**FMDB** ***Transactions on Sustainable Environmental Sciences***

# Sustainable Restoration of Degraded Wetlands Focusing on Biodiversity and Hydrological Balance

**Ni Made Eka Mahadewi**[1, *]

[1]Department of Tourism, Bali Tourism Polytechnic, Kabupaten Badung, Bali, Indonesia.
eka.mahadewi@gmail.com[1]

**Abstract:** The threat of wetland degradation to human activities because of biodiversity loss, disturbances in hydrological cycles, and loss of ecosystem services, including climate change, urbanization, and anthropogenic activities, calls for a more sustainable strategy for restoring degraded wetlands. This paper addresses the biodiversity and hydrological balance in such wetlands for their restoration. This study employs an ecological and hydrological methodology and an integrated socio-economic approach to develop the framework. Techniques include native vegetation restoration, invasive species management, and optimised water inflow and retention. These studies based their research on global wetland case studies that showcase good practice and innovative techniques. It proved that restoration projects with biodiversity and hydrological balance interventions are possible if interventions are actively participatory within a community, adaptive management practices are applied, and interventions are carefully designed. Recommendations may also be useful from the point of view of efficient project designs for policymakers, researchers, and conservations. Future studies should measure and quantify restoration's long-term ecological and socio-economic implications.

**Keywords:** Wetlands Restoration; Biodiversity and Hydrological Balance; Ecosystem Services; Ownership and Sustainability; Socio-Economic Implications; Management of Invasive Species; Agricultural Intensification.

**Received on:** 05/01/2024, **Revised on:** 09/03/2024, **Accepted on:** 03/05/2024, **Published on:** 07/09/2024

**Journal Homepage:** https://www.fmdbpub.com/user/journals/details/FTSESS

**DOI:** https://doi.org/10.69888/FTSESS.2024.000298

**Cite as:** N. M. E. Mahadewi, "Sustainable Restoration of Degraded Wetlands Focusing on Biodiversity and Hydrological Balance," *FMDB Transactions on Sustainable Environmental Sciences*., vol. 1, no. 3, pp. 117–125, 2024.



## 1. Introduction

Wetlands are perhaps the most productive ecosystems on earth, offering crucial services such as the purification of water, control of floods, carbon sequestration, and providing a home to various species. Despite all these important uses, wetlands face various anthropogenic pressures, such as land-use alteration, agricultural intensification, pollution, and urbanization. Over 50% of wetlands globally have been lost or degraded, and urgent restoration efforts are needed to preserve their ecological integrity and the services they provide [1]. This implies, therefore, that wetlands are very crucial in conserving the ecological balance and biodiversity; however, the degradation linked with wetlands has far-reaching effects since the loss of wetland ecosystems causes the massive loss of species of flora and fauna which depend mainly on habitats for survival and disruption of the cycles of water that function within the context of the hydrology of wetland. It is an important buffer that stores excess

*Corresponding author.

water in its system during heavy rainfall. When these systems get degraded, water flow patterns are altered, resulting in unpredictable, sometimes disastrous consequences. One of the direct effects caused is the depletion of groundwater recharging as the wetlands will replenish the aquifers through their filtering and rainwater storage actions to ensure constant water availability within the surrounding communities and ecosystems [2]. The loss of wetlands directly results in increased water scarcity. Therefore, it becomes difficult to fulfil the human and wildlife requirements in those areas where large volumes of groundwater are extracted for irrigation and domestic needs.

In general, with deteriorating conditions, the vulnerability of humans and the ecosystem to floods and droughts increases. Of utmost importance is that wetlands are the natural water purification ponds of any given watershed because they can store floodwaters and mitigate the effects of heavy rains. It becomes much more possible to flood areas when there are no healthy wetlands, as their systems of natural water storage and filter-related works are not as effective as they used to be [3]. On the other hand, the absence of wetlands degrades the state of droughts because they sustain moisture within the environment. This means the surrounding environment becomes more vulnerable to extreme events, such as human population effects and biodiversity impacts due to the loss of wetlands [4].

