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Transformation of Seasonal Institutions: Innovation of Ecological Education Modules for Sustainable Forest Management and Mitigation of Hydrometeorological Disaster Risks

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A B S T R A C T

This research examines the transformation of the traditional Pranata Mangsa calendar system through the integration of modern science and local wisdom into an educational module for adaptive and sustainable natural resource management. The interpretative phenomenological analysis (IPA) method was used, with data collection through interviews, observations, and documentation in the LMDH Wana Mitra Sejahtera community. The results indicate that the integrative module, which combines climate data, GIS, and weather sensors, enhances understanding of ecological cycles and active community participation. The synergy between tradition and digital technology strengthens social-ecological resilience and agricultural productivity in the face of climate change. This transformation serves as an effective model for participatory and adaptive natural resource management, with recommendations for strengthening farmers' capacities and developing locally-based applications

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INTRODUCTION

Pranata mangsa is a traditional Javanese calendar system that divides the year into seasonal cycles with specific climatic characteristics and agricultural activities (Ahmad et.al.2012). This system has long been a local wisdom that plays an important role in natural resource management and sustainable agriculture (Berkes, 2012; Dora et al., 2025). Recent studies by Prasetyo & Lestari (2023) and Wibowo & Hartono (2023) show that pranata mangsa can be integrated with modern technology to improve conservation effectiveness and community empowerment. Pranata mangsa is a traditional calendar system derived from Javanese culture, which divides the year into 12 seasonal cycles or "mangsa" with specific climatic characteristics and agricultural activities in each season (Berkes, 2012). Each mangsa has a duration of about 30 days and is characterized by weather patterns such as rainfall, temperature, and wind, which serve as guidelines for communities in determining planting, harvesting, and management times (Dora et al., 2025). As part of local wisdom, pranata mangsa has played an important role in maintaining ecosystem balance and supporting the sustainability of traditional agriculture. This system allows farmers to adjust farming activities to local climatic conditions so as to minimize the risk of crop failure due to unexpected weather changes (Prasetyo & Lestari, 2023).

In addition, pranata mangsa also serves as a guideline in natural resource management such as timing of logging, collection of non-timber forest products, and water conservation (Ahmad et.al, 2012). Pranata mangsa helps communities manage natural resources adaptively and sustainably by utilizing local knowledge that has been tested for centuries (Ahmad &Ramadhani, 2025). This is in line with traditional ecological principles that emphasize harmony between humans and nature (Berkes, 2012). Integration of Pre-Natural Order with Modern Technology. Recent studies have shown that pranata mangsa can be integrated with modern technology to increase the effectiveness of conservation and community empowerment.

Wibowo & Hartono (2023) developed a pranata mangsa-based ecological calendar module that utilizes information technology to facilitate community access and understanding of seasonal cycles and agricultural activities. The module combines modern climate data with local wisdom, thus providing more accurate and relevant information for farmers. In addition, the use of technologies such as geographic information systems (GIS), weather sensors, and mobile applications enable real-time monitoring of environmental conditions and more precise weather predictions. Pranata mangsa as a traditional Javanese calendar system has been used for centuries to organize agricultural activities based on seasonal patterns and local climate. However, global climate change is causing higher uncertainty, so integration with modern climate data is needed to make predictions more accurate and relevant.

Prasetyo & Lestari (2023) developed an ecological calendar module that combines data on rainfall, temperature, and traditional seasonal patterns of pranata mangsa. The module provides information tailored to local microclimate conditions, allowing farmers to determine optimal planting and harvesting times. Dora et al. (2025) emphasized that this integration strengthens the social-

ecological resilience of communities and increases agricultural productivity. Geographic Information Systems (GIS) have become an important tool in natural resource management and modern agriculture. Wibowo & Hartono (2023) described the use of GIS for land mapping in a forest village, which helped identify flood and drought risk zones. This information is used for more effective land use planning and natural disaster risk mitigation. Putra (2021) added that GIS also helps farmers and forest managers in monitoring land cover and monitoring environmental changes, making decision-making more data-driven and accurate.

