

A Multi-Criteria Policy: Community Based Irrigation Governance for Dryland Agricultural in Semi-Arid Areas

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ABSTRACT

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Agricultural water management in semi-arid regions increasingly depends on institutional capacity rather than hardware-based interventions. This study evaluates and prioritizes irrigation policy action using a Multi-Criteria Policy (MULTIPOL) framework to identify the most contextually appropriate strategies for smallholder agriculture in Kupang Regency East Nusa Tenggara, Indonesia. Five strategic scenarios were assessed using eight evaluation criteria representing technical, ecological, economic, social, and institutional dimensions. The results showed that Rotation Irrigation (RotIrr) achieved the highest stakeholder consensus with a mean score of 18.5 (SD=0), followed by Adaptive Rainfall (AdaptRF) with 17.4 (SD=0.3), while Subsurface Irrigation (SubIrr) ranked lowest with 16.8 (SD=0.3). At the policy level, Irrigation Subsidy and Renewable Energy (SubIrrER) obtained the highest total marginal, yet meaningful advantage of subsidy-based support when coupled with institutional facilitation. These findings reinforce global evidence that governance-based measures outperform infrastructure heavy interventions in semi-arid systems by reducing institutional risk and improving social acceptance. The study concludes that community led governance instruments coupled with low-cost adaptive training deliver the greatest policy resilience and suitability, providing a viable pathway for strengthening agricultural water governance in the dryland landscape of Kupang Regency.

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1. Introduction

Water scarcity and climate variability have intensified the need for governance reform in community-based irrigation systems across semi-arid regions. Recent scholarship shows that irrigation performance is determined less by physical infrastructure and more by the legitimacy of locally embedded institutions and the fairness with which allocation rules are enforced [1]. Institutional credibility and user trust therefore represent core conditions for long term governance stability and equitable water distribution. However, many smallholders' irrigation system in the Global South continue to operate under policy regimes that limit user participation, weaken local autonomy, and reduce governance effectiveness [2].

When formal policy frameworks fail to secure acceptance at the community level, locally grounded governance arrangements have been shown to achieve higher rule compliance and distributive equity

in water scarce settings [3]. Semi-arid irrigation system faces heightened governance fragility because ecological stress intersects with socioeconomic vulnerability. Resilience in such system depends not only on physical supply interventions but also on communities' ability to negotiate water rights, resolve conflicts, and adapt operational rules to changing conditions [4]. To account for the multidimensional nature of governance performance, recent policy evaluations studies increasingly employ multi-criteria policy (MULTIPOL) frameworks to assess institutional effectiveness alongside hydrological and socio-economic factors. However, empirical applications in Southeast Asia particularly in semi-arid Indonesia remain limited, resulting in a notable evidence gap regarding governance performance in highly climate stressed smallholder system [5]. This study addresses that gap by evaluating community-based irrigation governance in Kupang Regency East Nusa Tenggara, using a multicriteria assessment tailored to semi-arid agricultural context.

2. Method

This study aims to identify and prioritize agricultural water management strategies that are both effective and contextually appropriate through the application of a Multi-Criteria Policy (Multipol) framework. Primary data collected from stakeholder assessment were analyzed using the MULTIPOL (Multi-Criteria Policy Analysis) software developed by LIPSOR (Laboratoire d'Investigation en Prospective, Strategie et Organisation). This method was applied to evaluate the degree of consensus (robustness) and strategic closeness (proximity) among the assessed policy action based on multi-criteria evaluations provide stakeholders. The Weighted Sum Model (WSM) was adopted as the main analytical technique because of its ability to address complex strategic planning problems that require simultaneous evaluation of multiple and interdependent criteria. This approach has been widely applied in water resource management and agricultural policy planning [6], [7]. The total score (S_i) for each scenario is calculated using the standard WSM formulation as proposed by [7], [8] :