Now that wetlands provide many advantages, restorations of degraded wetlands take precedence in mitigating such negative impacts and sustaining ecological balance. Restoration of degraded wetlands, on the other hand, cannot be executed in straightforward steps because it entails complex procedures that involve an insight into various factors. The major considerations must include ecological interaction from plant, animal, and microbial species so the restored wetland supports diverse and functioning ecosystems [5]. Similarly, a study on hydrodynamics within wetlands- the water movement through the system, its dynamics in interaction with the landscape, and its control of soil and vegetation- should be a prime focus for designing efficient restoration strategies. Thus, wetland restoration without considering these hydrological and ecological dynamics may result in ineffective outcomes where the system fails to function as it used to do before degradation [6]. Socio-economic factors also play a crucial role in wetland restoration [7].

Local communities rely on the resources of wetlands mostly for agricultural activities, fishing, and tourism. Therefore, these restorations must be sensitive to the needs and concerns of these communities so that the people who lost something from restoration should benefit from restoration instead of losing a livelihood. This involves knowing the wetland land use practices, local economic dependencies, and cultural values that impact such wetlands [8]. Restoration efforts would resist and risk jeopardizing long-term project success without active involvement from local communities. Restoring degraded wetlands, therefore, must encompass an interdisciplinary approach that combines ecological science, hydrological modelling, and social considerations [9]. Conclusion Wetland degradation comes with severe environmental and socio-economic issues, from biodiversity loss to enhanced vulnerability to climate change. However, their restoration is significantly essential in dealing with these problems, requiring adequate knowledge of interactions among ecological, hydrological, and socio-economic variables. Only when each of these can be adequately addressed can restoration strategy designs result in the continued service of wetlands, which constitute an important nexus for human and ecological communities [10].

This paper looks at sustainable strategy in wetland restoration with a perspective on recovering biodiversity and regaining a balance in terms of hydrological balances. Integrating ecological and hydrological perspectives concerning the best evidence worldwide will empower a richly textured approach towards effective wetland restoration, as per [11]. Its objectives include defining best practices and analyzing community involvement's effects and long-term restorative impacts on health and ecosystem services [12].

The paper is divided into four sections. Starting with the literature review, the current knowledge concerning wetland degradation and restoration is synthesized. Then, the methodology shows how data were gathered and analyzed. Finally, results and discussion where the study findings are presented and interpreted, respectively. Finally, the conclusion underlines implications for further research and practice by Somogyi [13] in 2001. The findings shall be evidence-based from international restoration projects with ecological and social aspects forming the pillars of restoration [14]. Besides, during the review, scientific advancement in wetland restoration was observed within the last few years, as outlined by Kajári et al. [15]. Both research areas were considered for the literature review.

## 2. Review of Literature

Biró et al. [1] greatly appreciated that wetlands play a large role in conserving ecological and hydrological stability. Wetlands were proved several years ago to conserve ecological stability and hydrological conditions. They continue playing fundamental ecosystem roles, including water treatments, flood prevention, carbon fixation, and life habitat for unique species, for most of these are endemic and can only exist if these wetlands persist.

Pinke et al. [2] have an opinion on how seriously threatening wetlands are. Though ecologically significant, wetlands face increasing threats against their functionality and long-term health. The primary cause of degradation of wetlands is due to anthropogenic activities: agricultural drainage, industrial waste discharge, urban sprawl, and deforestation. Climate change enhances all of them, Fluet-Chouinard et al. [3]. In addition, it has encompassed the one threatening affected ecosystems through changed precipitation patterns, increased frequency and severity of extreme weather events, and accelerated habitat loss. Putting all these together, ecological degradation and impairment in delivering important ecosystem services are expected to contribute.

Pinke et al. [4], disclosed that restoring degraded wetlands involves a multifaceted approach. Restoration of degraded wetlands has been considered a multifaceted process, including passive and active approaches. Passive restoration restores the ecosystem through natural processes, for instance, by ceasing the activities causing disruptions and leaving the site to be at the site awaiting ecological succession.

Kabisch et al. [5] emphasized methodologies of active restoration. Active restoration, however, does require strategic intervention, such as the introduction of native species, the rearrangement of hydrology to mimic natural hydraulic regimes, and the elimination of alien species supplanting native flora and fauna.

Seddon et al. [7], restoration of wetlands requires interdisciplinary methods. Therefore, A wetland restoration method should address ecological, hydrological, and socio-economic aspects. Restoration of habitat seeks to reconstruct an ecosystem by allowing the regeneration of plant communities that once existed.