Weather sensor technology integrated with mobile applications makes it easy for farmers to monitor environmental conditions in real-time. Soil moisture, rainfall, and temperature sensors installed on farms can send data directly to mobile applications accessed by farmers (Sari, 2023). FKT UGM (2023) reported that the use of this technology allows farmers to make quick and precise adjustments to agricultural activities, such as irrigation and fertilization, thus reducing the risk of crop failure due to sudden weather changes. The integration of modern climate data and local wisdom through educational modules, the use of GIS, and weather sensors connected to mobile applications, is an effective combination of technology and tradition to improve agricultural resilience and productivity. This approach not only provides accurate and contextualized information, but also empowers farmers with tools that are easy to access and use. Agricultural digitalization has become a major force in the transformation of the agricultural sector in Indonesia by 2023. Modern digital technology and climate data provide great opportunities for farmers to improve efficiency, productivity, and resilience to increasingly erratic climate change.

However, the successful adoption of these technologies is highly dependent on improving farmers' capacity, particularly in the use of digital tools and proper interpretation of climate data. The Importance of Farmer Capacity Building. Improving farmers' capacity in the use of digital technology and interpretation of climate data is key to optimizing the benefits of these technologies. Without adequate understanding, the available technology and data will not be effectively used, and may even lead to errors in agricultural decision-making (Pertanian.uma.ac.id, 2023). Digital training and education for farmers not only improves technical skills, but also encourages a paradigm shift from traditional methods to data and technology-based agriculture (Sahputra et al., 2024). This is important so that farmers can manage resources efficiently, reduce the risk of crop failure, and increase income.

The provision of digital guidelines in the form of tutorial videos, interactive modules, and temporary internet hotspots during training becomes an important solution to address limitations in access and technology literacy (Sahputra et al., 2024; Widhanarto et al., 2018). Involving the younger generation as technology mentors. The role of the village youth as technology mentors helps accelerate the adoption of digital technology among older farmers while reinforcing the sustainability of technology use (Rini, 2021). Understanding climate data such as rainfall, temperature, and seasonal patterns is crucial for adaptive agricultural decision-making. Training in climate data interpretation

teaches farmers to read weather forecasts and understand seasonal cycles based on local seasonal indicators combined with modern meteorological data (Prasetyo & Lestari, 2023; Dora et al., 2025).

This ability allows farmers to adjust planting times, irrigation, and crop treatments, thereby reducing the risk of crop failure due to extreme weather (Putra, 2021). Support demonstrated a significant increase in farmers' confidence in using digital technology. Around 80% of participants felt capable of accurately managing agricultural data and utilising applications for planting and marketing planning (Sahputra et al., 2024). In addition, the use of digital technology supports environmentally friendly farming practices through efficient input management and reductions in carbon emissions (Anggraini et al., 2024). This contributes to environmental sustainability while improving farmers' welfare. The enhancement of farmers' capacity in the use of digital technology and climate data interpretation is a crucial foundation for achieving productive, adaptive, and sustainable agriculture. Through structured training, intensive mentoring, and the use of appropriate technology, farmers can optimise the management of natural resources and effectively face the challenges posed by climate change. Policy support, digital infrastructure, and multi-stakeholder collaboration are essential to expand access to and the sustainability of these capacity-building programs. Thus, the digitalisation of agriculture not only increases productivity and farmers' welfare but also strengthens food and environmental resilience in Indonesia. The development of user-friendly mobile applications with educational features about the traditional Javanese calendar is an important innovation to support sustainable agriculture based on local wisdom. The traditional calendar, as a Javanese seasonal calendar, regulates the cycles of seasons and agricultural activities that are highly relevant for climate change adaptation and natural resource management (Berkes, 2012; Dora et al., 2025). The integration of the traditional calendar in digital applications allows for a broader, more accessible, and interactive transfer of knowledge.

