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Review

Improvement of Integrated Watershed Management in Indonesia for Mitigation and Adaptation to Climate Change: A Review

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Abstract: Climate change is a major challenge for Indonesia due to its impact on food, water, energy sustainability, and environmental health. Almost all Indonesian regions are exposed to floods, landslides, soil erosion, drought, and heavy rains. In response to these challenges, the Government of Indonesia has determined integrated watershed management (IWM) to be one of the key programs to reduce greenhouse gas (GHG) emissions, as stated in the updated Indonesian nationally determined contribution (NDC). This paper intends to review Indonesia's efforts in mitigating and adapting to climate change through an IWM approach, and its attempts to realize a decent life and environment for all communities. Improvement of the IWM can be conducted by strengthening the synergy between the responsible institutions for watershed management and the responsible institutions for handling mitigation and adaptation of climate change impacts. In addition, it is important to prioritize coordination, participation, and collaboration not only at the national government level but also at the international level, since numerous problems may exist in the transboundary between countries, and finding solutions should involve planning, implementation, monitoring, and evaluation. Implementing the micro watershed model (MWM), supported by culture, local wisdom, and traditional knowledge in communities, can be used to improve the current IWM.

Keywords: Paris Agreement; nationally determined contributions; Indonesia's FOLU Net Sink 2030; micro watershed model; change paradigm

1. Introduction

Climate change is one of the greatest threats to human beings and the environment. Concerning this pressing issue, various international commitments and actions have been conducted to mitigate climate change and adapt to its negative impacts. In this regard, the Government of Indonesia has ratified the United Nations Framework Convention on Climate Change and the Kyoto Protocol [1]. The Kyoto Protocol is an international agreement to reduce greenhouse gases (GHGs). Due to its commitment, Indonesia has a responsibility to regularly report the National Communications and Biennial Update Reports of GHGs [2]. To fulfill and implement the commitments, the Government has submitted related documents to the UNFCCC. The submission was conducted in 1999, 2010, and 2017 for the First, Second, and Third National Communication, respectively [3]. The Government also submitted the First, Second, and Third Biennial Update Report in 2016, 2018, and 2021, respectively. The Third Biennial Update Reports presents the updated national GHG inventories, adaptation and mitigation actions, and also the needs and supports received [3].

The Kyoto Protocol is a non-legally binding international commitment, and it was replaced by the Paris Agreement (PA), which is legally binding between developed and developing countries. The PA established a global framework for avoiding dangerous climate change by limiting global warming to below 2 °C and pursuing efforts to limit it to 1.5 °C compared to the pre-industrial level. As a replacement for the 1997 Kyoto Protocol, which expired in 2012, the PA was adopted by 196 parties on 12 December 2015, and it went into effect on 4 November 2016.

Prior to the PA, the Government of Indonesia submitted the document of intended nationally determined contribution (INDC) to the Conference of Parties 21, UNFCCC, on 24 September 2015 [4]. Before COP 22, INDC was improved and known as nationally determined contributions (NDCs) through strengthening its clarity, transparency, and understanding for national and international levels. The NDCs is a national commitment to control global climate change in order to achieve the goals of the PA and the UNFCCC. Through NDCs, countries submit their commitments to reducing GHG emissions and building resilience to adapt to the impacts of rising temperatures [1].

The Government of Indonesia (GoI) has determined that NDCs will reduce GHG emissions by 29% unconditionally and up to 41% with international assistance compared to a business as usual scenario in the 2020–2030 period [3]. This commitment was updated at the 2021 UN Climate Change Conference, known as the 26th Conference of the Parties (COP26) [5]. At the COP26 forum, which was held in Glasgow, Scotland, United Kingdom, from 31 October to 13 November 2021, Indonesia committed to achieving the NDC target in 2030 by carrying out a low carbon compatible with Paris Agreement (LCCP) target scenario with the expectation that net-zero emissions can be achieved by 2060 or earlier. To realize the NDC, the Ministry of Environment and Forestry [6] determined the policy and implementation of Indonesia's Forestry and Other Land Use Net Sink 2030, abbreviated as Indonesia's FOLU Net Sink 2030 (Regulation of Minister of Environment and Forestry: SK. No. 168/PKTL/PLA.1/2/2022) with the principal of sustainable forest management, environmental governance, and carbon Governance [7].

Climate change disrupts the hydrological cycle [8–10], and the disruptions drive various impacts on watershed systems [11,12]. The diverse impacts are not only related to physical factors [13] but also to socioeconomic factors [14,15]. The physical factors can include a decrease in water resources, drought, and flooding due to extreme weather, land degradation, disease, or loss of agricultural production [16–19]. Climate change may affect socioeconomics through declining agricultural production because of a lack of water for the plants to grow [18], or by affecting fish production [20].

One of the main goals in watershed management is the continuous adequacy of clean water [21]. Water is the main medium for climate change to influence the Earth's ecosystem and all its inhabitants [9,22]. Water availability becomes a determining factor in the strategy to reduce emissions and facilitate climate adaptation. For example, planting biodiesel crops as a strategy to mitigate GHG emissions becomes a dilemma when water availability is limited [23]. Therefore, an integrated watershed management (IWM) approach, which deals with flood prevention, drought mitigation, planting for erosion control, and carbon sequestration, including its socioeconomic aspects, is appropriate and relevant for mitigation and adaptation of the climate change impacts [24]. Wang, et al. [25] defined an "IWM as an integration of multidisciplinary aspects in managing a watershed in order to maintain the continuity of productivity and ecosystem function in relation to water, soil, plants, and animals within the watershed. Thus, the IWM activities should involve protection and restoration of ecosystem services for environmental, social, and economic benefit".

The IWM approach has been explicitly stated in the updated Indonesian NDC and the Roadmap NDC Adaptation for climate change [26], and inexplicitly in the Roadmap NDC Mitigation of climate change [27]. Mitigation as efforts to prevent or reduce the emission of GHGs is mentioned in the Roadmap NDC Mitigation. The mitigation actions as part of IWM activities can be grouped into "reducing deforestation and forest degradation, sustainable forest management, increasing carbon stock through the development of forest plantation in mineral and peat lands, forest and land rehabilitation, increasing the role of conservation, and management of peat land by water management" [27].

The contribution of IWM to the reduction in GHGs emissions can be estimated by the total area of rehabilitated or reforested watersheds. According to MoEF [6], the total area of rehabilitated in watersheds in Indonesia in 2017, 2018, and 2019 was 200,990, 188,630, and 395,168 hectares, respectively. The amounts of CO_2 sequestered in the tree biomass planted in the watershed for rehabilitation were 353,151 t CO_2e in 2017 [28], 713,079 t CO_2e in 2018 [29], and 771,653 t CO_2e in 2019 [30].

As an archipelagic country of more than 17,000 islands with highly variable rainfall and altitude, Indonesia is very vulnerable to climate change [31]. Almost all regions in Indonesia are exposed to the risk of floods, landslides, soil erosion, and heavy rains during the rainy season. Meanwhile, some parts of Indonesia, especially in the eastern regions, experience drought. In this context and also considering the disruption of climate change on the hydrological cycle, the use of watersheds as a natural resource management unit that transcends administrative boundaries can be an effective approach to adapting to climate change [32,33]. Further, a watershed approach can be used to measure and evaluate the whole of natural systems in relation to social aspects beyond the administrative boundaries in order to communicate and understand the impact of their activities on the watershed [33]. In the updated Indonesian NDCAdaptation, the IWM is one of the key programs to be achieved through two strategies, i.e., (1) enhancing synergy across sectors and regions in watershed management and (2) mainstreaming/integrating climate change adaptation in watershed management to reduce risks/loss as a result of climate-related natural disasters [3]. Using the IWM approach, the natural processes and socioeconomic dynamics involved, as well as the causal relationship between the two, can be understood by the community in a simple way [32]. The social and economic aspects of IWM include livelihood, resilience, food security, and poverty reduction benefits [33]. Using a watershed as a management unit could reduce uncertainty in the projection of global climate change impacts on hydrology at the regional level. This is because of the large variation in applying global climate models (GCMs) for studying climate change effects on hydrological at the local scale [34].

Although the IWM approach has been stated in the NDC documents, it has not been completely implemented, especially at the local level. Apart from the IWM, the monitoring and evaluation (MONEV) of catchment hydrology have been affirmed in the regulation of the Director of Land Rehabilitation and Social Forestry No. P.15/V-SET/2009 on the development of the micro watershed model (MWM) [35]. In this regulation, the hydrological MONEV is intended to observe and measure the effects of the applied treatments, i.e., forest and land rehabilitation and soil and water conservation measurements in the catchments/micro watersheds, on hydrological conditions. This MONEV has not directly interlinked with the NDC program to mitigate GHG emissions because the MONEV regulation was issued earlier than the determination of NDC. Recently, the implementation of watershed management at the local scale emphasized the rehabilitation of woody plants in the expanse lands, or site levels and plots. Commonly, rehabilitation using woody plants is focused on preventing runoff and soil erosion of the degraded lands [36]. Thus, the communities receive less information on the benefits of woody plants for climate change mitigation [37].

At the local level, the integration of projects dealing with climate change mitigation and adaptation with watershed management projects has not been completely realized yet. Hence, the environmental issues, i.e., the impact of climate change and watershed degradation, cannot be solved within a project. Meanwhile, climate change and degraded watersheds affect the availability of water sources, and they can be quantified using a watershed approach [38].

In this paper, we present a narrative literature review. A narrative review provides an essential scientific role by presenting various sources of information on a certain topic within an article [39]. This paper aims to provide an overview of the roles of the existing IWM in mitigation and adaptation to the impacts of climate change, and to provide insights for IWM improvement in Indonesia. This paper is based on an analysis of published research papers, unpublished reports, books, and related documents. The overview is started from the international agreement to the national commitment and strategy, as well as the current role of IWM in mitigating and adapting to climate change. Then, the implementation and barriers of the existed IWM, including regulations, institution, planning, implementation, monitoring, and evaluation systems, are presented. In addition, this paper discusses climate change threats and challenges in Indonesia's watershed, consisting of national adaptation strategy, threats, and challenges in biophysical, economic, and sociocultural aspects. The closing remarks section will provide recommendations for improving IWM on climate change mitigation and adaptation. In summary, the perspective of the review that will be discussed throughout this paper is illustrated in Figure 1. This figure shows the cause of climate change, its environmental impacts, and the existing condition. The negative impacts of climate change will be solved through improvements of IWM to achieve the expected condition.

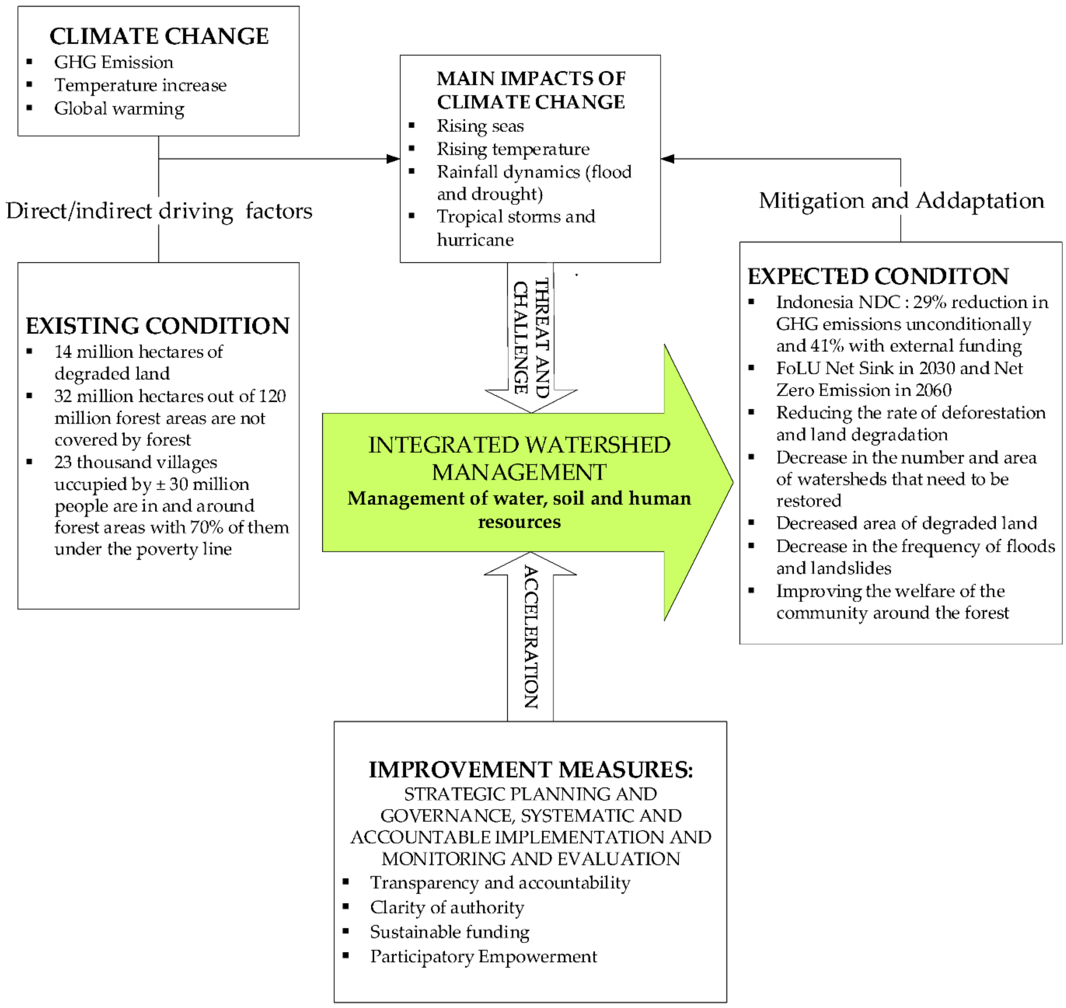

Figure 1. Perspective improvement of integrated watershed management for mitigation and adaptation of climate change in Indonesia.