The insights based on case studies by Mitsch et al. [12], reflect improvement in the participation of communities, bringing about better restoration effectiveness. Such case studies from which integrated measures improve are when a reforestation approach coupled with altering hydrology is carried out with active community participation, showing marked improvement in the indices indicating biodiversity plus real effective improvement in ecosystem functioning.

Mateo-Sagasta et al. [14] summarized the technological changes, largely or at least mainly remote sensing-related, affecting wetland restoration. Technology involving mostly remote sensing, such as GIS and drone surveillance, has significantly altered work relating to wetland restoration. This offers a better ability to monitor change, signals ecological and hydrological changes, and measures progress over time to support adaptive management.

Kajári et al. [15], described their challenges in the wetland restoration area. However, there are many other challenges within the wetland restoration area. The most significant is steady long-term funding that surprisingly funds restoration activities and monitors the restoration's success for longer.

## 3. Methodology

This study is multi-disciplinary, so the efficiency of restoration strategies can be considered. The elements included in the research consist of ecological, technological, and socio-economic aspects. This field observation method captures evaluative information about vegetation cover, species diversity, and hydrological parameters of degraded and restored wetlands. Advanced remote sensing technology, including high-resolution satellite images, can improve land use, vegetation dynamics, and water flow patterns. Wetland ecosystems, therefore, have complex interactions that can be explained using advanced modeling techniques to explain their macroscopic and microscopic changes.

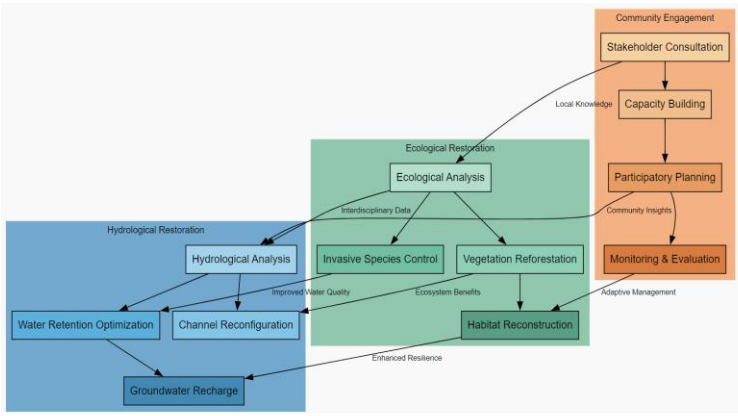


**Figure 1:** Comprehensive framework for restoration of wetland

Figure 1 presents the integrated approach to the restoration of the ecosystem. Hydrological Restoration, Ecological Restoration and Community Engagement Hydrological Restoration includes maximum water retention. There is an emphasis on channel re-development to boost groundwater recharge through improved hydrology, better quality waters, and ecological benefits analysis simultaneously, as well as on ecological analysis intended for biodiversity and resilience enhancement of the habitat. It also covers invasive species control, associated vegetation reforestation, and habitat reconstruction for ecological benefits such as enhanced resistance and better water quality. The data included are interdisciplinary and integrate hydrological and ecological restoration. It is anchored on community involvement. The stakeholders are consulted, and capacity building is conducted with them, hence the increase in local knowledge and participatory planning. The adaptive management strategy draws upon the information flowing from the engagement activities. Monitoring and evaluation enhance the continuous improvement of the restoration activity.

Therefore, with community involvement, hydrological and ecological processes are coupled in an interactive framework. It has two dimensions, namely, ecological and social, wherein it applies interdisciplinary knowledge to enhance the outcome of restoration. The synergy of scientific know-how with community engagement offers a robust adaptive pathway for restoring degraded ecosystems, integrating technical interventions like optimization of water retention with a participatory approach toward enhancing the overall resilience of the environment and ensuring long-term success with local ownership of sustainable, resilient ecosystems.