$$S_i = \sum_{j=1}^m W_j \cdot V_{ij}$$

where S_i represents the total suitability score of scenarios i W_j denotes the weight assigned to criterion j , V_{ij} is the normalized performance value of scenario i against criterion j , m is the total number of evaluation criteria ($m = 8$). The analytical process began with identification of alternatives strategies and the establishment of evaluation criteria. Five strategic scenarios were defined as alternatives, namely *Sce_ModSub*, *Sce_InfCom*, *Sce_AdoptD*, *Sce_CWMDem*, and *Sce_RotReg*. This scenario was evaluated against eight criteria, *water efficiency*, *productivity*, *cost*, *social impact*, *sustainability*, *water availability*, *policy support*, and *conflict reduction*. Collectively, these criteria represent five main strategic dimensions – technical, social, economic, environmental, and institutional. Each criterion was assigned a relative weight on a scale of 1 to 5, based on its perceived importance in agricultural water management. The weights were validated through consultation with local policymakers and agricultural authorities in Kupang Regency. Performance assessment for each alternative (X_{ij}) was conducted using a descriptive scoring approach based on a likert scale (1-5), where 1 indicates a very low and 5 indicates a very high. Since the criteria included both benefit type and cost type attributes, normalization was applied to standardize the values and allow meaningful comparison. For benefit type criteria, normalization followed the equation:

$$V_{ij} = \frac{X_{ij}}{\max(X_{ij})}$$

and for cost type:

$$V_{ij} = \frac{\min(X_{ij})}{X_{ij}}$$

After normalization, the total suitability score for each scenario was obtained by aggregating the weighted normalized values. The scenario with the highest total score was considered the most

suitable and prioritized for implementation within the study context. To ensure robustness, a sensitivity analysis was conducted by systematically varying the assigned weights to assess the stability of the ranking results. The sensitivity test indicated that the ranking of alternatives remained consistent under different weighting assumptions, confirming the reliability and methodological soundness of the analysis.

3. Results and Discussion

1. Evaluation criteria and weighting

Based on the analysis of strategic criteria in **Table 1** shows that water availability and socioeconomic impact emerged as the most critical factors in the formulation of agricultural irrigation policies, each receiving the highest importance score of 5.0. This reflects a primary focus on ensuring sustainable water access alongside the broader social and economic benefits for farming communities. Other criteria, such as water use efficiency, support for food security, policy support, infrastructure capacity, farmer’s readiness, environmental sustainability, and crop productivity, received slightly lower scores of 4.0, indicating their important supporting roles in the effective and sustainable implementation of irrigation policies. Interestingly, cost of technology was rated lowest (3.0), suggesting that financial aspects are considered less critical compared to the long term strategic benefits of improved irrigation systems.

Table 1 Evaluation criteria and weighting

Short label	Long label	Weight	Description
WaterEff.	Water use efficiency for agriculture	4	Efficiency allows the crops to get water throughout the growing period.
Product	Productivity of corn and sorghum crops	4	Because it will impact the farmers' income
Cost	Technology implementation cost	3	Because it relates to harvest productivity
Social	Socio-economic impact on farmers	5	The importance of social acceptance and farmer readiness is rated, because many farmers do not yet understand the technology and its usage.
Sustain	Environmental sustainability and water resource conservation	4	Very important so that natural conditions are not disturbed due to implementing this strategy.
WaterAv	Year-round water availability	5	Crucial for efficient, continuous farming activities.
Policy	Policy support and incentives from local government	4	Can guarantee and convince farmers in the evolution of farming.
Conflict	Potential to Reduce Water Conflict	4	Social importance in water management.

These findings are consistent with previous studies that emphasize the interdependence between sustainable water governance and socio-economic resilience in agriculture policy design. [9] demonstrated that the expansion of irrigation systems without sufficient attention to surface water availability may exacerbate water scarcity in Brazil, underscoring the importance of balancing water demand and adaptive management strategies. Similarly, [10] found that both climatic and socio-economic variables, reinforcing the prioritization of water availability and socio-economic impacts identified in the present study. Moreover, recent empirical evidence supports the view that farmer’s readiness and institutional support exert greater influence on the adoption of irrigation technologies in China. Likewise, (Belaidi, Chehat and Benmehaia (2022) revealed that governments subsidies and cost sharing mechanisms can effectively encourage adoption by mitigating the perceived financial burden of technological investment. Overall, the finding underscore that effective irrigation policy must not only safeguard water availability and promote socio economic resilience but also enhance farmer’s technical capacity and institutional preparedness. Strengthening these dimensions will be crucial for fostering the sustainable adoption of modern irrigation technologies and ensuring long term agricultural water security.

