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Integrating Indigenous Knowledge into Sustainable Forest Management for Climate Change Adaptation and Mitigation Strategies: Case from Southern Slopes of Mount Slamet, Indonesia

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Abstract

Rural communities near forests are highly vulnerable to climate change due to frequent natural disasters and extreme weather. This study investigated local wisdom in forest management as a strategy to address climate challenges. Conducted in April–May 2024 on the southern slopes of Mount Slamet, Central Java (i.e., Gununglurah, Sokawera, and Sunyalangu Villages), the research used a participatory learning action approach and descriptive-quantitative analysis based on interpretive and critical sociology. Key findings highlight three aspects of community-based forest management: spatial categorization of forests into sacred conservation forests (tabet), protected forests in steep areas, and production forests managed through agroforestry; temporal scheduling based on the traditional pranatamangsa seasonal calendar; and plant selection for production, conservation, and spiritual purposes. These practices reflect a deep socio-cultural connection to forests and provide a foundation for integrating traditional wisdom with modern management methods. Legal recognition is essential to protect the rights of indigenous communities and their forest management systems, ensuring that these practices contribute to sustainable forest management and effective climate change adaptation and mitigation strategies.

Keywords: *traditional conservation, tabet, forest rehabilitation, pranatamangsa, participatory learning action*

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Introduction

The frequent natural disasters, extreme weather, and shifting seasonal patterns have made people more aware of the tangible effects of climate change (Intergovernmental Panel on Climate Change, 2022). The impacts of climate change, including global warming, are felt across various levels of society, particularly among field workers like foresters (Permatasari et al., 2024; Putra et al., 2024). This recognition is also increasingly acknowledged by rural communities living near forests, which are among the most vulnerable to the impacts of climate change (Intergovernmental Panel on Climate Change, 2023). These circumstances forced these communities to cultivate adaptation and mitigation skills based on local knowledge (Alandra et al., 2018; Abdurrahim et al., 2022). This expertise evolved naturally and was transmitted from one generation to the next, both knowingly and unknowingly, inherently and sustainably (Cordero et al., 2018; Dorji et al., 2024).

The conservation of tropical forests is essential in mitigating climate change, as they absorb greenhouse gases like carbon dioxide in the air. However, Indonesia's forest management in the 1990s to 2000s was excessively focused on economic exploitation, neglecting social needs and long-term ecological sustainability (Margono et al., 2012; Santoro et al., 2023). In contrast, communities living near forests traditionally have indigenous knowledge that allows them to manage forest resources while maintaining ecological balance, conserving biodiversity, and supporting sustainable livelihoods (Zannini et al., 2021; Susanto & Numata, 2023; Widianingsih et al., 2023; Zurba & Papadopoulos, 2023).

Indigenous peoples are defined as those whose ancestors inhabited a territory prior to colonization or the establishment of a modern nation-state (Sarivaara et al., 2013). They possess unique cultural traits, languages, and customs that set them apart from other populations (United Nations, 2013). In forest resource management, Indigenous communities have developed customary practices and regulations to ensure the sustainable use of natural resources (Raj et al., 2018; Widianingsih et al., 2023; Zurba & Papadopoulos, 2023). Additionally, their resource utilization methods are often closely tied to spiritual beliefs, highlighting the importance of conserving these resources out of respect for nature and for the benefit of future generations (Arthur et al., 2020; Zannini et al., 2021; Dahlan et al., 2022).

Integrating indigenous knowledge into sustainable forest management can be achieved by incorporating traditional wisdom values into all forest management activities, starting from planning, implementation, monitoring, and evaluation (Intergovernmental Panel on Climate Change, 2003; Widiyatno et al., 2013; Smallidge, 2016). This represents a holistic approach to utilizing forest resources, where the

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health of the forest is closely linked to the well-being of the community and the ecosystem. Several forest management practices, such as sacred forest conservation, implementing agroforestry systems, and rotational harvesting, have been demonstrated to enhance the resilience of forests and protect them from damage (Alandra et al., 2018; Zannini et al., 2021; Widianingsih et al., 2023).

Indigenous knowledge provides valuable perspectives on climate change adaptation and mitigation in forest management (Dorji et al., 2024). This includes a deep understanding of local species and their uses and knowledge about local climate patterns to predict and respond effectively to environmental change (Raj et al., 2018; Sumarwati, 2022). By integrating indigenous knowledge with modern forest management insights, governments and policymakers can develop more suitable strategies for coping with climate change challenges (Intergovernmental Panel on Climate Change, 2022; 2023).

The people living on the southern slopes of Mount Slamet are Indigenous people who have a deep historical relationship with the forests in the area (Fikriyya et al., 2022). From generation to generation, they have maintained local knowledge of sustainable forest management through the rules they apply in their daily lives. In addition, the community has developed disaster mitigation strategies based on their traditional knowledge, which is worthy of being studied and developed to strengthen the ecosystem's resilience to climate change (Suwarno et al., 2022).

Despite a growing recognition of the importance of indigenous knowledge in forest management and climate adaptation, there are still significant gaps in its practical application, integration with scientific methods, and incorporation into policy frameworks. Historically, forest management in Indonesia has prioritized economic exploitation over ecological and cultural sustainability, leaving unresolved questions about how to balance these priorities. This study examines the indigenous practices of communities on the southern slopes of Mount Slamet, emphasizing their potential to enhance sustainable forest management and climate resilience while providing actionable insights for policymakers. Moreover, it provides an overview of the relationship between current practices and modern scientific approaches. This study also demonstrates how this integration effort could lead to more effective and sustainable in forest ecosystem management. Ultimately, integrating local knowledge helps preserve cultural heritage and impacts sustainable forest management to cope with the global climate crisis.

Methods

The research was conducted from April to May 2024 in Gununglurah Village (S7°15'–S7°23', E109°08'–E109°09') and Sokawera Village (S7°15'7°23', E109°09'–E109°11') in Cilongok District, and Sunyalangu Village (S7°19'–S7°23', E109°10'–E109°11') in Karanglewas District, Banyumas Regency, Central Java, Indonesia. These three villages have communities that still actively use the forest as a source of livelihood. They were selected as examples of the general types of communities living around the state forest on the southern slopes of Mount Slamet due to their unique integration of local and modern knowledge related to forest management (Tambotoh et al., 2015; Nugroho & Nuraini, 2016; Desmiwati et al., 2024).

Gununglurah Village (hereafter called GL) is located at 200 to 2,150 m above sea level (masl), Sokawera Village (hereafter called SW) at 160 to 2,200 masl, and Sunyalangu Village (hereafter called SL) at 200 to 950 masl. This indicates that all three villages have both lowland and highland ecosystems. Most of the highland ecosystems in these villages consist of tropical forests, including both natural and plantation forests, which cover more than 50% of the total area of the villages (Nugroho & Nuraini, 2016). The map in Figure 1 explicitly shows the location of the research villages along with land use and cover.

The study used the participatory learning action (PLA) approach, which emphasizes the involvement of the community to gain a comprehensive understanding of their unique situation (Napier & Simister, 2017). This approach involves the community in various processes such as problem collection, field observations, problem analysis, and decision-making for alternative solutions (Chambers, 2008). The PLA approach underscores the importance of effective communication between researchers and the community to accurately capture social phenomena related to the environment and natural resources (Desmiwati et al., 2024).

Data was collected using various techniques, including in-depth interviews, rural observations, questionnaires, and focused group discussions (FGD). In-depth interviews were conducted with community leaders, religious leaders, and representatives of the village government. Rural observations focused on settlements adjacent to the State Forest Area.

This study distributed questionnaires to representatives of the communities living near the State Forest Area. These communities rely heavily on the forest for their daily lives economically and culturally. The study covered approximately 630 families residing along the forest boundary in the study area, the data processed from SiDesa Jateng (2020), which was confirmed by village government in in-depth interviews. To ensure adequate representation, 90 respondents were selected to participate in the survey, with each respondent representing one family. The participants were evenly distributed across three villages (GL, SW, and SL), with 30 participants chosen from each village.

Respondents filled out the questionnaires individually, and trained enumerators were present to help interpret the questions in a way that was easy for the respondents to understand. The enumerators were also responsible for organizing the collected data to ensure accurate information in line with the facts observed in the field. The questionnaire consists of nine topics, namely: a) basic information from respondents; b) opinions, knowledge, and perceptions of respondents regarding climate change; c) readiness and adaptation activities of respondents to climate change; d) planning and mitigation of risks of respondents to climate change; e) education, training, and technology owned related to climate change; f) the role of communities and collaboration to cope with climate change; g) capital, markets, and supply chains of production activities in the forest; h) irrigation networks and systems; i) local wisdom and knowledge related to forest management. The collected data was then validated by representatives of forest land

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farmer groups (in this study by the Forest Village Community Institution, or *Lembaga Masyarakat Desa Hutan* abbreviated as LMDH) and village government representatives.