Socio-economic surveys with local communities are conducted to understand people's perception of restoration projects and the socio-economic benefits from such efforts in attaining the human dimension. It's more about knowing how restorations change livelihoods, cultural values, and community resilience. It would take a participatory approach in which all the phases of the restoration process, from planning and implementation to monitoring and evaluation, involve all the stakeholders, from residents to policymakers and organizations operating in conservation for the sake of ownership and sustainability. The data will be an important constituent of qualitative and quantitative restorative efforts in helping define correlations and even causal relationships associated with restoration input and ecological effects. Qualitative research will be essential in understanding communities' feedback during stakeholder engagement. For example, instead of defining restoration strategies employed and the consequences that ensued, restorative work involves assessing adaptive management practices used to ensure responsiveness to environmental and socio-economic changes, among others.

### 3.1. Data Description

These sources would include satellite images from NASA's Landsat program, biodiversity survey works of the International Union for Conservation of Nature, and hydrological data from local water management authorities. In addition, socio-economic data would be sought through structured interviews conducted with community members and other relevant stakeholders. All these data sets would depict an in-depth understanding of the wetland dynamics and the result of restoration.

## 4. Results

The integrated restoration strategy has brought high gains in biodiversity and hydrological balance. Gains achieved include improved native vegetation cover, restoring habitats and ecological stability. Many folds reduced the invasive species, providing an avenue for developing native species, thereby increasing the biodiversity index. In the restored wetlands, continuous improvement in some water quality parameters, such as nutrient loading and sedimentation, indicated efficient nutrient cycling and filtration. The recharge of groundwater was enhanced substantially with the assurance of the hydrological integrity of the immediate surroundings. These case studies are all centred on community involvement and adaptive management toward a sustainable, restorative outcome. The restorations led by communities saw an encouragement of local participation, incentives for stewardship commitment, and long-term protection of wetlands. Adaptive management, or the monitoring and decision-making process within continuous cycles, is part of the project teams' offer to provide an adaptive response to issues that arise and optimize restoration processes. Species Diversity Index (Shannon-Wiener index) is given.

By:

$$H' = -\sum_{i=1}^{S} p_i \ln (p_i) \qquad (1)$$

Where:

$H'$: Shannon-Wiener diversity index
$S$: Total number of species
$p_i$: Proportion of individuals of species $i$ relative to the total population.

The restoration and recovery of key ecosystem services were well correlated with a strong positive association based on the statistical analysis. Restoration had a detectable change in biodiversity indices that made for native flora and fauna responsible for the stability of the ecosystem. The restoration of hydrology was first implemented with enhanced capacity to retain water. This facilitated successful restoration that retained natural cycles with less per cent seasonal and reduced numbers of the percentages lost into evaporation and runoff. On top of that, the action related to the restoration improved carbon sequestration potential, yet an important ecological service related to climate regulation concerning greenhouse gas levels within the atmospheric space. The hydrological flow balance equation is:

$$Q_{out} = Q_{in} - (ET + P) + \Delta S \qquad (2)$$

Where:

$Q_{out}$: Outflow discharge
$Q_{in}$: inflow discharge
$ET$: Evapotranspiration losses
$P$: Precipitation
$\Delta S$: Change in storage within the wetland

**Table 1:** Impact of species diversity metrics that recover ecological balance

| Criterions | Before Restoration | After Restoration |
|---|---|---|
| Vegetation Cover (%) | 40 | 80 |
| Water Clarity (NTU) | 25 | 10 |
| Nutrient Loading (mg/L) | 15 | 5 |
| pH Level | 5.5 | 6.8 |
| Dissolved Oxygen (mg/L) | 3 | 8 |

Table 1 vividly contrasts the metrics of vegetation cover and water quality before the restoration of wetlands and after wetland restoration-projection of ecological consequences of targeted intervention. The increase in vegetation cover has been from 40% to 80%. Apart from this, an increase in the cover of wetlands as a habitat reflects reforestation success. Improved water transparency is manifested through the decrease in turbidity, from 25 NTU to 10 NTU. Restoration practices are relatively effective for upgrading the physical removal of suspended sediments and trapping of sedimentation. A sharp reduction in nutrient loading from 15 mg/L to 5 mg/L reflects reduced risks of eutrophication and better conditions for aquatic life. It shifted the pH level closer to the neutral point, improving it from 5.5 to 6.8, which is more favourable for living organisms. Besides, the DO level, which is very important for sustaining aquatic life, increased from 3 mg/L to 8 mg/L, indicating a general improvement in water quality. Such holistic efforts in restoration results indicated that ecological functions needed for survival could be recovered and conditions improved in wetlands.