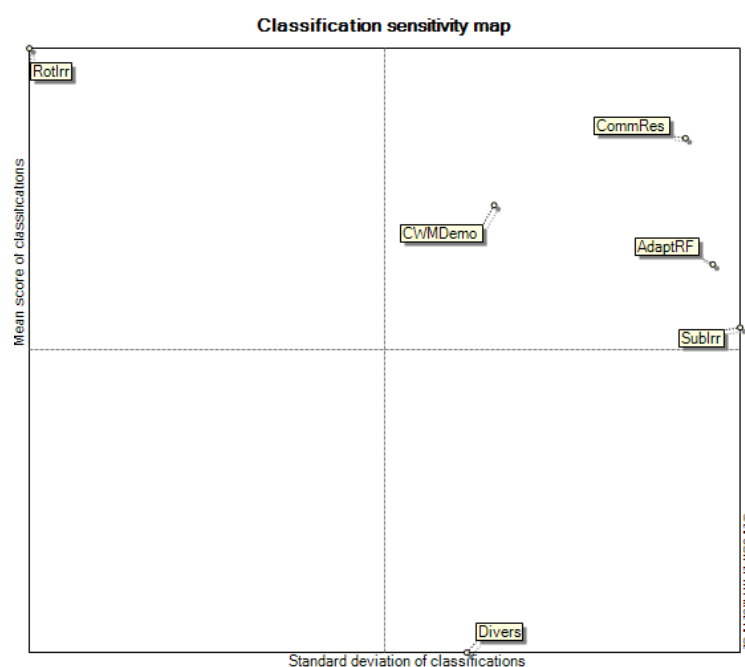
2. Study of action related policies

This analysis of the eight strategic criteria revealed significant performance variations among the evaluated action. After normalizing the scores on a 0–100 scale, the community based institutional innovation such as Rotational Irrigation (RotIrr) and Communal Reservoirs (CommRes) achieved the highest performance, primarily because they operated effectively through Village Regulatory (VillageReg) support without heavy reliance on external policy interventions.

Table 2 Evaluation of action with respect to policy

Number	Ec. Ty	Moy.	CWMTtrain	InsentiDi	VillageReg	VillageFund	SubIrrER
2	0.3	17	17.1	17.5	16.8	16.9	16.8
5	0.3	18	18.2	17.6	18.2	18	18.2
3	0.3	17.4	17.7	16.9	17.5	17.4	17.5
4	0.2	17.7	17.6	18	17.5	17.6	17.6
6	0	18.5	18.5	18.5	18.5	18.5	18.5
1	0.2	15.4	15.2	15.1	15.6	15.4	15.5

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Figure 1 Sensitivity action with policy Map

The analysis revealed that water availability and socio-economic impact emerged as the two most influential factors in shaping agricultural irrigation policies. This finding aligns with the classification sensitivity map in **Figure 1** and quantitative assessment in **Table 2**, which highlight varying degrees of importance and consensus among the evaluated adaptation actions. RotIrr occupies the most robust position with the highest mean score (18.5) and standard deviation (0), indicating a strong consensus among stakeholders. This action is perceived as the most effective and socially acceptable measure to ensure equitable water distribution and maintain productivity under

limited water conditions. In contrast, AdaftRF hold a moderate to high score (mean 17.4;SD 0.3), reflecting its recognized relevance for climate variability adaptation but also uncertainty in institutional and farmer readiness. SubIrr has the lowest rating (mean 16.8; SD 0.3), suggesting that despite its technical efficiency, it remains a lower priority due its high investment cost and limited operational familiarity among farmers. This finding aligns with the studies of B. and T (2015), Madjid (2022); Punuf (2025), which emphasize that community driven water governance strengthens both the efficiency and sustainability of irrigation systems in dryland regions. In contrast, Crop Diversification (Divers) and Subsurface Irrigation ranked lowest due to their high investment costs and limited policy support, consistent with findings from Triana et al., (2023). Therefore, it can be concluded that strengthening local institutions and promoting participatory regulatory frameworks constitute key determinants of enhancing the resilience of agricultural system in Indonesia dryland areas.