2. IWM in Indonesia: Concept and Reality

2.1. Regulation

Law No. 7/2004 on Water Resources [40], as amended by Law No. 17/2019 [41], states that water resources should be managed following the principles of sustainability, balance, public benefit, integration and harmony, justice, independence, transparency, and accountability. Furthermore, according to Article 5, Law No. 17/2019, water resources should be controlled and used to maximize people's prosperity. This is in accordance with the management principles of natural resources outlined in the 1945 Constitution of the Indonesian Government [42].

The first regional government law, Law No. 22/1999 on Regional Government, was enacted in 1999 [43]. The responsibility for watershed and forestry management is delegated to the provincial and district/city governments under this law. Law No. 22/1999 was amended by Law No. 23/2014 [44] on Regional Government. Based on this law, responsibility for watershed management and forestry was transferred to the provincial level, and the forestry services and watershed management activities in districts and cities no longer exist [44].

Article 3 of Law No. 41/1999 on Forestry states that forest management aims to maximize people's prosperity, justice, and sustainability. The third verse of this law determines that forest management is conducted to increase the carrying capacity of the watershed [45]. According to Government Regulation No. 37/2012 on Watershed Management [46], watershed management activities include planning, implementation, monitoring, and evaluation, as well as training and supervision. In addition, watersheds are divided into two categories based on their carrying capacity, i.e., (1) those that must be restored and (2) those that must be maintained. A guideline for developing and determining a watershed management plan is provided in the Ministry of Forestry Regulation No. P.60/Menhut-II/2013 [47]. Meanwhile, a guideline for the MONEV of watershed management is stipulated by the Regulation of the Ministry of Forestry No. P.61/Menhut-II/2014 [48].

At the implementation level, there are several regulations, including (1) Law No. 37/2014 on Soil and Water Conservation [49], (2) Law No. 17/2019 on Water Resources [41], and (3) Government Regulation No. 26, 2020 concerning Forest Reclamation and Rehabilitation, which mentions general planning for watershed rehabilitation. The general planning is based on national forest planning, watershed planning, water resources planning, spatial planning, degraded land maps, mangrove maps, the ground water basin, and land cover map.

Before the laws mentioned above, Law No. 5/1960 on Basic Agrarian was issued [50]. Article 15 of Law No. 5/1960 obligates every citizen to preserve soil, including increasing its fertility and preventing damage. However, no land and water violators or destroyers have been brought to court so far. It is understood that those who are responsible for an area are the stakeholders of that area. However, the law does not stipulate what concepts are related to territorial maintenance, and it does not refer to using the watershed approach in the forestry law itself. Article 43 of Law No. 41/1999 concerning forestry states that everyone who owns, manages, and/or utilizes critical or unproductive forests is obliged to carry out forest rehabilitation for the purpose of protection and conservation [51].

The integrated management of watersheds requires the coherence of various regulations related to environmental conservation and the use of natural resources. Regulations are a framework for stakeholders, especially government agencies, to act and, therefore, these regulations greatly affect the efficiency and effectiveness of the implemented watershed management strategies. The reality of regulations, as found by Irawan and Dharmawan [52] shows that watershed management regulations in Indonesia have a very high level of complexity and tend to be sectoral in nature, so regulatory disconnections are still very prominent. This complexity, on the one hand, indicates that watershed management has been regulated in detail and, on the other hand, shows that there is a neglect of complexity and ambiguity in implementation. Weak law enforcement also adds to implementation problems. The implication of this is that government efforts are needed to synchronize various regulations in watershed management.

2.2. Institution

Watershed management can be viewed institutionally as the management of natural resources with various ownership, roles, actors, powers, and interests [21]. Effective watershed management requires better compatibility between those with authority over land use and those who own it and govern it. Lastiantoro and Cahyono [53] discovered that various stakeholders have an interest and power in the effectiveness of watershed management. The institution′s primary tasks and functions define its level of interest and power. This means that the institution which is responsible for watershed management must consider the public's aspirations and roles to achieve success in the implementation of watershed management.

Contextually, watershed management in Indonesia is based on the Government Regulation No. 37/2012 with the following principles: (1) watershed management is conducted through the stages of planning, implementing, monitoring, evaluating, and directing and controlling, (2) watershed management is harmonized and mainstreamed with spatial planning and water resource management patterns, and (3) the coordination is carried out across institutions, sectors, and administrative areas while still involving communities. Watersheds are managed by involving many parties with various roles and functions at various scale levels. The non-linear watershed boundaries with administrative boundaries cause the complexity of governance to integrate management circulation with stakeholders' involvement [54,55]. Government Regulation No. 37/2012 mandates that the MoEF, a government institution in charge of the forestry sector, serves as the main authority for watershed management [46]. The involvement of several key institutions is also explicitly mentioned, namely the Ministry of Public Works and Housing, the Ministry of Agriculture, the governors, and the regents/mayors [55].

The institutional framework for integrated watershed management consists of established rules, norms, practices, and organizations that provide a structure for human activities in watershed management [56]. According to Narendra et al. [21], institutional challenges in the IWM include hierarchical confusion, inconsistency, asynchrony among legislation, and a lack of participation, synchronization, and coordination among watershed management stakeholders. Limitations at the planning stage include a lack of integration between sectors, a lack of community participation, and a reluctance to integrate watershed planning into regional planning [55,57,58].

In the reality of implementing institutions for watershed management, there is no mechanism that encourages conservation activities and integrated natural resource management on a watershed scale between sectors and between regions, as well as strict sanctions against mismanagement of natural resources [59]. Furthermore, these shifts were closely linked to the power balance between central and local governments, which saw extreme decentralization followed by recentralization. This shift in the institution has a significant impact on regional governance. For example, in the Bribin watershed, management has been hampered by Law No. 23 of 2014. These limitations are related to the availability of human resources in the field and local government participation in the Bribin watershed's management plans [60]. A study conducted by Harmiati, et al. [61] has concluded that some district governments′ failure to realize the institutions′ aspect in IWM is caused by the absence of a legal rule, lack of coordination, low participation, a top-down approach, and a lack of transparency in watershed management. Conflicts of interest between central and local governments and/or between local governments have exacerbated the situation upstream. Many regulations have been adopted (central and local), but in reality, many regulations overlap. There is confusion in this area in terms of authorities [62].

2.3. Planning, Implementation, and Monitoring and Evaluation Systems

The concept of watershed management has been recognized for thousands of years. A study of ancient civilizations showed that humanity was experienced in the use and management of water [63]. In China, the concept of watershed management, including soil and water resources, was introduced around 2880 BC, and regulations concerning forest protection laws have been applied since 300 BC [64].

At the end of the 20th century, an increasing population and demand for land, water, and other natural resources resulted in the need for more intensive watershed management. Ensuring the continuity of watersheds' services in a changing climate requires the application of technical breakthroughs and holistic, cross-disciplinary methods in watershed management [25].

Planning, implementation, and MONEV in watershed management are needed for mitigation and adaptation to climate change. Monitoring and evaluation of watershed management can be used to detect climate change, especially from the hydrological aspect, and MONEV related to the increase or decrease in the forest or other land covers within watersheds can be used to calculate carbon stock in the plantation. Thus, it can be used to estimate the reduction in CO_2 in the atmosphere. If any indication of climate change is observed, then watershed management planning and implementation must be adjusted for climate change mitigation and adaptation.

2.3.1. Watershed Management Planning

In Indonesia, watershed management planning is carried out based on the Ministry of Forestry Regulation No. P.60/Menhut-II/2013 on Guidelines for the Development and Determination of Watershed Management Plans [47]. The concept of a watershed management plan in the regulation has accommodated the roles of all parties, from planning, implementation, and MONEV. All parties are involved in identifying watershed management problems. Afterwards, the goals and objectives of watershed management are set. Subsequently, a program plan is prepared to address watershed management problems.

The National Planning Board coordinates the watershed management planning process if the watershed is located in two or more provinces, while planning is coordinated by the Provincial Planning Board if the watershed is located between districts within a province [47]. The results of the watershed management plan are signed by the Governor as a planning document. The watershed management plan is used as a reference by the sectors in preparing more detailed programs and activities. It also becomes the input for provincial and district governments in the Long Term Development Plan (RPJP), Medium Term Development Plan (RPJM), and Regional Government Activity Plan (RKPD) [47].

In fact, the watershed management plan that has been approved by the Governor is rarely referred to by the sectors involved in watershed management. This is due to the absence of legal force underlying the watershed management plan [62]. Other sectors are more compliant with the RPJP, RPJM, and RKPD, which have a strong legal basis, i.e., regional regulations. For the watershed management plan to be referenced by other sectors, the watershed management plan must be integrated into the RPJP, RPJM, and RKPD. Unfortunately, this integration has not been fully performed, because each region is more interested in obtaining economic benefits [65]. Consequently, the watershed management plan is only implemented by the forestry sector, and the results have not met the determined targets.

2.3.2. Watershed Management Implementation

Technically, the implementation of watershed management is closely related to soil and water conservation (SWC) activities, whether aimed at soil conservation, water conservation, or both. The applied SWC can be mechanical or vegetative measures. Soil conservation has typically been discussed concerning crop production and maintaining the soil in place. Soil conservation was studied in the early 2000s in terms of its benefits for boosting crop yields, reducing water pollution, and reducing GHG concentrations in the atmosphere as an impact of the climate change phenomenon [66]. In the watershed context, these impacts need attention in their management by utilizing technological advances in a holistic and interdisciplinary approaches to ensure that watersheds can continue to serve their ecological, social, and economic functions sustainably [67].

The implementation of inter-provincial watershed management by the central government involves the Ministry of National Development Planning, the Ministry of Environment and Forestry, and the Ministry of Public Works and Public Housing (see Figure 2). Meanwhile, the implementation of watershed management in the province involves the Ministry of National Development Planning and the Ministry of Home Affairs (see Figure 3).