**Figure 2:** Comparison of the biodiversity indices across restored and degraded wetlands

Figure 2 refers to the importance shown in the ecological sense; species richness and evenness of biodiversity were higher in wetland restoration than in degraded ones. This depicted an efficient way of restoring native flora and fauna from ecological restoration actions like reforestation and elimination of invasive species. The rehabilitation wetlands had high levels of indigenous species, which enhanced the stability and functioning of the ecosystem. In contrast, degraded wetlands were mostly dominated by alien species, where biodiversity was poorer and ecological resilience was also not high. This bar graph shows the demand for an action restoration strategy for reversing biodiversity loss, especially for healthier and improved wetland functioning. Besides building up the ecosystem's carrying capacity for carbon sequestration, water filtration, and habitat provision for numerous species, the restoration of ecological balance enhances biodiversity. This graph opens one's eyes to the assimilation of biodiversity-orientated policies into wetland restoration projects worldwide. Nutrient load reduction in wetlands is:

$$C_{out} = C_{in}\, e^{-k \cdot t} \qquad (3)$$

Where:

$C_{out}$: Nutrient concentration at the outflow
$C_{in}$: Nutrient concentration at the inflow
$k$: First-order decay rate constant
$t$: Retention time in the wetland. Carbon sequestration in wetland soils is given as:

$$C_t = C_0 + \int_0^t (NPP - R_{soi1} - L)dt \qquad (4)$$

Where:

$C_t$: Carbon stock at time $t$
$C_0$: initial carbon stock
$NPP$: Net primary productivity
$R_{soi1}$: Soil respiration
$L$: Carbon loss due to leaching

This implies that a mix of ecological, hydrological, and social approaches in wetland restoration can offer the momentum required to achieve these objectives. Ecological approaches, such as afforestation and removing invasive species, set the foundation for habitat recovery and biodiversity enhancement. Hydrological approaches, like the restoration of the flow of water into the dynamics of sediments, helped sustain the sustainability of wetland ecosystems over time. It has also been assumed that social approaches are necessary and most effective when community involvement and decision-making participation are incorporated.

**Table 2:** Impacts of species diversity metrics that recover ecological balance

| Criterions | Before Restoration | After Restoration |
|---|---|---|
| Species Richness | 10 | 25 |
| Species Evenness | 0.3 | 0.7 |
| Invasive Species Count | 20 | 5 |
| Native Species Count | 5 | 20 |
| Biodiversity Index | 0.5 | 0.85 |

It can be viewed from Table 2 that restoration drastically impacts species diversity metrics that recover ecological balance. Species richness increased remarkably from 10 to 25, meaning a surge in biodiversity and habitat suitability. Species evenness improved from 0.3 to 0.7, which means a better-balanced ecosystem; therefore, species distribution also became equitable. The number of invasive species reduced from 20 to 5, and the number of native species increased from 5 to 20. This reflects the effectiveness of managing invasive species and restoring native habitats. Their biodiversity index improved considerably, changing from 0.5 to 0.85, meaning that the holistic ecological benefits from restoration have been obtained. Such results indicate the effects of wetland restoration on biodiversity and ecological stability. The groundwater recharge rate equation is:

$$R = \frac{P-(ET+I+Q_{surf})}{A} \qquad (5)$$

Where:

$R$: Groundwater recharge rate

$P$: Precipitation
$ET$: Evapotranspiration
$I$: Infiltration losses
$Q_{surf}$: Surface runoff
$A$: Wetland area

