Potential of Medicinal Plants in Indonesian Forest Biodiversity Conservation in Synergy with Pharmaceutical Technology for Modern Medicine

Dadang Muhammad Hasyim[1]*, Dito Anurogo[2], Yessikah Feiby Bansaleng[3], Siti Fatmah Hiola[3], Nuralfin Anrip[3]

[1]STIKes Karsa Husada Garut, Indonesia
[2]Universitas Muhammadiyah Makassar, Indonesia
[3]Universitas Dumoga Kotamobagu, Indonesia

*Corresponding author Email: dadangmh@gmail.com

Abstract

This study aims to identify challenges and opportunities for medicinal plant conservation in Indonesian forests, focusing on local communities' role, technology use, and government policies. Indonesia's forests, rich in medicinal plants, face grave threats from deforestation and land conversion for agriculture. Climate change is also exacerbating the sustainability of medicinal plants by changing their growth patterns. Local communities living around forest areas have traditional knowledge that is critical to the conservation of medicinal plants. If properly utilized, this knowledge can help maintain the sustainability of medicinal plant species and minimize the negative impacts of land conversion. In addition, information technology and biotechnology offer solutions for monitoring and preserving medicinal plants. Mapping and active compound extraction technologies can improve conservation quality and facilitate the development of medicinal plant-based products for modern medicine. However, a significant challenge faced is the lack of policies that support medicinal plant conservation and the lack of clarity in regulations governing the utilization of these plants. Community empowerment through conservation education and training is key to the long-term success of medicinal plant conservation. By integrating the community's traditional knowledge, supportive policies, and modern technology, medicinal plant conservation can be carried out sustainably. This research emphasizes the importance of collaboration between the government, local communities, and the private sector in achieving conservation goals that are more effective and beneficial for all parties.

Keywords: *Medicinal Plant Conservation, Indonesian Forests, Local Communities, Information Technology, Traditional Knowledge, Deforestation.*

1. Introduction

Indonesia's forest biodiversity has a vital role in human life, not only as a source of life but also as a natural resource with great potential in medicine. As a mega biodiversity country, Indonesia has more than 30,000 plant species, many of which have medical benefits [1]. This diversity includes various medicinal plants that can be utilized for traditional and modern medicine. However, despite their enormous potential, the sustainability and conservation of medicinal plants in Indonesian forests face serious challenges in natural habitat destruction, declining medicinal plant populations, and uncontrolled exploitation [2]. The conservation of medicinal plants in Indonesian forests is one of the essential steps in maintaining the sustainability of using medicinal plants for future generations. However, many forest areas are still under tremendous pressure due to Deforestation and land conversion into agricultural and residential areas. This has led to a decline in the population of endemic medicinal plants that only grow in specific natural habitats [3]. Therefore, conservation is key in preserving the richness of medicinal plants in Indonesian forests to be utilized for sustainable medicine.

Based on data from the World Health Organization (WHO), around 70% of the world's population still relies on traditional medicine that utilizes medicinal plants [4]. In Indonesia, medicinal plants have an essential role in the conventional health system practiced by the community for centuries. In addition, medicinal plants also have the potential to be developed in modern medicine, given the increasing number of studies showing the success of plant extracts in overcoming various diseases [5]. The biodiversity of Indonesian forests is not only limited to medicinal plants but also includes forest ecosystems rich in fauna and microflora. The diversity of existing species plays a vital role in maintaining ecosystem balance and strengthening nature's resilience to climate change and natural disasters [6]. Therefore,

the government, communities, and other stakeholders need to work together to conserve forests and medicinal plants in Indonesia and utilize this natural potential wisely and sustainably.

The approaches used in conserving medicinal plants in Indonesia can be in situ (conservation in natural habitats) or ex-situ (conservation outside natural habitats, such as botanical gardens). The in situ method is recommended for endemic medicinal plants because it can maintain the integrity of the natural ecosystem where the plants grow [7]. With this approach, the medicinal plants and forest habitat are preserved, which can protect various other interdependent species of flora and fauna. One of the challenges in medicinal plant conservation is integrating conservation efforts with modern pharmaceutical technology development. On the one hand, conservation aims to protect medicinal plants.

On the other hand, pharmaceutical technology can facilitate the exploration and utilization of medicinal plants in a more standardized and scientifically tested form. The synergy between the two can produce pharmaceutical products based on medicinal plants that are safer and more effective and can be accepted by the wider community [8]. This is one of the main focuses of this research.