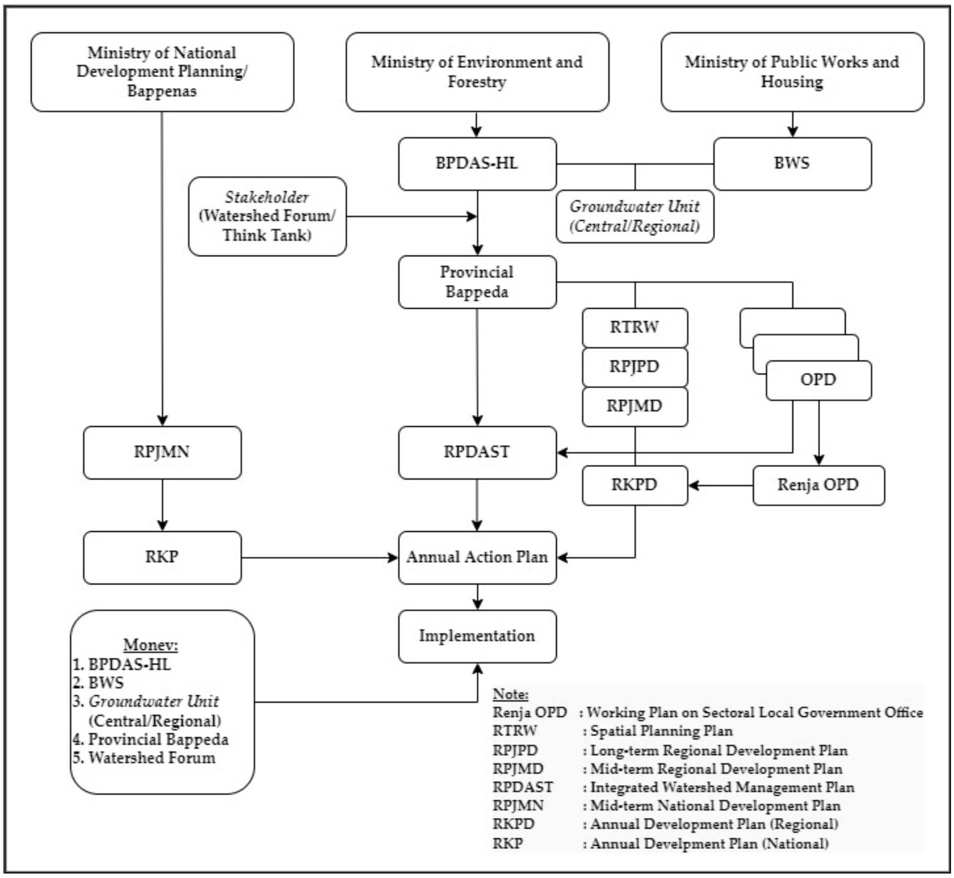

Figure 2. Organogram implementation of watershed management at the national level. Source: Reproduced with permission from [55].

The target area for watershed management implementation is generally divided into upstream and downstream areas, depending on the region. An upstream area is a conservation and water-producing area with sections of significant rainfall and a sloping landscape with high altitudes [68,69]. A downstream area is a lowland area that is frequently classified as a disaster-affected area, as well as a benefit area in terms of water supplies [69]. The upstream–downstream distribution has ramifications for differences in SWC implementation, both in terms of activity types and field implementation strategies [36].

Spatial integration (upstream–downstream) and sectoral integration in watershed management in Indonesia has not yet fully occurred. Since 1983, a watershed management pattern has been developed, and in 2009 it was updated with an integrated watershed management plan. The Governor signs the integrated watershed planning document when a watershed is in his/her administration area. Unfortunately, this document has not been used for guidance by all stakeholders [70].

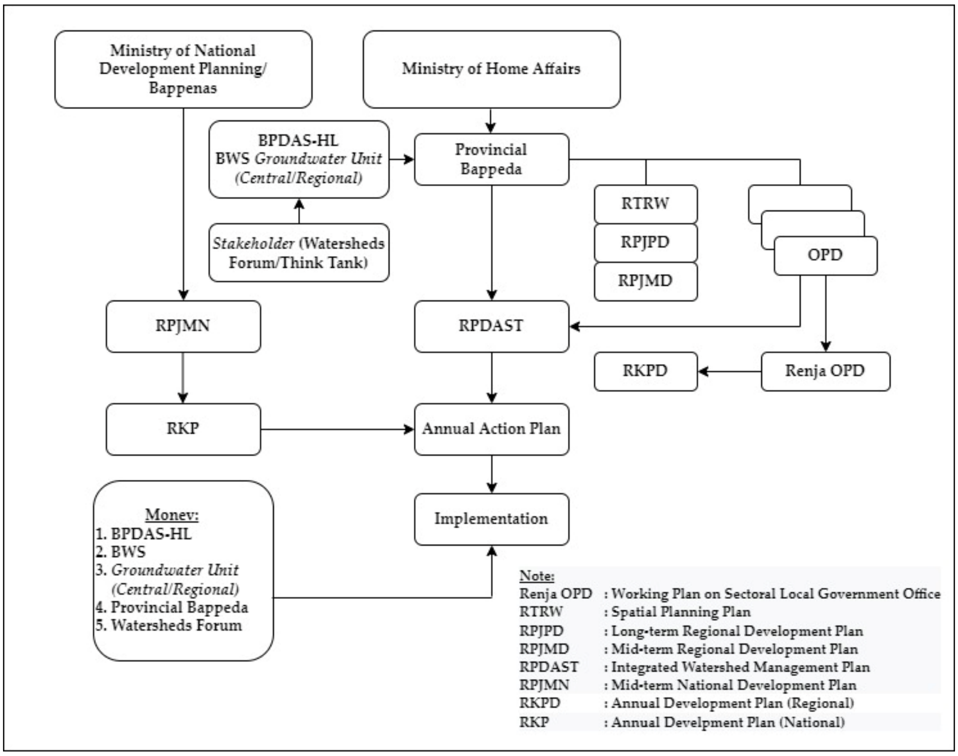

Figure 3. Organogram implementation of watershed management at the provincial level. Source: Reproduced with permission from [55].

Although there is a lack of integration in watershed management, there is an example of good watershed management in Indonesia. The management of the Cidanau Watershed is an example of the successful integration of resource sharing between the upstream and downstream areas of a watershed. Integration between sectors is also built in the management of the watershed. The private sector downstream of Cidanau, namely the industry in Cilegon City, offers a payment for environmental services to farmers to maintain the trees on their land. This activity was initiated by the non-governmental organization Rekonvasi Bhumi, and the Serang Regency Government acts as a mediator for transactions between water users from Cidanau watershed and land managers in the upstream part of the watershed [71]. The success of this sectoral integration is due to the commitment of all parties [72]. In this way, the sustainability of the Cidanau watershed can be guaranteed.

The key issue in the upstream areas that requires watershed management activities is the high level of soil erosion produced by intensive cultivation of seasonal crops on steep slope lands [73,74]. This is exacerbated by the lack of proper implementation of the SWC measures, particularly in terms of the suitability of the technique chosen to solve the problems [75,76]. The downstream area issues are mostly related to hydrometeorological disasters, such as floods, sedimentation, and drought [57].

One of the reasons for the less successful implementation of upstream watershed management in Indonesia is the lack of integration in the application of SWC and the lack of integration among the parties in carrying out management activities [77,78]. In addition, a less optimal selection of activities that correspond to the root of the problems frequently leads to partial and ineffective problem solving [79]. Therefore, MWM was developed as a management model in the upstream watershed and is expected to be a prototype for the implementation stage. A micro watershed is a cohesive ecosystem unit with natural features, such as slope, soil, drainage, and geomorphology, covering one or more villages or one or more sub-districts, and functions to collect, store, and drain rainwater [80,81]. According to the Director General of Land Rehabilitation and Social Forestry Regulation No. P.15/V-SET/2009 concerning the Guidelines for the Development of Micro Watershed Model Areas (MWM), the area of a micro watershed is less than 5000 ha, and the management plan is prepared by the stakeholders. However, the field reality shows that the development of the MWM has not been carried out as expected. The large area of the micro watershed (5000 ha) makes integration among stakeholders and building community participation difficult [57,67]. Therefore, several improvements must be made to realize MWM as an implementation unit.

2.3.3. Watershed Management Monitoring and Evaluation

Climate change causes changes in rainfall patterns and increases in temperature. Along with climate change impacts, water demand in Indonesia will increase by 31% from 2015 to 2045 [33]. Consequently, efforts to meet future water needs must be performed intensively and in an integrative manner with the watershed as a management unit. Based on their research findings, Marshall and Randhir [12] predicted that climate change would significantly affect river flow, sediment and nutrient loads, and the timing and peak of flooding. Therefore, MONEV is essential in watershed management to obtain activity-related data or information for the improvement of watersheds, and also to observe the changes in some climate variables.

Monitoring and evaluation are undertaken to determine the progress of watershed management and to assess whether the managed watershed is heading towards improvement or is still degraded. Based on the Ministry of Forestry Regulation No. P.61/Menhut-II/2014, MONEV of watershed performance indicators comprises five criteria, i.e., (1) land, (2) water quality, quantity, and continuity (hydrology), (3) socioeconomic, (4) building investment value, and (5) regional space utilization [48]. The results of MONEV can be used to determine the condition of a watershed, either as healthy and should be maintained, or degraded and should be restored [82]. The results also provide information on the severity level of the watershed degradation as a basis for selecting priority areas for restoration. Thus, the results of the MONEV can serve as inputs for watershed management planning improvement in the following period. However, these results have not been widely used to improve the plan. This is due to the lack of communication between the parties conducting MONEV and the parties developing watershed management planning [21]. In IWM, all the parties should work together to establish the priority areas to restore and assign the targets to achieve.

Almost all watershed management projects have not performed sufficient MONEV on the impacts of watershed improvements in the upstream and downstream areas [83]. Similar to the implementation aspect, MONEV of watershed management in Indonesia has only been conducted by the forestry sector, especially the Watershed and Protected Forest Management Office, and the results have not been socialized to the parties. Ideally, MONEV of watershed management is executed jointly by related parties, such as the monitoring of water management and building investment by the Ministry of Public Works and Housing (MoPWH), monitoring of land use and land cover (LULC) by the MoEF and MoA, monitoring of regional space utilization by the Ministry of National Development Planning (MoNDP), and monitoring of socioeconomic conditions by the Ministry of Agriculture [84]. Then, the evaluation of watershed management is carried out together by the parties coordinated by the Governor. Unfortunately, the integration of MONEV has not been implemented. This happens because each party feels they have the same position. In fact, in Government Regulation No. 37/2012, it has been stated in Article 50 that the Minister, in this case, the Minister of Forestry, under his authority and responsibility, carries out monitoring and evaluation of watershed management across provinces, and the Governor carries out monitoring and evaluation of inter-districts. Therefore, the Government may need to issue a Presidential Regulation that authorizes the minister and the Governor to coordinate MONEV of watershed management, and to divide the tasks of MONEV of watershed management among the parties involved.

3. Climate Change Threats and Challenges to Indonesian's Watershed

Starting in the industrial era, GHG emissions, especially CO_2, have increased rapidly. The main factor in GHG emissions is the use of fossil fuels, such as coal, natural gas, and petroleum. According to data released by the US Department of Energy's Center for Carbon Dioxide Information Analysis Center (CDIAC), humans have added more than 400 billion metric tons of CO_2 into the atmosphere since 1751. About half of that amount was produced from the late 1980s to the present and, in 2014, the global carbon emissions estimated from fossil fuels was 9855 million metric tons of carbon [85]. This increase in GHGs has caused an increase in temperature and induced global warming.

Climate change due to global warming can be observed from changes in the pattern and intensity or shifts in climate's main parameters, such as precipitation, temperature, humidity, wind, cloud cover, and evaporation [86]. In general, climate change affects water availability, water-related ecosystems, and also the magnitude and occurrence of hydrometeorological disasters, such as floods and droughts [87,88]. Eventually, it will influence many sectors, including agriculture, energy, fisheries, tourism, health, and biodiversity [87]. It is projected that increasing global warming will increase the frequency and intensity of hot extremes, heavy precipitation, and, in some areas, agricultural and ecological droughts [89]. It will certainly pose greater threats and challenges for watershed management. The strengths, weaknesses, opportunities, and threats of integrated watershed management in Indonesia are shown in the SWOT framework (Table 1).

Table 1. The SWOT framework for integrated watershed management improvement and climate change in Indonesia.

Strength	Weaknesses
1. Indonesia has committed to take real actions and efforts to reduce GHG emissions, increase carbon sequestration, ratification international, IFOLU net sink, use watershed to mitigate-adaptation climate change, and improve social welfare and environmental quality [3,5,7,32,33,90–93]. 2. The Climate Village Program or the ProKlim and SDGs that intended to increase community and stakeholder participation in strengthening adaptation capacity to climate change impacts and reducing GHG emissions, as well as to recognize adaptation and mitigation efforts that can improve local welfare [86,94]. 3. IWM was one of the key programs of the climate resilience activities, particularly to support economic resilience and also the ecosystem and landscape resilience [3,95].	1. Weak coordination among sectors and regions, lack of community participation, overlapping regulations, sectoral egos, lack of commitment, absence of regulation that rules each stakeholder to implement the IWM plan, very high complexity, overlapping management areas, and asymmetric information among sectors in watershed management activities [21,36,52,56,57,65,96]. 2. The IWM approach has not been completely implemented, lack integration, and ambiguity in implementation, especially at the local level [26,52,77–79]. 3. The results of the monitoring and evaluation (MONEV) cannot serve as inputs for watershed management planning improvement in the following period [21]. 4. The availability of high-quality data is not ready and not real-time [97–99]. 5. Indonesians have a lot of local wisdom and culture in natural resources management, which also affects mitigation and community adaptation capacity to disasters and climate change. Unfortunately, several local pearls of wisdom are currently being neglected [100,101].

