Smart Farming and Its Governance for Rural Agricultural Resilience in Indonesia

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Abstract. Access to clean water remains a persistent barrier to agricultural development in many rural regions of Indonesia. This study highlights the utilization of smart farming technologies, such as solar-powered irrigation, soil moisture sensors, and digital water monitoring systems to improve production efficiency, mitigate climate risks, and optimize resource management in rural agricultural areas. Using a qualitative case study approach, data were gathered through field observations, interviews, focus group discussions, and document analysis. The findings show that the effective implementation of technologies such as solar-powered irrigation and digital water monitoring is shaped by local institutional structures, cultural norms, and collective capacity. Cunca Lolos and Cunca Wulang benefit from strong social cohesion but face technical barriers that limit adoption of smart farming tools. Banyuurip, by contrast, presents a more balanced configuration of social organization and technological readiness. The study highlights that the success of agricultural innovation is not determined solely by access to technology, but also by the ability of communities to adapt, manage, and embed new tools within their existing social frameworks. Integrating technological interventions with participatory governance offers a path to improve water efficiency and build resilient farming systems, particularly in areas experiencing ecological and infrastructural constraints.

1 Introduction

Clean water is essential to human well-being and serves as a foundation for rural development. Its availability supports agriculture, public health, and economic activity, particularly in remote and agrarian communities. However, unequal access to water remains a structural issue across Indonesia, driven by topographic barriers, infrastructure limitations, institutional weaknesses, and uneven state investment. Although global commitments such as Sustainable Development Goal 6 aim to guarantee universal and sustainable access to

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water, these ambitions remain difficult to realize for rural and marginalized populations. According to the 2024 UN World Water Report, more than 2.2 billion people worldwide still lack access to safely managed drinking water, while 1.9 billion are without adequate sanitation services [1] . In rural contexts, water insecurity is intricately tied to poverty, food instability, livelihood vulnerability, and social exclusion, all of which impede efforts to achieve integrated and inclusive development targets [2]. These vulnerabilities are further amplified by the effects of climate change, including erratic rainfall, prolonged droughts, and growing pressure on freshwater availability [3].

Within Southeast Asia, accelerated urbanization and rapid economic development have created dualism in water governance. While urban regions experience increased infrastructure investment and technical innovation, rural areas continue to grapple with outdated systems, institutional fragmentation, and governance deficiencies [4]. Indonesia, as the largest archipelagic state in the region, reflects this dichotomy. Although the country possesses substantial water resources at the national level, access to clean and reliable water remains unevenly distributed. In Java, access to improved drinking water exceeds 90%, whereas parts of Eastern Indonesia, particularly East Nusa Tenggara (NTT), consistently report access rates below 50% [5]. This spatial inequality is shaped by geographic isolation, limited fiscal allocation, and the enduring marginalization of peripheral rural regions.

National development programs, such as Pamsimas (Community-Based Water Supply and Sanitation) and SDGs Desa, have made strides in addressing rural infrastructure gaps. Yet, significant challenges remain, especially in remote villages where institutional support, technical maintenance, and sustained community participation are inconsistent [6]. In areas like Manggarai Barat, NTT, dry-season water shortages and recurrent infrastructure breakdowns expose systemic vulnerabilities. Meanwhile, in semi-urban rural zones such as Banyuurip in Central Java, increasing population density and climate variability continue to place stress on existing water systems. These persistent challenges highlight the limits of infrastructure-based solutions alone and point to the importance of multi-dimensional strategies that integrate technological innovation with adaptive social governance.