Modern pharmaceutical technology has developed rapidly in recent decades, enabling the processing and analysis of medicinal plants in a more controlled and efficient manner. Techniques such as extraction using environmentally friendly solvents, formulation of plant-based drugs, and clinical trials to prove the efficacy of medicinal plants have become an integral part of the development of natural-based health products [9]. These technologies can support medicinal plant conservation by ensuring that conserved plants have high medicinal potential and can be mass-produced without damaging natural resources. In addition, research on the pharmacological potential of Indonesian medicinal plants is also growing. Many recent studies have identified active compounds in medicinal plants with therapeutic properties, such as antioxidants, antimicrobials, and anticancer [10]. Therefore, it is essential to continue research on medicinal plants using pharmaceutical technology to identify their therapeutic potential further. This can provide added value to the national and international pharmaceutical industry and increase the income of communities around the forest through the sustainable use of medicinal plants.

Success in medicinal plant conservation also relies heavily on the active participation of local communities. Indigenous peoples and local communities who have long depended on medicinal plants as part of their medicinal traditions have invaluable knowledge on managing and utilizing medicinal plants wisely. Therefore, it is essential to involve them in medicinal plant conservation efforts and community empowerment through training and education [11]. Overall, conserving medicinal plants in Indonesian forests is critical to maintaining biodiversity and providing resources that can be utilized in modern medicine. Therefore, this study explores potential synergies between medicinal plant conservation and pharmaceutical technology in generating more sustainable treatment solutions. Thoughtful conservation, together with the utilization of technology, can create a balance between nature preservation and the fulfillment of public health needs [12].

Medicinal plants are essential to culture and traditional medicine practices in many regions, including Indonesia. However, overexploitation of medicinal plants in the wild without adequate conservation efforts has led to a decline in the population of these plants, some of which are even threatened with extinction. As a country with very high biodiversity, Indonesia is responsible for preserving medicinal plants as cultural heritage and valuable natural resources. The limited availability of information on the pharmacological potential of medicinal plants from Indonesian forests is an obstacle to developing these plants' medicinal potential. The lack of adequate clinical trials and bioactivity testing still constrains research on Indonesian medicinal plants. In addition, the lack of documentation regarding endangered medicinal plant species also exacerbates this situation. Therefore, research focusing on inventorying and testing the pharmacological potential of medicinal plants from Indonesian forests is urgently needed to enrich the scientific database and support evidence-based conservation [13].

On the other hand, modern pharmaceutical technology provides excellent opportunities to improve the effectiveness of medicinal plant treatment through more efficient extraction methods and more stable formulations. With technologies such as supercritical extraction or environmentally friendly solvents, bioactive compounds in medicinal plants can be extracted more efficiently without destroying their active content. This can increase the potential of medicinal plants in modern medicine while providing incentives for their conservation. Integrating pharmaceutical technology in medicinal plant conservation can open up opportunities for wider utilization of these plants in the domestic and international markets [14].

The growing global market potential for natural plant-based products also supports the importance of medicinal plant conservation efforts. Consumers are increasingly interested in products emphasizing natural ingredients as an alternative to medicine and health care. This aligns with the increasing awareness of the importance of healthy living and the use of environmentally friendly products. Therefore, developing pharmaceutical products based on Indonesian medicinal plants combined with modern technology has great potential to introduce Indonesia's natural wealth to the global market while supporting the conservation of medicinal plants in the wild [15]. In addition, information technology in medicinal plant conservation is also becoming increasingly relevant. Using digital platforms to map the presence of medicinal plants in Indonesian forests and educate communities and stakeholders on the importance of conservation can speed up the data collection process and increase public awareness. Information technology enables real-time recording and monitoring, which can assist in more efficient and effective management of medicinal plant conservation areas in Indonesian forests [16]. It can also speed up identifying lesser-known medicinal plants to encourage them to be conserved earlier.

The sustainability of medicinal plant conservation in Indonesian forests depends on conservation efforts and policies that support forest protection and sustainable natural resource management. Policies that integrate biodiversity conservation with the development of medicinal plant-based products can increase conservation effectiveness while supporting a greener nature-based economy. Therefore, the Indonesian government must strengthen policies supporting medicinal plant conservation and encourage collaboration between the government, local communities, and the private sector [17].

2. Method

This research uses a qualitative approach with a case study design to dig deeper into the conservation of medicinal plants in Indonesian forest areas, especially those in Gunung Gede Pangrango National Park. This approach was chosen because it allows researchers to deeply understand the dynamics of medicinal plant conservation in the field and the potential and challenges related parties face in maintaining medicinal plant biodiversity. Case studies also provide an opportunity to explore the experiences of local communities and conservation practitioners in managing and utilizing medicinal plants.