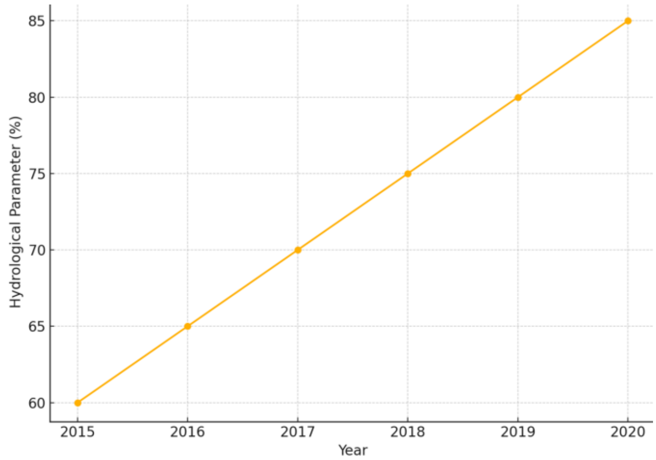


**Figure 3:** Depiction of changes in hydrological parameters over time

Figure 3 is helpful for the description of progressive recovery in the balance of restored wetlands hydrology. However, some parameters indicated consistent progressive improvement regarding retention capacity and flow rates. Such parameters were related to the effectiveness of targeted hydrological interventions implemented during restoration. It reflects the large reductions in seasonal variability. That is, wetlands restored today can smoothen out such extreme weather events from penetrating water tables. Higher recharge rates of groundwater accompanied by quality improvements reflect some other long-term benefits of having channels realigned together with inflows being managed in the optimum sense. Such hydrological gains constitute an important source of sustenance for the wetland ecosystem to survive for longer periods and for resilience built in it to counter climatic changes. The line graph underscores the value of adaptive management, which allows iteration based on observed outcomes in hydrological recovery. This is a good visual with strong arguments about hydrological restoration being the core of sustainable wetland recovery projects because of its role in restoring ecosystem services and ecological resilience.

Results show the integrated, holistic approach to delivering both ecological and hydrological benefits; with good restoration goals, these are aligned to meet the needs at the local socio-economic level and bring a feeling of ownership and stewardship about community ownership inside projects that enhance durability about restoration outcome. These results, therefore, indicate that the process is reproducible and, hence, an ideal model for restoring global wetlands. After the improvement and application of such techniques, the restorations can be carried out worldwide and turned into wetlands, thus becoming potent systems for biodiversity and useful services to both human and environmental systems.

### 4.1. Discussion

Discussion Interpretation: Against this backdrop of earlier literature, results highlighted the associated successes concerning biodiversity recovery and restoring balanced hydrological conditions with integrated approaches to restoration. As presented in Table 1 and Table 2, findings indicate restoration's positive impact on ecosystems and hydrology, thus justifying the effectiveness of targeted intervention in the restoration exercise. For instance, Table 1 presents the quantitative changes in biodiversity indices and native vegetation cover for restored wetlands. In contrast, Table 2 shows improvements in hydrological parameters such as retention capacity and groundwater recharge rates.

The above results show that ecological restoration activities such as afforestation and invasive species management play a crucial role in the habitat provision of native species. These data also describe the effects of hydrological restorations, like channel rearrangement and control water inflow, that increase water quality and retain natural flux patterns. In Figure 2 and Figure 3, a better view is given that can be represented by biodiversity and hydrological regimes over time to strengthen these opinions. Figure 2 Relative biodiversity indices that degraded and rehabilitated wetland areas have concerning each other show a significant increase in the rehabilitated plots. Figure 3 Temporal changes in key hydrological parameters and water flow and quality are stabilizing.

The discussions on socio-economic dimensions focused on the community's participation in sustainability in the long run. The community-based initiatives provided a sense of ownership amongst the local stakeholder groups, thus making it a feasible mechanism for effectively implementing and monitoring restoration activities. Adaptive management practices, with iterated feedback loops and flexible decision-making, allow project teams to address unforeseen challenges and maximize outcomes.

Such findings are placed in a global restoration context by referencing comparisons with other successful projects worldwide. Restoration projects in Europe and North America have shown effects that are almost in line with this research regarding ecological and hydrological responses. However, socio-political and finance-related barriers inhibit large-scale implementation. This points out that ecological, hydrological, and social dimensions interface to set up wetlands for restoration. Thus, the research advocates a multi-level response involving the scientific fraternity, the political leadership, and the people affected by such problems, and it improves restoration efforts. In this respect, introducing remote sensing and GIS innovation will find a niche in enhancing the science and practice of wetland restoration globally.