Data analysis uses a descriptive-quantitative approach with a sociological-critical interpretation. This type of analysis involves the subject actively in analyzing actual problems that occur. The emphasis is explicitly dedicated to progressive societal change (Buechler, 2016). Its use was very flexible and was applied by applying various knowledge perspectives in social sciences, humanities, law, economics, politics, natural sciences, and engineering. The entire research process was summarized in the framework shown in Figure 2.

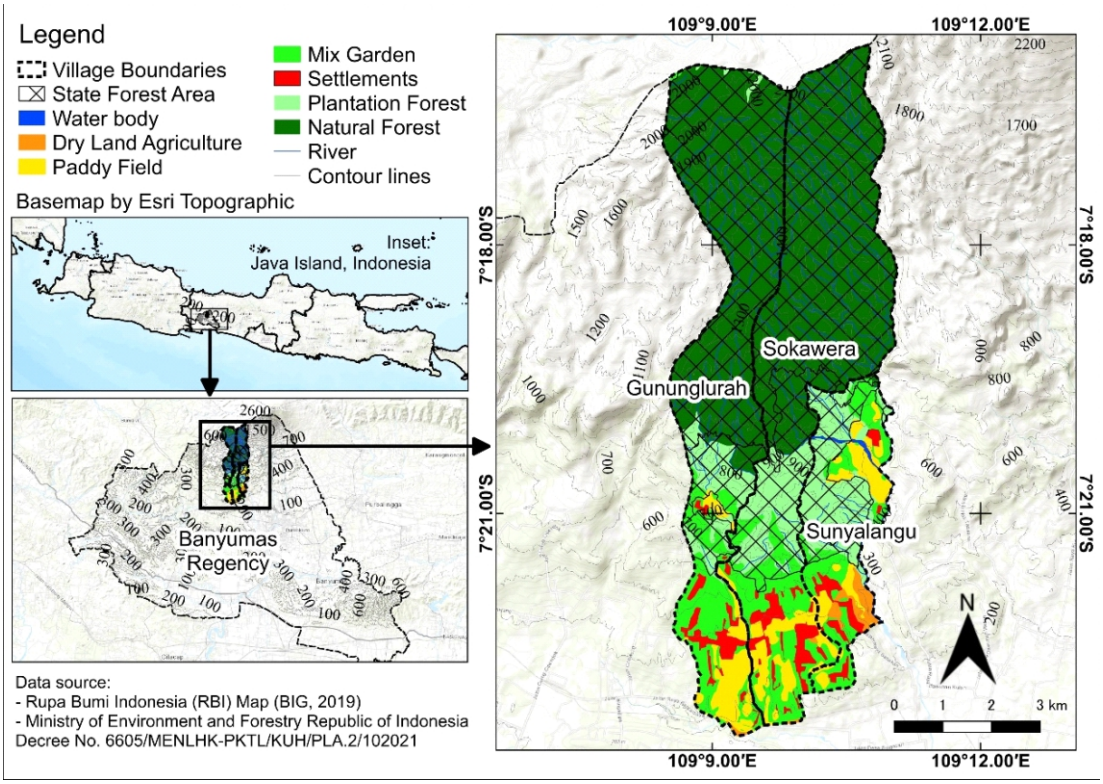

Figure 1 Land cover and use of the study area.

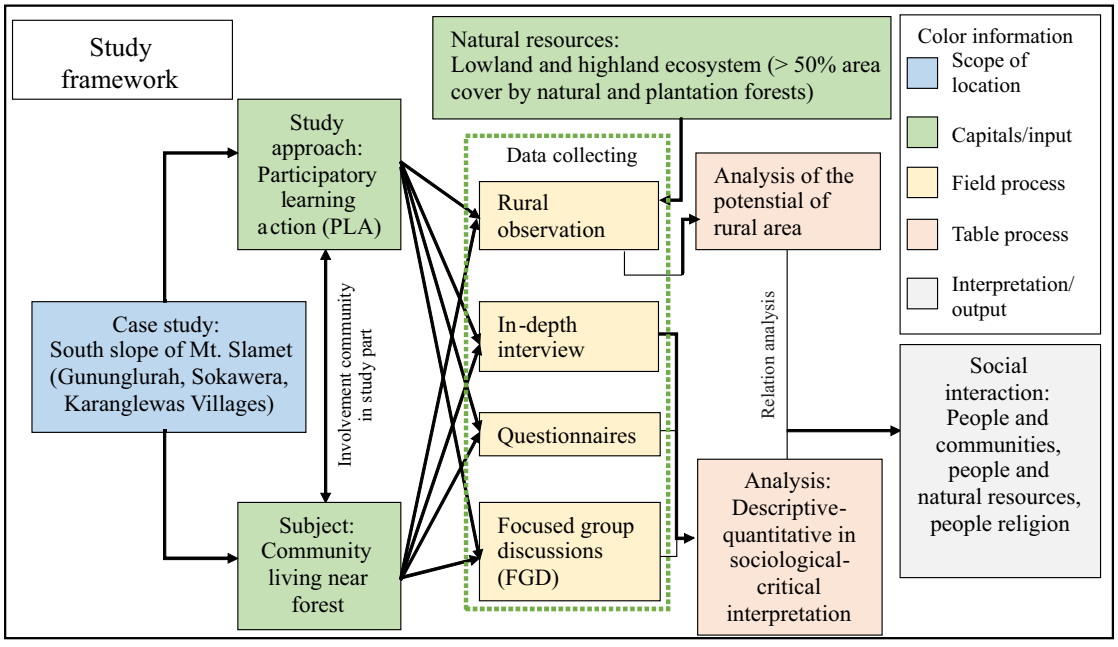

Figure 2 Study framework.

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Results

General characteristics of community around forest The community living on the southern slopes of Mount Slamet is part of the *Banyumasan* Javanese ethnic group, known for their openness to new knowledge (Purwoko, 2016; Muftihah & Rakhmawati, 2024). This characteristic is reflected in their language, customs, norms, and rituals. In the three studied villages (GL, SW, and SL), which are predominantly Muslim, the community utilizes formal rules, customs, and religious teachings as moral guides to differentiate between right and wrong (Khasbullah, 2022). This openness is valuable social capital for sustainable forest management, as the community possesses significant indigenous knowledge (Bott et al., 2020). They manage to preserve traditional values while also adapting to change. Viewing forests as common-pool resources (CPR), they feel a strong sense of responsibility to maintain the forests, which are deeply connected to their livelihoods and daily lives (Ostrom, 1990).

Between the 1960s and 1970s, a state-owned company (hereafter called company) managed forest concessions in the area, introducing the cultivation of production trees such as sumatran pine (*Pinus merkusii*), dammar pine (*Agathis dammara*), and needlewood (*Schima wallichi*) (Kosuke et al., 2023). The community, collaborating with the company, referred to the area as *alas kontrak* ("contracted forest") and actively participated in forest management, including harvesting non-timber forest products and collecting pine resin. In the 2000s, conflicts emerged due to mis-communication about timber ownership during the company's harvesting activities. The tension escalated when community members were arrested for alleged theft. Local leaders facilitated reconciliation, fostering a better understanding of forestry regulations and establishing an agroforestry-based agreement that addressed the interests of both parties (Mulyoutami et al., 2023; Gunawan et al., 2024).

The relationship between the community and the company resulted in a unique spatial management pattern created by the community. Based on rural observations, the community is generally familiar with dividing space based on topography. In certain areas, they protect and maintain the existence of sacred forests. Agricultural and residential activities primarily focus on the foothill valleys, while the rivers irrigate rice fields and fish ponds. The community also uses dry land agriculture and cultivates medicinal plants around their homes. Additionally, they have fruit trees and bamboo as other valuable resources. The general transverse pattern formed is illustrated in Figure 3.

Conception of local leadership A forest community known as *grumbul* consists of a maximum of 300 households and features an integrated leadership structure that includes formal, customary, and spiritual roles. This well-organized and mutually reinforcing leadership system is crucial for community governance and cohesion. The formal leadership is often elected democratically (by *musyawarah*/consensus) and represents the village government at the *grumbul* level. Key positions such as the head of the neighborhood association (*rukun tetangga*/RT), the head of the resident association (*rukun warga*/RW), and the head of the hamlet (*ketua dusun*/kadus) are responsible for managing administrative tasks, collecting population data, and addressing local aspirations in forums involving the village government[1]. This structure ensures the effective delivery of state services and governance at the grassroots level.