Table 1. *Cont.*

Opportunities	Threats
1. Climate change funding from international and multilateral [102–104]. 2. The best practice for applying a watershed management model is based on a combination of local knowledge and modern science-based knowledge in a scope that can be managed according to shared interests or needs [105]. 3. Development of agroforestry pattern is the best land management from ecological and economic aspects [36,106–112] to climate change mitigation [113–115] and adaptation [114,116–118]. 4. Strengthening and extending the forest moratorium policy, restoring degraded forest and peatland, implementing energy conservation efforts, renewable energy development, a carbon tax on fossil-fuel power plants, replacing new development of coal power plants with clean and renewable energy sources (wind or solar), and providing subsidies and better feed-in tariffs for promoting renewable energy sources [119].	1. The sectors rarely refer to the watershed management plan that has been approved by the Governor. Involved in watershed management [62], and each region is more interested in obtaining economic benefits [65]. 2. Climate change influences many sectors, including economy, agriculture, food security, energy, fisheries, tourism, health, flood, disaster, drought, forest fire, landslide, fishery, human health, conflict, culture, indigenous people's existence, and biodiversity [87,88,120–139].

Source: Based on the analysis for the current study.

3.1. National Regulation and Policy on Climate Change Adaptation

Indonesia has been actively involved in efforts to combat global climate change since the ratification of the United Nations Framework Convention on Climate Change [1] through Law No. 6/1994 [90], followed by the ratification of the Kyoto Protocol in 2004 through Law No. 17/2004 [91]. By ratifying the Kyoto Protocol, Indonesia has committed to take real actions and efforts to reduce GHG emissions, increase carbon sequestration, and improve social welfare and environmental quality [92]. Furthermore, in 2009, the Government of Indonesia (GoI) issued Law No. 32/2009 on the Protection and Management of the Environment, which authorizes the Ministry of Environment (MoE, later MoEF) to determine and implement policy on controlling the impact of climate change [140].

As a vulnerable country, Indonesia urgently needs to develop climate change adaptation actions as a process to strengthen and develop a strategy to anticipate the negative impacts of climate change [141]. The adaptation efforts should be integrated and synergistic with the mitigation efforts to increase local community acceptance and guarantee the sustainability of the programs [26]. Implementing climate change adaptation efforts in Indonesia has been a lengthy process. It began in 2010 with the development of the Indonesia Climate Change Sectoral Roadmap (ICCSR), which was later translated into the 2014 National Action Plan for Climate Change Adaptation (*Rencana Aksi Nasional Adaptasi Perubahan Iklim*/RAN-API) [142,143]. The RAN-API provides a framework for adaptation initiatives that have been mainstreamed into the National Development Plan [144]. The main objective of climate change adaptation in the RAN-API was the implementation of a development system that is sustainable and has high resilience to the impacts of climate change [143].

To strengthen its commitment to tackling global climate change, Indonesia has signed and ratified the Paris Agreement through Law No. 16/2016 [145]. In 2016, the first NDC document as the state's commitment to supporting climate change action had also been submitted to the UNFCCC [26,144]. However, since it was submitted in 2016, Indonesia's NDC-adaptation is still a commitment, and has not been formulated in quantitative target numbers as the climate change mitigation target, with a commitment to reduce GHG emissions from 29% (unconditional) to 41% (conditional) by 2030, compared to a business as usual scenario [26].

In 2016, the MoEF issued Regulation No. P.33/Menlhk/Setjen/Kum.1/3/2016 on Guidelines for Developing Climate Change Adaptation Actions [141]. This regulation aims to guide the Government and local governments in developing climate change adaptation plans for specific regions and/or sectors, which consists of five steps, i.e., (1) identification of area coverage and/or specific sector targets and climate change impact problems, (2) preparation of climate change vulnerability and risk assessments, (3) preparation of climate change adaptation action options, (4) prioritization of climate change adaptation actions, and (5) integration of climate change adaptation actions into policy, planning, and/or development program [141]. To support the preparation of climate change vulnerability and risk assessments, the MoEF developed an information system for vulnerability index data [146], which was initiated in 2015 [105] to identify an area′s exposure, sensitivity, and adaptability to climate change (http://sidik.menlhk.go.id/ accessed on 28 May 2022). Moreover, the Directorate of Climate Change Adaptation [147] states that (1) exposure to climate change is related to the location of an area; for example, the coastal area is highly exposed to climate change because it is affected by the increase in tidal waves, (2) the sensitivity of an area depends on how the area is affected by climate change, and (3) adaptability is associated to the capability of a system/area to adapt to climate change.

At the end of 2016, the MoEF reissued the Climate Village Program, which was previously launched by the MoE in 1992, through Regulation No. P.84/Menlhk/Setjen/Kum.1/11/2016 [94]. The Climate Village Program, or *ProKlim*, is a site-based climate change adaptation and mitigation activity that involves the community, government, businesses, universities, and non-profit organizations [86]. As a national-level program managed by the MoEF, the *ProKlim* is intended to increase community and stakeholder participation in strengthening adaptation capacity to climate change impacts and reducing GHG emissions, as well as to recognize adaptation and mitigation efforts that can improve local welfare [94]. In 2017, the Directorate General of Climate Change Control (DGCCC) published a roadmap of *ProKlim*, which outlines the national policy steps in increasing community climate resilience at the local level, both in the pre-2020 (2017–2019) and post-2020 (2020–2030) periods, to calculate its contribution to the achievement of GHG emission reduction [148]. To facilitate monitoring activities related to the first NDC implementation pre-2020 and post-2020, the MoEF issued Decree No. SK.679/MENLHK/SETJEN/KUM.1/12/2017 on Monitoring the Implementation of Nationally Determined Contribution [95]. This decree stipulated the establishment of a steering team and, also, a technical team, for monitoring the NDC's implementation.

In 2018, the DGCCC issued Regulation No. P.2/PPI/SET/KUM.1/1/2018 on Guidelines for Facilitating Climate Change Adaptation Plan Development in the Regions [149]. It was intended to serve as a guide for the Climate Change and Land–Forest Fire Control Agency (*Badan Pengendalian Perubahan Iklim dan Kebakaran Hutan dan Lahan*—BPPIKHL) in implementing regional capacity building through facilitation activities for the preparation of climate change adaptation plans in the regions. In addition, the MoEF issued MoEF Regulation No. P.7/Menlhk/Setjen/Kum.1/2/2018 on Guidelines for Assessing Vulnerability, Risk, and the Impact of Climate Change [150]. It was issued to follow up Law No. 32/2009 on the Protection and Management of the Environment, which stipulates that the Government and local government must prepare the Strategic Environmental Assessment, which consists of, among others, assessments of vulnerability and capacity for adaptation to climate change [140], and also the MoEF Regulation No. P.33/Menlhk/Setjen/Kum.1/3/2016 on Guidelines for Developing Climate Change Adaptation Actions [141], which requires information on climate change impacts, vulnerability assessment, and climate change risks.

Indonesia is committed to realizing ecosystem and landscape resilience from the impacts of climate change following the NDC. In 2019, the DGCCC issued Regulation No. P.4/PPI/SET/KUM.1/11/2019 on Guidelines for the Identification of Ecosystem-based Climate Change Adaptation [151]. Based on this regulation, ecosystem-based climate change adaptation is an adaptation activity to protect or maintain ecosystems from the impacts of climate change while at the same time assisting communities in adapting to the impacts of climate change through the services they produce. Identification of ecosystem-based climate change adaptation is needed to support the implementation of the MoEF

Regulation No. P.33/Menlhk/Setjen/Kum.1/3/2016, as well as the MoEF Regulation No. P.7/Menlhk/Setjen/Kum.1/2/2018, and aids in assisting the implementation of the assessment of climate change impact on ecosystems, as well as in the preparation of adaptation action options related to the existence of ecosystem services [151].

The MoNDP/Bappenas reformulated the 2014 RAN-API, i.e., National Adaptation Plan (NAP). The NAP is a document that will serve as the primary reference for planning climate change adaptation efforts that are on target through adaptive criteria [152]. The NAP was created through a scientific, inclusive, and iterative process that considered the characteristics of the sector and region through scientific studies that were strengthened by experiences and practices from various parties on the ground. The NAP, as a national strategic plan, includes four priority sectors for climate change adaptation, i.e., (1) marine and coastal, (2) water, (3) agriculture, and (4) health, as well as four clusters of adaptation strategies, i.e., (1) infrastructure, (2) technology, (3) capacity building, and (4) governance, that must be developed in each priority sector [152]. To provide technical direction on the adaptation aspect of the NDC implementation needed to achieve the NDC 2030 target, the MoEF published the NDC Adaptation Roadmap in 2020 [26]. This document serves as a reference for the preparation of more technical planning and implementation of climate change adaptation at sectoral and regional levels to realize climate change adaptive national development. In 2021, the MoEF published an updated NDC by enhancing, among others, Indonesia's ambition for adaptation as specified in the programs, strategies, and actions to achieve economic, social, and livelihood resilience, as well as ecosystem and landscape resilience [3].

To fulfill the Paris Agreement commitment, the MoNDP/Bappenas has designated Climate Resilience Development (*Pembangunan Berketahanan Iklim*-PBI) as one of the seven Development Agenda/National Priorities (*Prioritas Nasional*-PN) in the 2020–2024 National Medium-Term Development Plan (*Rencana Pembangunan Jangka Menengah Nasional*-RPJMN), i.e., PN.6 enhancing the environment and resilience to natural disaster and climate change impacts, as stipulated by Presidential Regulation No. 18/2020 [3,153]. In 2021, the MoNDP/Bappenas published Climate Resilience Development Policy 2020–2045 as a reference for stakeholders in implementing PN.6 of RPJMN 2020–2040, consisting of six books, i.e., (1) a list of locations and actions of climate resilience, (2) institutional arrangement for climate resilience, (3) roles of non-government institutions in climate resilience, (4) climate resilience funding, (5) monitoring, evaluating, and reporting on climate resilience actions within the framework of national development planning, and (6) an executive summary of the Climate Resilience Development Policy 2020–2045 [142].

Referring to the first and updated NDC documents, the strategic approach used to achieve the NDC target employed an integrated landscape-scale approach, covering terrestrial, coastal, and marine ecosystems [3,144]. The IWM was one of the key programs of climate resilience activities, particularly to support economic resilience and also the ecosystem and landscape resilience [3,95]. Climate resilience is a planned or unplanned anticipatory action to reduce the value of potential losses caused by climate change threats, vulnerabilities, impacts, and risks on people′s lives in affected areas [142]. There is a need to integrate climate change into public policy and planning initiatives. Climate change integration is a process that involves strengthening links between scientific and policy communities and learning from past experiences [154]. Implementing best management practices (BMPs) at the sub-watershed level is an effective way to enforce climate resilience in a watershed [10,155].

3.2. Threats and Challenges of Climate Change on the Biophysical Aspect of Watershed Management

3.2.1. Climate Change Impacts on the Land Productivity

Disruption of the hydrological cycle due to changes in temperature and rainfall patterns can affect the biophysical conditions of watersheds, i.e., land, hydrology, and vegetation. As an agricultural country, Indonesia is highly dependent on agricultural products. Rising temperature and changes in the rainfall pattern significantly affect the agricultural sector [120], causing a significant loss of agricultural products and threatening food security [121,122]. Several modeling studies suggested that the mean rice yield will decrease in 2040–2050 by 11.7% in the Keduang Sub watershed, Central Java [156], 32.0% in Sumedang, West Java [157], and 12.1% for all of Indonesia [158]. A simulation model estimated that Indonesia will have a husked rice deficit of 90 million tons by 2050 [159]. In addition, extreme weather also causes a decline in the production of coffee [160], cassava [161], and tobacco [162].

Climate change has forced farmers to adapt to changes in cropping patterns [121] and select more tolerant species [163]. Over generations, the farmers used a traditional system called *Pranotomongso* (in Java) and *Kerta Masa* (in Bali) as part of the agronomy calendar to determine the beginning of the planting season, the crop selection, and the crop rotation time [162,164–166]. The system was based on the signals of the environment; for example, when a specific tree grows its leaves, a certain type of insect emerges [162]. However, this system has now become less accurate due to climate change with its unpredictable weather [162], and farmers have been forced to reconsider their current agricultural practices. Adjusted planting time to rainfall patterns could suppress the yield reduction by 16.2% [157]. Moreover, adjustments to varieties, fertilizer, and feed should be made to be more compatible with local conditions to prevent further decline in agriculture productivity [167].