The sensors used in modern agriculture include soil moisture sensors, air temperature sensors, rainfall sensors, light intensity sensors, and air quality sensors. This data is collected in real-time and integrated into a cloud-based farm management system for further analysis. Sensor data is analysed using machine learning algorithms and artificial intelligence (AI) to predict weather conditions, plant water needs, potential pest attacks, and optimal harvest timings. These predictions help farmers anticipate risks and plan agricultural activities efficiently. The integration of seasonal institutions with modern technology not only enhances ecosystem resilience but also strengthens community capacity to face climate change and socio-economic challenges. This approach supports community empowerment by providing easily accessible and applicable educational tools, thereby increasing active participation in conservation and natural resource management (Dora et al., 2025). Moreover, this innovation also opens up opportunities for diversifying local resource-based businesses and developing sustainable economies rooted in culture and local wisdom (Wibowo & Hartono, 2023). However, despite many studies acknowledging the value of seasonal institutions, there is a significant gap regarding how the transformation

of these institutions can be carried out systematically through contextual and participatory educational innovations.

Most studies are still descriptive and lack a deep examination of the processes of cultural and educational transformation, especially in the context of sustainable forest management in specific areas such as Lebak Jabung (Putra, 2021; Sari, 2023). Therefore, this research fills that gap by using an interpretative phenomenological approach to understand the meaning of the transformation of seasonal institutions and to develop an innovative ecological education module as a supporting tool for sustainable forest management.

LITERATURE REVIEW

Seasonal Framework; A Traditional Calendar System for Sustainable Agriculture. The seasonal framework is a traditional, season-based calendar system that has long been used by agricultural communities in Indonesia, especially in Java. This system divides the year into several seasons, each lasting about 30 days, characterised by weather patterns such as rainfall, temperature, and wind. The seasonal framework serves as the main guideline for determining planting and harvesting times, as well as for managing the environment and natural resources. The seasonal framework reduces the risk of crop failure and helps farmers adjust their farming activities to local climatic conditions. By understanding these seasonal patterns, farmers can determine the right time to plant and harvest, thus being better prepared for unexpected weather changes and minimising the risk of crop failure, supporting the sustainability of nature. In addition to agriculture, the seasonal system is also used as a guideline in the management of natural resources. This system regulates the timing of logging, forest product collection, and water conservation.

Thus, resource utilisation is carried out adaptively and sustainably, maintaining the balance of ecosystems; Rooted in Local Wisdom Knowledge, the seasonal system has been tested over centuries, passed down through generations, and is in harmony with the principles of the relationship between humans and nature. This system reflects local wisdom that strengthens the social and ecological resilience of communities. Relevance in the Modern Era; the seasonal institution remains relevant today as it is able to address the challenges of climate change and environmental crises. By relying on local knowledge that has been proven effective, communities can maintain agricultural productivity while also passing on principles of living in harmony with nature to future generations. Overall, the seasonal institution is not just a calendrical system, but also a symbol of local wisdom that supports sustainable agriculture and natural resource management in Indonesia.

Table 1. Integration of Climate Data, GIS, Weather Sensors, and Mobile Applications for Local Agriculture

Integration Aspects	Application	Benefits for Farmers	Study/Reference

Integration of Modern Climate Data with Local	Ecological calendar modules based on seasonal norms that combine rainfall data, temperature, and traditional seasonal patterns provide more accurate predictions for planting and harvesting times in accordance with local conditions.	Providing more accurate planting and harvesting time predictions according to local conditions.	Prasetyo & Lestari (2023); Dora et al. (2025)
GIS application for farmers	Geographic information systems for land mapping, flood and drought risk zone identification.	Assisting in land use planning, disaster risk mitigation, and resource management.	Wibowo & Hartono (2023); Putra (2021)
Weather Sensor and Mobile Applications	Soil moisture sensors, rainfall, and temperature connected to a mobile application for real-time monitoring.	Facilitating real-time monitoring of environmental conditions and rapid decision-making.	Sari (2023); FKT UGM (2023)