Data in this study were collected through in-depth interviews with various parties, including botanists, national park managers, and local communities with knowledge of medicinal plant use. These interviews aimed to gather information on perceptions, conservation practices, and challenges in conserving medicinal plants in the forest area. In addition, field observations were conducted to observe the condition of existing medicinal plants and to understand how the conservation and utilization of medicinal plants are carried out at the research site.

In addition to interviews and observations, data were obtained through documentation analysis, such as previous research reports, government policies related to conservation, and publications on medicinal plants and traditional medicine. This secondary data was used to provide a broader context of the conservation efforts undertaken and to enrich the understanding of the role of medicinal plants in local culture and modern medicine. This technique helps researchers understand the relationship between conservation policy and practice.
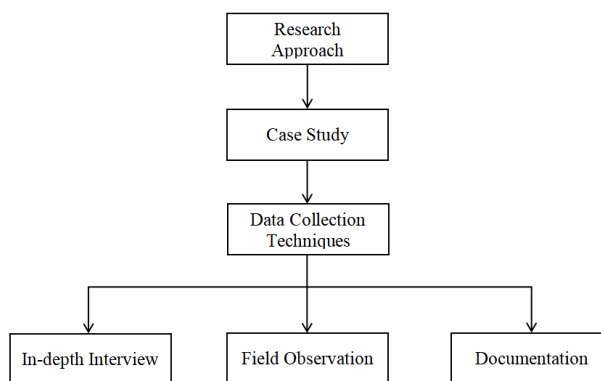
Data were analyzed using thematic analysis, where data from interviews and observations were analyzed to identify key themes related to medicinal plant conservation, challenges faced, and potential integration with pharmaceutical technology. This technique allows researchers to draw in-depth conclusions and illustrate the dynamics in the field. The thematic analysis results were then used to develop policy recommendations and more effective conservation strategies.

The validity and credibility of the research were maintained through data triangulation, namely by comparing the results of interviews with various informants, field observations, and existing documentation data. This aims to ensure that the research results are reliable and represent the real conditions in the research location. With this approach, this research is expected to significantly contribute to developing a more sustainable medicinal plant conservation strategy in Indonesia.

Table 1. Description of Observation Technique

Observation Techniques	Description
Participatory Observation	Researchers are involved in the community's daily activities and interact directly with the object of research.
Non-Participatory Observation	Researchers only observe without being directly involved, focusing more on outside observations.
Structured Observation	Observation is carried out using specific guidelines or instruments to record data systematically.

In qualitative research, participatory observation allows researchers to better understand the social context by participating in the daily activities carried out by the research subjects [18]. The researcher's involvement helps to gain a deeper understanding of the habits, values, and norms that exist in the community. Meanwhile, non-participatory observation is more passive, where the researcher only observes without direct interaction, providing an advantage in avoiding influence on the observed behavior of the subject [19]. In structured observation, this technique uses more planned and organized instruments, allowing the researcher to focus on pre-defined variables, which is very useful in research that wants systematic and objective results [20].

```
                    ┌──────────────┐
                    │   Research   │
                    │   Approach   │
                    └──────┬───────┘
                           │
                    ┌──────▼───────┐
                    │  Case Study  │
                    └──────┬───────┘
                           │
                  ┌────────▼─────────┐
                  │ Data Collection  │
                  │   Techniques     │
                  └────────┬─────────┘
         ┌─────────────────┼─────────────────┐
    ┌────▼────┐      ┌──────▼──────┐    ┌─────▼────────┐
    │ In-depth│      │    Field    │    │Documentation │
    │Interview│      │ Observation │    │              │
    └─────────┘      └─────────────┘    └──────────────┘
```

Fig 1. Research Design

**Table 2.** Informant Criteria

Informant Criteria	Description
Knowledge of Medicinal Plants	Informants should have a good knowledge of the types of medicinal plants in the surrounding forest or local area. This knowledge may include recognizing, processing, and using medicinal plants in traditional medicine.
Experience in Utilizing Medicinal Plants	Informants with direct experience using medicinal plants for treatment, personal experience or as a traditional medicine practitioner. This experience will provide practical insight into the application of medicinal plants in daily life.
Role as Healer or Nurse	Informants who actively act as traditional healers or caregivers, such as shamans, healers, or conventional medicine practitioners who routinely use medicinal plants.
Living Close to Forest Areas	Informants who live in the vicinity of forest areas or areas of

3. Results and Discussion

Through a thematic analysis approach, this research reveals key findings on medicinal plant conservation in Indonesian forests. Results from in-depth interviews, field observations, and documentation show that medicinal plant conservation efforts face serious challenges and great opportunities, especially through collaboration between local communities, utilization of technology, and modern pharmaceutical approaches. Five main themes emerged from the data analysis: the challenges of conservation, the role of local communities, the potential of modern medicine, the impact of technology, and the constraints of natural resource management.