3.2.2. Climate Change Impacts on Hydrometeorological Disasters

Climate change also increases the incidence of disasters [123], especially hydrometeorological disasters, such as floods, droughts, and landslides [124–127], as a result of changes in rainfall patterns and intensity [125]. Warmer temperatures on land and oceans cause more water to evaporate, change the intensity and frequency of rainfall events and, in turn, affect the magnitude and frequency of river flooding [168,169]. Paradoxically, the dry season in some places becomes more intense due to more water evaporating from the land and changing global weather patterns [170]. From observing 50 years of flood events at 774 stream gauge stations in the central United States, climate change has led to a significant increase in the frequency of flooding events, but not in peak floods [171]. However, the same data shows that, in a small number of areas, the frequency of flooding has decreased. Over the past two decades, climate change has resulted in floods and droughts affecting 3 billion people [170].

In Indonesia, data from the National Disaster Management Agency shows that over the last two centuries, the frequency of flood events, as the type of disaster that most often occurs with the most casualties, has steadily and significantly increased as the country entered the 21st century [172,173]. Climate change has caused high rainfall, particularly in the western region of Indonesia, triggering floods [174]. In 2020, there were 1518 flood occurrences across all Indonesian regions, causing 132 deaths and displacing 782,054 people [173].

In contrast to flood disasters, which occur in a relatively short time and affect smaller areas, drought occurs gradually and over a large area [175]. In terms of impacts, drought also adversely impacts the environment, the economy, and wider society [176]. It will significantly threaten food security through its impacts on food availability (crop production, stock, and trade), food accessibility (food trade, income, and market price), and food stability (adequate access to food) [177]. In Indonesia, drought needs more attention, considering that, as a tropical country, Indonesia is very sensitive to the El Niño-Southern Oscillation [178], which is the cause of drought [179]. From historical records, the greatest drought experienced by Indonesia was in 1997/98, when the ENSO phenomenon occurred [126]. Due to increasing global warming, it is projected that some regions will experience agricultural and ecological droughts [89]. The provinces most vulnerable to drought in Indonesia are Riau, Jambi, South and North Sumatra, and all Kalimantan, except for North Kalimantan [179].

Drought also triggers forest and land fires. During the 1997/98 ENSO drought period, forest and land fires were estimated to have affected 11.7 million hectares (ha) of areas, mostly forested peatland [180]. The fires significantly threaten sustainable development due to their direct impacts, such as the decline in forest vegetation and biodiversity, loss of property and even lives, and their indirect impacts, such as air pollution due to smoke, carbon emissions, and a decline in human health [180,181]. Forest fires are not only caused by drought but also by human behavior [182], such as using fire for land clearing [181] and drainage in peatland preparation that makes peatland susceptible to fire [183].

Extreme weather conditions, in particular increasing rainfall intensity, escalate the landslide risk for areas with unstable steep slopes, such as in mountainous regions [127,184]. Landslides are one of the most disastrous natural hazards in terms of fatalities and economic losses [185], particularly in highly populated and developed areas. In 2021, landslides were the third most frequent natural disaster after floods and hurricanes, causing 124 casualties and 5192 refugees [173]. From 2003 to 2008, Indonesia was one of the top three countries with the highest percentage of landslide fatalities [185]. As a result of the changing climate, it was predicted that the damage and loss due to landslide events would significantly increase [128].

Climate change has also triggered other hydrometeorological hazards, such as coastal erosion, inundation, tropical cyclones, and heatwaves. As an archipelagic country with many small islands, Indonesia is highly vulnerable to coastal erosion and inundation [186]. Several studies reported the phenomena of coastal erosion and inundation in Indonesia, which were intensified by an increase in sea level due to global warming [131,187–189]. Coastal erosion and inundation cause shoreline change, coastal wetlands and settlements losses, and household displacement, as well as damage to fishponds, agricultural lands, and infrastructure [131,187], negatively affecting the environment and socioeconomic aspects of human life.

Recently, tropical cyclones struck the Indonesia region annually, i.e., there were tropical cyclones in the southeastern Indian Ocean between January and April, and there were tropical cyclones in the eastern Pacific Ocean between May and December [190]. During 1983–2017, 51 tropical cyclone incidents were reported in the southern region of Indonesia [191]. Although tropical cyclones tend to move away from the equator, they can still cause high-intensity rainfall and strong wind, leading to severe storm surges and floods [191–193]. There were several notable tropical cyclones reported across Indonesia which caused heavy rainfall and strong wind, including Tropical Cyclone Cempaka in 2017, Tropical Cyclone Mangga in 2020, and Tropical Cyclone Seroja in 2021 [192–194].

The phenomena of heatwaves due to rising surface air temperature become more frequent and intense under a changing climate [195–198]. Due to the urban heat island (UHI) effect, urban areas tend to be more vulnerable to heatwaves [197]. Heatwaves cause adverse effects on human health, increasing mortality and morbidity globally [198,199], particularly in elderly people over 65 years old [198]. In addition, heatwaves, as a specific type of extreme temperature event, negatively affect agriculture, workplace productivity, wildfire frequency and intensity, and public infrastructure [200]. Several studies also reported the increase in marine heatwaves (MHWs) in Indonesia [201]. Indeed, MHWs have significant impacts on marine biodiversity and ecosystems [178,202], such as coral bleaching [203] and the mass mortality of marine invertebrates due to heat stress [204], as well as impacting regional fisheries [205,206].

3.2.3. Climate Change Impacts on Environmental Quality

Landscape-scale soil erosion rates are affected by geology, topography, slope, climate, soil type, and vegetation [207]. The changes in temperature and precipitation due to climate change [208,209] have an impact on plant biomass production, infiltration rate, soil moisture, land use, and crop management, which cause the escalation of surface runoff and soil erosion [210]. The declining quality of rivers, lakes, and drinking water due to eutrophication is also affected by climate change [211], exacerbated by human activities that trigger a high rate of nutrient input of point and non-point sources into the water bodies [212,213]. Eutrophication is considered the most serious water pollution problem in aquatic ecosystems, such as lakes [214–217].

Pollution that occurs on agricultural land or other water bodies is caused by nutrient leaching and sedimentation processes from the upstream areas, which are accelerated by climate change. Research results from Biswas, et al. [218] suggested that climate change affects the movement and storage of pollutants in the soil, increasing human exposure to soil contaminants. Leached nutrients in the intensive agricultural land may also contaminate groundwater [219]. The major sources of water pollution include human settlements, industries, and agriculture [220]. In addition to water pollution, air pollution due to forest and land fires increases with global warming.

3.3. Threats and Challenges of Climate Change on the Economic Aspect of Watershed Management

Climate change adversely affects all aspects of human life. Changes in water supply and demand pose significant threats to global food security and peace. [221]. It also negatively impacts the agricultural sector, such as in terms of crop productivity and food supply [222–226]. Consequently, climate change causes economic loss and jeopardizes livelihood security [227–229].

Numerous studies have been conducted to quantify the economic impact of climate change. Frankhauser and Pearce [230] estimated that each ton of carbon released into the atmosphere costs USD (United States Dollar) 20. Brown [231] estimated that the economic benefit lost from climate change is between USD 0 and USD 300 per ton of carbon. Stern [232] estimated that the damage from climate change is between 1.5% and 2% of gross domestic product (GDP). Due to climate change, direct and indirect economic losses in Indonesia range between 2.5% and 7% of GDP [233]. In addition, as the world's largest archipelagic country, Indonesia might lose 2000 islands and its coastline, resulting in a loss of USD 11,307 million per year for every 60 cm rise in sea level [234]. Indonesia also faces difficulties transporting food between the cities, and approximately 6000 inhabited islands exacerbate issues with its food delivery system [235].

The Jakarta flood due to the overflow of the Ciliwung River caused an economic loss of IDR 6.7 billion in 2002 [236], IDR 1.5 billion in 2013, IDR 5 billion in 2014, IDR 1.5 billion in 2015, and IDR 960 million in 2020 [237]. Economic loss due to the Solo River flood was IDR 33 billion in 2016 [238], IDR 10.5 billion in 2018 [239], IDR 1.8 billion in 2019 [240], and IDR 22.3 billion in 2021 [241]. Prihantini [242] reported that the total economic losses affected by the flood in Dalpinang District, Madura Island were over IDR 5.8 billion. In Indramayu District, the flood caused an economic loss of about IDR 744 million [243]. From 2014 to 2019, it was estimated that the average economic loss due to flooding in North Aceh Regency was approximately IDR 675.35 billion [244].

In addition, economic losses due to floods and droughts also cause significant economic losses to communities. Nabila [245] reported that the total economic loss for the community due to drought in Gunung Sari Village, Pamijahan District, Bogor Regency exceeded IDR 131 million in 2018. The drought in Ciderum Village, Caringin District, and Bogor Regency resulted in economic losses reaching IDR 118.23 million/year [246]. Nationally, rice fields that experienced drought in 2018 reached 127,101 ha, and harvest failure was 25,405 ha [247]. Moreover, drought has reduced rice productivity in two subdistricts in East Nusa Tenggara, namely Boronubaen Village, and East Taunbaen Village, by 1810 kg/ha/year and 2400 kg/ha/year, respectively [248].

Based on the data above, poor people and developing nations consistently bear the brunt of climate-related calamities [249]. Poverty has several complex effects on access to resources and, thus, triggers vulnerability [250]. In this regard, vulnerability is determined by the economic, institutional, and political capacities of the many groups of people impacted by climate change [251].

Climate change threatens economic losses caused by damage to ecosystems and human activity systems. On the other hand, climate change presents challenges for efficient use of resources with green technology, better resource management, such as forest rehabilitation and restoration activities in watersheds, tree planting for conservation and capturing carbon in watersheds, and soil and water conservation that can maintain land fertility and prevent erosion. These activities can not only mitigate the damage caused by climate change in the watershed, but also generate new economic potential from activities in watershed management and more sustainable development.

Ecosystems in watersheds offer crucial functions that can aid in climate change adaptation. According to Pramova, et al. [252], forests and trees can aid in adaptation in the following ways: (1) by providing goods to local communities facing climatic threats; (2) by regulating water, soil, and microclimate in agricultural fields for more resilient production; (3) by regulating water and protecting soils in forested watersheds to reduce climate impacts; (4) by protecting coastal areas from climatic threats; and (5) by regulating temperature and air quality in urban areas.

3.4. Threats and Challenges of Climate Change on the Sociocultural Aspects of Watershed Management

The impact of climate change on agriculture and fishery productivity results in threats to food security that lead to malnutrition and human health as long-term effects [129–132]. Malnutrition is a condition of inadequate, excessive, and unbalanced nutritional intake in human physiology [253]. Malnutrition, as a long-term effect of climate change, commonly occurs in the developing world, particularly in countries with low-middle income and tropical climates [254]. The World Food Program (WFP) estimates that malnutrition and famine could increase by approximately 20% by 2050. Thus, global society should cooperate to address this challenge by mitigating and preventing the adverse effects of climate change [255].

The climate change threat to human health is a consequence of food insecurity, decreased air quality, extreme weather, the scarcity of safe drinking water, and infectious diseases [131,133]. According to a World Health Organization (WHO) assessment, between 2030 and 2050, there will be 250,000 additional deaths per year from malnutrition, malaria, diarrhea, and heat stress due to climate change [256]. Moreover, food insecurity following climate change intensifies disease transmission through high temperatures and heavy rain [257]. The risk of water-borne disease outbreaks, such as cholera, will likely be exacerbated during extreme rainstorms, particularly in poor water and drainage management area [258]. Furthermore, other illnesses related to climate change are stress, fatigue, heatstroke, respiratory problems, cardiovascular disease, chronic diseases including cancer, and low birth weight of newborns [84,259,260]. Grace, et al. [261] stated that the decreased precipitation and food insecurity caused by the increase in global temperatures give rise to the number of low birth weight (LBW) infants, with a decrease in weight of 4.3%. Similarly, Hajdu and Hajdu [262] found that the weight of a fetus decreased by 0.46 g as a result of exposure to temperatures of more than 25 °C during the gestation period of pregnancy, and also determined that the number of LBW infants was predicted to increase as a result of climate change by the middle of the 21st century.