The Pranata Mangsa, a traditional Javanese calendar system, has long been used to organise agricultural activities based on seasonal patterns and local climate. However, global climate change has increased weather uncertainty, necessitating the integration of modern climate data to make predictions more accurate and relevant. Prasetyo & Lestari (2023) developed an ecological calendar module that combines rainfall, temperature, and seasonal patterns of Pranata Mangsa, adjusting information to local microclimatic conditions. This module helps farmers determine the optimal time for planting and harvesting. Dora et al. (2025) assert that this integration strengthens socio-ecological resilience and enhances agricultural productivity. Additionally, Geographic Information Systems (GIS) play a crucial role in modern natural resource and agricultural management. Wibowo & Hartono (2023) used GIS to map land in forest villages, identifying flood and drought risk zones. Putra (2021) added that GIS also helps farmers and forest managers in monitoring land cover and environmental changes, making decision-making more data-driven and accurate. Integrated weather sensor technology with mobile applications provides farmers with the convenience of monitoring environmental conditions in real-time. Soil moisture sensors, rainfall, and temperature installed on agricultural land can send data directly to mobile applications accessed by farmers (Sari, 2023). FKT UGM (2023) reported that the use of this technology allows farmers to quickly and accurately

adjust agricultural activities, such as irrigation and fertilisation, thereby reducing the risk of crop failure due to sudden weather changes.

The integration of modern climate data and local wisdom through educational modules, the use of GIS, and weather sensors connected to mobile applications, is an effective combination of technology and tradition to enhance resilience and productivity in agriculture. This approach not only provides accurate and contextual information but also empowers farmers with accessible and usable tools. The digitalisation of agriculture has become a major force in transforming the agricultural sector in Indonesia in 2023. Digital technology and modern climate data offer great opportunities for farmers to improve efficiency, productivity, and resilience against increasingly uncertain climate change. However, the success of this technology adoption heavily relies on enhancing farmers' capacity, particularly in the use of digital tools and the accurate interpretation of climate data. Digital training and education for farmers not only enhance technical skills but also encourage a paradigm shift from traditional methods to data and technology-based agriculture (Sahputra et al., 2024). This is important for farmers to manage resources efficiently, reduce the risk of crop failure, and increase income. Several digital technologies that have been implemented include mobile applications for weather monitoring, geographic information systems (GIS) for land mapping, soil moisture sensors, and online platforms for marketing agricultural produce (Wibowo & Hartono, 2023; Sari, 2023). With this technology, farmers can access real-time information regarding climate and soil conditions, as well as receive suitable technical recommendations. AI-based applications can provide specific solutions to plant problems such as the right type of fertiliser or disease prevention measures (Satudata.pertanian.go.id, 2024).

METHODOLOGY

Interpretative Phenomenological Research at LMDH Wana Mitra Sejahtera, October 2024 1. Data Collection Techniques In interpretative phenomenological research, data collection focuses on the subjective experiences and meanings attributed by participants to the phenomena experienced (Smith, 2006 in Rahman, 2017; Lofland & Lofland, 1984 in Moleong, 2017). At the LMDH Wana Mitra Sejahtera location, the data collection techniques used include: In-depth Interviews Semi-structured interviews were conducted with farmers and members of LMDH to explore their experiences in adapting to seasonal institutions and the process of developing educational modules. These interviews allowed the researcher to obtain rich data in the form of words, stories, and deep meanings from the participants' perspectives (Creswell, 2013; Kuswarno, 2004). Participatory Observation. Researchers were directly involved in community activities and the implementation of educational modules to observe social interactions and forest management based on seasonal institutions, enriching contextual data (Moleong, 2017). Documentation such as field notes, educational modules, and reports from LMDH were collected as supporting data (Lofland & Lofland, 1984). Purposive sampling selected active

farmer informants in LMDH who understood seasonal institutions and participated in educational modules (Langdridge, 2007; Rahman, 2017).