Customary leadership is embodied by influential figures called *kamitua*, who are custodians of the community's history, indigenous knowledge, traditions, and cultural practices (Taqwa, 2017; Sumarwati, 2022; Susanto & Numata, 2023). They lead rituals and guide customary

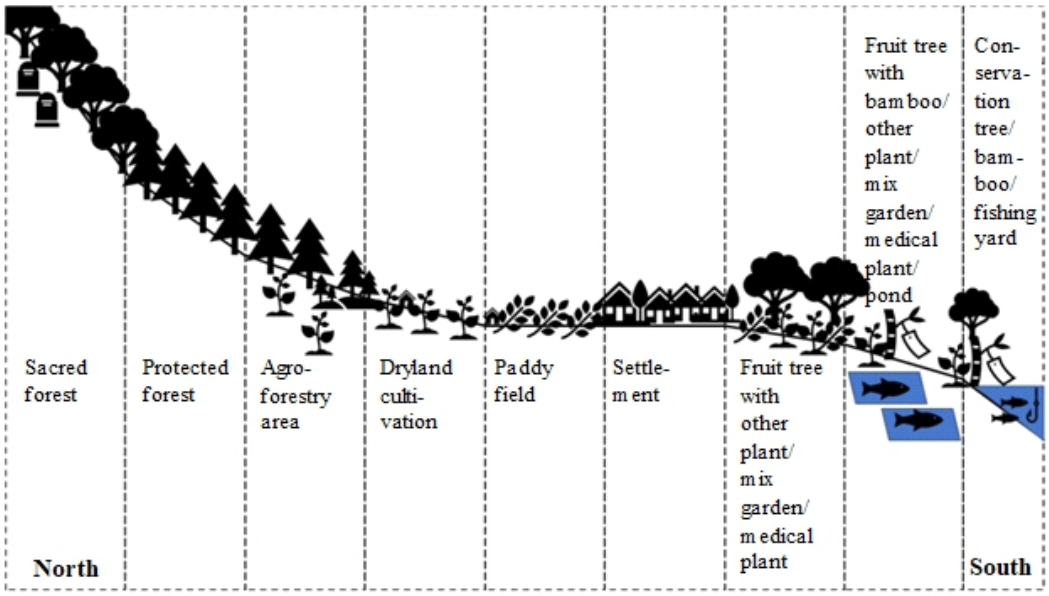

Figure 3 Illustration of general transverse pattern of space drawn from the north to the south side of the area. The component size does not represent the actual size and quantity.

[1]One neighborhood unit consists of less than 100 families, one resident association unit consists of several neighborhood units, one hamlet consists of several resident association units.

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values, adapting these practices to contemporary contexts while preserving the community's heritage. *Kamitua* are respected for their dedication and knowledge, regardless of playing a critical role in maintaining the continuity of local customs and practices.

Spiritual leadership naturally arises from respected religious figures, such as *kyai* and *ustadz*. *Kyai* are highly respected figures renowned for their deep knowledge of Islamic studies and their leadership in teaching to *santri* (Islamic boarding students)[2] at *pondok pesantren* (Islamic boarding schools)[3] They play a central role in imparting Islamic teachings and guiding moral and spiritual development. *Ustadz*, who typically receive their education in Islamic theology at universities or similar institutions, also significantly contribute to religious education and community spirituality, though they are generally regarded with slightly less reverence than *kyai* (Alkatiri & Kiwang, 2023).

The interaction between formal, customary, and spiritual leadership promotes harmony and social control within the community. This dynamic relationship ensures community actions align with formal norms, traditional customs, and religious principles, creating a balanced social framework (Heydir et al., 2017). Moreover, these leadership roles are crucial in sustainable forest management, as community members adhere to laws, engage in customary practices, and incorporate religious values into their activities. This collaborative system underscores the deep integration of governance, culture, and spirituality in managing social and environmental responsibilities.

Transfer of knowledge from each generation The transmission of indigenous knowledge within forest communities primarily occurs orally, with *kamitua* playing a vital role in preserving and sharing traditional practices. This knowledge transfer becomes particularly significant during preparations for customary celebrations, as *kamitua* is often assisted by family members. This collaboration fosters a deeper familial understanding of cultural traditions. The *kamitua* typically focuses on teaching rituals to their children or siblings, especially those most dedicated to upholding these customs. The community also believes that *kamitua* has a magical ability inherited through their bloodline, enabling them to connect the community with supernatural elements related to managing forest resources.

To ensure the continuity of these traditions, successors are prepared to take on traditional roles under the guidance of religious leaders such as *kyai* or *ustadz*. These figures offer Islamic perspectives to help maintain the integrity of the customs while integrating them with religious teachings. Local religious organizations support this effort by promoting Islamic knowledge and practices, ensuring that traditional rituals align with Islamic principles. Over time, this integration has resulted in a harmonious blend of indigenous traditions and Islamic practices, reflecting a dynamic syncretism that adapts to the evolving religious and cultural landscape.

Respondent profiles The survey was completed by 90 individuals living near the forest. In the study area, each village was represented by 30 respondents distributed across seven *grumbul*s. In GL, *Grumbul* Pesawahan had 20 respondents and *Grumbul* Rinjing had 10 respondents. In SW, *Grumbul* Kubangan had 15 respondents, *Grumbul* Semingkir had 5 respondents, and *Grumbul* Baron had 10 respondents. In SL, *Grumbul* Semaya had 15 respondents, and *Grumbul* Cibun had 15 respondents. These seven *grumbul*s are a representation of the characteristics of the community that lives directly adjacent to the forest, the distribution of groups is shown in Figure 4. FGD also

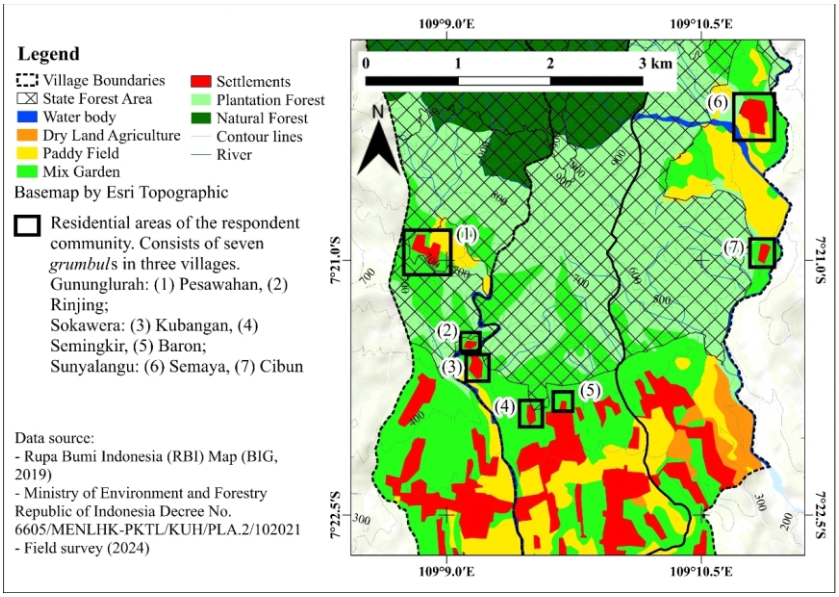

Figure 4 Map of *grumbul* locations representing residential areas of the respondent community.

[2]*Santri* are students at Islamic boarding schools who live in dormitories and follow Islamic religious education programs to prepare them as spiritual leaders in the community.
[3]*Pondok pesantren* are Islamic educational institutions with a dormitory system legally recognized by the state and society.

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involved representatives of the communities around the forest in each village, with 20 farmers working on forest land in each village attending.

The survey respondents were primarily men between the ages of 40 and 50 who worked as forest farmers. Most of them earned less than IDR500,000 month^{-1} (equivalent to USD33.33 at the exchange rate as of September 2024) and had four dependents. Most of the participants had only completed elementary school. These characteristics indicate that people rely on forests for their livelihoods. It was evident from the survey that most respondents utilized state forest land, each with an area of less than 0.25 ha. This suggests that

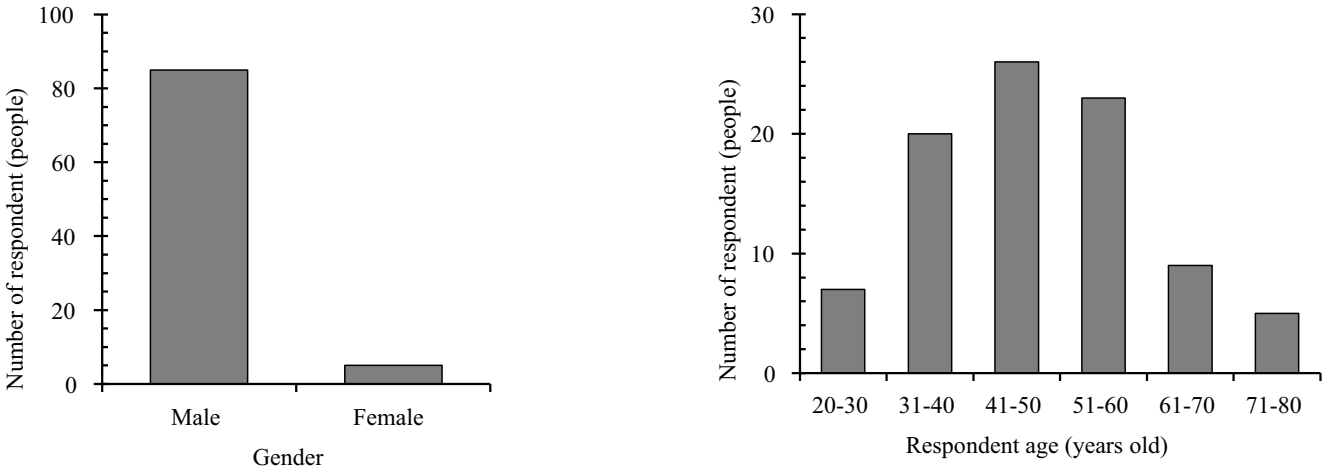

Figure 5 Distribution of gender and age of respondents.