Climate change also affects social conflicts, especially conflicts over natural resources, such as a diminishing clean water supply due to long-term drought [134], land tenure, and changes in social interactions within a society [135]. In addition, Fritsche et al. [136] indicated that the impact of climate change on social conflict is that a group of people in a certain area tend to be more sensitive and cautious of other groups that they feel can threaten their lives and disrupt stability within the group. Climate change also causes an escalating number of car accidents during the rainy season, where heavy rains can increase the likelihood of errors while driving [135]. Koubi [137] stated that there is an increasing tendency for conflict to occur as the impact of climate change, particularly in people who live in areas that are very precarious to certain weather, less effective government, and poor access to public services.

Culture is also threatened by climate change. In the past, the Javanese people used *Pranotomongso* when regulating the planting season but, due to climate change, this is no longer appropriate and must be modified according to existing conditions [263]. The livestock herding culture is no longer being carried out due to the increasing area affected by drought, which threatens the availability of fodder grass in nature [138]. Climate change threats to culture can also occur as a result of a loss of access to places due to climate disasters or adaptation and mitigation efforts [138].

The last factor to consider is climate change′s impact on indigenous people′s existence. Commonly, indigenous people live in forest areas. Thus, they depend on natural resources around them. Ironically, they are the first group of society facing the impact of climate change and the loss of land and resources, as well as violations of human rights, discrimination, unemployment, and marginalization [139]. The International Labor Organization (ILO) reported that many indigenous communities are not involved in the policymaking process, particularly in exploiting natural resources. Hence, they lose their living space and source of livelihood, experience a faded way of life, and eventually migrate to urban areas where they are commonly marginalized and cannot access public health properly [264]. Nevertheless, indigenous peoples have great potential to become change agents in overcoming climate change impacts because they have unique skills and knowledge when it comes to managing natural resources [264].

The complexity of social threats due to climate change is a challenge for the government to overcome. The challenge is very difficult because it involves aspects of human security, such as food and water security, livelihood, and health. Therefore, adaptation and mitigation to climate change must be carried out systematically and integrated by involving stakeholders from the government, private sector, NGOs, and the community [131,265].

4. Improvement Strategy of IWM for Mitigation and Adaptation of Climate

Watershed management is a natural resource management concept that is the most appropriate hydrological unit to assess, predict, and manage water to achieve the objectives of optimizing the quality, quantity, and spatial and temporal distribution. Watershed management includes assessing water resources for the benefit of human welfare and the sustainability of natural resources. The strategy to improve IWM for climate change mitigation and adaptation can holistically be in line with efforts to achieve sustainable development goals. Potential trade-offs between different SDG targets could lead to suboptimal or even detrimental results. This can be anticipated with a properly designed course of action to consider these interrelationships [266,267]. In this context, IWM is the most relevant approach due to its simultaneous contribution potential to the achievement of several SDGs, especially among other goals, such as #1 (no poverty), #2 (zero hunger), #3 (good health and well-being), #6 (clean water and proper sanitation), #7 (affordable and clean energy), #13 (climate action), and #15 (life on land).

Based on the implementation of IWM in Indonesia as the existing condition, as well as the constraints analysis and the existing challenges, some essential efforts are needed to fill the gaps and improve the current IWM. The improvements of IWM for all elements of the process, consisting of planning, implementation, monitoring, and evaluation, are intended to address real-world challenges of watershed management.

4.1. Planning Stage: Integrated Approaches

Watershed planning is the stage where management options are identified and developed based on evidence-based knowledge coupled with the management objectives of a particular watershed [97]. The evidence-based knowledge needed to support decision-making results from a structured and reliable set of watershed analysis processes. Meanwhile, determining appropriate activities for a particular watershed relies on considering potential future conditions, objectives, legal mandates, and management constraints. There is a trade-off between the cost of doing something versus the quality and quantity of output achieved. The main constraints include political, policy, economic, social or institutional, and technical factors [67]. In fact, planning procedures often do not allow sufficient scope for an interdisciplinary, rather than multidisciplinary, or holistic approach to landscape conditions and potential management options [97]. Hence, in adaptive management, the watershed management plan should be adaptable to dynamic changes in external and internal conditions and should involve the parties transparently, as we formulated in the flow chart in Figure 4.

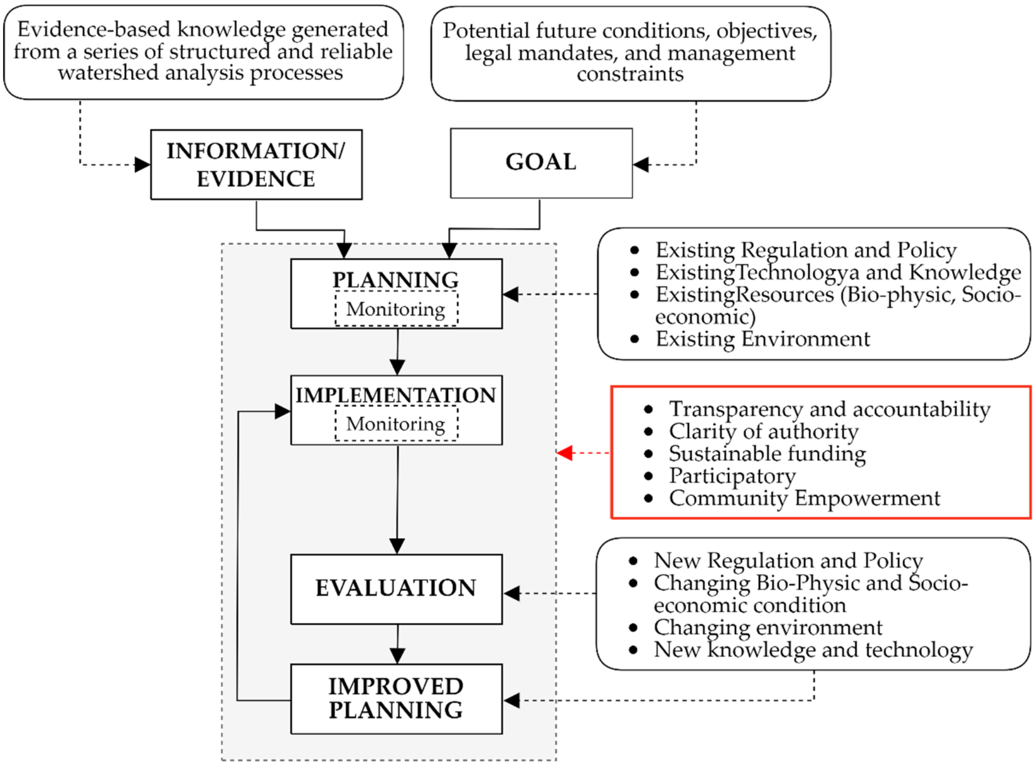

Figure 4. Planning improvement in adaptive watershed management (based on the analysis for this current study).

Facing the global situation which results in increasing watershed vulnerabilities on a national and regional scale, watershed management must take into account the impacts of climate change using technological advances and a holistic and cross-disciplinary approach to ensure that watersheds are able to continue to perform their ecological, social, and economic functions optimally [25]. Thus, the improvement of IWM must be started from the planning stage. Programs to mitigate and adapt to climate change must be arranged and incorporated into watershed rehabilitation or restoration programs.

Building a holistic watershed management system involving orderly and coherent management is very important [268]. Watershed management must start from the "upstream". In watershed management, the concept of upstream–downstream is not only related to the physical or spatial context but also to the context of the planning system.

In the physical or spatial context, upstream is related to the improvement of the MWM approach. To overcome the obstacle in stakeholders′ collaboration and monitoring, the area of a micro watershed should be ±1000 ha in densely populated regions, such as Java Island, and ±5000 ha in non-densely populated regions, such as Sumatra and Kalimantan [57,80]. A micro watershed allows problems and needs to be adapted to the characteristics of the community effectively and specifically [269,270]. In addition, small-scale watershed management will facilitate community participation, coordination, and collaboration among stakeholders and MONEV [271]. This is also relevant to the upstream context in planning. Upstream in the context of planning is upstream in the context of the basic planning material, that is, in terms of data; the availability of valid data as a basis for planning is a deciding factor [36]. In developing such a system, it is very important to ensure the availability of high-quality data for planning [98,99]. It is crucial to ensure data quality by employing GIS, remote sensing, and technology information, including temporal and spatial resolution, reliability, ownership, and accessibility of data, which will be closely related to the resources that can be utilized effectively [98]. Montgomery et al. [97] emphasized that incorporating scientific input at the front end of the planning process can help avoid crisis management through more effective and complete use of such information in decision-making. In Indonesia, to support the implementation of IWM, the Government established an information system for watershed management, which is part of the national spatial data node in each province, and which can be accessed by related agencies [46].

The next upstream factor in the context of planning concerns actors. Planning must involve as many parties or communities as possible, including upstream, middle, and downstream communities [36]. One of the important effects of the participatory process is its potential use as an instrument for learning, empowering, and articulating the voices of previously marginalized people [272]. A demonstration plot developed collaboratively should be made to show a concrete example of best practice for applying a watershed management model based on a combination of local knowledge and modern science-based knowledge in a scope that can be managed according to shared interests or needs [98]. However, the participatory process must consider the long-term political and environmental implications, jurisdiction, time frame, and suitability of complex scientific procedures [272]. The Government of Indonesia, through Government Regulation No. 37, 2012, formally stipulates that community participation can be carried out individually or through watershed management coordination forums to support the integrated implementation of watershed management [46].

Another "upstream" prerequisite for the watershed management process is to increase literacy and understanding of watersheds, forests, potential disasters, and how to mitigate and adapt them to the community, especially those living in upstream areas as potential "disaster sources," as well as downstream areas; one way to do this is by incorporating this education into the curriculum of local content in schools in the upstream to urban watershed areas. The development of a culture of environmental awareness, and disaster alertness, must start from an early age [36,273]. Indeed, UNICEF and UNESCO agree that education plays an important role in reducing vulnerability and building resilience to disasters by increasing the knowledge, skills, and attitudes needed to prepare for and cope with disasters and to help accelerate recovery from disaster trauma [274]. In Indonesia, in early 2019, the President of the Republic of Indonesia requested that relevant ministries and institutions increase disaster preparedness, part of which involves incorporating learning about disasters into school education [275]. This was then followed up with communication between the head of the National Disaster Management Agency and the Ministry of Education to hasten the inclusion of disaster-related information into the national education curriculum [276]. In Garut Regency, West Java, the disaster preparedness school curriculum is even implemented from kindergarten to junior high school [277].

4.2. Implementation Stage

4.2.1. Change in Paradigm

The IWM is participatory and collaborative watershed management among regions and stakeholders to harmonize management between upstream and downstream areas [55,57,271]. However, the IWM still faces several challenges, such as weak coordination among sectors and regions, lack of community participation, overlapping regulations, overlapping management areas, and asymmetric information among sectors in watershed management activities [21,56,57,65]. As a result, the watershed condition has not been optimally improved. However, climate change also threatens the sustainability of the watershed. Therefore, improving the IWM in Indonesia for mitigation and adaptation to climate change can be realized through a paradigm change (as depicted in Figure 1), especially by prioritizing coordination, participation, and collaboration [57,81], including ensuring a transparent and accountable implementation process [278], clarity of authority [56], and opening up opportunities for sustainable funding from various sources [279].

The concepts of coordination, participation, and collaboration in watershed management in Indonesia began in the 1980s to 1990s, but these concepts have not been successfully implemented [36]. This is not only because of sectoral egos and a lack of commitment from each stakeholder, but also because of the absence of regulation that rules each stakeholder to implement the IWM plan [96]. Therefore, to integrate the watershed management plan into regional spatial planning, regulations with a strong legal position are needed from the level of laws, government regulations, and regional regulations.

An inappropriate participatory approach will hamper community self-reliance and commitment in carrying out activities, thus, affecting the sustainability of watershed management [280]. Therefore, since the 2000s, the Indonesian government has included community empowerment programs in every program related to watershed management [36]. In empowerment programs, the community is the decision-maker, so the approach is purely bottom-up. This is because, at the implementation stage, the community is the main implementer of watershed management activities to promote community welfare and sustainability [281]. Economic considerations usually influence community decisions more than watershed sustainability [81]. Therefore, a combination of bottom-up and top-down approaches is needed to achieve sustainable watershed management. The bottom-up approach is used in the community decision-making, such as the type of activity, land use, and other resource use, while the top-down approach is used as a guide for decision-making by the community because it contains guidance for appropriate management based on biophysical conditions.