In this regard, agricultural technology, particularly smart farming, emerges as a critical area of intervention. In the Indonesian context, smart farming includes IoT applications for land monitoring, sensor-based precision irrigation, and mobile farming platforms such as *SIPINDO*, which enable real-time management of agricultural inputs and outputs. Studies by Greco et al. (2025) and Grant et al. (2022) found that the adoption of digital technologies significantly improves water-use efficiency and crop yields in marginal farming areas. Innovations such as solar-powered water pumps have also shown the capacity to reduce input costs while enhancing irrigation reliability in smallholder settings [7]. The application of Internet-of-Things (IoT) tools, including precision irrigation and environmental sensors, enables dynamic monitoring of field conditions, contributing to significant improvements in both crop and livestock productivity [8]. Furthermore, optimized models such as the Solar-Powered Drip Irrigation Optimal Performance (SDrOP) system have demonstrated not only lower lifecycle costs but also technical reliability under harsh rural conditions [9]. Conservation-oriented crop–livestock systems, when integrated with digital platforms and decision-support technologies, have improved water use efficiency, stabilized farmer incomes, and reduced system vulnerabilities in dryland ecosystems. In pilot practices across East Nusa Tenggara, combining solar-powered irrigation with community-managed livestock watering schedules has also led to reduced conflict over access and stronger local ownership of water governance [10].

However, the implementation of smart farming technologies in rural Indonesia is not a purely technical matter. The success or failure of such innovations is fundamentally shaped by sociological variables, including institutional capacity, cultural attitudes toward technology, inter-household cooperation, and the role of community leadership. In many cases, access to tools and infrastructure is insufficient if not accompanied by collective ability to use, maintain, and adapt them to local conditions. Sociological theory provides a useful framework for understanding this dynamic. William F. Ogburn's concept of cultural lag illustrates how technological advances often outpace the readiness of social systems to absorb them, leading to friction, rejection, or underutilization [11].

Empirical studies from comparable settings underscore the importance of participatory and context-sensitive approaches. Apipalakul et al. (2015) demonstrated how community-based conflict resolution contributed to effective water management in Thailand [12]. Madrigal et al. (2024) revealed that grassroots mobilization in water governance could trigger broader socio-technical transitions, especially under environmental duress [13]. In the Indonesian context, Setyati et al. emphasized the contribution of networked governance in strengthening the adaptive capacity of rural farming systems in Java [14]. This study aims to address that gap by conducting a cross-village analysis in three sites, Cunca Lolos and Cunca Wulang in NTT, and Banyuurip in Central Java. These locations differ in terms of geography, infrastructure, and social capital. By examining how local institutional frameworks, community cooperation, and technical knowledge interact with the adoption of agricultural technology, this study seeks to understand how smart farming tools can be effectively embedded within participatory governance systems.

The findings show that in Cunca Lolos and Cunca Wulang, strong communal ties support the potential for collective action, but low technical capacity hinders the practical application of smart farming systems. Conversely, Banyuurip benefits from a more integrated configuration of social organization and technological awareness, creating a more conducive environment for technology uptake. Ultimately, this research argues that sustainable rural agriculture in water-scarce regions cannot be achieved through technology alone. It requires the alignment of innovation with social structures, institutional arrangements, and cultural values that enable communities to manage and sustain these tools effectively.

2 Research method

This study adopted a qualitative case study approach to examine how the integration of smart farming technologies and community-based water governance contributes to the sustainability of rural agriculture. The design follows common scientific practice in qualitative inquiry, where field procedures, instruments, and analytical frameworks are clearly defined to support transparency and repeatability. The research was conducted in three rural villages, Cunca Lolos and Cunca Wulang in Manggarai Barat, East Nusa Tenggara, and Banyuurip in Sragen, Central Java. These sites were selected purposively to reflect different ecological, infrastructural, and social dynamics relevant to agricultural water governance and technology adoption. The variation across sites allowed the research to capture context-sensitive insights into how institutional capacity and social structure interact with technology. The population of the study included village leaders, water managers, customary authorities, farmers, youth, and household members involved in agriculture and community water management. Sampling was conducted purposively, with criteria based on participants' experiential knowledge and involvement in water-related decision-making or farming activities using either conventional or smart technologies.