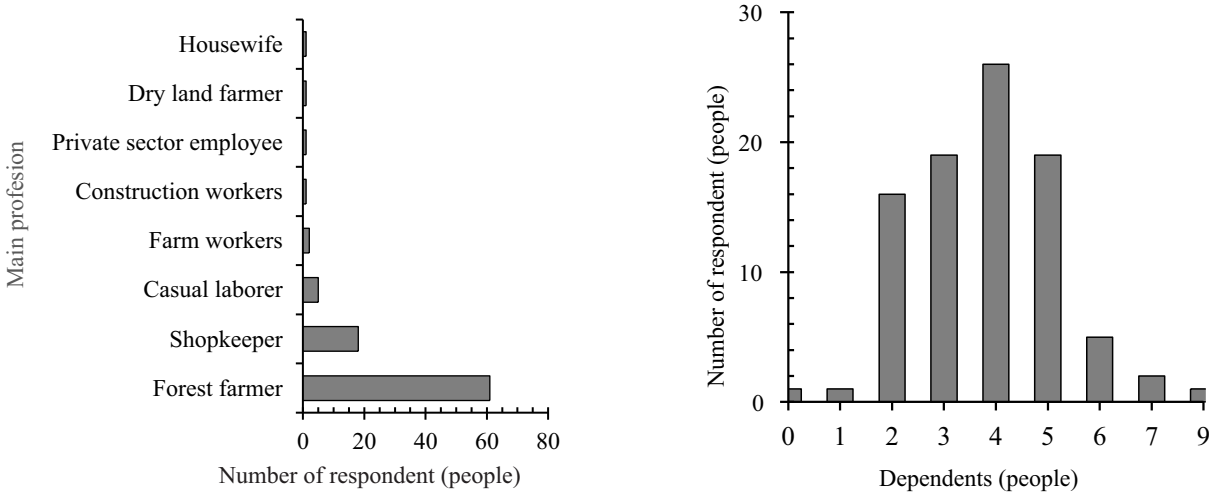

Figure 6 Distibution of main profession and dependents numbers.

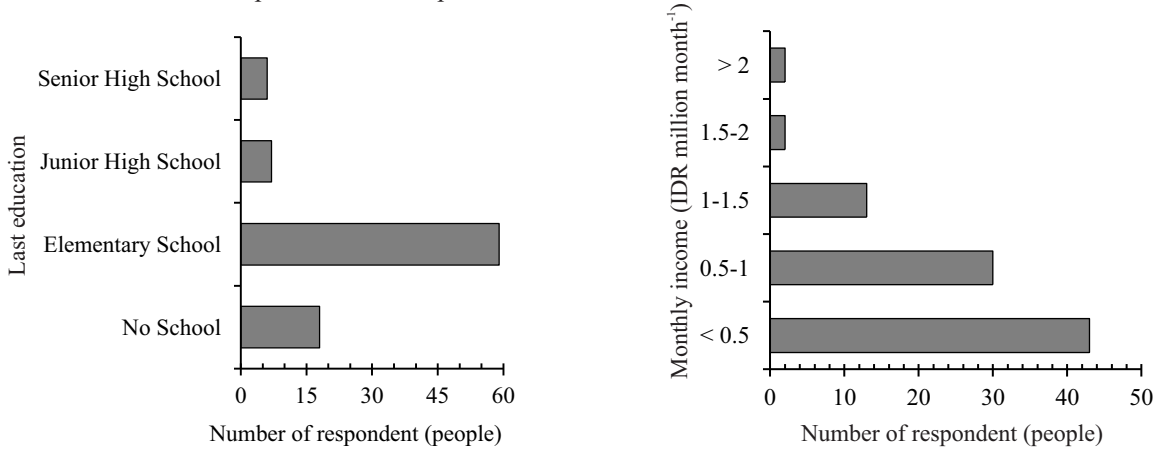

Figure 7 Distribution of last education and monthly income of respondents.

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people primarily manage forests to meet their basic daily needs. This has been a long-standing practice, with most respondents admitting to having used forest land for more than ten years for their livelihood activities. The complete graph of the characteristics of the respondents is provided in Figure 5 until Figure 8.

The study results show that the community in the study area has a strong connection to the forest resources. The community heavily relies on the forest, so they use and take care of it with caution. Communities also make efficient use of forest land by cultivating it under forest stands using traditional ways without intensive farming tools.

Forest utilization pattern The community has long practiced forest utilization based on indigenous knowledge passed down from generation to generation. This knowledge holds values that are relevant to modern development (Dorji et al., 2024). The core values of sustainable management are upheld and preserved, guided by the *kamitua*. Indigenous knowledge was passed down through three management types: spatial, temporal, and functional.

Forest management based on spatial designations This knowledge involves conservation, protection, and production areas. Conservation areas are determined by sacred sites indicated by the presence of *tabet*, signifying "remnants of important past events" in the Javanese Banyumas dialect. Based on information from *kamitua*, these sites are considered historical landmarks believed to be the location of significant activities in the past. They often take the form of specific structures, whether restored or not, as shown in Figure 9.

Until now, no institution has managed these sites formally. However, some volunteers accompanied by *kamitua* dedicate themselves to maintaining these sites. As a result, these sites can be preserved, which will have a significant impact on the sacred areas that are traditionally conserved.

The study identified a total of 40 *tabets*, all of which were natural sacred sites. Each village had different numbers of *tabets*: GL had 18, SW had 12, and SL had 10. Out of these, 12 *tabets* were located in the state forest area, while the remaining 28 were outside the state forest area near settlements, mixed gardens, rice fields, or dry fields. All these sites were equally respected by the community and were conserved based on indigenous knowledge. The distribution of all the *tabets* found is shown in Figure 10. While the names and distribution of identified *tabet*s are presented in Table 1.

The management system of the *tabet* and surroundings follows a zoning approach similar to modern conservation area management (Figure 11). This approach was passed down and taught from generation to generation. The community is also familiar with the boundaries between zones, marked by the growth of specific trees such as the Ceylon Ironwood tree (*Mesua ferrea*), known locally as the *Nagasari* Tree. This tree was also an important species to the community, and it believed in helping avoid supernatural disturbances such as ghosts and demons.

The zoning division in this area follows a specific pattern that includes sacred forests, forest areas outside the sacred

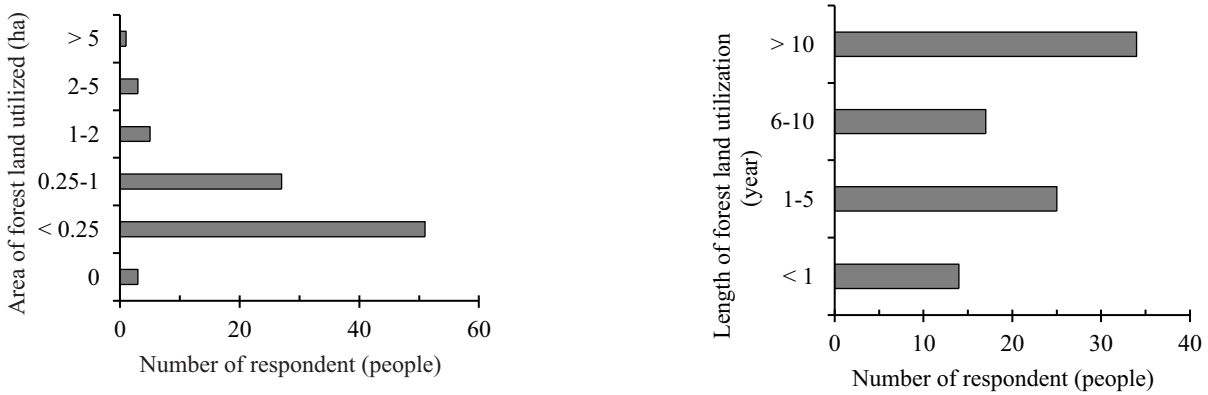

Figure 8 Distibution of utilization of forest by area and length of time.

Figure 9 The structure of the sacred site (*tabet*). a) *tabet* Nangka, located in GL; b) *tabet* Rantan sari, located in SW; and c) *tabet* Tlangkop which is currently being excavated and restored for archaeological purposes, located in SW.