Humans are an inseparable part of watershed management. Human behavior affects watershed conditions and vice versa. In addition, human activities or actions are the main contributors to climate change [100,133]. One of the causes of forest and land rehabilitation failure, as well as mitigation and adaptation efforts to climate change, is the absence of a sociocultural approach [138]. Culture is closely related to consumption, production, and lifestyle patterns that affect the increase in emissions of GHGs, so culture is important to understand the community′s mitigation and adaptation capabilities to climate change [138]. Indonesians have significant local wisdom and culture in natural resource management, which also affects mitigation and the community adaptation capacity to disasters and climate change. Unfortunately, several local pearls of wisdom are currently being neglected [100,101]. Considering the role of sociocultural aspects, utilizing local wisdom and culture in IWM for climate change mitigation and adaptation is necessary.

4.2.2. Technical Aspect Improvement

Soil conservation was studied in the early 2000s in terms of its benefits for boosting crop yields, reducing water pollution, and reducing GHG concentrations in the atmosphere as an impact of the climate change phenomenon [66]. However, improvements in SWC technology in developed countries are based more on the phenomenon of erosion as a danger to food security, agricultural sustainability, and a country′s environment. As a result, proper and stronger soil conservation measures based on an integrated agronomic, economic, social, and political approach are required to counteract soil erosion [25,66]. Existing SWC practices should be improved and developed based on the level of natural resource degradation [79]. A collaborative management pattern preceded by participatory planning is one of the improvements needed to overcome the weak integration of management at the site level. The MWM approach is a practice which facilitates this improvement.

The MWM has some benefits over the prior pattern. The MWM, as the most appropriate planning unit, can help to encourage sustainable development [282]. The source of the problem will be more accurately identified with the MWM, allowing for more targeted implementation strategies to be chosen. The MWM also prioritizes participatory planning as a planning pattern that emphasizes the bottom-up idea. The MWM enables more coordination amongst stakeholders in watershed implementation operations at the site level. The MWM′s planning and management units maximize and rationalize local potential.

The impact of management operations will be easier to quantify with a small hydrological unit [81,283,284].

Techniques for improving vegetative land management can be performed by developing agroforestry patterns. It has been empirically tested that the agroforestry pattern is the best land management method in terms of the ecological and economic aspects [106,107]. Agroforestry is categorized as an integrated soil and water conservation measure practice [36]. An agroforestry system with high canopy densities will lead to high infiltration rates and can positively impact the maintenance of hydrological functions [108–111], increasing soil porosity and soil cover, which can improve retention in the soil profile, thereby reducing moisture stress in low rainfall years [112], reducing surface runoff and erosion [116]. In addition, the agroforestry system plays a key role in climate change mitigation [113,114] and adaptation [114,117,118].

Agroforestry makes a very important contribution to environmental services, including maintaining forest functions in supporting watershed management, reducing GHG concentrations through the absorption of CO_2 in the atmosphere and accumulating it in the form of plant biomass, and maintaining biodiversity. Given the magnitude of this role, agroforestry is often used as an example of a "Healthy Agricultural System" [285]. In addition, an agroforestry system contributes to climate change mitigation by significantly increasing carbon stock and reducing net emission rates [115].

Regarding watershed management, upstream–downstream connections are critical in adopting SWC approaches [286–288]. A comprehensive water management and disaster reduction program, including overcoming water scarcity in downstream areas, might be a successful implementation method upstream [286,288]. Watershed management in downstream areas, including urban areas, was initially more directed at efforts to mitigate the impacts of disasters, such as floods, flash floods, droughts, and environmental pollution [288]. In terms of IWM, this approach has been abandoned because it is merely curative and does not address the basis of the disaster problem, which is linked to the upstream area. Integrated water resources management (IWRM) is a technique for improving downstream watershed management strategies. Hydrometeorological catastrophe mitigation is performed in an IWRM, commencing upstream and working downstream. The IWRM can also be used to improve climate resilience and adapt to calamities, such as floods and droughts [289].

For example, in dealing with downstream floods, the activity will begin with the deployment of SWC in the upstream watershed to reduce the potential for runoff, which will then become a source of flood water downstream. Meanwhile, in the downstream and urban regions, greater efforts are being made to modify infrastructure to reduce flood water damage, such as by building infiltration wells, retention ponds, and bio-pores. These water conservation buildings are intended to be able to recharge groundwater levels, in addition to lowering surface runoff [290]. Technical integration is also achieved by combining efforts to improve catchment cover through vegetative land rehabilitation activities, with the implementation of technical civil SWC buildings that are quick to respond to climate events [21,36].

Another technological improvement is the modification of traditional processes by modifying specific site conditions. The silt pit technique, used in forest regions to prevent erosion and sedimentation, is one example of these alterations [291,292]. In addition, biopore infiltration holes are an appropriate technology to overcome flooding that is very environmentally friendly [293]. Another environmentally friendly drainage system suitable for application in urban areas is infiltration wells [294].

The use of remote sensing (RS) and geographic information system [15] technologies in watershed management is also a solution and an improvement strategy. Many domains benefit from the use of RS and GIS applications, such as identifying areas prone to hydrometeorological disasters [295], identifying degraded land as possible sites for reforestation and restoration initiatives [296], as well as identifying erosion sources for mechanical SWC works [297]. Modeling tools, weather forecasting methodologies, and weather modification technology can all be used to implement an integrated early warning system for hydrometeorological disasters [298].

4.2.3. Socioeconomic Aspect Improvement

Ensuring Livelihood Resilience

Based on the livelihoods of the Indonesian population aged 15 years and over who are working, data from 1986–2022 show that their main livelihood is related to agriculture. By 2022, the livelihood of around 30% of the 135.6 million-strong population in the agricultural sector will depend on nature to a great extent. Although still dominant, this percentage is much lower than the 1986 data, where 52% of the working-age population worked in the agricultural sector [299]. Moreover, more than 50% of farmers have an agricultural land ownership of less than 0.5 ha [300]. From this real condition, improving the management of natural resources in terms of technical, socioeconomic, and institutional aspects must be directed to create resilience agricultural-based livelihoods that are adaptive to climate change.

Climate change adaptation aims to maximize the positive effects of climate change while minimizing the negative effects. Adaptation activities can include infrastructure repair, as well as farming and commodity capacity building [301]. Improvement of IWM in the climate change adaptation activities in Indonesia includes the following: (1) the development and acceleration of farming technology that is more productive and adaptable to climate change; (2) the provision of effective agricultural infrastructure to support the application of climate change adaptive technology; (3) the development of an agricultural climate information network; (4) the development of institutional protection for farmers against the negative impact of extreme weather on farming; and (5) a farming input and output price policy that is conducive to farmers′ income [302]. In their research in Kebumen, Central Java, Sekaranom et al. [163] stated that local farmers had implemented some adaptation measures, primarily crop diversification, crop intensification, and socioeconomic adaptation. The study results show the importance of building climate-resistant infrastructure in the agricultural sector, developing the technical capacity of farmers, and increasing farmers′ knowledge regarding climate change and its implications as an effective adaptation and mitigation effort.

Mainstreaming Local Wisdom and Traditional Knowledge

Traditional knowledge, a distinct culture, norms, beliefs, and value systems, and strong links to surrounding natural resources are considered to be the true characteristics of the indigenous people of Indonesia [303]. Traditional values from different places, times, and communities are still relevant today [304]. Local wisdom is a product of a cultural community formed by values, norms, and rules as a model which guides actions. However, in the last few decades, there have been allegations that the norms and values of indigenous peoples are slowly being eroded due to consumerism and short-term pragmatism culture triggered by sociocultural assimilation [303]. Internalizing ecological values from local wisdom can help develop a good ecological attitude [237].

Climate change adaptation requires collective adaptation, which is a collective action of a community or ecosystem in response to climate change, both reactive and anticipative. The synergy of norms, values, beliefs, and local wisdom can help foster this collective action [237].

In his study in Tanzania, Theodory [305] concluded that the challenge of adapting to climate change is to integrate indigenous and modern knowledge with balanced priorities. The essential measure in adapting to climate change by mainstreaming local wisdom and traditional knowledge, however, is adapting indigenous knowledge to meet current needs and conditions. Agriculture-based activities that enhance farming income while avoiding forest and land degradation must be promoted and supported by implementing formal laws that respect local norms, values, and beliefs [306].

Local wisdom and traditional values related to natural resource management play a role in mitigating and adapting to climate change, including *Subak* and *Kerta Masa* in Bali, *Sasi* in Maluku and East Indonesia, *Pranotomongso* and *Samin* in Central Java and West Java (Kampung Naga, Ciptagelar, Baduy), *Ruwatan, Selamatan, Merti Kali, Memetri,* and *Metri Desa* in Java, *Lubuk Larangan, Rimbo Larangan*, and *Alam Takambang Jadi Guru* in Minangkabau, as well as others. Improvement of traditional values and local wisdom needs to be combined with modern scientific knowledge so that it is more appropriate, effective, and not mystical in order to mitigate and adapt to climate change. The improvement that can incorporate local wisdom and traditional values in the education system starts from basic/early education. This will allow students to internalize the value of local wisdom that is wise, friendly, and ethical when it comes to natural resource management.

Prioritizing Villages as the Spearhead of Sustainable Development

The present Indonesian government, under President Joko Widodo, through Nawacita, emphasized the phrase of developing Indonesia from the periphery by strengthening regions and villages within the framework of a unitary state. Law No. 6 of 2014 concerning villages mandates improving the welfare and quality of life of rural communities by encouraging independent and sustainable village development in line with social, economic, and environmental concerns [307].

The main priority in order to achieve the SDGs is to change strategies and methods that are appropriate and in accordance with social, economic, environmental, cultural, and local wisdom conditions, as well as Indonesia′s geography. The gaps that occur between regions, archipelagic geography, and data that are not integrated require a more rooted approach, one of which is the step initiated by the Ministry of Villages, Development of Disadvantaged Regions and Transmigration (KEMENDES PDTT) through Ministry Regulation (PERMENDES) No. 13 of 2020, which focuses on the use of village funds to achieve village SDGs [308]. This regulation regulates the priority of using village funds in 2021, which leads to the achievement of SDGs. The village SDGs are a derivative of Presidential Regulation No. 59 of 2017 concerning the implementation of sustainable national development goals or the national SDGs. The goal is that the national SDGs be achieved through achieving village SDGs in an integrated manner, tailored to local culture, social, and environmental conditions and resources.

With the focused development based on the village SDGs, it is expected to be able to provide results in the form of village development planning directions based on factual conditions (evidence) in the village, thereby facilitating the intervention of ministries and agencies, regional governments (provincial, regency, and city), and the private sector to support village development [309].

Considering the unique and diverse culture and wisdom of each village in Indonesia, the village SDGs consist of 18 goals, with 1 additional goal compared to the global SDGs, namely the 18th goal, which is related to dynamic village institutions and adaptive village culture. According to the village SDGs′ 18 goals, the government and community will undoubtedly participate actively and collaborate to implement these 18 goals in stages and on time. As a result, a strong community and village government will facilitate the attainment of the SDGs at the national level and establish prosperous, strong, and independent communities [310].

In PERMENDES No. 7 of 2021 concerning priority for the use of village funds in 2022, village development priorities through village funds can be focused on four important points, namely the achievement of the village SDGs, national economic recovery, national priority programs, and mitigation and handling of natural and non-natural disasters [311]. The improvements made are to increase the capacity of the Climate Village Program, or the *ProKlim*, and village SDGs so that they can mitigate and adapt to climate change in villages or local communities and improve local welfare.

4.2.4. Institutional Aspect

In general, Indonesia′s watershed is cross-border management not only across villages, regencies, or provincial boundaries, but also across national borders [312]. Some of Indonesia's land areas are directly adjacent to neighboring countries, i.e., Timor Leste (south), Malaysia (north), and Papua New Guinea (east), so there is a transboundary watershed [313]. Thus, it is ensured that the management of watersheds will involve stakeholders from many national institutions, neighboring countries′ institutions, and possibly international institutions. Moreover, it is related to the issue of climate change adaptation and mitigation and, therefore, it is necessary to have good alignment and multi-stakeholder cooperation. Indeed, the sectoral approach makes it complicated and difficult to understand the watershed system as an integrated management unit, and this, therefore, is the challenge in watershed management in Indonesia [65]. The IWM must take a participatory approach involving multiple stakeholders by considering the diversity of biophysical, socioeconomic and cultural, and climate change aspects in Indonesia and neighboring countries [312,314].

The complexity of IWM for sustainable resource use is exacerbated by climate change. Thus, mitigation and adaptation efforts need to be integrated into IWM. Strategic approaches concerning mitigation and adaptation of climate change as an integral part of the country's NDC should be mainstreamed in the IWM activities.

