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Awareness-Driven Determinants of Methane Mitigation Practices in Rice–Livestock Farming Systems of Central India: Implications for Sub-National Climate Governance

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ABSTRACT

Background: Agricultural methane emissions represent a critical yet understudied component of India's greenhouse gas inventory, with limited empirical evidence linking farmer awareness to actual mitigation behaviors at district scales. This study examines the role of farmer awareness and attitudes as determinants of methane emission practices across rice cultivation, livestock rearing, and agricultural waste management in Narmadapuram district, Madhya Pradesh. **Methods:** A cross-sectional mixed-methods design was employed with 600 farmers across three development blocks (Pipariya, Bankhedi, Sohagpur). Validated scales (Cronbach's α: 0.76–0.83) quantified methane-related practices. Awareness and attitudes were measured using a 40-item Likert instrument. One-way ANOVA and multiple linear regression analyzed relationships between awareness levels and practice scores. Institutional perspectives were gathered from 43 officials and analyzed thematically.

Results: Overall, 51%, 56%, and 62% of farmers adopted high methane-emitting practices in rice cultivation, livestock rearing, and waste management, respectively. Farmer awareness was low in 63% of respondents, with only 8% demonstrating high awareness. ANOVA revealed significant differences in practice scores across awareness categories for all three domains ($p<0.001$). Regression analysis demonstrated that livestock practices were the strongest predictor of awareness ($\beta=0.574$), followed by waste management ($\beta=0.289$) and rice cultivation ($\beta=0.125$), with the model explaining 77% of variance ($R^2=0.77$). Block-wise analysis identified Bankhedi as the highest emission block and Sohagpur as the lowest. Institutional assessment revealed weak coordination (60%), low technical capacity (59%), and irregular monitoring (63%).

Conclusion: Farmer awareness is a powerful determinant of methane mitigation practice adoption, with livestock management serving as the most influential pathway for enhancing climate literacy. The strong awareness–practice linkage underscores the need for integrated capacity-building interventions. Block-specific emission patterns and institutional fragmentation

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necessitate spatially targeted, coordinated governance responses aligned with India's Nationally Determined Contributions and State Action Plan on Climate Change.

Keywords: Methane mitigation, Farmer awareness, Agricultural emissions, Climate-smart agriculture, Sub-national governance, Madhya Pradesh

1. INTRODUCTION

Methane (CH_4) is the second most significant anthropogenic greenhouse gas after carbon dioxide, contributing approximately 20% of global radiative forcing since the pre-industrial era (1). With a global warming potential 28 times that of CO_2 over a 100-year horizon and 84 times over 20 years, methane reductions offer the most rapid pathway for near-term climate mitigation (2). Agriculture constitutes the single largest anthropogenic methane source globally, responsible for an estimated 40–47% of total emissions, predominantly through enteric fermentation in ruminants, flooded rice cultivation, and manure management (3,4).

India occupies a particularly consequential position in the global methane landscape. The country maintains the world's largest cattle population and ranks second in rice production, resulting in agricultural methane contributions exceeding 65% of national CH_4 emissions (5). Despite this significance, empirical understanding of methane-emitting practices at sub-national scales remains critically underdeveloped. National inventories rely extensively on generalized IPCC Tier 1 emission factors that fail to capture local variability in cropping systems, irrigation regimes, livestock management, and farmer behavior (6,7). This knowledge gap constrains the design and implementation of targeted mitigation strategies essential for achieving India's Nationally Determined Contributions (NDCs) under the Paris Agreement.

Within India, Madhya Pradesh represents a pivotal state for agricultural methane research. As one of the country's largest agrarian economies, the state hosts extensive rice cultivation belts and substantial livestock populations (8). Narmadapuram district (formerly Hoshangabad), located in the central Narmada valley, exemplifies the confluence of high-emission agricultural practices: canal-irrigated paddy systems that maintain prolonged anaerobic soil conditions, dense bovine populations contributing enteric and manure-related methane, and widespread residue burning practices (9,10). Yet no prior study has systematically quantified methane-emitting behaviors or examined their behavioral determinants at the district or block level in this region.

Contemporary research on agricultural technology adoption increasingly recognizes that cognitive and attitudinal factors—awareness, perceptions, and beliefs—mediate the translation of technical knowledge into behavioral change (11,12). In the context of climate mitigation, farmer awareness of agriculture–climate linkages may constitute a necessary precursor to adoption of low-emission practices (13). However, empirical evidence linking awareness to actual methane-mitigating behaviors remains limited, particularly in South Asian smallholder systems characterized by resource constraints, institutional fragmentation, and deeply embedded traditional practices (14,15).