Data collection was carried out through direct field observation, semi-structured in-depth interviews, focus group discussions (FGDs), and document analysis. The interview and FGD protocols were adapted from standard semi-structured interview models, tailored to fit the specific social dynamics and language context of each village. Observations focused on water infrastructure, usage practices, and technological presence, while documents such as village regulations, planning reports, and technical notes were used to support contextual understanding. All data were recorded using field notes, audio devices, and photographic documentation. Triangulation across methods and sources was applied to strengthen the validity and confirmability of the findings. Data analysis was interpretative and reflective, relying on sociological frameworks to guide the identification of meaning and relationships within the data. John Rawls's theory of justice was used to assess the equity of resource distribution, while William F. Ogburn's concept of cultural lag provided insights into social readiness for technological change. No categorical variable coding or statistical models were applied. Instead, all findings were developed narratively based on observed patterns, informant perspectives, and institutional processes. All procedures and interpretations were documented in detail to ensure that the research could be repeated or verified in similar contexts, in line with established qualitative research standards.

3 Results and discussion

3.1 Technological implementation of smart farming systems

The implementation of smart farming systems in rural Indonesia requires a context-sensitive approach that acknowledges both ecological constraints and social dynamics. Rather than focusing on high-cost, precision agriculture technologies, the studied communities Cunca Lolos, Cunca Wulang, and Banyuurip have adopted or experimented with affordable, modular tools aimed at improving water management and agricultural productivity.

A highly promising intervention is the solar-powered water pump system, ideally suited to Indonesia's consistently high solar intensity year-round. Currently, local communities in Cunca Lolos and Cunca Wulang primarily depend on gravity-fed piping systems from nearby springs, while certain households use small diesel-driven pumps in the dry season (July–August). These diesel systems are expensive to operate and generally water only small areas of 0.5–1 hectare, rendering them unsustainable as a long-term option. Conversely, solar-powered pumps do not need grid electricity, function automatically in sunlight, and have relatively low upkeep expenses. A single solar pump, when combined with community reservoirs, can irrigate larger regions based on its capacity, reaching up to 10–20 hectares of farmland or several dozen homes. Demonstrations in similar arid areas have shown that these systems enhance irrigation dependability and greatly lower energy costs.

The implementation of solar-powered irrigation, soil sensors, and digital monitoring applications has been shown to improve the accuracy of water delivery in horticultural fields, reduce operational costs, and enhance farmers' responsiveness to climate variability and drought. Field trials using the *SIPINDO* application demonstrated improved accuracy in predicting fertilizer and water requirements for chili and tomato crops in Banyuurip, enabling farmer groups to make timely adjustments to their production inputs. This implementation aligns with best practices in adaptive water governance, as it promotes transparency, community accountability, and data-informed decision-making.

Additionally, soil moisture sensors have been used in various test areas to observe land conditions. These cost-effective tools enable farmers to gauge factors like soil moisture, pH level, and temperature, with information relayed to mobile devices through Bluetooth or IoT platforms. In areas with restricted internet access, certain systems continue functioning with offline data recording or SMS-based reporting, guaranteeing usability in rural locations. For example, the SIPINDO application supported by SMARTseeds offers farmers soil nutrient details and fertilizer suggestions directly on their mobile devices, allowing for location-specific guidance on crops like chili, tomato, and cucumber [11].

Mobile-based coordination tools, particularly WhatsApp groups, have become essential in supporting water distribution. In Banyuurip, these groups allow quick damage reporting and coordination during system breakdowns, such as PAMSIMAS service interruptions.

While not traditionally considered smart farming tools, such platforms effectively support decentralized governance and participatory maintenance.

Other notable low-cost technologies include drip irrigation systems, which deliver water directly to plant roots and are ideal for uneven or dry terrains. These systems can be paired with solar-powered pumps or tanks and have been demonstrated to reduce water usage while improving crop yields. In Banyuurip, innovations have also extended to the livestock subsector, where alkaline water systems are being trialed. Filtered rainwater is adjusted to a higher pH and supplied to goats and cattle, reportedly improving immunity and health outcomes.