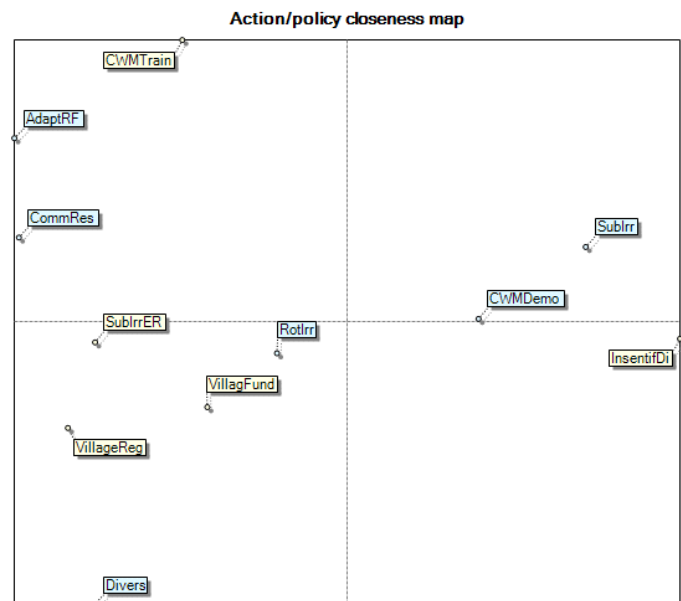


Figure 2. Closeness Map of Policy Action

The sensitivity classification map in **Figure 1** indicates that RotIrr achieved the highest level of robustness among all policy actions. This suggests that the policy option gained strong stakeholder consensus regarding its effectiveness in improving water management efficiency and enhancing farm level economic sustainability. Furthermore, the closeness map of policy action in **Figure 2** illustrates the strategic relationship within the agricultural water management policy system. The proximity between RotIrr and VillagFund reflects the interconnection between technical innovation and community based institutional support. This visualization represents depicting the spatial relationship among policy options based on their degree of similarity or strategic compatibility. When interpreted from the upper left to the lower right quadrant, the classification sensitivity map demonstrates a clear transition from action with strong consensus and proven effectiveness (RotIrr) toward those that are increasingly sensitive and contested (AdaptRF, SubIrr, and Divers). This visual gradient represents a strategic shift from conventional and well established water management solutions to more adaptive, innovative approaches that demand higher technical capacity and institutional coordination.

3. Study of policies related to scenarios

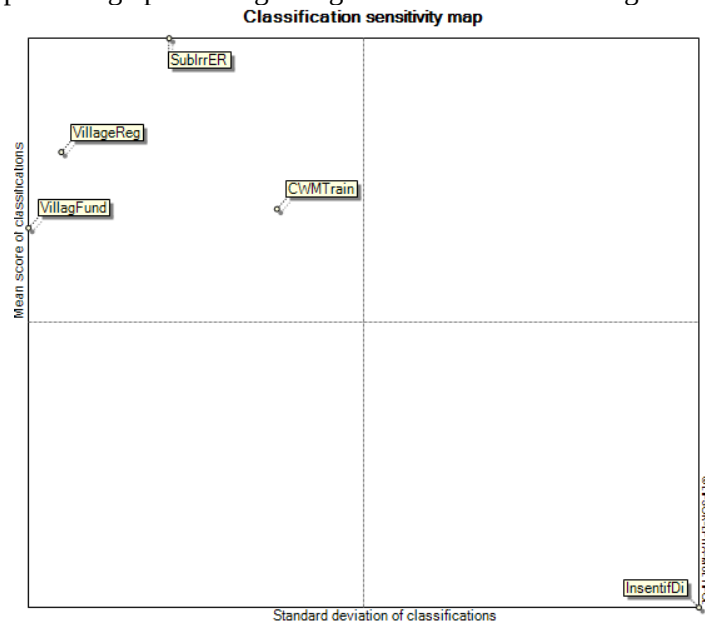
The evaluation results in **Table 3** revealed that the Irrigation Subsidy and Renewable Energy (SubIrrER) policy achieved the highest total score of 79, slightly outperforming the Village Regulation (VillageReg) policy which scored 78. Although the difference is relatively small, this indicates that SubIrrER demonstrates a stronger integration of technical efficiency and economic feasibility, particularly in enhancing water use efficiency and benefiting from grater policy support from local authorities.

Table 3 Evaluation of policy with respect to scenario

	Sce_ModSub	Sce_InfCom	Sce_AdapID	Sce_CWMDem	Sce_RotReg	Moy.	Ec. Ty	Number
SubIrrER	15	11.3	10.7	11.3	12.7	12.2	1.6	5
VillagFund	14.3	11.2	10.7	12.6	12	12.1	1.3	2
VillageReg	14.6	11.3	10.7	11.6	12.6	12.2	1.4	4
InsentifDi	16.7	9.1	9.9	12.3	11.9	11.9	2.7	1
CWMTtrain	15.4	11.1	10.2	11.6	12.3	12.1	1.8	3