## 5. Conclusion

The primary importance of the study to be applied through integrated approaches on the wetland restoration sites, particularly regarding the recovery of biodiversity and maintaining hydrological equilibria, is that it ensures the restoration of biodiversity that allows the native flora and fauna to survive to constitute the base supporting the ecological equilibria, and hydrological equilibria forms the support given to the very important restoration activity in the clean water, water recharging functions of the underground, and in the climate regulating functions. It is a mutualistic structure, for it will utilize the ecological gains of restoration for socio-economic payoffs. The study insists on stakeholder involvement for sustainable outcomes. Community, conservation, and the political desk would encourage active participation in resource mobilization while at the same time guaranteeing ownership and accountability by the actors involved. Restoration projects are, therefore, bound to become well-integrated into local socio-economic contexts, increasing their feasibility over a long period. The findings also highlight the adaptive management element as one of the foundational bases for successful wetland restoration. The dynamic approach comprises iterative feedback loops and constant monitoring, allowing restoration teams to respond to climate variability and other unforeseen ecological disruptions. Projects are, therefore, able to remain fluid and resilient concerning environmental changes. Lastly, the study provides policy and practice recommendations to adopt evidence-based approaches, integrate new technologies that could be invented with GIS technologies for wetland monitoring, and even more long-term ecologic and hydrologic benefits for the environment. The findings would be useful and valuable knowledge concerning restoration ecology science and could build a replicable model to answer the global problem of wetland degradation.

### 5.1. Limitations

While the paper generally encompasses comprehensive information on strategies used in wetland restorations, the study also has some drawbacks. One of the critical constraints that probably comes to light during this process is that the long-term data set is narrow. Long-term data may prevent complete assessment in evaluating sustained ecological and hydrological effects from the restorations. Long-term trends are not feasible as restoration work may take years or even decades to assimilate any change, and longitudinal studies can hardly be carried out in the context of long trends. Moreover, it is also a limitation regarding the generalizability of results in various wetlands. Wetlands vary considerably regarding ecological features, hydrological processes, and socio-economic background; hence, generalisability is tough. In this case, the result will surely be of poor quality for generalization of this change that might occur in any wetland, say, salt marshes or peat bogs, between coasts and floodplains.

The case study types and region-based data sources increase skewness or unknown variance. Less representation of the global aspect of wetlands thus constrains and might also leave out significant regional differences at different levels. Methodological limitations are data inaccuracies for remote sensing and the unavailability of uniform access to communities in all project sites. Lastly, more extensive, long-term observation funds and resources appear poorly maintained. To strengthen these weaknesses, collaborative effort has to standardize methodology to allow consistent funding, different types of wetlands, and wider geographical scopes to be represented in further studies.

### 5.2. Future Scope

Future research on wetland restoration opens a wide avenue for further advancement of ecological, hydrological, and socio-economic understanding. The benefits to be quantified in the socio-economic realms include improved livelihoods, enhanced ecosystem services, and climate resilience. These will make up some of the best evidence for rallying support for policy and community involvement in restoration. Restoration technologies will be innovative, with advanced hydrological modelling, drone-based monitoring, and biotechnologies, which make restoration both accurate and efficient. Another critical aspect would be assessing restored wetlands regarding climate change. This should go hand in hand with how restored wetlands handle climate variability regarding precipitation patterns, temperature increases, and extreme weather patterns. Climate-resilient practices, such as using climate-adaptive plant species flexible hydrological management, among others, would be significant in ensuring long-term sustainability in restoration activities. Scaling up restoration efforts globally will require researchers, policymakers, conservationists, and local communities to collaborate. Integrating traditional ecological knowledge with scientific methods may foster innovative, culturally relevant solutions. Finally, the scope of restoration research should be broadened to incorporate underrepresented regions and wetland types for a more comprehensive understanding of global wetland dynamics. Further research should also focus on the proper socio-political and economic frameworks needed to support the continuation of these restorative efforts, which should be compatible with biodiversity and climate goals at the global level.

**Acknowledgement:** The author would like to express sincere gratitude to the Department of Tourism, Bali Tourism Polytechnic, Kabupaten Badung, Bali, Indonesia, for their valuable support and contributions to this work.

**Data Availability Statement:** Data is available upon request from the corresponding author.

**Funding Statement:** This research received no financial support.

**Conflicts of Interest Statement:** No conflicts of interest were declared by author.

**Ethics and Consent Statement:** The research adhered to ethical guidelines, with informed consent and confidentiality ensured.