Despite the demonstrated potential, several challenges persist. In Cunca Lolos and Cunca Wulang, a lack of technical literacy has limited the long-term use of installed devices. Many villagers are unfamiliar with operating or maintaining solar pumps or sensor-based tools. Without proper training, the equipment often falls into disrepair or is used incorrectly. Institutional weaknesses, such as the inactivity of village water committees like KPSPAM (*Kelompok Pengelola Sistem Penyediaan Air Minum)* due to regulatory and financial gaps, further undermine system sustainability.

These challenges echo the theory of cultural lag as posited by William Ogburn (1922), where technological progress outpaces the social systems required to support it [15]. For example, in Cunca Wulang, water pipes and valves were tampered with or repurposed for personal use due to an absence of usage norms and shared accountability. In contrast, Banyuurip's experience suggests that when smart farming tools are introduced gradually, accompanied by local facilitation, and supported through collective governance, community uptake and maintenance improve significantly.

As such, smart farming implementation in rural Indonesia cannot be separated from its social embeddedness. Technologies must be tailored to the local context, socially legitimized, and supported by institutions capable of maintaining them. Participatory planning, clear communication, and a focus on behavioral change are key to transforming technological interventions into sustainable, long-term solutions.

3.2 Social acceptance and cultural response to technological innovation

The success of technological innovation in rural areas is not determined solely by the availability of tools or infrastructure, but significantly by how such technologies are received and interpreted within local social systems. In this regard, William F. Ogburn's theory of *cultural lag*, which describes the gap between rapid technological advancement and slower social adaptation offers a useful framework for understanding community responses to smart farming technologies and water infrastructure in the studied villages. In Cunca Wulang, attempts to introduce an automatic valve system as part of a smart irrigation setup were met with confusion and disuse. Residents frequently left taps open all day, leading to water waste and pipe damage. More alarmingly, some pipes were intentionally dismantled or redirected to serve individual households without proper coordination. As one resident In Cunca Wulang noted during an interview,

> *"The pipe was moved from our house. Someone changed the connection at night, and no one took responsibility,"* (Interview, Cunca Wulang, March 2025).

This situation exemplifies a breakdown not in technology itself, but in the absence of shared norms and local ownership over its management. Without adequate preparation and consensus, even well-intentioned innovations can be rendered ineffective. A similar pattern appeared in Cunca Lolos. Taps installed as part of an earlier water project were abandoned or broken due to improper use. There was little guidance on how to operate or maintain them, and no institutional framework in place to monitor usage or enforce water-saving behavior. According to one villager:

> *"There was a faucet at our house before, but no one explained how to use it. It broke quickly, and now we just use buckets again,"* (Interview, Cunca Lolos, March 2025).

These cases reflect a mismatch between technological assumptions and everyday practice. Community members did not necessarily reject the idea of better water systems but lacked the support and shared rules needed to incorporate them into daily life. This reinforces Ogburn's view that innovations often fail when social institutions and cultural norms do not evolve alongside technological change [12]. In contrast, Banyuurip displayed higher levels of acceptance and engagement with smart farming tools, including digital monitoring via WhatsApp groups and flow meters for tank water regulation. These tools were not only introduced with clear explanations but were also accompanied by village meetings (musrenbang) and hands-on demonstrations. As one community facilitator stated:

> *"People understand the technology because we involve them from the start. We explain what it is, why it matters, and how to use it properly,"* (Interview, Banyuurip, April 2025).

Even so, not all residents practiced water-saving behaviors consistently. Some continued to use water excessively, despite knowing the system could track usage. This suggests that while technological literacy may be improving, behavioral change and long-term commitment remain gradual processes Multiple factors shape social acceptance in these contexts: the clarity of initial communication, the visibility of immediate benefits, and the degree of community involvement in planning and monitoring. In Nusa Tenggara Timur (NTT), where prior exposure to agricultural technologies is limited, resistance stems not from outright rejection, but from unfamiliarity, mistrust, and lack of follow-up engagement. Conversely, in Banyuurip, the presence of previous pilot projects and stronger social networks facilitated faster uptake.