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Previous studies support this finding, showing that subsurface drip irrigation can significantly improve water productivity reducing evapotranspiration by 26% and increasing irrigation water productivity by 19.6% compared to flood irrigation [16]. Similarly, deficit irrigation strategies have been shown to enhance water use efficiency without compromising yields in semi-arid environments [17]. Meanwhile, the VillageReg policy performed notably well in institutional and social dimensions, strengthening local water governance through village level regulatory frameworks. This is consistent with the findings of Luo & He (2023), who showed that community-based irrigation governance in the rice terraces of Southwest China relies on locally negotiated rules, shared responsibility, and social justice principles to ensure fair water distribution and collective maintenance of irrigation systems. Their research highlights that the sustainability of local irrigation institutions depends on the integration of customary norms and formal village regulations, which enhance legitimacy and long-term cooperation among farmers. However, limited technological readiness and infrastructure capacity in rural areas can still constrains the full effectiveness of such institutional approaches. Overall, both policies are contextually relevant, as SubIrrER appears more comprehensive and adaptive to the challenges of agricultural water management in dryland areas. This policy effectively balances technical efficiency, economic resilience, and institutional support, making it the most promising option for guiding sustainable water management policy formulation.

**Figure 3** Policies related to scenarios sensivity map

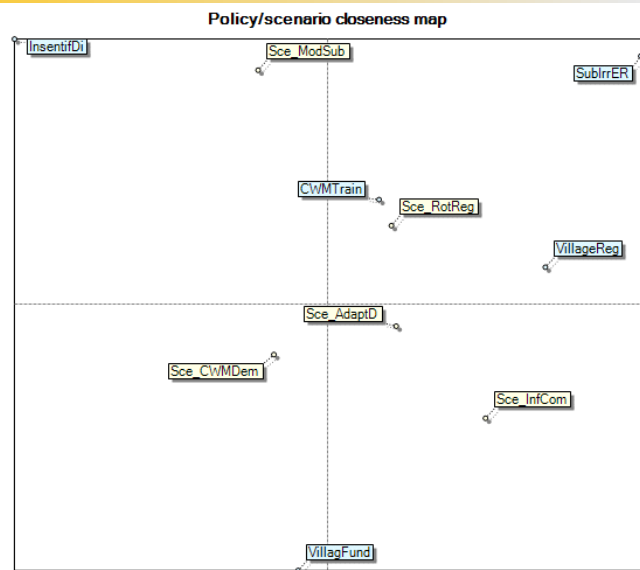


Figure 4 Policies related to scenarios closeness map

The analysis in **Figure 4** show that community and institution-based water management strategies offer significant advantages compared to approaches relying solely on financial incentives or infrastructure investments. These strategies have proven to be efficient, stable, and resilient to changing conditions, reflecting both institutional robustness and the adaptive capacity of socio ecological systems [19]. CWM training (Sce-CWMDem) achieved the highest efficiency. This success was accomplished through minimal institutional investment that nevertheless had a substantial impact on the performance of the CWMDemo intervention, consistent with the concept of governance leverage [20]. This finding emphasizes that strengthening human capacity and social behavior is more strategic than allocating large funds solely for infrastructure or financial incentives, as it can generate broader systemic impacts. Sensitivity analysis revealed that strategies based on village regulations and local funding, such as VillageReg, VillagFund, and SubbIrrER, exhibit high performance while maintaining low sensitivity. In contrast, purely financial incentives, such as Crop Diversification Incentives, showed low performance and high sensitivity, indicating considerable uncertainty under market dynamics and policy changes. Furthermore, the policy scenario closeness map indicates strong synergy between villages funding (VillagFund) and the implementation of CWM demonstration technologies (Sce-CWMDem), underscoring that the success of community-based water management innovation depends heavily on local institutional support and the integration of technical and social aspects. This aligns with the concept of *socio material bricolage*, which emphasized the importance of collaboration between technological innovation and local institutional strengthening for achieving systemic sustainability [21]. Overall, CWMDem and CommRes emerge as optimal strategies, successfully integrating technological innovations with the strengthening of local farmers' institutions. This approach not only enhances resilience providing a stronger foundation for long-term planning and policy development.

4. Conclusion

This study concludes that the policy scenario closeness map indicates strong synergy between villages funding (VillagFund) and the implementation of CWM demonstration technologies (Sce-CWMDem), underscoring that the success of community-based water management innovation depends heavily on local institutional support and the integration of technical and social aspects. Community-based training and adaptive water management strategies are the most efficient and resilient approaches for improving water governance in semi-arid regions. These models strengthen local institutions and support sustainable agriculture, providing a foundation for evidence-based policy formulation.

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