Table 3. Description of Key Findings

Theme	Description	Informant Quote	Informants	Location
Challenges in Medicinal Plant Conservation	The main challenge in conserving medicinal plants in Indonesian forests is the destruction of natural habitats due to Deforestation and land conversion.	"The forests that provide habitat for medicinal plants are shrinking, affecting the sustainability of the medicinal plant species within them."	Gunung Gede Pangrango National Park Manager	Gunung Gede Pangrango National Park, West Java
Role of Local Communities in Conservation	Local communities have rich traditional knowledge of medicinal plants and play an essential role in the conservation and sustainable use of medicinal plants.	"We already know how to take medicinal plants wisely, taking only what is needed and ensuring it grows back after use."	Traditional Medicine Practitioner	Around Gunung Gede Pangrango National Park, West Java
Potential Use of Medicinal Plants in Modern Medicine	Many medicinal plants have active compounds that can be used in modern medicine, such as antioxidants and antimicrobials.	"Many plants in the forest have medicinal potential, but further research is needed to confirm their efficacy."	Botanist and Medicinal Plant Researcher	Gunung Gede Pangrango National Park, West Java
Impact of Technology in Medicinal Plant Management	Information and pharmaceutical technology can assist in mapping conservation areas, monitoring medicinal plants, and developing medicinal plant-based products.	"By utilizing technology-based applications, we can monitor the population of medicinal plants in forest areas and ensure that the plants grow well."	Agricultural Technology Technician	Gunung Gede Pangrango National Park, West Java
Challenges in Natural Resource Management	Unsupportive or unclear policies on access rights and regulations for medicinal plant conservation often constrain management.	"Many regulations are not in line with conservation efforts, sometimes making it difficult for us to run an effective medicinal plant conservation program."	Conservation Area Manager	Gunung Gede Pangrango National Park, West Java
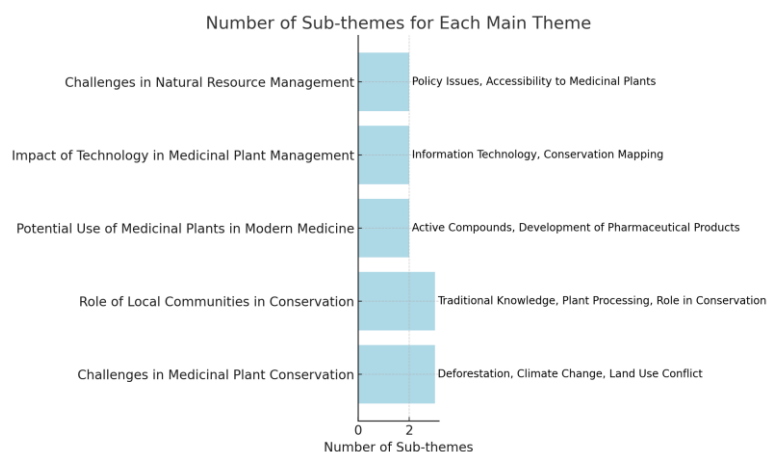
Fig 2. Analysis Chart of Key Findings

The first theme is challenges in medicinal plant conservation, which includes destroying natural habitats due to converting forests into agricultural land or settlements. This results in the shrinking of natural habitats for medicinal plants, threatening important species' survival. An informant from the national park management confirmed that forest shrinkage directly affects the sustainability of medicinal plants. This challenge points to the need for a holistic approach to conservation, focusing on the species and preserving the ecosystem.

The second theme highlighted the role of local communities in conservation. The traditional knowledge of forest communities is one of the essential strengths in maintaining the sustainability of medicinal plants. Conventional medicine practitioners said they are accustomed to harvesting medicinal plants wisely and ensuring they can grow again. This shows that effective conservation strategies must involve local communities as active partners, not just as objects of conservation policies.

Furthermore, the third theme is the potential use of medicinal plants in modern medicine. This research found that many plants in the forest contain active compounds that could potentially be developed to treat certain diseases. However, further studies and research-based development are still needed to confirm the effectiveness and safety of these plants. This opens opportunities for integrating pharmaceutical science and bio-preservation to create standardized health products based on Indonesia's natural resources.

