, dredging and normalizing rivers and embankments, cleaning operations, procurement of water master/harvester equipment and excavators, procurement of truck boats, water hyacinth cutting, and socialization and arrangement of cages and beds. Strategy two is in line with the procurement of a clean water distribution pipe network system and drilling wells. Strategy three is in line with the facilitation of the Wastewater Treatment Plant (IPAL), Wastewater Treatment Ducts and Ponds (SAKPAL), monitoring of water quality, cleaning rivers, and fostering efforts to control water pollution. Strategy four is in line with the procurement of water hyacinth waste storage land, construction of dikes and inspection roads and jogging tracks, installation of stakes and notice boards, and the zoning of the lake riparian/borderland and the determination of the lake riparian line. Strategy five is in line with the composing of the spatial planning, construction of conservation buildings such as retaining dam and gully plugs, farming land management, procurement and planting of seeds, afforestation, protection of natural resources, rehabilitation of protected areas, creating infiltration wells, and environmental damage control. Strategy six is in line with the optimization of agricultural waste for the manufacture of organic fertilizers. Strategy seven is in line with the enrichment of local fish species, agroforestry, afforestation, inventory of endemic flora and fauna, and biogas production. Strategy eight is in line with the composing of regulations and criteria guidelines for the sector of environmental health for settlement, agroforestry, waste control and processing, optimization of agricultural waste for the manufacture of organic fertilizers, environmentally friendly rice cultivation, post-harvest processing of rice, structuring of tourist sub-areas, community assistance, forestry counseling, community empowerment, technical guidance for the development of integrated healthcare (Posyandu), and facilitation in composing of village mid-term development plan (RPJMDes). Strategy nine is in line with the implementation of monitoring and evaluation of lake management. Strategy ten is in line with the mitigation of adaptation and prevention of pollution and environmental damage, the environment drainage management system for settlement, and lake information systems. Strategy eleven is in line with the biogas installation assistance, intensification of plantation crops, procurement and planting of seeds, technical guidance for village-owned enterprises (BUMDes) management, facilitation of technical guidance for the establishment of village Posyantek, tourism workforce training, certification and competence of tourism human resources, entrepreneurship coaching and training, increasing the capacity of the tourism community, actualization of tourism awareness, organizing festivals, developing human resources for innovation and creativity of non-agricultural industries as well as partnership-network marketing, and fostering the social environment and community economic empowerment.

Lake Rawapening's recovery cannot be separated from the classic problem of management based on administrative units, even though they generally do not overlap with the physical boundaries of the lake's catchment [107]. This means that lake management needs to be designed and conducted across boundaries. At the same time, it should have multi-sectoral and multi-level systems because the programs are regulated by the national/central government but implemented by regional governments/governmental agencies and ministerial task forces in the regions [108]. In other words, a successful lake management integrates different sectors, levels, and regions where the lake and its catchment are located.

Institutional arrangement can help realize integrated lake management [65]. It contributes to the success of relevant programs and activities (by observing the distribution and participation of stakeholders [72]) with the supports of legal frameworks [109], basic knowledge of the biophysical and socio-economic conditions of the lake basin, and sustainable funding [69]. Presidential Regulation Number 60 of 2021 refutes the statement that there is no legal framework that specifically regulates lakes [110]. Moreover, the Lake Management

Plan document for Lake Rawapening has been published and is expected to increase the commitment and integration of programs and activities in lake management [10].

The document provides details on management programs, activities, and stakeholder-in-charge [111]. As with other policy outcomes, management plans generally end with the completion of leadership or governance in an area. The limited duration of leadership (political time scale) poses a challenge to the sustainability of integrated lake management because it is not as long as the lake's time scale [69]. Regardless of changes in leadership, the role of the person in charge of lake management should be maintained within the framework of the institution arrangement. However, the problem does not stop here since there is no one specific institution responsible for lake management, even though many are tasked with its elements (e.g., biotic, abiotic, or cultural). It means that the entire work involved in lake management is an additional responsibility for these institutions (especially for Lake Rawapening). The document, therefore, sets the benchmark for Lake Rawapening's management by a joint secretariat.