Adoption in rural Indonesia relies heavily on social cohesion, particularly the extent to which innovations are introduced through community networks, explained in local terms, and supported by training and facilitation. Technologies introduced top-down, or without regard for social dynamics, often face tacit resistance or passive disengagement. In short, the introduction of smart farming tools and irrigation systems in rural Indonesia cannot be reduced to technical interventions alone. Cultural habits, informal power structures, and collective trust shape how technologies are received and sustained. The experiences of Cunca Wulang and Cunca Lolos demonstrate that technology without context can create confusion or even exacerbate local tensions. Meanwhile, Banyuurip shows that when innovation is presented as a collaborative process with space for community feedback and cultural alignment, acceptance and adaptation become more feasible.

3.3 Participation and justice in community water governance

Community participation is a central principle in ensuring fairness and sustainability in rural water governance. However, participation must be understood not merely as presence in meetings or labor contributions, but as a meaningful involvement in planning, implementation, and monitoring processes that uphold equitable distribution and accountability. This section explores how participatory mechanisms operate in the three studied villages, Cunca Lolos, Cunca Wulang, and Banyuurip, and how these affect the justice of water access and governance outcomes. In Cunca Lolos, participatory meetings are routinely held by the village government to engage residents in infrastructure development and planning. Interview data indicate that communities are invited to discussions, particularly during the early stages of water distribution planning:

> *"Each village planning meeting involves the community. Discussions always take place to make sure no one lacks water during the dry season,"* (Interview, Cunca Lolos).

Despite these effort, distributive challenges persist. The piped system in Cunca Lolos is primarily intended to serve household consumption, but in practice it is also diverted for small-scale agricultural irrigation. As a result, eight households still do not receive piped water, partly due to informal infrastructure adjustments and weak institutional oversight. Although local management units like KPSPAM were initially formed to oversee maintenance and equity, their inactivity due to financial and logistical limitations has left a vacuum in enforcement and coordination. Moreover, perceptions of injustice have emerged due to acts like unauthorized pipe redirection. As one local resident shared:

> *"There are still families using private hoses to get water because their pipes were disconnected or diverted by others,"* (Interview, Cunca Lolos).

These patterns reveal that despite formal participation, the absence of binding rules, technical capacity, and follow-up leads to unequal outcomes. Injustice arises not from deliberate exclusion but from institutional fragility and the lack of community-led enforcement mechanisms. This condition aligns with recent findings that highlight the risk of "participatory superficiality" where inclusion exists on paper but not in practice.

In Cunca Wulang, efforts were made to establish localized water committees in each hamlet. These teams were expected to manage water access and act as intermediaries between residents and the government. While this structure suggested a decentralized and participatory model, its execution fell short:

> *"Yes, the team was formed, but they were left to do everything without monitoring. Now they control access arbitrarily,"* (Interview, Cunca Wulang).

The lack of transparency and supervision led to perceptions of elite capture and unequal distribution, particularly in lowland areas that often receive less water. Complaints remain unresolved due to the absence of grievance systems or conflict mediation forums:

> "*Conflicts are frequent but hidden. People are angry, but no one speaks up because there's no system to solve it,"* (Interview, Cunca Wulang).

Such dynamics indicate a disjuncture between institutional design and social legitimacy when participation mechanisms lack accountability or local relevance, they risk being superficial and ineffective. In contrast, Banyuurip demonstrates a more embedded participatory governance model. Here, forums like *musrenbang* and community water councils allow residents to co-determine infrastructure priorities, such as tank locations or new pipeline routes. Community members are also involved in construction and oversight, often through *swadaya* (self-supporting) initiatives.

> *"It was the community that suggested the rainwater system. We even helped build it. That's why people respect and maintain it,"* (Interview, Banyuurip).

Additionally, village authorities actively respond to concerns and incorporate them into budget planning. This two-way interaction not only builds trust but encourages equitable resource allocation. Banyuurip's case aligns with the concept of institutional bricolage, where formal governance structures are combined with local socio-cultural practices to enhance implementation and relevance. For instance, roles are clearly distributed between government and civil society actors, and systems are in place to track water use and prevent abuse through collective agreements.