Furthermore, the governance architecture for agricultural methane mitigation operates across multiple scales—from international climate agreements to national policies, state action plans, and district-level implementation mechanisms. Effective sub-national climate action requires not only farmer-level behavioral change but also robust institutional capacity, inter-departmental coordination, and evidence-based policy alignment (16,17). Systematic assessment of these institutional dimensions remains scarce in the Indian context, creating a critical evidence–policy disconnect.

The present study addresses these interconnected gaps through a comprehensive, multi-level investigation in Narmadapuram district, Madhya Pradesh. The specific objectives were: (1) to quantify the prevalence of methane-emitting practices across rice cultivation, livestock rearing, and agricultural waste management; (2) to examine farmer awareness and attitudes regarding agriculture's climate contribution; (3) to analyze the relationship between awareness levels and methane-related practice adoption; (4) to identify predictors of farmer awareness from among agricultural practice domains; and (5) to assess institutional capacities and coordination mechanisms for methane mitigation at the district level.

2. METHODOLOGY

2.1 Study Design and Setting

An ex-post facto mixed-methods research design was employed, integrating quantitative farmer surveys, qualitative institutional assessments, and spatial emission mapping. The study was conducted in Narmadapuram district (22°45′N, 77°43′E), Madhya Pradesh, purposively selected for its high paddy cultivation intensity, extensive canal irrigation from the Tawa Dam system, and significant livestock holdings—characteristics that collectively create high methane emission potential.

2.2 Sampling Strategy

The target population comprised farmers engaged in both paddy cultivation and livestock rearing across the three development blocks with highest paddy intensity: Pipariya, Bankhedi, and Sohagpur. Purposive sampling with criterion-based focus was employed. Multi-stage stratification involved: (1) purposive block selection based on paddy area and irrigation coverage; (2) random selection of village clusters within each block; and (3) household verification using agriculture and livestock registers. A total of 600 farmers (200 per block) were selected. Additionally, 43 officials from agriculture, animal husbandry, rural development, and Panchayati Raj departments were purposively selected for institutional insights.

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Table 2.1: Sample Distribution and Key Characteristics

Block	Farmers (n)	Officials (n)	Dominant Crops	Irrigation Source	Livestock Density*
Pipariya	200	12	Paddy–Wheat–Soybean	Canal (Tawa)	High
Bankhedi	200	17	Paddy–Wheat	Canal (Tawa)	Moderate–High
Sohagpur	200	14	Paddy–Wheat–Pulses	Canal (Tawa)	High
Total	**600**	**43**	—	—	—

*Based on district livestock census data

2.3 Research Instruments

- **Rice Cultivation Methane Emission Practices Scale (RCMEPS):** This 5-section instrument assessed water management (40% weight), organic inputs (25%), establishment method (20%), and chemical inputs/pest practices (15%). Higher scores indicated lower methane-emitting practices. Reliability: Cronbach's α = 0.78.
- **Livestock Methane Emission Mitigation Practices Scale (LMEMPS):** This 7-section tool evaluated rearing system (20%), diet management (30%), manure management (25%), housing (15%), herd health (7%), and climate awareness (3%). Higher scores reflected greater adoption of mitigation practices. Reliability: Cronbach's α = 0.76.
- **Agricultural Waste Management Practices Scale (AWMPS):** This 5-section instrument assessed residue handling (40%), composting (30%), manure storage (20%), and waste reuse (10%). Higher scores indicated climate-smart waste management. Reliability: Cronbach's α = 0.83.
- **Farmers' Awareness and Attitude Measurement Scale:** A 40-item Likert-type instrument covering 10 domains (5 awareness, 5 attitude) measured farmers' knowledge and perceptions regarding agricultural methane emissions and climate change. Reliability coefficient (Spearman-Brown) = 0.81. Scores were categorized using stanine norms: Low (≤77), Average (78–163), High (≥164).
- **Semi-Structured Questionnaire for Officials:** A 12-item instrument explored institutional mandates, climate integration, scheme effectiveness, coordination, technical capacity, monitoring, funding, training, challenges, gaps, and recommendations.
- **Focus Group Discussion (FGD) Guide:** A 10-question guide across seven themes facilitated qualitative exploration of farmer perspectives.