5. Summary and Outlook

Lake Rawapening has become an icon of resource utilization, with the catchment area as the physical system and the administrative area as the social system. Recovering priority lakes with the slogan "preventing is better than treating" is in line with the recommendation of controlling the use of resources (preventive measures) more intensively than treating or reversing degradation/damage (curative measures) [112]. In response to this, a lake management plan can be used as the basis for preventive measures against environmental disasters that threaten the lake ecosystem, and if the designed programs do not run effectively, curative measures can be used as an alternative.

As part of the lake management planning, this review observes and evaluates actions, which should be followed by necessary re-planning [113], that consider pillar-based and object-based management holistically, for instance, by examining two relevant legal frameworks: the Memorandum of Understanding in 2019 [84] and Presidential Regulation Number 60 of 2021 [7]. Based on the pillar-based lake management review, *finance and technology* are the least discussed in both frameworks, even though both are key to effective and efficient lake management. The object-based lake management review shows two strategies that are not well considered or represented in current management activities and programs, namely (1) *management and monitoring of erosion–sedimentation and regulating the use of fertilizers that cause eutrophication* and (2) *monitoring of the operational performance of existing programs and/or activities using an information system*. For these reasons, the future management plan should include erosion–sedimentation and eutrophication control, particularly because both processes have created serious problems in Lake Rawapening. In addition, to ensure that all programs of the working group are implemented, the lake management needs an information system for monitoring and evaluation.

Considering the outputs of this study, future work will likely manage the lake conceptually together with the object as the targets that should be controlled. The proposed method in this study could also be considered in the process of obtaining the selected articles until synthesizing the practices of lake management. The points of pillar-based and object-based become the advantages resulting from the proposed method. On the other hand, there is a potential disadvantage to be found in the search process using the database. Therefore, to minimize it, the selection of published articles should be conducted as objectively as possible. Another advantage of this study is that other lakes could adopt a similar way to synthesize and even apply conceptual pillar-based management. However, for object-based management, other lakes, especially those in other countries or in different climate regions, will likely adopt only pillar-based management over object-based management, because adjustments of the objects targeted should be done according to the needs in a certain region.

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Appendix A

Table A1. Synthesis of pillar-based lake management.

Conceptual Pillars	Born and Rumery, 1989 [74]	Birch and McCaskie, 1999 [75]	ILEC, 2005 [69]	World Bank, 2005 [76]	Hecky et al., 2006 [77]	World Lake Vision, 2007 [78]	Kauneckis and Imperial, 2007 [43]	Nakamura and Rast, 2014 [1]
Finance	financial constraints	funding	finance	finance	adequate funding			finance: seeking sustainable sources at appropriate levels
Planning, designs, management scenarios, and actions		planning, design, and management scenario				planning and management action based on lake catchment	developing a shared definition of the problem	
Institutions	functional program responsibilities, coordination		institutions	institutions				institutions: developing effective organizations
Power, authorities	limited authority, areal jurisdiction						establishing a balance of power	
Policies, rules	public awareness and consensus	policy	policy tools	policy, rules			increasing policy instrument diversity	policies: broad directions and specific rules
Participations	private-sector roles		people	public participation		participation in identifying and resolving critical lake problems	defining mutual interests	participation: expanding the circle of involvement

Table A1. Cont.

Conceptual Pillars	Born and Rumery, 1989 [74]	Birch and McCaskie, 1999 [75]	ILEC, 2005 [69]	World Bank, 2005 [76]	Hecky et al., 2006 [77]	World Lake Vision, 2007 [78]	Kauneckis and Imperial, 2007 [43]	Nakamura and Rast, 2014 [1]
Good governance						good governance: fairness, transparency, empowerment of all stakeholders	establishing trust across organizations	
Information, sciences			information	information		science- and information-based policy development		information: pursuing the sources of knowledge and wisdom
Technology			technological responses					technology: possibilities and limitations

Table A2. Synthesis of pillar-based lake management.