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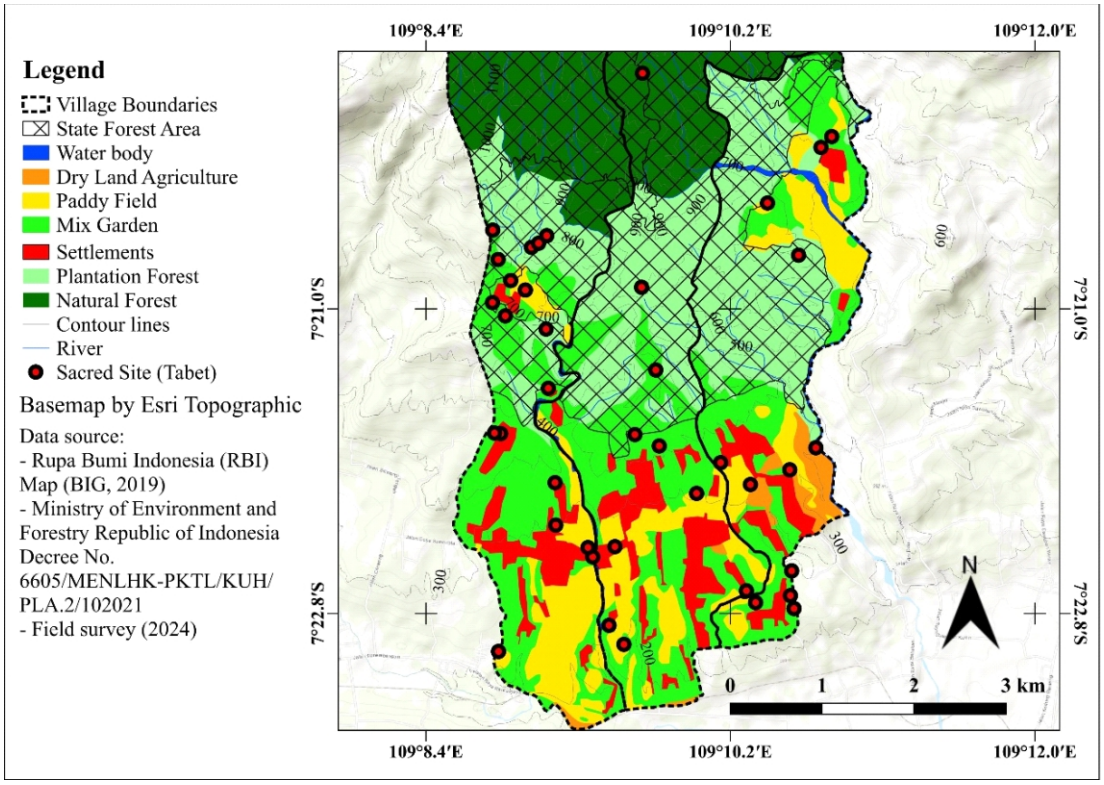

Figure 10 Distribution of natural sacred sites (*tabet*) in research area.

forests, and agroforestry areas (illustrated in Figure 11). Sacred forests surround *tabets* and are characterized by large trees over 10 meters tall and *Nagasari* trees. Outside the sacred forests, the forest serves as a transition zone and is marked by steep contours or specific landmarks such as large rocks or trees like *pucung* (*Pangium edule*), *benda* (*Artocarpus elasticus*), *pakis tiang* (*Cyathea contaminans*), bamboo (Bambusoideae), and *aren* (*Arenga pinnata*). This transition zone is a protected area to safeguard the ecosystem and prevent landslides. Protected areas may extend to other steep terrains, even without sacred areas (Zannini et al., 2021).

The agroforestry area is the utilization zone where the community plants crops like cardamom (*Wurfbainia compacta*), coffee (*Coffea* sp.), and spices that can thrive under the shade of production trees such as sumatran pine, dammar pine, and needlewood. The knowledge related to agroforestry practices was Indigenous knowledge passed down through generations within the community. The community deeply understands which forest species could be cultivated to meet daily needs and for economic purposes. In the past, the community also cultivated *padi gogo* (dryland rice) as a food source during the dry season (Mulyoutami et al., 2023; Prabawani et al., 2024). But now people prefer to grow cardamom, coffee, and other spices because they can serve both daily needs and economic needs.

Forest management institutions based on space design were reflected in the customary rules that bind the community. The community implements these rules through the *kamitua*, their customary leader. The customary system employs deliberation to address issues such as violations, preparation for the rituals, and organizing customary activities related to forest management (Girot et al., 2012). However, until now this customary institution has not had a formal form, so that sometimes the community has difficulty when violations are committed by newcomers. They cannot give warnings or punishments according to customary law because they are hampered by the applicable legal rules of freedom (Amador-Jimenez et al., 2024). These customary rules are detailed in Table 2.

Based on observations, interviews, and FGDs, three sacred forests were considered regarding their physical characteristics. These forests have specific spatial arrangements based on information provided by the *kamitua*. All of the mapped sacred forests were located in the forest area, highlighting the importance of using traditional knowledge to support the sustainability of forest resources. These practices were crucial for mitigating the effects of climate change by forest conservation through indigenous knowledge. Mapping sacred forests can also enhance forest management perspectives, emphasizing the need to incorporate traditional knowledge into the activities of forest area managers (Arthur et al., 2020; Dahlan et al., 2022). The locations of the three mapped sacred forest areas are shown in Figure 12.

Forest management based on the time The community still follows a traditional calendar called *pranatamangsa*. It is used for various activities, including managing natural resources such as forests, by determining the timing. The calendar helps in understanding the weather and seasons by observing natural phenomena. It is passed down from generation to generation.

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Table 1 Name of *tabets* and distribution based on forest areas and villages

No	Location*	*Tabet* name	Village**		
			GL	SW	SL
1	OSFA	Bumiwastu	✓		
2	OSFA	Krangean (Mbah Sapu Jagad Atas Angin)	✓		
3	OSFA	Ronggeng	✓		
4	OSFA	Joko Wuluh	✓		
5	OSFA	Watu Jaran	✓		
6	OSFA	Watu Janji	✓		
7	OSFA	Jaran	✓		
8	OSFA	Jrakah	✓		
9	OSFA	Sambang Renan	✓		
10	OSFA	Bandayuda	✓		
11	OSFA	Kemuning		✓	
12	OSFA	Mbah Gleong		✓	
13	OSFA	Adipati Mruyung		✓	
14	OSFA	Seliling		✓	
15	OSFA	Peh Budha		✓	
16	OSFA	Celeng Karung		✓	
17	OSFA	Rantan Sari		✓	
18	OSFA	Pasuruan		✓	
19	OSFA	Tlangkop		✓	
20	OSFA	Batu Laya/Baturana			✓
21	OSFA	Singaperbangsa			✓
22	OSFA	Pertapan Sokaciri			✓
23	OSFA	Wanagiri			✓
24	OSFA	Suryani			✓
25	OSFA	Lengger			✓
26	OSFA	Pejaten (Nyi Kuntul Putih)			✓
27	OSFA	Ebeg (Mahesa Birawa)			✓
28	OSFA	Kali Sekar			✓
29	ISFA	Sumur Sobali	✓		
30	ISFA	Watu Paron	✓		
31	ISFA	Watu Rajut	✓		
32	ISFA	Nangka	✓		
33	ISFA	Watu Gajah	✓		
34	ISFA	Watu Jenang	✓		
35	ISFA	Sudem	✓		
36	ISFA	Waru	✓		
37	ISFA	Mbah Jlari		✓	
38	ISFA	Pondok Mandom		✓	
39	ISFA	Watu Mbako		✓	
40	ISFA	Pecokol			✓

The management activities in the *pranatamangsa* calendar were generally associated with agriculture outside the forest (Retnowati et al., 2014). However, the community adapted it for agricultural activities within the forest using an agroforestry system. The primary plants cultivated in the forest were usually spices, but the community also had the option to cultivate other plants suitable for dry land, such as beans and taro, along with *palawija*[4]. All of these agricultural products were utilized by the community to fulfill both daily and economic needs.

The *pranatamangsa* calendar consists of 365 days or 366 days for leap years, divided into 12 *mangsa*[5]. Each *mangsa*

[4]Various agricultural crops other than rice, such as corn, cassava, and sweet potatoes. Typically grown on dry land to meet the staple food needs of Javanese people (Dewi & Bijker, 2020; Setiawan et al., 2015; Susila et al., 2024).
[5]Various agricultural crops other than rice, such as corn, cassava, and sweet potatoes. Typically grown on dry land to meet the staple food needs of Javanese people (Dewi & Bijker, 2020; Setiawan et al., 2015; Susila et al., 2024).

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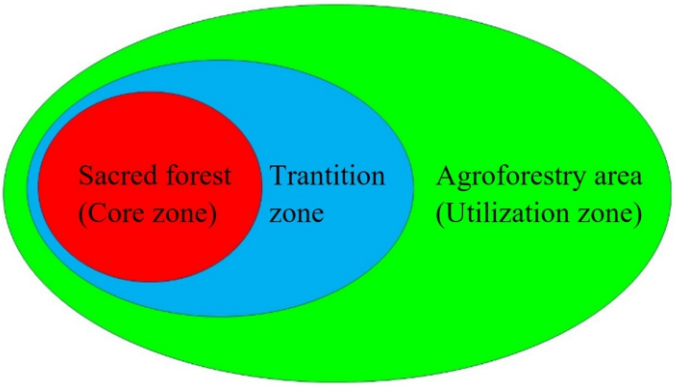

Figure 11 Illustration of zoning system in conservation area based on natural sacred sites.