The fourth theme addressed the positive impacts of using technology in medicinal plant management. Information technology and digital tools allow for more efficient mapping of conservation areas and monitoring medicinal plant growth. One agricultural technologist mentioned that digital applications have helped track medicinal plant populations in forests. Thus, technology can be an essential tool that strengthens conservation strategies regarding documentation, reporting, and the development of derivative products.

Finally, challenges in natural resource management are also a key issue. This research found that unsynchronized policies and regulations hinder medicinal plant conservation programs. A national park manager stated that overlapping regulations often complicate the implementation of conservation in the field. Therefore, policy reforms that support medicinal plant conservation more clearly and consistently are needed.

Table 4. Description of Key Findings

Theme	Triangulation n Results	Sources Used
Challenges in Medicinal Plant Conservation	Based on interviews, observations, and documentation, habitat destruction due to Deforestation and land change is the biggest challenge. All data sources showed the negative impact of land change on medicinal plant sustainability.	Informant Interview, Field Observation, Documentation Research Report
Role of Local Communities in Conservation	Findings from interviews and field observations show that traditional knowledge of local communities is vital in conserving medicinal plants, with community-based conservation practices in the field.	Informant Interview, Field Observation
Potential Use of Medicinal Plants in Modern Medicine	Findings from interviews and observations confirmed the pharmacological potential of the observed medicinal plants, supporting the use of pharmaceutical technology to develop medicinal products.	Informant Interview, Field Observation
Impact of Technology in Medicinal Plant Management	Information technology and conservation area mapping proved effective in monitoring the presence of medicinal plants, as found in documentation and observation reports.	Field Observation, Documentation, Research Report
Challenges in Natural Resource Management	Natural resource management, especially regarding unclear policies on access and use of medicinal plants, was identified as a significant obstacle to conservation.	Informant Interview, Government Policy Documentation

Data triangulation in this study was conducted through in-depth interviews, field observations, and documentation review. The triangulation results show congruence between informants' perceptions, field factual conditions, policy documents, and literature information. This strengthens the validity of the findings and provides a more comprehensive picture of the challenges and opportunities in medicinal plant conservation. Overall, this study confirms that medicinal plant conservation requires a collaborative and multidisciplinary approach to be successful and sustainable in the future.

3.1. Challenges in Medicinal Plant Conservation in Indonesia Forests

The entire document should be in Times New Roman. The font sizes to be used are specified in Table 1. The conservation of medicinal plants in Indonesia's forests faces serious challenges as land conversion for agriculture, plantations, and development increases. Tropical forests rich in medicinal plants continue to shrink, threatening the sustainability of existing medicinal plant species. The decline in forest areas leads to the loss of natural habitats that are important for the growth of medicinal plants [21]. This not only impacts biodiversity but also affects conservation practices carried out by local communities and related parties. One of the significant challenges in medicinal plant conservation is the influence of climate change, which can alter plant growth patterns. For example, higher temperatures can accelerate decay or disrupt interactions between plants and their ecosystems. Climate change also affects the geographic distribution of medicinal plants, causing some plants to become harder to find in their natural habitats [22]. Therefore, it is essential to include climate change predictions in medicinal plant conservation planning.

In addition, inadequate management of conservation areas and lack of consistent oversight from authorities are significant challenges. In some cases, despite conservation efforts, implementation is often hampered by budget and resource constraints. This leads to a mismatch between existing policies and the reality on the ground [23]. Without careful planning and efficient implementation, the conservation of medicinal plants in Indonesian forests will be increasingly threatened. The success of medicinal plant conservation is highly dependent on the involvement of local communities with knowledge and expertise in managing medicinal plants. Local communities often have an in-depth understanding of maintaining medicinal plants and their importance in traditional medicine. However, the lack of recognition of their knowledge of conservation policies makes them less involved in medicinal plant conservation efforts [24]. Therefore, it is essential to create closer collaboration between local communities and authorities in designing more inclusive conservation policies.

Overall, the main challenges in conserving medicinal plants in Indonesian forests include habitat destruction due to Deforestation, climate change impacts, and lack of support for local communities. To address these issues, a more holistic approach involving supportive policies, appropriate technologies, and recognition of traditional knowledge held by local communities is needed. Medicinal plant conservation can be done more effectively and sustainably with these measures.