Conceptual Pillars	Chidammodzi and Muhandiki, 2015 [68]	Cookey et al., 2016 [70]	KC et al., 2020 [79]	Nunan, 2020 [80]	Shadkam et al., 2020 [81]	Akbar et al., 2022 [82]	McEwen and Hosey, 2022 [83]
Finance	finance	resource management systems		financial management	allocation of funds for required technologies, appropriation of the required funds		
Planning, designs, management scenarios, and actions							
Institutions	institutions	actors, institutions				institutional objectives	
Power, authorities		adaptability, resilience		power			
Policies, rules	policies						
Participations	participation	collaboration, integration, participation	facilitating community participation				board participation, membership
Good governance		decentralization		good governance: co-management, transparency			
Information, sciences	information and science						
Technology	technology	resource management systems			allocation of supply of the required technologies to increase the efficiency of usage of the remaining water		

Appendix B

Table A3. Synthesis of object-based lake management.

	Identified Management Strategies	Heiskary et al., 1987 [85]	Gough and Ward, 1996 [86]	Maitland and Morgan, 1997 [87]	Birch and McCaskie, 1999 [75]	Melzer, 1999 [88]	Drenner and Hambright, 2002 [89]	Premazzi et al., 2003 [90]	Hecky et al., 2006 [77]	World Lake Vision, 2007 [78]	Qin et al., 2010 [91]	Carvalho et al., 2011 [92]
1.	Management, restoration, or monitoring of lake basins, hydrology, and water bodies in general	lake restoration		access to waters: trampling, digging turf, disturbance, deposition of litter, lighting of fires, use of boats	lake maintenance, wild-fowl/waterfowl management: physical exclusion, management scenario			investigative monitoring (sudden phenomenon), surveillance monitoring (monitoring obligation)	proper basin management	preventing lake degradation		
2.	Management and monitoring of water quantity		supplementation from Rakaia River	raising of the water level	inputs from water supply (quantity)							
3.	Management and monitoring of water quality	managing water quality	providing freshwater, increasing water transparency, reducing fecal coliforms		improving water quality: nutrient sources, chemical status, oxygen levels, microbiology; improving water quality from biological influence, zooplankton and other invertebrates, algae, nutrient and organic enrichment			limiting pollution, establishing water quality objectives				lengthening total P retention time
4.	Management of riparian or littoral zones		land reclamation around the lake margin, conservation management of lakeshore margins, controlling non-point sources of nutrients by clearing riparian zone		ground maintenance							

Table A3. Cont.

Identified Management Strategies	Heiskary et al., 1987 [85]	Gough and Ward, 1996 [86]	Maitland and Morgan, 1997 [87]	Birch and McCaskie, 1999 [75]	Melzer, 1999 [88]	Drenner and Hambright, 2002 [89]	Premazzi et al., 2003 [90]	Hecky et al., 2006 [77]	World Lake Vision, 2007 [78]	Qin et al., 2010 [91]	Carvalho et al., 2011 [92]
5. Management of catchments, watersheds, or habitats		upstream management	habitat management: groins, fishing jetties, artificial spawning areas; blocking access to inflow: removal of barriers, liming, cutting weeds, cutting bankside vegetation, construction of fishing pools	wildfowl/waterfowl management: habitat modification, modification management							
6. Management of erosion–sedimentation and regulating the use of fertilizers (sources of nutrients, P and N) that cause eutrophication		reducing sediment, reducing nutrients in the lake, nutrient removal	blocking outflows, addition of fertilizers, use of herbicides, use of grass carp, introduction of food crop species	sediment treatment	reducing sediment from nutrients, P N					controlling excessive nutrient loading, prevent accelerated eutrophication	reducing nutrient loads from the catchment
7. Management and preservation of biodiversity by controlling invasive biotic components (afforestation, reforestation) and biological manipulation		reducing suspended sediment by revegetation (submerged macrophytes) of margin, controlling non-point sources of nutrients by afforestation, controlling poultries number	fish introductions; removal of fish: angling, trapping, poisoning, electro-fishing, netting, drainage; fish stocking: egg, fry, juveniles or adults; ground baiting; accidental introduction of disease and parasites; predator control	vegetation replanting	reducing diatom sediment	increasing piscivore, declining phytoplankton biomass				controlling cyanobacteria bloom, flushing the lake of the bloom	reducing cyanobacteria abundance

Table A3. Cont.