## Reference

1. M. Biró, Z. Molnár, K. Öllerer, L. Demeter, and J. Bölöni, "Behind the general pattern of forest loss and gain: A long-term assessment of semi-natural and secondary forest cover change at country level," Landsc. Urban Plan., vol. 220, no. 4, pp. 1-11, 2022.
2. Z. Pinke, B. Decsi, and Z. Kozma, "A spatially explicit analysis of wheat and maize yield sensitivity to changing groundwater levels in Hungary, 1961–2010," Sci. Total Environ., vol. 715, no. 5, pp. 1-12, 2020.
3. E. Fluet-Chouinard, B. D. Stocker, Z. Zhang, A. Malhotra, J. R. Melton, B. Poulter, J. O. Kaplan, K. K. Goldewijk, S. Siebert, T. Minayeva, G. Hugelius, H. Joosten, A. Barthelmes, C. Prigent, F. Aires, A. M. Hoyt, N. Davidson, C. M. Finlayson, B. Lehner, and P. B. McIntyre, "Extensive global wetland loss over the past three centuries," Nature, vol. 614, no. 8, pp. 281–286, 2023.
4. Z. Pinke, M. Kiss, and G. L. Lövei, "Developing an integrated land use planning system on reclaimed wetlands of the Hungarian Plain using economic valuation of ecosystem services," Ecosyst. Serv., vol. 30, no. 4, pp. 299–308, 2018.
5. N. Kabisch, J. Stadler, H. Korn, A. Bonn, "Nature-based solutions to climate change mitigation and adaptation in urban areas," Ecol. Soc., vol. 21, no. 2, pp. 2-16, 2016.
6. M. Kardos and A. Clement, "Predicting small water courses' physico-chemical status from watershed characteristics with two multivariate statistical methods," Open Geosci., vol. 12, no. 1, pp. 71–84, 2020.
7. N. Seddon, A. Smith, P. Smith, I. Key, A. Chausson, C. Girardin, J. House, S. Srivastava, and B. Turner, "Getting the message right on nature-based solutions to climate change," Global Change Biology, vol. 27, no. 8, pp. 1518–1546, 2021.
8. Á. Vári, Z. Kozma, B. Pataki, Z. Jolánkai, M. Kardos, B. Decsi, Z. Pinke, G. Jolánkai, L. Pásztor, S. Condé, G. Sonderegger, and B. Czúcz, "Disentangling the ecosystem service 'flood regulation': Mechanisms and relevant ecosystem condition characteristics," Ambio, vol. 51, no. 2, pp. 1855–1870, 2022.
9. J. P. Donnelly, J. N. Moore, M. L. Casazza, and S. P. Coons, "Functional wetland loss drives emerging risks to waterbird migration networks," Frontiers in Ecology and Evolution, vol. 10, no. 3, pp. 1–18, 2022.
10. G. Ungvári, "Combining flood risk mitigation and carbon sequestration to optimize sustainable land management schemes: Experiences from the middle-section of Hungary's Tisza River," Land, vol. 11, no. 7, pp. 1-16, 2022.
11. W. Warachowska, G. Ungvári, A. Kis, P. Matczak, and Z. Zwoliński, "Social, economic, and legal aspects of polder implementation for flood risk management in Poland and Hungary," Journal of Flood Risk Management, vol. 18, no. 1, pp. 1–13, 2025.
12. W. J. Mitsch, B. Bernal, and M. E. Hernandez, "Ecosystem services of wetlands," Int. J. Biodivers. Sci. Ecosyst. Serv. Manag., vol. 11, no. 1, pp. 1–4, 2015.
13. S. Somogyi, "Natural and social impacts on the current water system of the Danube," Hungarian Geographical Bulletin, vol. 50, no. 1-4, pp. 299–310, 2001.
14. J. Mateo-Sagasta, S. M. Zadeh, H. Turral, and J. Burke, "Water pollution from agriculture: A global review. Executive summary," Pensoft Publishers, Sofia, Bulgaria, 2017.
15. Z. Kajári, C. Bozán, and B. Van Leeuwen, "Monitoring of inland excess water inundations using machine learning algorithms," Land, vol. 12, no. 1, pp. 1-22, 2023.