Data analysis used Interpretative Phenomenological Analysis (IPA) with steps including reading the data, making initial notes, and developing emergent themes that reflect the meanings of the participants' experiences (Smith, 2006; Biggerstaff & Thompson, 2008). Emergent themes are grouped into superordinate themes to build comprehensive meaning (La Kahija, 2017). The researcher constructed a narrative that combines descriptions and interpretations of participants' experiences with the socio-cultural context of LMDH and seasonal institutions (Smith, 2006). Data validation was carried out through triangulation (interviews, observations, documentation) and discussions with informants to ensure the accuracy of interpretations (Moleong, 2017).

Primary data were obtained from in-depth interviews with active members of LMDH Wana Mitra Sejahtera who manage forests and participate in the educational programme of seasonal institutions, containing stories of experiences, attitudes, and perceptions regarding the educational module and natural resource management. Secondary data includes the official documents of LMDH, educational modules on seasonal institutions, field notes of researchers, and related literature that supports the analysis of phenomena. An interpretative phenomenological approach allows researchers to understand the experiences and meanings of adaptations of seasonal institutions within the sociocultural context of LMDH in depth. Rich data collection techniques and systematic IPA analysis result in a holistic understanding that supports the development of contextual and participatory educational modules.

RESULTS

Table 2. Result

Aspects	**Research Results.**	**Impact**
Seasonal System Transformation,	Integration of modern science and local wisdom	Innovative educational modules enhance public understanding
Understanding Ecological Cycles	Community understanding of ecological cycles in greater depth	Forest conservation awareness increases
Community Participation.	Active participation in natural resource management	Natural resource management becomes more collective and sustainable

Conceptual Formula for Season Institutional Transformation (TPM)TPM = f(K, P, M, T, S); Where: KKK = Local wisdom of the seasonal system (traditional knowledge of seasons and natural signs); PPP = Ecological and

hydrometeorological parameters (precipitation, temperature, humidity, plant phenology, animal behaviour); MMM = Education module based on seasonal systems (interactive and contextual learning media); TTT = Innovative technology (digitalisation, sensors, AI, drones for monitoring and prediction; SSS = Strategies for sustainable forest management and disaster risk mitigation based on seasonal systems.

Explanation:

Local wisdom (K) serves as the knowledge base linking communities with seasonal cycles and natural signs, which is essential for ecological adaptation (Sutopo, 2014). Ecological parameters (P) are quantitative and qualitative data that validate the seasonal system against real environmental conditions (Setiawan et al., 2020). Education modules (M) function as media for knowledge transfer. Educational modules (M) serve as a medium for transferring knowledge that combines tradition and modern science (Nurhadi et al., 2021). Technology (T) enhances the accuracy and effectiveness of monitoring and mitigation (Prasetyo & Wijaya, 2019). Strategy (S) is the application of the transformed institutional results in forest management and disaster mitigation (Wahyudi et al., 2018).

DISCUSSION

The Pranata Mangsa is a traditional calendar system of the Javanese people that divides the year into seasonal cycles with specific climatic characteristics and agricultural activities. This system has long been a local wisdom that plays an important role in the management of natural resources and sustainable agriculture (Berkes, 2012; Dora et al., 2025). However, the development of modern science and technology demands the transformation of Pranata Mangsa to remain relevant and effective in the context of climate change and current socio-economic dynamics. This research examines how Pranata Mangsa has undergone significant transformation through the integration of modern science and local wisdom in educational modules, and its impact on the community's understanding of ecological cycles and active participation in natural resource management. The findings of this research are important to support the development of adaptive, participatory, and sustainable natural resource management models.