Identified Management Strategies	Heiskary et al., 1987 [85]	Gough and Ward, 1996 [86]	Maitland and Morgan, 1997 [87]	Birch and McCaskie, 1999 [75]	Melzer, 1999 [88]	Drenner and Hambright, 2002 [89]	Premazzi et al., 2003 [90]	Hecky et al., 2006 [77]	World Lake Vision, 2007 [78]	Qin et al., 2010 [91]	Carvalho et al., 2011 [92]
8. Management of cultural components: harmonizing human–nature interaction through legal permits and sustainable cultivation									conflict resolution sustainability based on human–nature interactions		
9. Monitoring of operational performance of existing programs							monitoring of operational performance (programs, activities)				
10. Monitoring of weather, climate, and other physical conditions				weather condition						minimizing impacts of physical factors such as air temperature, wind speed and direction, radiation	
11. Economic empowerment-based management (supporting livelihoods dependent on fisheries and other ecosystem services, alleviating poverty, optimizing business opportunities)				fish management						maintaining viable fisheries	

Table A4. Synthesis of object-based lake management.

Identified Management Strategies	Sayer et al., 2012 [93]	Zalewski, 2012 [94]	Cookey et al., 2016 [70]	Bocaniov and Scavia, 2016 [95]	De Keyzer et al., 2020 [96]	KC et al., 2020 [79]	Larson et al., 2020 [97]	Nunan, 2020 [80]	Susilo, 2020 [98]	Wosnie et al., 2020 [99]
1. Management, restoration, or monitoring of lake basins, hydrology, and water bodies in general	sediment dredging to optimize restoration		resource systems				dam removal		sustainability in the waters' conditions	
2. Management and monitoring of water quantity		enhancement of water resources								
3. Management and monitoring of water quality				controlling oxygen deficiency (hypoxia)						
4. Management of riparian or littoral zones					protecting spawning areas, stopping constructing buildings close to the lake, allowing littoral zones to remain open					
5. Management of catchments, watersheds, or habitats			stressors		making the neighboring countries stop polluting the lake	enhancement of environmental protection	habitat improvements			
6. Management of erosion–sedimentation and regulating the use of fertilizers (sources of nutrients, P and N) that cause eutrophication	sediment removal, combatting nutrients, combatting eutrophication								controlled sedimentation	reducing sediment loading by preventing resuspension, reducing sediment loading by reducing deposition

Table A4. Cont.

Identified Management Strategies	Sayer et al., 2012 [93]	Zalewski, 2012 [94]	Cookey et al., 2016 [70]	Bocaniov and Scavia, 2016 [95]	De Keyzer et al., 2020 [96]	KC et al., 2020 [79]	Larson et al., 2020 [97]	Nunan, 2020 [80]	Susilo, 2020 [98]	Wosnie et al., 2020 [99]
7. Management and preservation of biodiversity by controlling invasive biotic components (afforestation, reforestation) and biological manipulation		maintenance and restoration of biodiversity			Reforestation, combat deforestation		preservation and maintenance of beavers, monitoring and maintenance of biodiversity		sustainability in fish diversity, the existence of protected species, zooplankton community structure, forest areas	
8. Management of cultural components; harmonizing human–nature interaction through legal permits and sustainable cultivation					forbidding extraction of sand and stones, providing alternative livelihood	local stakeholder empowerment				
9. Monitoring of operational performance of existing programs										
10. Monitoring of weather, climate, and other physical conditions		building resilience to climate change and anthropogenic impact								
11. Economic empowerment-based management (supporting livelihoods dependent on fisheries and other ecosystem services, alleviating poverty, optimizing business opportunities)	fishing license: management requirements for fishing	provision of ecosystem services for society	economic sector		limiting fishing, providing law-comfort fishing materials, avoiding imported fishing materials, providing credit to buy new materials, improving fisheries with different techniques, raising awareness of regulations, licensing, cold chambers and cooler boxes, industrialization	enhancement of economic productivity		income to alleviate and prevent poverty, fish-based management, conservation, and protection		

Table A5. Synthesis of object-based lake management.