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2.4 Data Collection

Quantitative scales were administered in group mode at locally arranged venues. Items were read aloud in Hindi, and farmers recorded responses individually. FGDs were conducted separately with purposively selected farmer representatives. Institutional data were collected through scheduled interviews. All procedures were conducted following ethical guidelines with informed consent.

2.5 Data Analysis

Quantitative data were analyzed using SPSS 26. Descriptive statistics summarized practice categories and awareness levels. One-way ANOVA examined differences in practice scores across awareness groups. Multiple linear regression identified predictors of farmer awareness. Qualitative data were thematically coded. Stanine norms guided categorical classification.

3. RESULTS

3.1 Prevalence of Methane-Emitting Agricultural Practices

Table 2.1: Distribution of Farmers by Methane Emission Practice Category Across Agricultural Domains

Practice Category	Rice Cultivation n (%)	Livestock Rearing n (%)	Waste Management n (%)
High Emission	306 (51.0)	336 (56.0)	372 (62.0)
Moderate Emission	168 (28.0)	150 (25.0)	144 (24.0)
Low Emission	126 (21.0)	114 (19.0)	84 (14.0)
Total	**600 (100)**	**600 (100)**	**600 (100)**

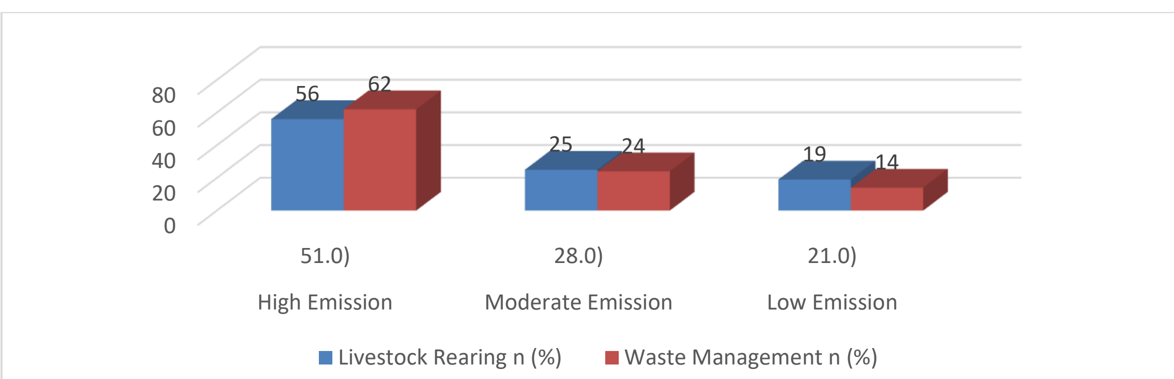

Figure 3: Comparative Bar Chart – Percentage of Farmers in High, Moderate, and Low Emission Categories Across Three Agricultural Domains

A majority of farmers adopted high methane-emitting practices across all three domains, with agricultural waste management exhibiting the highest proportion (62%). The consistency of this pattern across domains indicates systemic reliance on emission-intensive methods.

Table 2.2: Block-wise Variation in High Methane Emission Practices

Block	Rice Cultivation (% High)	Livestock Rearing (% High)	Waste Management (% High)	Overall Emission Ranking*
Bankhedi	82.0	42.0	53.0	Highest
Pipariya	31.0	62.0	69.0	Intermediate
Sohagpur	51.0	61.0	60.0	Lowest

*Based on composite emission scores; lower score indicates higher emission intensity

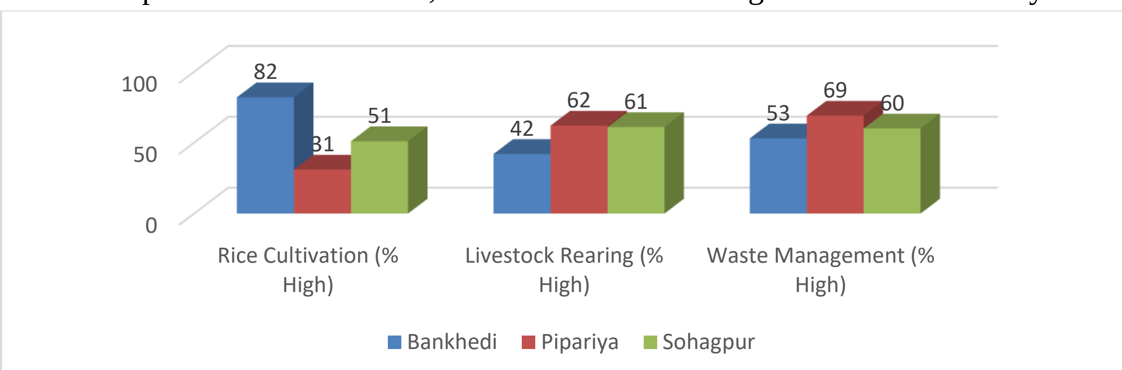

Figure 4: Heat Map – Block-wise Emission Intensity Across Three Agricultural Domains

Bankhedi demonstrated markedly elevated rice-related emissions (82% high practices), while Pipariya showed particularly concerning levels in livestock (62%) and waste management (69%). Sohagpur exhibited comparatively moderate practices across domains.