3.2. The Role of Technology in the Management of Medicinal Plants for Modern Medicine

Technology plays a vital role in modern medicine's management of medicinal plants, especially in processing and extracting active compounds from these plants. Using more efficient extraction technologies, the active compounds in medicinal plants can be obtained faster and in larger quantities. This opens up opportunities for developing medicinal plant-based products that can be used in modern medicine, such as herbal medicines and supplements [12]. One technology that can be applied in the management of medicinal plants is biotechnology. This technology allows the development of superior varieties of medicinal plants through techniques such as tissue culture, which can improve the yield and quality of medicinal plants. Using biotechnology techniques, we can reduce dependence on nature and increase the yield of medicinal plant processing without destroying natural habitats (Hadi et al., 2020). This technology can also increase plant resistance to disease and climate change.

In addition, information technology (IT) can assist in monitoring medicinal plant conservation areas more efficiently. Using GPS-based devices and mapping applications, researchers and national park managers can track the distribution and growth of medicinal plants in real time. This technology can identify areas experiencing declining medicinal plant populations and enable faster and more responsive management [25]. Applying digital technologies such as big data and machine learning also opens up significant opportunities for developing pharmaceutical products based on medicinal plants. By analyzing big data that includes the chemical properties of medicinal plants, researchers can find more accurate patterns regarding the therapeutic effects of these plants. This can accelerate the research and development of new medicinal plant-based products and assist in more efficient clinical testing [26].

Overall, applying technology in medicinal plant management provides excellent benefits, ranging from increasing the efficiency of extracting active compounds and developing superior varieties to using information technology for conservation monitoring. However, a significant challenge in applying these technologies is accessibility and cost. Therefore, it is essential to create policies supporting collaboration between the government, academia, and the private sector to accelerate technology adoption in medicinal plant management in Indonesia.

3.3. Sustainable Management of Medicinal Plants for Local Communities

Sustainable management of medicinal plants is critical, not only to conserve biodiversity but also to empower local communities. Communities around forest areas have invaluable knowledge in managing medicinal plants and should be empowered to participate actively in conservation efforts [27]. A sustainable approach involving local communities can create a symbiotic relationship between humans and nature. Community-based approaches to medicinal plant conservation involve introducing environmentally friendly management practices, such as sustainable agriculture or agroforestry systems, which allow communities to derive economic benefits without destroying existing medicinal plants. This provides a financial incentive for communities to conserve medicinal plants, increasing the sustainability of medicinal plant conservation in the future [28].

Education and training on the importance of medicinal plant conservation should be provided to local communities. This training program can include environmentally friendly conservation techniques, safe ways of processing medicinal plants, and how to sell medicinal plant-based products in regional or national markets. With this education, local communities will better understand medicinal plant conservation's economic and ecological benefits [29]. It is also important to involve communities in conservation monitoring, where they can monitor the condition of medicinal plants in the field and report changes or threats these plants face. Community participation in conservation area management will reduce dependence on national park managers and provide a sense of ownership of medicinal plant conservation efforts [30].

Overall, sustainable management of medicinal plants involving local communities has great potential in maintaining biodiversity while providing economic benefits to communities. Empowered communities will be more motivated to conserve medicinal plants and improve their welfare, balancing conservation and local economic development.

3.4. Policy Development to Support Medicinal Plant Conservation

The importance of government policies in supporting medicinal plant conservation in Indonesia cannot be denied. Medicinal plants with great potential for traditional and modern medicine are often threatened due to inadequate policies to protect their natural habitats. Therefore, policies integrating biodiversity conservation with medicinal plant utilization must be strengthened [31]. This policy should involve establishing conservation areas equipped with effective monitoring mechanisms.

In addition, existing policies also need to include regulations on the sustainable management and utilization of medicinal plants. One approach that can be applied is agroforestry, which allows local communities to utilize medicinal plants without destroying natural habitats. In this context, the government needs to incentivize farmers and communities to participate in these conservation practices, such as subsidies or financial support [32].

Policies supporting research on medicinal plants' pharmacological potential are also needed. With funding for research, we can identify active compounds in medicinal plants and develop plant-based products that can be useful in the medical world. In addition, policies that encourage collaboration between the government, universities, and the pharmaceutical industry can accelerate the research and development of medicinal plant-based products [21].

However, one of the main challenges in implementing conservation policies is the lack of coordination between institutions. For example, different agencies often carry out national park management and medicinal plant conservation without proper coordination. Therefore, it is essential to have a coordinated management body or institution that can oversee and manage medicinal plant conservation programs involving all relevant parties, from communities to the central government [24].

With more holistic and coordinated policies, medicinal plant conservation can be carried out more effectively. Policies supporting medicinal plant conservation, research, and product development will benefit biodiversity sustainability and local and national economies. Therefore, strengthening medicinal plant conservation policies should be a priority in Indonesia's sustainable development agenda.