Identified Management Strategies		Nakatsuka et al., 2020 [100]	Zhu et al., 2020 [101]	Shadkam et al., 2020 [81]	Abdurrahim et al., 2021 [102]	Djihouessi et al., 2021 [103]	Akbar et al., 2022 [82]	McEwen and Hosey, 2022 [83]	Moreno et al., 2022 [104]	B. Zhang et al., 2022 [105]	X. Zhang et al., 2022 [106]
1.	Management, restoration, or monitoring of lake basins, hydrology, and water bodies in general	promote integrated flood management; conserve groundwater; restore and improve the balance of ecosystem services							lake regime shift and stratification processes, ecological status	Water saving	hydrological management
2.	Management and monitoring of water quantity	multiplex of the water supply system, strengthen water environment crisis management		reducing water allocated to the farmers through purchasing system, enhancing the productivity of the remaining water, acceleration transfer of water from the rivers to the lake basin				providing water level logger, maintaining water levels		recycling treated sewage for irrigation, recycling treated industrial wastewater for irrigation recycling intercepted sewage inside watershed for irrigation	
3.	Management and monitoring of water quality			transferring treated wastewater from the lake basin into lake				Fecal-coliform test, checking time-series oxygen, identifying heavy filaments and phosphorus, monitoring chloride		upgrading the wastewater treatment facilities, enhancing rate of sewage	water quality restoration
4.	Management of riparian or littoral zones							meandering survey, shoreline survey: 40–60% littoral zone should be vegetated		planned farmland lying fallow	
5.	Management of catchments, watersheds, or habitats	restoring the regional water culture and mutual beneficial relations between upstream and downstream users									

Table A5. Cont.

Identified Management Strategies	Nakatsuka et al., 2020 [100]	Zhu et al., 2020 [101]	Shadkam et al., 2020 [81]	Abdurrahim et al., 2021 [102]	Djihouessi et al., 2021 [103]	Akbar et al., 2022 [82]	McEwen and Hosey, 2022 [83]	Moreno et al., 2022 [104]	B. Zhang et al., 2022 [105]	X. Zhang et al., 2022 [106]
6. Management of erosion–sedimentation and regulating the use of fertilizers (sources of nutrients, P and N) that cause eutrophication	promoting comprehensive sediment management				reduce nutrient input, control water hyacinth		reduce herbicides		remove rate of nutrient	
7. Management and preservation of biodiversity by controlling invasive biotic components (afforestation, reforestation) and biological manipulation		removing macrophytes, stocking herbivorous and omnivorous fish		living around (lake, upstream, downstream)			plants survey: assess distribution and coverage aquatic plant community (curly), controlling aquatic invasive species			biological manipulation
8. Management of cultural components: harmonizing human-nature interaction through legal permits and sustainable cultivation				living around (lake, upstream, downstream)			stimulating farmers to join programs, facilitating fabric management permission		restricting secondary industry, sustainable cultivation	
9. Monitoring of operational performance of existing programs	measures against ageing of water infrastructure									
10. Monitoring of weather, climate, and other physical conditions							early detection and fast response plan			

Table A5. Cont.

Identified Management Strategies	Nakatsuka et al., 2020 [100]	Zhu et al., 2020 [101]	Shadkam et al., 2020 [81]	Abdurrahim et al., 2021 [102]	Djihouessi et al., 2021 [103]	Akbar et al., 2022 [82]	McEwen and Hosey, 2022 [83]	Moreno et al., 2022 [104]	B. Zhang et al., 2022 [105]	X. Zhang et al., 2022 [106]
11. Economic empowerment-based management (supporting livelihoods dependent on fisheries and other ecosystem services, alleviating poverty, optimizing business opportunities)		rational fishing				livelihood; business opportunities	enhance fisheries			

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