Transformation of Seasonal Institutions: Integration of Modern Science and Local Wisdom; 1.1 Seasonal Institutions as Local Wisdom Seasonal institutions are traditional calendar systems that divide the year into 12 seasons, each lasting about 30 days, reflecting typical climate patterns and agricultural activities (Berkes, 2012). This system has been inherited by the Javanese people as a guideline for determining planting times, harvesting, and environmental management. This local wisdom not only serves as practical knowledge but also contains cultural and spiritual values that reinforce community identity and harmonious relationships between humans and nature (Dora et al., 2025); 1.2 The Need for Transformation of Seasonal Institutions Global climate change, which causes uncertainty in weather patterns and seasons, demands the adaptation of seasonal institutions to remain relevant (Ahmad et al., 2012).

Additionally, advances in science and technology provide new data and methods that can enhance the accuracy of predictions and the effectiveness of resource management. The transformation of seasonal institutions through the integration of modern science, such as meteorological data and digital technology, with local wisdom is an important strategy for maintaining the sustainability of agriculture and environmental conservation (Prasetyo & Lestari, 2023). Educational Modules as a Medium for Transformation The developed educational modules combine traditional seasonal institutions with modern climate data and information technology. These modules are designed participatively, involving the community, academics, and government, to ensure they are relevant to the local context and easily understood (Wibowo & Hartono, 2023). This module contains information on the cycles of seasonal institu2. Increased Understanding of the Community about Ecological Cycles.

Understanding Ecological Cycles Through Educational Modules Research results show that educational modules successfully increased the community's understanding of ecological cycles, especially the relationship between seasonal changes, climate conditions, and agricultural activities (Dora et al., 2025). The community became more aware of the importance of following natural cycles to maintain soil fertility and prevent environmental degradation. The Role of Education in Conservation Awareness This increased understanding contributes to forest and environmental conservation awareness. The community has begun to adopt more environmentally friendly agricultural practices, such as the use of organic fertilisers, water conservation, and integrated pest management (Prasetyo & Lestari, 2023). This awareness also encourages the community to preserve ritual practices as part of their cultural heritage as well as a tool for adapting to climate change (Berkes, 2012). Positive Impacts on Ecological and Social Resilience A better understanding of ecological cycles strengthens ecological resilience by maintaining the balance of forest ecosystems and agricultural land. Socially, this understanding reinforces social relations and community solidarity in managing shared natural resources (Dora et al., 2025). Active Community Participation in Natural Resource Management. Strengthening Participation Through Educational Modules Educational modules not only enhance knowledge but also encourage active community participation in natural resource management. Communities are involved in the planning, implementation, and evaluation of conservation and sustainable agricultural activities (Wibowo & Hartono, 2023).

Forms of Participation in Natural Resource Management Community participation includes activities such as mutual cooperation, forest monitoring, preservation of seasonal institutions, and the development of environmentally friendly agricultural enterprises. This involvement increases the sense of ownership and collective responsibility towards sustainability (Prasetyo & Lestari, 2023). The Impact of Participation on Sustainability Active participation strengthens local institutions such as LMDH (Village Forest Community Institution), which play a key role in natural resource management. The sustainability of conservation programs and community empowerment is more

assured due to the support and direct involvement of the community (Dora et al., 2025).

The Synergy of Science, Culture and Tradition. Synergy of Science and Local Wisdom The transformation of seasonal institutions through educational modules is an example of synergy between modern science and effective local wisdom. This approach not only preserves cultural values but also enhances the effectiveness of natural resource management in facing contemporary challenges (Berkes, 2012). The Role of Education in Community Empowerment. Interactive modular-based education plays a key role in community empowerment. With better knowledge, communities can make informed decisions and actively contribute to environmental preservation and improved welfare (Prasetyo & Lestari, 2023). The results of this study indicate the need for policy support that encourages the development of educational modules based on local wisdom and modern technology, as well as strengthening community institutions in the management of natural resources (Dora et al., 2025).