Although no system is perfect, Banyuurip's relatively balanced governance contrasts sharply with the more fragmented approaches in Cunca Lolos and Cunca Wulang. The evidence suggests that justice in rural water governance depends on more than technical delivery. It requires active citizen agency, functional institutions, and a commitment to procedural and distributive equity.

3.4 Governance capacity and institutional sustainability

The sustainability of water infrastructure and smart farming technologies in rural Indonesia is intricately linked to the governance capacity of local institutions and their embeddedness within community norms. While formal programs like PAMSIMAS have introduced infrastructure and management frameworks, the long-term success of such efforts varies widely across the studied villages. In Cunca Lolos, local actors including village officials and past KPSPAM units have made attempts to involve communities in water governance. Planning meetings (*musyawarah*) were reportedly held at the village level, and aspirations were communicated from residents to the government. As one respondent noted,

> *"The village government has built the infrastructure well. The question now is how it will be managed moving forward so that it remains sustainable."*

However, while the infrastructure exists, institutional arrangements remain weak. The KPSPAM unit became inactive due to a lack of legal mandate and financial sustainability. Additionally, community oversight was limited and enforcement mechanisms for equitable access were essentially absent. Cases of pipe tampering and selective water rerouting reflect a breakdown in both monitoring and shared norms.

In Cunca Wulang, a more fragmented governance structure is evident. While the village administration once established a water management team, this body lacked accountability and did not effectively coordinate access or respond to disputes. One resident observed,

> *"The village only formed a team and then let it go unchecked. They managed everything on their own, and in the end, water access was limited to only certain people".*

The absence of routine monitoring and grievance redressal mechanisms led to persistent feelings of injustice and distrust. Moreover, damage to pipes, unauthorized alterations, and lack of maintenance reflect institutional fatigue and technical neglect. By contrast, Banyuurip exhibits stronger institutional readiness and coordination. Village leaders work alongside community facilitators and technical teams to ensure routine oversight, participatory planning through forums like *musrenbang*, and the integration of smart monitoring tools such as WhatsApp-based alerts and flow meters. A community facilitator explained: *"If the water supply is disrupted, residents immediately report it through the hamlet's WhatsApp group, so the technicians can respond quickly".* Banyuurip also benefits from previous experience with NGO-led pilot projects and CSR funding, which strengthened their administrative and technical foundations.

Comparative insights highlight that governance capacity is not only about formal structures, but also about institutional sustainability, which is determined by role clarity, consistent support, and mutual trust between authorities and citizens. Rural water governance systems with a model of shared authority across actors and levels tend to be more adaptive and resilient, particularly in responding to shocks and managing collective resources. Furthermore, when informal norms such as mutual cooperation (gotong royong) are recognized and aligned with institutional rules, compliance increases, and infrastructure is more likely to be maintained.

Yet, as seen in Cunca Lolos and Wulang, formal roles without community engagement, technical training, or financial viability often collapse into symbolic governance. Respondents expressed a desire for regulation, routine education, and institutional revitalization through village-level ordinances and broader involvement of BUMDes as potential service managers. The demand is not merely for infrastructure, but for predictable, fair, and participatory systems that reflect local realities and offer accessible redress.

4 Conclusion and recommendation

This study highlights that the implementation of smart farming systems in rural Indonesia is most effective when aligned with local water governance structures, institutional capacity, and embedded cultural practices. The application of smart farming technologies, from soil moisture sensors to digital monitoring applications has made a tangible contribution to improving production efficiency, water management, and crop yields in rural agriculture. Policy recommendations include prioritizing digital technology training and facilitation for farmer groups, as well as strengthening community-based information systems to support sustainable and adaptive farming practices. However, the success of these tools does not rely solely on their technical function, but critically on the presence of capable institutions, active community engagement, and shared norms that enable sustainable operation, maintenance, and equitable access.