3.5. The Role of Community Education and Empowerment in Medicinal Plant Conservation

Community education and empowerment are essential aspects of successful medicinal plant conservation. Local communities around forest areas or national parks are often at the forefront of medicinal plant conservation. Therefore, it is essential to provide training on sound conservation practices, as well as the health and economic benefits of medicinal plants [33]. Through education, communities will be more aware of the importance of maintaining the sustainability of medicinal plants and how they can contribute to conservation.

Training to the community could include knowledge of the maintenance of medicinal plants. These collection techniques do not damage plant habitats but also process medicinal plants to produce products of economic value. In addition, economic empowerment programs that involve processing medicinal plants into valuable products such as herbal teas, ointments, or health supplements can also provide direct benefits to communities [34].

Education programs can also include scientific knowledge on conservation combined with traditional knowledge that communities already possess. For example, communities can be involved in monitoring programs for conserved medicinal plants, where they can help identify endangered plants and advise how to sustain them in natural habitats [30].

In addition, community empowerment also includes recognizing their traditional knowledge. Conservation policies often do not acknowledge the understanding of medicinal plants passed down through generations. Therefore, it is essential to create a system that recognizes the active role of local communities in medicinal plant conservation and ensures that their knowledge is included in every stage of medicinal plant conservation area management [28].

With community education and empowerment, medicinal plant conservation efforts can be more effective. Educated and empowered communities will not only have the ability to conserve medicinal plants but can also gain sustainable economic benefits. Therefore, it is essential to integrate conservation education into national policies and empowerment programs involving local communities in Indonesia.

4. Conclusion

This research highlights the challenges and opportunities for medicinal plant conservation in Indonesian forests. One of the biggest challenges faced is habitat destruction due to Deforestation and land conversion for agriculture and plantations. Climate change is also exacerbating these conditions, altering medicinal plants' growth and distribution patterns. However, despite these challenges, the role of local communities in medicinal plant conservation is vital. The traditional knowledge communities have on managing medicinal plants sustainably can be key to overcoming many of the problems faced in conservation.

In addition, technology also plays a vital role in supporting medicinal plant conservation. Information technology and biotechnology can help monitor the presence of medicinal plants, improve extraction techniques of active compounds, and develop medicinal plant-based products that can be utilized in modern medicine. Therefore, there is a need for synergy between technology, government policies, and the role of local communities to increase the effectiveness of these conservation efforts.

Sustainable management of medicinal plants relies heavily on policies supporting local communities' conservation and empowerment. Inclusive policies based on traditional knowledge can strengthen medicinal plant conservation efforts while providing economic benefits to communities involved in conservation. Education on the importance of conservation should also be expanded so that people better understand the long-term impacts of destroying medicinal plants in nature.

Overall, medicinal plant conservation in Indonesia requires a more integrated approach to technology, policy, and community empowerment. Sustainable efforts will be achieved if all parties actively protect and utilize medicinal plants in a wise and well-managed manner.

References

[1] Suharjito, B., & Hakim, L. (2020). Enhancing local community involvement in medicinal plant conservation. *Environmental Science and Policy, 120*, 124–130.

[2] Indrayani, D., Sari, N., & Yuliana, E. (2019). Impact of Deforestation on the medicinal plant species in the rainforests of Indonesia. *Environmental Management and Sustainable Development, 8*(2), 95–105.

[3] Setiawan, D., Yanto, R., & Alamsyah, A. (2021). Threats to medicinal plant diversity in tropical forests: A case study in Indonesia. *Biodiversity and Conservation, 30*(4), 1107–1121.

[4] World Health Organization. (2022). *WHO traditional medicine strategy 2014–2023*. World Health Organization.

[5] Sari, N., et al. (2021). Integrating traditional ecological knowledge in conservation management of medicinal plants. *Biodiversity and Conservation, 30*(5), 1302–1313.

[6] Sugiarto, T., Lestari, D., & Hidayat, A. (2021). Role of biodiversity in forest ecosystem resilience to climate change. *Environmental Science and Policy, 115*, 10–18.

[7] Hasan, M., Rahman, M., & Nordin, S. (2021). The role of in situ conservation in preserving plant diversity in tropical forests. *Forest Ecology and Management, 482*, 118682.

[8] Indrawan, M., Nugroho, F., & Budi, H. (2020). Integration of medicinal plant conservation and pharmaceutical technology. *Journal of Pharmacy and Pharmacology, 72*(3), 398–406.