3.2 Farmer Awareness and Attitudes

Table 2.3: Distribution of Farmers by Awareness and Attitude Level (N=600)

Awareness Level	Score Range	Overall n (%)	Pipariya n (%)	Bankhedi n (%)	Sohagpur n (%)
Low	≤77	378 (63.0)	118 (59.0)	136 (68.0)	126 (63.0)
Average	78–163	174 (29.0)	70 (35.0)	44 (22.0)	52 (26.0)
High	≥164	48 (8.0)	12 (6.0)	20 (10.0)	22 (11.0)

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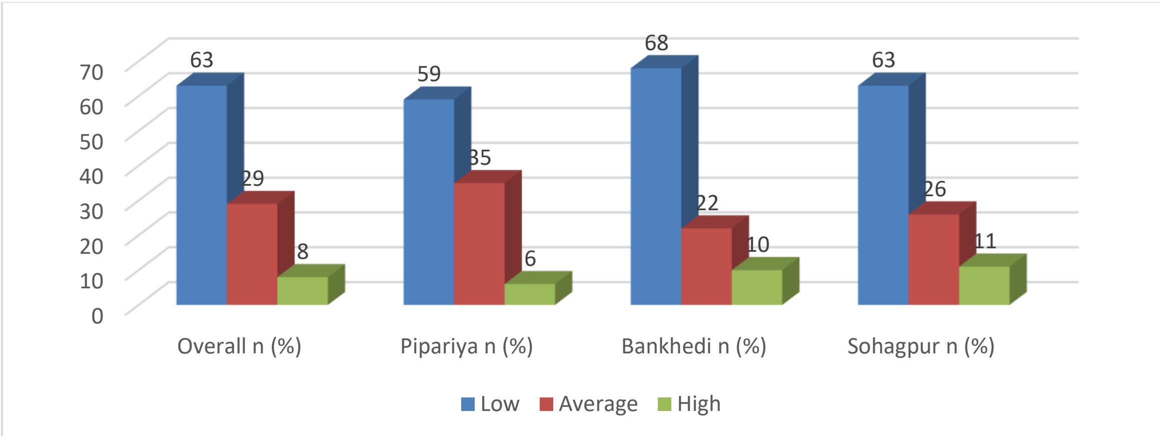

Figure 5: Stacked Bar Chart – Awareness Level Distribution by Block

Approximately two-thirds of farmers (63%) demonstrated low awareness regarding agriculture's contribution to climate change, with only 8% exhibiting high awareness. Block-wise variation was modest, suggesting a systemic rather than localized knowledge deficit.

3.3 Relationship Between Awareness and Methane Emission Practices

Table 2.4: Mean Practice Scores by Awareness Level and ANOVA Results

Practice Domain	Awareness Level	n	Mean ± SD	F (df=2,597)	p-value
Rice Cultivation	Low	375	2.21 ± 1.38	45.60	<0.001
	Average	176	2.65 ± 1.24		
	High	49	4.06 ± 0.85		
Livestock Rearing	Low	375	1.27 ± 0.32	723.17	<0.001
	Average	176	2.30 ± 0.50		
	High	49	2.86 ± 0.04		
Waste Management	Low	375	1.21 ± 0.25	679.93	<0.001
	Average	176	2.04 ± 0.54		
	High	49	2.86 ± 0.03		