Table 2 Forest management rules based on spatial according to indigenous knowledge

Zonation	Traditional used	Traditional rules	Violation sanction
Sacred forest (Core zone)	Certain traditional or spiritual rituals	Not to enter the area carelessly, need permission from a *kamitua*, watch the words and actions, prohibit entering sacred areas on certain days	Social sanctions: being shunned and ostracized, even to the point of being hated by society
Transition zone	Sacred area boundary sign	No cutting down of trees, no hunting of wild animals, no farming activities in the transition zone (also in protected areas)	Customary sanctions: replanting 10 times as many trees as were cut down, returning captured wild animals to their original location, if the hunted animal dies then a replacement of the same species must be found, agricultural crops planted in the transition zone are removed
Agroforestry area (Utilization zone)	Cultivation of local trees that produce forest fruits or spices with an agroforestry system	Only allowed to plant annual crops under forest stands for production purposes, allowed to plant trees for production purposes, and trees belonging to government companies must be maintained	Violations brought to the legal realm, forest ranger, or police

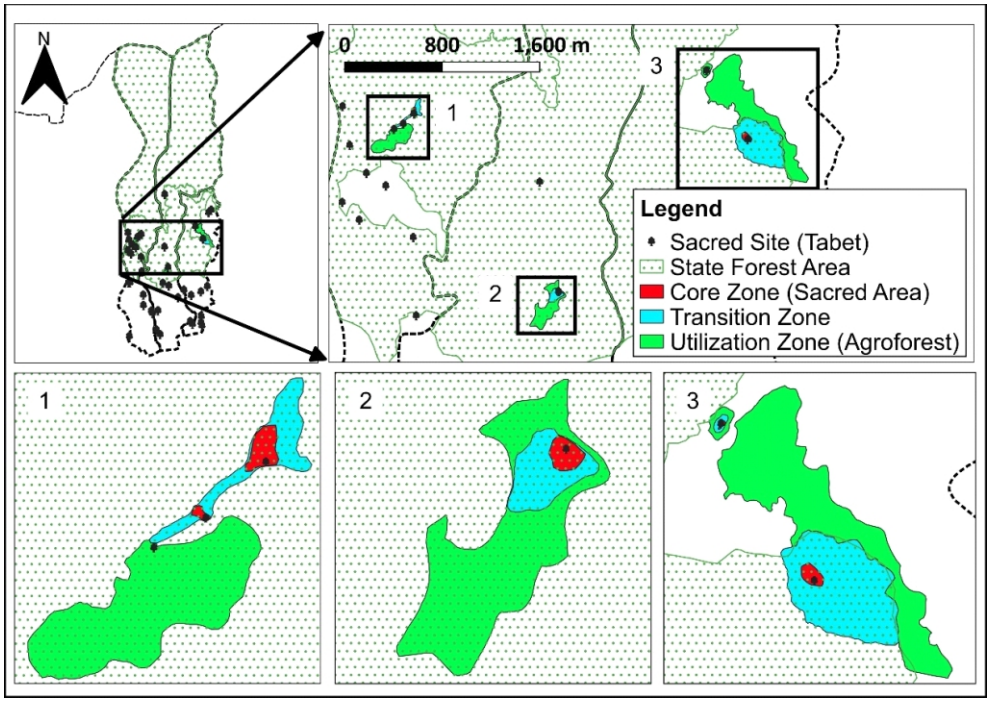

Figure 12 Sacred forests mapped in the research area.

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Table 3 *Pranatamangsa* calendar along with the characteristics and activities of resource management

No	*Mangsa*/ season name	Number of days	Time periods	Season characteristics	Management activity
1	*Kasa*	41	June 22–August 1	Leaves are falling, trees are shedding leaves, grasshoppers are laying eggs	Start planting *palawija*, land clearing from bush
2	*Karo*	23	August 2–August 24	The ground is dry and cracked, the *kapok* trees (*Ceiba pentandra*) are flowering	Care to *palawija* plants
3	*Katelu*	24	August 25–September 17	Climbing plants climb trellises, bamboo shoots appear, spice rhizomes sprout	Harvest time to *palawija* plants
4	*Kapat*	25	September 18–October 12	The springs began to clog, the wells dried up, the *kapok* trees began to bear fruit, and weaver birds (*Ploceus* sp.) began to make nests	Nursery land preparation
5	*Kalima*	27	October 13–November 8	Starting the rainy season, the tamarind trees (*Tamarindus indica*) begin to appear with young leaf shoots, the *gadung* (*Dioscorea hispida*) and turmeric appear leaves, and many snakes come out of their burrows	Selection and planting of seedlings
6	*Kanem*	43	November 9–December 21	Seasonal fruits (e.g. *durian* – *Durio* sp. and *rambutan* – *Nephelium lappaceum*) starting to fill out and ripen	Preparation of planting holes, moving seedlings to the forest
7	*Kapitu*	43	December 22–February 2	Peak of the rainy season, numerous cases of fevers and diarrhea, rivers flooding, storms, and strong winds	Planting the seedlings
8	*Kawolu*	26 or 27	February 3–February 28 or 29	Cat mating season, green paddy fields, lots of beetle larvae on the ground or tree trunks	Land control from weeds
9	*Kasanga*	25	March 1–March 25	Many *gangsir* (*Tarbinskiellus portentosus*) appear and rice enters the heading phase	Control of plants from pests and diseases
10	*Kasepuluh*	24	March 26–April 18	Season for wild animals and livestock pregnant, many birds making nests and laying eggs, rice starting to turn yellowing	Starting for first harvest
11	*Dhesta*	23	April 19–May 11	The chicks hatch and are fed by their parents, and the rain becomes less frequent	Peak harvest season
12	*Sadha*	41	May 12–June 21	The air temperature is decreasing, and the season is getting drier	Final harvesting

varies in length, with a minimum of 23 days and a maximum of 43 days, based on natural phenomena. This method of dividing time is very effective for planning management activities. For detailed information on the division of *pranatamangsa*, their characteristics, and suitable management activities, are shown in Table 3.

Forest management based on function Community harvests consist of various species, including trees and seasonal understory crops. Communities manage forest resources in agroforestry areas based on three functions: production, conservation, and spiritual use. These functions were managed in an area of forest land using an agroforestry system with two or more layers (Bande et al., 2022). Each function is explained in the following points.

Production function Forest management typically follows the *tumpang sari*[6] method, where communities are familiar with the environmental requirements for each utilized species. This knowledge was passed down organically within the community, with older generations sharing their farming experiences in the forest with the younger generation. The role of *kamitua* was also essential, as they were responsible for identifying prohibited species that serve conservation or spiritual purposes.

[6]A traditional farming system that combines several species in one area of land. This system was passed down from generation to generation based on periodic trials (Prabawani et al., 2024).

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Table 4 Forest resource management products by communities around the forest

No	Commodity name	Number of harvesters from questionnaire respondents (people/s)		Product origin		Part that harvests by people/s
		As main commodities	As by-products	Cultivars	Wild harvest	
1	Acacia (*Acacia* sp.)	2		✓		Wood
2	Albizia (*Albizia chinensis*)	9	1	✓		Wood
3	Avocado (*Persea americana*)	6		✓		Fruit
4	Bamboo (Bambusoideae)		20	✓	✓	Bamboo shoot, stem
5	Banana (*Musa* sp.)	1		✓	✓	Leaves, fruit
6	Cardamom (*Wurfbainia compacta*)	82	23	✓		Fruit, seeds
7	Clove (*Syzygium aromaticum*)	13	1	✓		Flower, leaves
8	Coffee (*Coffea* sp.)	29	11	✓		Fruit, seeds
9	*Durian* (*Durio* sp.)	3	1	✓		Fruit
10	Fern (Athyriaceae)	1	1		✓	Young leaves
11	Firewood		1		✓	Stem, twigs
12	Forest fruits	4			✓	Fruit
13	Grass		1		✓	Leaves
14	Bees (*Apis* sp.)		3	✓	✓	Beehive, honey
15	*Jengkol*/Dog fruit (*Archidendron pauciflorum*)	1	3	✓		Legumes, wood
16	Mushroom (*Gymnopus* sp.)	1	22		✓	All parts
17	Nutmeg (*Myristica fragrans*)		1	✓		Seeds
18	*Petai*/Stink bean (*Parkia speciosa*)		1	✓		Legumes
19	Sumatra pine (*Pinus merkusii*)		18	✓		Resin, wood
20	*Pucung*/Black nut (*Pangium edule*)	2		✓	✓	Seeds
21	*Puspa* woods (*Schima wallichii*)		1	✓	✓	Wood
22	Rattan (Calameae)		13	✓	✓	Stem
23	Sugar palm (*Arenga pinnata*)		1	✓	✓	Sugar sap
24	Torch ginger (*Etlingera elatior*)		1		✓	Flower
25	Vegetables		29	✓		All parts
26	Wild animals		8		✓	All parts, nests
27	Woods	10	16		✓	Wood

In this study, the respondents reported a total of 27 production species, which were identified as both main commodities and by-products. The respondents mentioned that in their cultivation areas, they cultivated more than one main commodity and more than one by-product. The harvested products originated from cultivars or wild harvests. Table 4 displays the production commodities of the community surrounding the forest. The top three main commodities were cardamom (*Wurfbainia compacta*), coffee (*Coffea* sp.), and cloves (*Syzygium aromaticum*), which were important plants to be developed under the tree canopy.