Participatory, community empowerment, and increasing prosperity programs in the context of IWM and climate change mitigation-adaptation efforts that are carefully practiced and implemented by the village government and local government with the support of the central government, private sectors, and each stakeholder show a better level of success. This can be observed in some areas of watersheds in Indonesia. In the slum area of Tallo Watershed, Macassar, the local government preserves the environment by considering the socioeconomic conditions of the community through strengthening institutional capacity, community participation, and the use of social knowledge based on local wisdom [281]. In the slum area of Maros city, community empowerment was able to control 72.83% of water pollution [315]. Furthermore, empowering women in community-driven development (CDD) programs to contribute to climate resilience in Indonesia, which has been operating in more than 60,000 villages across the country, will also be an entry point for IWM [316].

Participatory watershed management in Indonesia is easy to implement in the micro catchment management promoted by the Ministry of Forestry in 2014 as a community-based watershed management system. The village government will feel that watershed management is mandatory. Therefore, they take the initiative to form a farmer group to carry out environmental conservation activities using village funds. For example, the community in the Naruan micro catchment, upstream of the Bengawan Solo watershed, Indonesia, managed to inhibit 52–58% of gully development by building bamboo as slope stabilization [36]. On the other hand, in the Munding and Gebugan micro catchment, upstream of the Garang watershed, Semarang city, Indonesia, participatory water conservation is carried out by building ponds, and this can reduce the total watershed runoff potential, minimizing potential flooding downstream to 26.5% of what it would be without any intervention [80]. However, managing this micro watershed requires the presence of a watershed management technician in the village, assistance from relevant stakeholders, and funding sources [80]. In general, strengthening the active role of village governments and local governments supported by the central government and stakeholders will be promoted as governance for climate change-adaptive IWM in Indonesia.

Integrated management is also very much needed in transboundary watersheds. However, integrated transboundary watershed management (ITWM) is very complex due to the involvement of two or more countries, which have different characteristics and interests in the management process, from planning to monitoring and evaluation [313]. As part of managing transboundary watersheds, climate change adaptation requires appropriate institutional arrangements, flexible legal frameworks (transboundary agreement), and proper communication to support transboundary cooperation and foster a common understanding. In addition, a joint group of experts should be made available to provide a scientific basis for watershed assessment (problems, priorities, solutions, vulnerabilities, scenarios, and modeling), supported by comprehensive data and information, and decision-makers involvements to ensure the connection to policymaking and to facilitate the transfer of knowledge [87]. Referring to Mekong RB management, Mohammed, et al. [317] suggested that ITWM under a changing climate requires improving current transboundary water governance, strategic planning, financial capacity, information sharing, and law enforcement. They emphasize that water governance needs more stakeholder engagement, comprehensive strategic and adaptive planning, strong transboundary cooperation, adequate financial support for water resource development and management, effective information access and knowledge sharing, and the strengthening of law enforcement and compliance.

The MoEF, as the executing agency for watershed management, has technical implementing units spread throughout Indonesia to function as an integrated watershed management orchestration effort at the levels of government territory. Meanwhile, for the critical point, improvement can be conducted by promoting the role of the village government in watershed management at a micro level. In accordance with Nugroho et al. [36], the village government is the backbone of the implementation of management and development.

Bilateral cooperation between countries at the central government level is commonly conducted for watershed management at an international transboundary level, such as with Timor Leste. Improvements should be promoted to reduce conflicts and achieve the goal of sustainable watershed management. The improvement can be multilateral cooperation for all sub-regional areas.

4.3. Monitoring and Evaluation Stage

4.3.1. Monitoring

Smart management is needed to carry out monitoring activities for watershed management in the future. Smart management is monitoring watershed management, including data collection using information technology to produce better decision-making [318].

Monitoring watershed management in the future should also involve the communities and citizen scientists. The results of ecological, social, and economic monitoring should be presented on an online webGIS [319,320]. Development of an online mapping website or webGIS and supporting web content presents watershed management monitoring information, including land, water, social and economic aspects, as have been conducted by Marshall and Randhir [12] in the Colorado Watershed Planning Tool Box.

Monitoring of watershed management covers many aspects and is carried out by many stakeholders; therefore, it needs a coordinator to handle it. The coordinator collects the monitoring results from each stakeholder and then presents them on a publicly accessible website. According to authority, the coordinator for monitoring watershed management can be appointed by the governor for watersheds in one province or the ministry for inter-provincial watersheds. Each stakeholder can upload the monitoring results on the website. Therefore, the public can find out trends in the results of watershed management. For example, MoPWH can announce water management results in a watershed, including daily discharge data, maximum and minimum discharge, and sedimentation. The BMKG can provide instantaneous and daily rainfall data. Meanwhile, the MoEF can announce the development of the degraded land area in each watershed. The MoA or BPS can announce each watershed′s social and economic conditions. Currently, only the MoPWH has provided online data through the Tech4water (Flood Forecasting and Warning System) website in real-time; however, the data are still in the form of stream water levels, and these still need to be upgraded to discharge data using rating curves for each river.

Parameters for monitoring watershed management need to be simplified. According to Supangat et al. [81], the percentage and distribution of permanent vegetation can be used as a simple indicator. The distribution of permanent vegetation, such as shrub, swamp shrub, secondary mangrove forest, secondary swamp forest, secondary forest, plantation forest, and plantation, particularly in an area with a slope >15%, can give a clearer picture of the success of land rehabilitation because land rehabilitation using vegetation methods to combat soil degradation must be able to control erosion that occurs primarily on the sloping area. In addition, the more permanent the vegetation cover, the more carbon will be stocked in the vegetation.

Regarding hydrology, emphasis should be placed on water quality parameters, water volume, and flow continuity. The MoF Guidelines No. 61, 2014 does not include water quality parameters. Water quality parameters should not be too detailed to determine the current state of river flow quality because of drinking water requirements. Chaves and Alipaz [321] stated that BOD5 could represent water quality. Another water quality parameter is sediment load because Indonesia, with high its rainfall, will produce high sediment from degraded lands. The water use index can represent the quantity parameter, while the flow regime coefficient can represent the continuity parameter. The socioeconomic aspect, which previously consisted of population pressure, the level of population welfare, and the existence and enforcement of rules, should be simplified into one representing socioeconomic conditions, namely the human development index [239]. The HDI data is already available at the Central Bureau of Statistics. Using the HDI parameters will make monitoring and evaluating socioeconomic aspects easier, cheaper, and faster. This parameter was also used by [321].

Watershed management, especially hydrology monitoring, needs improvements to detect and anticipate climate change. Hydrological alterations due to climate change include the increase in air temperature and variations in rainfall which will change the flow of water and cause intensive extreme hydrological events [322]. Teshager, et al. [323], in the evaluation of agricultural and climate change scenarios′ effects on water quantity and quality, as well as crop production, concluded that maize-intensive farming scenarios with higher CO_2 emissions consistently produce more water in rivers but cause more water quality problems. On the other hand, planting more switchgrass produces less river water and a better water quality relative to the baseline. To anticipate impacts of climate change, the improvement in IWM, namely MONEV, must be conducted by including monitoring of water yields and water quality.

4.3.2. Evaluation

Evaluation in watershed management is required to observe and assess whether the objectives of the watershed management are being achieved. If the goals are not achieved, they require improvement in the next period. To anticipate climate change impacts, data availability for the evaluation of watershed management is required. The improvement can be undertaken through the provision of baseline data. Before and after the implementation, the monitoring data may become the reference. A lesson learned can be obtained from watershed management in the Himalayas. The assessment results of watershed management in the Himalayas indicate that there has been an improvement in socioeconomic factors, agricultural yields, and the environment. In addition, there has also been an increase in job opportunities, wages, and a reduction in poverty [324]. With the results of the evaluation mentioned above, it can be stated that the objectives of watershed management in the Himalayas have been successful and need to be maintained. The evaluation of the watershed management should be carried out annually so that the results can be used to improve planning for the following year.

Another factor in improving the evaluation of watershed management is the classification of the assessments. Based on several results of the application of the MoF No. 61, 2014, the status or condition of the watershed is included in the moderate criteria, and it is difficult to follow up on the watershed conditions with moderate criteria. Therefore, it is better if the watershed conditions are divided into good criteria (maintained) and bad (restored) by Government Regulation No. 37, 2012.

Dissemination and publication of the results from MONEV may increase public participation in watershed management and can be referenced by stakeholders. The use of the website may extend the dissemination of this information. They can be used as material to revise the RTRW (regional spatial plan) until its derivatives reach the work plans of regional units. In addition, to assess the success of environmentally sound development in a district or province, the results of the evaluation of watershed management can be seen as an indicator of the success of a regional head (district head or governor).

5. Closing Remarks

The IWM approach has been globally applied to manage natural resources. In Indonesia, the IWM has also been used to manage natural resources with the main activities related to SWC to preserve and ensure water availability, land productivity, social welfare, and economics. Owing to the benefit of using the IWM approach for combating climate change, the Government of Indonesia has emphasized using IWM as one of the key programs to achieve the NDC targets. Mitigation and adaptation of climate change as an integral part of the country's NDC should be incorporated into the IWM activities. Climate change has emerged as an important issue that necessitates adaptation in rules and policies governing IWM. As a result, new paradigms and innovations are required to improve the IWM approach in numerous aspects, including biophysics, economics, and sociocultural factors.

The improvement of the IWM approach must be carried out holistically, covering all iterative steps of watershed management, i.e., planning, implementation, and MONEV. In addition, the improved IWM approach encompasses the interlink between restoring degraded watersheds and mitigating climate change impacts. In this case, improving the IWM for mitigation and adaptation to climate change needs a change in paradigm by prioritizing coordination, participation, and collaboration in all management processes. This is essential to ensure all parties are involved and responsible in every step of the IWM process. Prioritization in coordination, participation, and collaboration is implemented at the local or national government level and the international level. This becomes a high priority since numerous problems exist in transboundary watershed management.

Integration of the watershed management plan into regional spatial planning is still facing obstacles. Hence, improvement of IWM through a strong legal position is needed from the level of laws, government regulations, and regional regulations. All of these instruments must explicitly integrate management to restore degraded watersheds and mitigate and adapt to climate change impacts.

Various barriers are still faced in applying the IWM for managing natural resources and mitigating and adapting to climate change. For example, the lack of coordination between the institutions responsible for watershed management and those responsible for mitigation and adaptation of climate change impacts at the local level. In this regard, the IWM improvement can be performed by strengthening the synergy between these institutions in handling the problems of watershed degradation and the impact of climate change simultaneously within a project.

Improvement of IWM implementation using a micro watershed approach provides some benefits, mainly its ability to identify existing problems and plan a strategy to solve the problems. In this small unit, exploring the local potential, participation, and coordination among stakeholders is easier to conduct. Using a micro watershed, the impact of the treatments can be easily monitored and quantified.

The agroforestry system is the technical improvement of IWM in mitigating and adapting to climate change impacts. It can fulfill the requirements for ecological and economic sustainability. The agroforestry system maintains and improves the hydrological functions, reduces CO_2 emissions through carbon accumulation in vegetation, litter, and soil, and increases community income through cash crops, fisheries, and livestock. Improvement of the implementation of IWM can be carried out through the modification of traditional processes by modifying specific site conditions, including biophysical and socioeconomic conditions.

Adaptation of climate change impact linked to the IWM must involve the governments at all levels. Therefore, funding sources and the active roles of the related stakeholders are needed. Strengthening the active role of the village and local governments supported by the central government and other stakeholders can be considered as governance for climate change-adaptive IWM in Indonesia. This is also considered one of the IWM improvements that should be promoted. To reach a meeting point between community needs and government plans, IWM improvement can be achieved by a combination of bottom-up and top-down approaches. The bottom-up approach can accommodate the aspirations of the local communities, while the top-down approach can serve as guidance for government programs.

Incorporation of culture, local wisdom, and local knowledge that exist in communities into IWM is also an improvement of IWM. These elements are believed to facilitate the conservation of natural resources and, at the same time, mitigate climate change impacts in watersheds. Meanwhile, adaptation measures can be carried out primarily through crop diversification, crop intensification, and socioeconomic adaptation. Monitoring and evaluation of watershed management related to mitigation and adaptation of climate change must pay attention to the climate parameters. In this regard, improvement in MONEV is achieved by including water quantity and quality. Lastly, the improvement of the IWM should consider the application of the appropriate technologies. Geographic information systems, remote sensing, and website applications are needed in all management stages. A publicly accessible website may be used to inform communities related to activities, progress, and achievement of the IWM from every stakeholder involved.

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