This research proves that seasonal institutions have undergone significant transformation through the integration of modern scientific knowledge and local wisdom in educational modules. This module has successfully increased community understanding of ecological cycles and the importance of forest conservation, while also strengthening active participation in natural resource management. This approach serves as an effective model for adaptive, participatory, and sustainable natural resource management. Due to the need for case studies, various mobile applications have been developed and tested in Indonesia, ranging from farmer data management, activity monitoring with GIS, to an interactive seasonal calendar prototype. The case studies show that applications with simple features and offline access are more easily adopted by farmers. Technical Analysis indicates that the technologies used include the Android platform, Google Map API, Agile Development, and cloud systems. Key features include data management, GIS visualisation, interactive calendars, and farming activity reminders. The key to success is a user-friendly interface and offline access capabilities. Application development should ideally integrate interactive seasonal education modules, weather notification features, and planting calendar integration, as well as data integration from BMKG and weather sensors. Community involvement in data validation and user training is highly recommended to enhance adoption. Optimising Mobile Technology for Indonesian Farmers: The Key to Successful Easily Adopted Agricultural Applications In the current digital era, mobile technology has become an important tool in various sectors, including agriculture. In Indonesia, with its diverse geography and uneven infrastructure conditions, the development of mobile applications to support agricultural activities presents both significant challenges and great opportunities. Various case studies have been conducted to test the effectiveness of mobile applications specifically designed for farmers, ranging from farmer data management, activity monitoring with Geographic Information Systems (GIS), to prototypes of interactive seasonal calendars. The results show that applications with simple features and offline access capabilities are far easier for farmers to accept and use.

Challenges in Agricultural Application Development in Indonesia. Indonesia is an archipelagic country with over 17,000 islands and diverse climatic conditions and infrastructure. In many agricultural areas, internet access is still limited and unstable. Additionally, the level of digital literacy among farmers varies, with most farmers still using simple mobile devices and not accustomed to complex applications. Therefore, agricultural applications that are developed must take these conditions into account in order to be widely adopted. Advantages of Applications with Simple Features and Offline Access. From various case studies conducted in the field, applications that offer simple features and can be accessed offline have proven to be more easily accepted by farmers. Here are the reasons: Ease of Use: Farmers feel more comfortable using applications that do not require many complicated steps. Features that are clear, intuitive, and go straight to their core needs.

The reasons are as follows: Ease of Use: Farmers find it more comfortable to use applications that do not require many complicated steps. Features that are clear, intuitive, and get straight to the core of their needs, such as data logging, activity reminders, and seasonal calendars, make the application more engaging and easier to understand. Offline Access: As many agricultural areas in Indonesia still face internet network limitations, the application's ability to function without an internet connection becomes very important. With offline access, farmers can continue to use the application anytime and anywhere without worrying about losing data or functionality. Time Efficiency: Simple features allow farmers to save time in entering data or accessing important information, enabling them to focus more on agricultural activities themselves.

Supporting Technologies Used Development of effective agricultural applications utilises various modern technologies suited to local needs. Some key technologies employed include: Android Platform: As the majority of mobile users in Indonesia utilise the Android operating system, developing Android-based applications is the most suitable choice to reach farmers broadly. Google Map API: Integration of digital maps allows for visualisation of agricultural land locations, monitoring of activities, and accurate spatial data management. This is very helpful in location-based planning and decision-making. Agile Development: This flexible and iterative software development method enables development teams to continually adapt applications based on user feedback in the field, making the applications increasingly relevant and user-friendly. Cloud Systems: Storing data in the cloud allows for automatic data synchronisation.

Key Features that Make Applications Successful. The success of agricultural applications is determined not only by the technology used but also by the features that are genuinely needed by farmers. Here are the key features: Farmer Data Management: Facilitates the recording of important information such as crop types, land area, fertiliser usage, and harvest yields. This data assists farmers and extension workers in evaluation and planning. GIS Visualization: Displays interactive maps that help monitor land conditions and agricultural activities in real-time. Interactive Seasonal Calendar: This feature is crucial as it aids farmers in following the seasonal cycles that significantly impact crop success. This calendar can be customised to local conditions and provides

recommendations for planting and harvesting times. Agricultural Activity Reminders: Notifications that remind farmers about their watering, fertilising, or pest control schedules so that agricultural activities can be carried out in a timely manner.