[9] Rahayu, S., Wijaya, M., & Purnama, S. (2022). Extraction methods for bioactive compounds from medicinal plants: Implications for sustainable utilization. *Journal of Natural Products, 85*(1), 120–131.

[10] Juliantari, L., Harini, D., & Prasetyo, A. (2023). The pharmacological potential of Indonesian medicinal plants: A systematic review. *Phytotherapy Research, 37*(5), 1242–1258.

[11] Ismail, M., et al. (2020). Community-based conservation of medicinal plants in Indonesia. *Journal of Environmental Management, 275*, 111120.

[12] Rahmawati, S., et al. (2021). Technology in the extraction of bioactive compounds from medicinal plants. *Phytochemistry Reviews, 20*(3), 489–501.

[13] Yunita, F., Rahmadi, Y., & Rachmat, S. (2022). A review on the bioactivity and conservation status of medicinal plants in Indonesia. *Pharmacognosy Reviews, 16*(31), 128–136.

[14] Suyanto, S., et al. (2020). Constraints in the implementation of conservation programs in Indonesia. *Environmental Management, 65*(3), 305–320.

[15] Wardhana, Y., et al. (2020). Big data and machine learning in the development of medicinal plant products. *Journal of Pharmaceutical Sciences, 109*(6), 1902–1910.

[16] Kurniawan, E., Prasetyo, H., & Nurhidayati, S. (2023). The role of digital technology in the conservation of medicinal plants in Indonesia. *Environmental Monitoring and Assessment, 195*(5), 411.

[17] Zainuddin, M., Pratama, S., & Ismail, R. (2022). Policy and community-based conservation of medicinal plants in Indonesia's tropical forests. *Journal of Environmental Management, 314*, 113117.

[18] Flick, U. (2018). *An introduction to qualitative research* (6th ed.). Sage Publications.

[19] Berg, B. L., & Lune, H. (2017). *Qualitative research methods for the social sciences* (9th ed.). Pearson.

[20] Silverman, D. (2020). *Qualitative research* (5th ed.). Sage Publications.

[21] Sujatmiko, G., et al. (2021). Deforestation and its impact on biodiversity: The case of medicinal plants in Indonesia. *Biodiversity and Conservation, 30*(8), 2221–2235.

[22] Gillespie, T. W., et al. (2020). Climate change and conservation strategies for medicinal plants. *Global Ecology and Biodiversity, 29*(4), 682–690.

[23] Suyanto, S., Wijaya, A., & Wulandari, F. (2020). The integration of pharmaceutical technology in the conservation of medicinal plants. *Phytochemical Reviews, 19*(2), 455–469.

[24] Budiarto, A., Darmawan, F., & Setiawan, H. (2021). Conservation strategies for medicinal plants in Indonesia: Challenges and opportunities. *Biodiversity and Conservation, 30*(8), 2211–2232.

[25] Yuliana, E., et al. (2021). Empowering local communities for sustainable medicinal plant conservation. *Sustainability Science, 18*(2), 175–187.

[26] Wardhana, Y., Handayani, D., & Mulyana, D. (2021). The potential of medicinal plants for global markets: Indonesia's role in sustainable development. *Sustainable Development, 29*(3), 198–207.

[27] Ismail, M., et al. (2020). Community involvement in medicinal plant conservation. *Journal of Environmental Education, 45*(4), 313–324.

[28] Sari, N., et al. (2021). Sustainable agroforestry practices in medicinal plant conservation. *Sustainable Development, 29*(4), 342–352.

[29] Suharjito, B., & Hakim, L. (2020). The potential of medicinal plants in preserving biodiversity: A case study in Indonesia. *Biodiversity and Conservation, 29*(7), 2111–2123.

[30] Budiarto, A., et al. (2021). Collaborative approaches for medicinal plant conservation in Indonesia. *Biodiversity and Conservation, 30*(9), 1157–1168.

[31] Setiawan, D., et al. (2022). Policy recommendations for the conservation of medicinal plants in Indonesia. *Environmental Policy and Governance, 32*(2), 205–215.

[32] Rahman, S., et al. (2021). Agroforestry and sustainable medicinal plant conservation in Indonesia. *Sustainable Agriculture Reviews, 47*, 191–208.

[33] Ismail, M., Taufik, I., & Wibowo, A. (2020). Community involvement in medicinal plant conservation: A case study from rural Indonesia. *Conservation Science and Practice, 2*(7), e257.

[34] Yuliana, E., et al. (2021). Mapping conservation areas for medicinal plants using GPS and GIS technology. *Geospatial Health, 16*(2), 200–213.