Conservation function The community selects specific plant species to protect important areas like steep areas, riverbanks, areas around springs, and rocky cliffs. They use a vegetative land conservation approach based on their customary knowledge of each function of tree species. According to the community information, the chosen species is divided into three conservation functions: controlling landslides, protecting springs, and strengthening riverbanks and cliffs. The species recognized by the community for their conservation functions are listed in Table 5. Based on data from interviews with *kamitua* and FGD results, 19 species were identified as having conservation functions. Species that have three conservation functions at once are *aren* (*Arenga pinnata*), *benda* (*Artocarpus elasticus*), *pucung* (*Pangium edule*), and *waru* (*Hibiscus tiliaceus*).

Spiritual function The final function of species-based forest management is for spiritual purposes. Communities are strongly connected to species that play a role in spiritual and religious activities. According to indigenous knowledge, forest management based on spiritual functions maintains the balance of the

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Table 5 Forest resource management products by communities around the forest

No	Species name	Conservation function		
		Prevent landslide	Spring protection	Riverbank and steep reinforcement
1	*Ara*/River fig (*Ficus racemosa*)		✓	✓
2	*Aren* (*Arenga pinnata*)	✓	✓	✓
3	Bamboo (Bambusoideae)	✓		✓
4	*Benda*/*Terap* (*Artocarpus elasticus*)	✓	✓	✓
5	*Bodhi*/Sacred fig (*Ficus religiosa*)		✓	✓
6	*Jengkol*/Dog fruit (*Archidendron pauciflorum*)	✓		
7	*Kaliandra merah*/Red calliandra (*Calliandra calothyrsus*)	✓		✓
8	*Kelapa*/Coconut (*Cocos nucifera*)	✓		✓
9	*Mbawang*/*Kuweni* (*Mangifera odorata*)			✓
10	*Nibung* (*Oncosperma tigillarium*)			✓
11	*Pakis tiang*/Tree fern (Tracheophyta)	✓		✓
12	Palm tree (Palmae)	✓		
13	*Petai*/Stink bean (*Parkia speciosa*)	✓		
14	*Pucung*/Black nut (*Pangium edule*)	✓	✓	✓
15	Rattan (Calameae)	✓		✓
16	*Salak hutan*/Forest salak (*Salacca zalacca*)	✓		
17	*Selatri*/*Mintak* (*Calophyllum soulattri*)			✓
18	*Sukun*/Breadfruit (*Artocarpus altilis*)		✓	✓
19	*Waru*/Sea hibiscus (*Hibiscus tiliaceus*)	✓	✓	✓

ecosystem, strengthens the relationship between humans and nature, and plays an important role in climate change adaptation and mitigation. Indigenous knowledge that teaches the importance of respecting and preserving forests as sacred entities helps reduce deforestation and forest degradation, which are major sources of greenhouse gas emissions (Heydir et al., 2017; Taqwa, 2017; Widianingsih et al., 2023; Zurba & Papadopoulos, 2023; Dorji et al., 2024).

Based on interviews with *kamitua* and focus group discussions with representatives of community farmers, six species have been identified as having strong spiritual significance to the community. These species are *nagasari* (*Mesua ferrea*), *beringin*/ weeping fig (*Ficus benjamina*), *kelor* (*Moringa oleifera*), *sayudan*/rain tree (*Samanea saman*), *kumpe* (Pandanaceae), and coconut (*Cocos nucifera*). They are closely associated with various traditional and religious activities. Specifically, these species serve the following functions:

Nagasari This species grows in the forest, either naturally or intentionally planted. Its role in spirituality is a marker of sacred areas (*tabet*). When this species exists, it usually indicates that an area has entered the scope of the sacred area.

Beringin/*Weeping fig* This particular species acts as a guardian tree in the sacred area. Through field observations, it has been noted that large Weeping fig trees surround the *tabet*. According to information from the *kamitua*, these large trees were believed to be over 50 years old and are intentionally preserved as shade trees in the *tabet* area.

Kelor This plant species was commonly cultivated by people in and around settlements, as well as in agroforestry areas. In spiritual practices, the leaves and wood of this plant were often used as a means of protection against negative supernatural forces. The community believes that regularly consuming this plant's leaves can promote overall health and improve skin complexion.

Sayudan/*rain tree* The community of GL and SW believes that this species has magical powers that help maintain a stable river flow. It is crucial to plant this species in key locations near the river. Field observations have shown that this species is commonly found on the riverbanks near settlements, bridges, and dams. Its presence is vital for safeguarding important structures and settlements from flash floods.

Kumpe This species was closely related to the establishment of the *Grumbul* Pesawahan in GL, so it was considered a characteristic plant with a spiritual attachment to the local community. Field observations have found that in *Grumbul* Pesawahan, a lake is overgrown with Kumpe plants. According to information from *kamitua*, this lake was named Kumpe Lake because the Kumpe plant grows abundantly there. The existence of this plant was related to the folklore of the establishment of the *grumbul*. Around the 18th century, the founders of the *grumbul* first found a lake overgrown with Kumpe plants in the middle. The lake was located in a forest

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adjacent to a sacred forest. With many water resources from the lake and the surrounding rivers, the founders of this *grumbul* made settlements and rice fields around the lake. Over time, the rice fields made by the founders expanded and were often visited by other villagers who wanted to visit the sacred forest. Consequently, the residents named it "*grumbul* Pesawahan," and the symbol of the *grumbul* was the Kumpe plant. As a result, local people believe that if the Kumpe plant disappears from the lake, a disaster could occur.

Coconut Coconut trees play important roles in religious and traditional activities for the community. Young leaves often make traditional ceremonial foods like *ketupat*, *lemet*, and *jenang wajik*[7]. Additionally, mature leaves were commonly woven into items to wrap and take-home food after communal religious events, locally known as "*mberkat*" or the smaller version called "*takiran*"[8]. Coconut leaves were also used as traditional decorations for customary events such as weddings, commemorating the Prophet Muhammad's birthday, and ceremonies celebrating blessings and growth at different stages of the baby's life[9].

The activities of species sorting, based on the functions conducted by the community, encompass production, conservation, and spirituality, all of which significantly support efforts to adapt to and mitigate climate change. The strong connection between the community and natural resources fosters a coexisting relationship (Bott et al., 2020; Alkatiri & Kiwang, 2023; Amador-Jimenez et al., 2024). As a result, the community will continue to uphold biodiversity and essential ecosystem functions. Sustainably managed forests offer reliable natural resources for local communities, including clean water and food, which are increasingly crucial in the face of climate change. By integrating spiritual values into forest management, indigenous communities can develop adaptation strategies rooted in local and traditional knowledge, often more effective and sustainable than modern approaches.

Discussion

The three villages in the research location have unique climate change mitigation and adaptation approaches. GL and SW were progressively integrating indigenous knowledge with modern bits of knowledge. In contrast, SL was more conservative and relied solely on indigenous knowledge without modern improvisation. This implies that in GL and SW, a development process is triggered by the existence of creative socio-cultural energy within the community (Sumardjo et al., 2019; Hentihu et al., 2020). This condition is driven by young people who care about the environment and local culture.

Young people initiated the forest rehabilitation movement in SW to mitigate climate change. The movement was based on a forest management approach that incorporates indigenous knowledge. The movement began as a response to growing concerns about the impacts of climate change. Over time, the movement has evolved into a collective action driven by social energy (Sumardjo et al., 2019; Hentihu et al., 2020). The movement also received support from the *kamitua*, who guided the selection of species to be planted. Climate change mitigation efforts were also reflected in the tradition of planting trees in the forest during significant events like childbirth and weddings. This tradition has declined with time, but some young people were trying to preserve it under the guidance of *kamitua*.

The tradition of planting trees in the forest has been passed down from generation to generation, as stated by *kamitua* and the initiators of the movement. It is a way of showing gratitude to God and expressing compassion for *ibu bumi* (natures). The chosen tree species also symbolize the prayers offered, focusing on fruit trees that are expected to bear fruit when they mature. This symbolizes the planter's hope that the important moment in question will yield positive results in the future.

In GL, the youth has taken the initiative to address climate change by establishing an educational institution. This institution provides informal education to children about climate change mitigation and adaptation. The main goal was to raise moral and spiritual awareness about the importance of preserving forests as a source of life. The educational activities combine general science, religious studies, and climate change knowledge. These activities include exploring biodiversity in the forest, learning agroforestry techniques, and simulating climate change scenarios.