Integration of Educational Modules and Weather Data To enhance the added value of the application, further development must integrate interactive educational modules on seasonal cycles and sustainable agricultural practices. In addition, weather notification features connected to data from the BMKG (Meteorology, Climatology, and Geophysics Agency) and local weather sensors can provide up-to-date information that is very useful in decision-making. Importance of Community Involvement One of the key factors for successfully adopting the application is the involvement of the farming community in the development and implementation process. Involving farmers in data validation and training on how to use the application helps: Build Trust: Farmers feel that the application was designed for them and meets their real needs in the field. Accelerate Adaptation: With direct training, farmers understand the benefits and how to use the application more quickly.

Obtain Feedback: The community can provide input regularly. Positive Impacts on Agricultural and Environmental Resilience. With user-friendly applications supported by comprehensive features, farmers can manage their land and agricultural activities more efficiently and sustainably. This contributes to: Increased Productivity: Farmers can plan planting and harvesting more accurately, reducing the risk of crop failure due to weather or timing errors. Environmental Preservation: Eco-friendly agricultural practices such as the use of organic fertilizers and water conservation are easier to adopt with application guidance. Social and Economic Resilience: Organised communities of farmers supporting each other through the application will be more resilient in facing climate change and economic challenges.

Table. 3. The Integration Table Between Case Studies, Technical Analysis, and Recommendations for Developing Mobile Applications Based on Seasonal Regulations

Case Study	**Technical Analysis Android**	**Development Recommendations**	**Library**
Various mobile applications in Indonesia: farmer data management, GIS monitoring, interactive calendar.	Technology, Google Map API, Agile Development, cloud, data management, GIS visualisation, interactive calendar	Integration of educational modules for seasonal institutions, weather notifications, planting calendars, BMKG data, weather sensors, community training.	SourcesPutri & Murti (2023); Wibowo & Hartono (2023); Sahputra et al. (2024)

CONCLUSIONS AND RECOMMENDATIONS

The transformation of Pranata Mangsa through the integration of modern scientific knowledge and local wisdom in educational modules has proven effective in enhancing community understanding of ecological cycles and encouraging active participation in the sustainable management of natural resources. Interactive modules that combine traditional seasonal calendars, GIS, and agricultural notifications help farmers adapt to changing seasons and environmental conservation. Digital applications with simple features and offline access facilitate farmers in managing data and agricultural activities, thereby improving productivity and socio-economic resilience. This approach maintains the relevance of Pranata Mangsa in the era of climate change as a participatory and innovative adaptation model.

Recommendations

1. Development of easily accessible and contextual integrated educational modules, supported by government policies and resources.
2. Training and community engagement in the use of applications and data verification to strengthen adoption and ownership.
3. Integration of BMKG weather data and early warning systems into the application for timely decision-making.
4. Prioritise applications with a simple interface, essential features, and offline access according to the needs of farmers in remote areas.
5. Strengthen local institutions and multisectoral synergy to ensure that innovation and sustainable natural resource management are maintained. With cross-sector collaboration, this model can be developed more widely and serve as an example for other regions in facing the challenges of climate change and promoting food and socio-economic resilience in rural communities.

FURTHER STUDY

Further studies can focus on evaluating the effectiveness of the digital Pranata Mangsa module in various agroecological regions of Indonesia, in order to understand local adaptations and implementation challenges at the ground level. More in-depth research on the role of technology, such as the integration of IoT sensors and artificial intelligence in weather prediction and farmers' responses to digital training, will enrich adaptive natural resource management models. Comparative studies between regions are also important to identify best practices and cultural constraints, including strategies to strengthen synergy among local governments, universities, and local communities to successfully implement transformations based on local wisdom and technology.

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