Findings from the three study sites illustrate this contrast. In Cunca Lolos and Cunca Wulang, limited institutional oversight, insufficient training, and weak enforcement have undermined the intended benefits of smart technologies. In contrast, Banyuurip demonstrates that where governance is participatory, culturally rooted, and technically supported, the integration of digital systems becomes both practical and accepted. These results affirm that innovation must be socially embedded to be impactful.

Looking forward, future interventions should focus on scaling low-cost, modular smart farming technologies tailored to local ecological and institutional conditions. These efforts must be supported by long-term capacity-building programs, including peer-led training, routine community facilitation, and regulatory support at the village level. Policymakers and development partners are advised to develop multi-actor governance frameworks that link technical design with participatory mechanisms, ensuring that digital innovation fosters inclusion rather than deepens inequality. While the study offers meaningful insights, generalizations should be made with caution, as sociocultural and institutional dynamics vary significantly between regions. Nevertheless, the integration of smart farming and community-based water governance offers a promising pathway toward more equitable and sustainable rural agricultural development in Indonesia.

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contribute to advancing Rural Sociology and Agriculture and support more inclusive and sustainable rural development policies.

References

1. UNESCO, The United Nations World Water Development Report 2024: Water for Prosperity and Peace
2. Grey, D., Sadoff, C.W., Sink or Swim? Water Security for Growth and Development. Water Policy. **9**, 6 (2007). https://doi.org/10.2166/wp.2007.021
3. IPCC, Climate Change 2022: Impacts, Adaptation and Vulnerability
4. Şen, Z., Reservoirs for Water Supply Under Climate Change Impact—A Review. Water Resources Management. **35**, 11 (2021). https://doi.org/10.1007/s11269-021-02925-0
5. BPS, Persentase Rumah Tangga yang Memiliki Akses terhadap Sumber Air Minum Layak Menurut Provinsi (Persen), 2024
6. DGAT Governance, Management Response to the Independent Evaluation of the Community-based Rural Water Supply and Sanitation (PAMSIMAS) Program (July – December 2022)
7. Hajer Guesmi, Hichem Ben Salem, Nizar Moujahed, (14) (PDF) Integration crop-livestock under conservation agriculture system / Intégration culture-élevage sous agriculture de conservation. **65**, 1 (2019)
8. Greco, C., Gaglio, R., Settanni, L., et al, Smart Farming Technologies for Sustainable Agriculture: A Case Study of a Mediterranean Aromatic Farm. Agriculture (Switzerland). **15**, 8 (2025). https://doi.org/10.3390/agriculture15080810
9. Grant, F., Sheline, C., Sokol, J., et al, Creating a Solar-Powered Drip Irrigation Optimal Performance model (SDrOP) to Lower The Cost of Drip Irrigation Systems for Smallholder Farmers. Applied Energy. **323**, (2022). https://doi.org/10.1016/j.apenergy.2022.119563
10. Harianto, E., Avianto, T., Mas'ud, R., et al, Innovating Pv Water Pump Business for Renewable Energy Industry in Indonesia Using Blue Ocean Strategy. Business and Accounting Research (IJEBAR) Peer Reviewed-International Journal. **6**, 3 (2022)
11. Leigh, R.D., Review Reviewed Work (s): Social Change. With Respect to Culture and Original Nature by William Fielding Ogburn Stable. **20**, 19 (1923)
12. Apipalakul, C., Wirojangud, W., Ngang, T.K., Development of Community Participation on Water Resource Conflict Management. Procedia - Social and Behavioral Sciences. **186**, (2015). https://doi.org/10.1016/j.sbspro.2015.04.048
13. Godinez Madrigal, J., Van Cauwenbergh, N., Ochoa-Garcia, H., van der Zaag, P., Can grassroots Movements in Water Conflicts Drive Socio-Technical Transitions in Water Management Systems? Environmental Innovation and Societal Transitions. **51**, March (2024). https://doi.org/10.1016/j.eist.2024.100837
14. Setyati, D., Su, M., Wulandari, D.R., et al, Effect of Colchicine and Bio-catharantin on the DNA Relative Content and Stomatal Structure of Black Rice (Oryza sativa L . var . Jeliteng). **39**, 2 (2024)