The community is trying to adapt to climate change by diversifying their food sources from the forest based on their indigenous knowledge. They have also slightly adjusted the *pranatamangsa* calendar based on their years of observations of natural signs. This modification, known as *ilmu titen*[10], passed down knowledge to future generations (Permana et al., 2023). However, these adjustments are not completely accurate, so it is important to improve the method of modifying the calendar using modern knowledge related to the weather.

The community made significant efforts to respond to the challenges of climate change through both planned and indigenous knowledge-based initiatives. However, there is a need to enhance the technical planning, implementation, and evaluation of these efforts to achieve more optimal results (Gunawan et al., 2024; M. R. Setiawan et al., 2024). This improvement can be achieved in three stages: identifying actions, making improvements, and promoting them. Table 6 presents suggestions for the development of adaptation and

[7]Some examples of traditional food from the Banyumasan Javanese people.
[8]Traditional way to wrap food hygienically, neatly, safely, and environmentally friendly. Sometimes coconut leaf weave can be replaced using *nyangku* leaves (*Molinera capitulate*).
[9]The community still holds ceremonies to celebrate blessings and growth at various stages of a baby's life: *ngupati* and *mitoni* (thanksgiving ceremonies for the fourth and seventh months of the fetus in the womb), *aqiqah* (naming ceremony for the baby), *puputan* (thanksgiving for the release of the baby's umbilical cord), and *tedak siten* (a ceremony for the baby's seventh month of age).
[10]The traditional Javanese method involves observing natural phenomena through consensus among a knowledgeable community, with the results conveyed orally.

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Table 6 Suggestions for developing climate change adaptation and mitigation actions that can be taken by community

Action stages	Action type					
	Adaptation			Mitigation		
	Identification	Improvement	Promoting strategies	Identification	Improvement	Promoting strategies
Planning	No planning regarding adaptation actions	Forming an institution focused on adapting to climate change is necessary and fostered by formal, customs, and religious leaders	Preparation of a forest management road plan according to customary rules by customs institution collaboration with village government	No planning regarding mitigation actions (not programmed)	Need to initiate formal legal recognition of customary institutions in each village or *grumbul*	Inventory of sacred forests and their management road plan
Implementation	Food diversification based on indigenous knowledge	Need for an inventory of local foods and their functions based on indigenous knowledge	Promotion through digital platforms and social media, creating trends among young people, and awareness movements for food diversification	Sporadic forest rehabilitation movements without planning	Arrangement of planting layout based on the capabilities and characteristics of the type of plant planted, adjustment of planting objectives based on planting location	Scientific and popular publications about the activities and results of the movement
	Forest management based on vertical and horizontal space	Adoption of forest management design based on customary knowledge in village regulations	Creating a participatory management layout that is known and agreed upon by all stakeholders	Forest protection and conservation for carbon sequestration	Periodic inventory of carbon stocks estimates at any given time using field data and satellite imagery	Promotion on the website and uploading updated results in the carbon stock development report
	Forest management based on activity time	Modification of *pranatamangasa* by adopting modern knowledge in the guidance of the nearest meteorological agency	Establishment of a community or forum of climate-aware forest farmers, forest farming training with adjustments to farming times	Awareness education and coaching for climate change mitigation activities for the younger generation	Provision of educational facilities, resources, infrastructure, and support for skilled teaching resources	Creating a formal curriculum to educate the younger generation to prepare qualified human resources
	Forest management based on species function	Optimizing the use of production species through downstreaming of the mass-scale industry, developing storage methods to reduce the rate of shrinkage and quality decline.	Increasing the role of youth in downstream industries to accelerate market absorption with competitive prices, post-harvest processing training, agribusiness management training			
	Conservation of forest biodiversity	Development of by-products in the form of environmental services such as clean water utilization, carbon trading, and ecotourism	Inventory of local species that have local conservation value based on toponymy, history, folklore and cultural value			
Evaluation	No evaluation activity	Preparation of periodic evaluation plans for each time period agreed upon by formal, customary and spiritual leaders and community members in community institutions or forums around the forest, preparation of a complaint flow system related to climate change issues	Periodic and gradual socialization with actual discussions at each meeting. This activity can be combined with regular community meetings	No evaluation activity	Regular monitoring and measurement of rehabilitation results by forums or institutions that deal with climate change issues at the site level	Strengthening information transparency through digital platforms, community meeting forums, and formal village government forums

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mitigation actions that can be undertaken in the near future.

After analyzing field findings, information from respondents, interview results, and FGD results, strategies for adapting to and mitigating the effects of climate change were identified. The sources of knowledge within the community were also pinpointed. Documenting these findings and establishing legal institutions to recognize and protect customary practices is essential shortly. This will help safeguard traditional institutions from being marginalized as new knowledge is integrated (Ostrom, 1990; Alkatiri & Kiwang, 2023; Susanto & Numata, 2023).

Practices within customary institutions in various regions offer powerful examples of how traditional and modern knowledge can work together to enhance legal certainty and promote sustainable forest management. These systems are rooted in indigenous traditions prioritizing ecological balance and community well-being while adapting to contemporary legal frameworks. Modern state laws have made significant progress in preserving their rich natural and cultural heritage by recognizing and supporting these institutions.

A notable example is the recognition of *hutan adat* (customary forests) following the 2013 Constitutional Court ruling in Indonesia, which gave control to indigenous communities. In areas like West Sumatra, the *nagari* system empowers communities to collectively manage forests, guided by traditional ecological practices such as rotational farming and preserving sacred groves (Asmin et al., 2019; Utami & Oue, 2021). In Kalimantan, the *Dayak* communities practice *tana' ulen*, which restricts forest use to conserve biodiversity while allowing for sustainable resource harvesting (Anau et al., 2019). These practices benefit from legal recognition, which helps resolve land disputes and affirms community rights over ancestral territories.

In other regions, modern legal and scientific approaches complement customary practices. For instance, in Sulawesi, the *Kajang* community protects their ancestral forests based on the *pasang ri Kajang* philosophy, emphasizing harmony with nature (Maruf et al., 2017; Mahbub et al., 2019). This community enforces strict rules against logging and environmental degradation, supported by local government recognition and partnerships with conservation organizations. These practices sustain local livelihoods while contributing to broader environmental goals, showcasing how Indonesia's customary institutions can lead to effective resource management.

The communities on the southern slopes of Mount Slamet can adopt institutionally feasible practices to enhance forest management and protection. This approach offers the advantage of granting the community greater authority and protection under state law, enabling them to preserve and manage forests passed down through generations. These communities have significantly contributed to climate change adaptation and mitigation efforts by utilizing indigenous knowledge, aligning with Sustainable Development Goal 13, which focuses on climate action (Intergovernmental Panel on Climate Change, 2022). By increasing the visibility and quality of their work, these communities could serve as a model for others. Additionally, preserving customary institutions can play a crucial role in safeguarding forests from harm. These efforts are expected to create opportunities for vulnerable groups, such as forest farmers, to manage forests and achieve long-lasting, impactful outcomes sustainably.

Conclusion

The social structure in the research area primarily comprises individuals who work in the forest, either as their main job or as a side job. This results in a forest management pattern that is based on customary rules. Leadership comprises three complementary components: formal leaders, such as the *RT*, *RW*, or *kadus*; customary leaders, such as the *kamitua*; and spiritual leaders, such as the *kyai* or *ustadz*. The transfer of traditional knowledge was primarily conducted by the *kamitua*, often accompanied by the *kyai* or *ustadz* to ensure that the knowledge aligns with Islamic laws. The community follows three management patterns: spatial-based, time-based, and function-based. Spatial-based management has three categories of forests: sacred forests (marked with *tabet*), protected forests, and agroforestry areas. Time-based management follows the *pranatamangsa* calendar, with adjustments using *ilmu titen*. Finally, forest plant function-based management is divided into production, conservation, and spiritual, all of which are important for the daily lives of the community. Climate change adaptation and mitigation actions were initiated by young people with the guidance of *kamitua*. These actions developed into a social movement that influenced other communities and inspired people to raise almost extinct and environmentally friendly traditions. Improving the quality and exposure of these actions ultimately requires improvement, which can greatly impact sustainable development goals. Therefore, formal protection of traditional institutions is necessary to guarantee the sustainability of their efforts.

Recommendation

Recognizing and integrating traditional knowledge and forest management systems into regional and national policies is essential for supporting the community's sustainable practices. This could include providing legal protections for customary institutions, fostering collaborations between local leaders and external stakeholders, and offering resources to enhance the community's ability to adapt to climate change. Raising awareness about the community's innovative practices and alignment with sustainable development goals could inspire similar global movements. By connecting traditional wisdom with modern frameworks, these efforts can serve as a model for achieving resilience and environmental stewardship in other forest-dependent regions.

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accounted for by the researcher. This research has met the ethical standards of social research applicable in Indonesia.

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