*Higher scores indicate lower methane-emitting practices

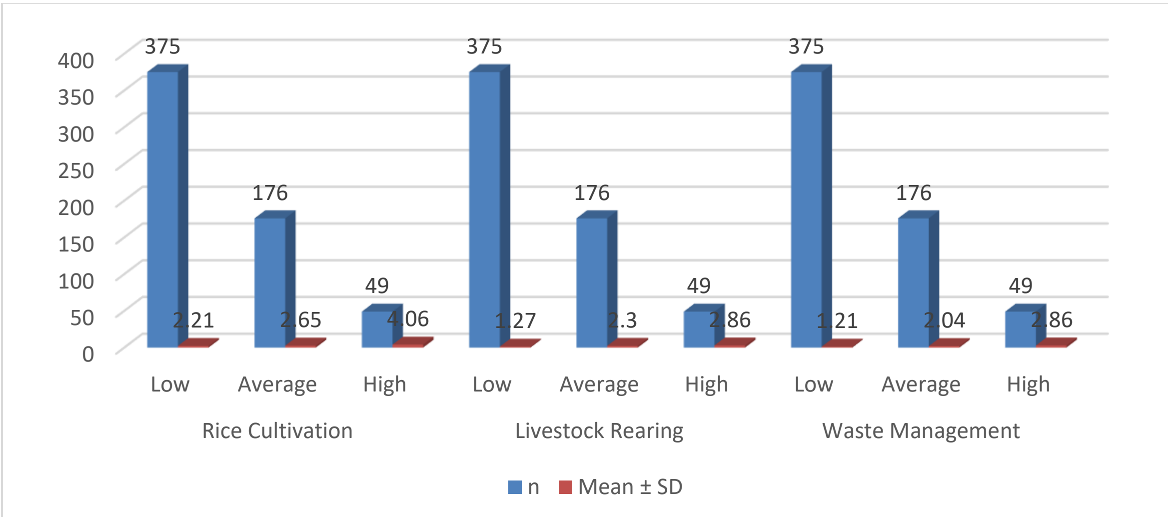

Figure 6: Line Graph – Mean Practice Scores Across Awareness Levels for Three Agricultural Domains

ANOVA revealed highly significant differences in practice scores across awareness categories for all three domains ($p<0.001$). Farmers with high awareness demonstrated substantially superior (lower emission) practices compared to those with low awareness. The effect was most pronounced in livestock rearing ($F=723.17$) and waste management ($F=679.93$).

3.4 Predictors of Farmer Awareness

Multiple linear regression was conducted with awareness score as the dependent variable and the three practice domain scores as predictors.

Regression Model Summary:

- Multiple R = 0.877
- $R^2 = 0.770$
- Adjusted $R^2 = 0.769$
- $F(3, 596) = 664.61$, $p < 0.001$

Regression Coefficients:

Predictor	Unstandardized B (SE)	Standardized β	t	p-value
Constant	-23.44 (2.92)	—	-8.02	<0.001
Rice Cultivation Practices	4.43 (0.72)	0.125	6.17	<0.001
Livestock Rearing Practices	41.38 (3.10)	0.574	13.34	<0.001
Waste Management Practices	22.44 (3.36)	0.289	6.67	<0.001

The regression model explained 77% of variance in farmer awareness scores. Livestock rearing practices emerged as the strongest predictor (β=0.574), followed by waste management (β=0.289) and rice cultivation (β=0.125). All predictors were statistically significant ($p<0.001$).

3.5 Institutional Capacity and Policy Mechanisms

Thematic analysis of official responses (N=43) revealed substantial institutional constraints:

- **Climate Integration:** 58% reported low integration of climate objectives within departmental programs; only 12% reported high integration.
- **Coordination:** 60% characterized inter-departmental coordination as weak; 15% as strong.
- **Technical Capacity:** 59% rated institutional technical capacity as low; 18% as high.
- **Monitoring Systems:** 63% indicated irregular or partial emissions monitoring; 12% reported regular systems.
- **Funding Adequacy:** 68% described financial resources as insufficient; 6% as adequate.

Major implementation challenges identified included low farmer awareness (67%), staff and resource shortages (21%), and weak enforcement mechanisms (12%). Policy gaps centered on absence of clear incentives or emission targets (56%), poor coordination (29%), and weak monitoring systems (15%). Officials prioritized increased training and awareness (35%), financial incentives (30%), improved monitoring (20%), and strengthened coordination (15%) as key reform areas.

[Insert Figure 8: Radar Chart – Institutional Capacity Assessment Across Six Dimensions]

3.6 Focus Group Discussion Insights

FGDs with farmers revealed several convergent themes:

- **Climate Experience:** Farmers reported irregular rainfall (20%), hotter summers (10%), and declining soil moisture (5%), indicating lived experience of climatic variability.
- **Methane Awareness:** While 48% possessed general awareness of "harmful gases," only 10% had heard specifically of methane, and fewer connected it to their farming practices.
- **Perceived Emission Sources:** Farmers identified flooded paddy fields (45%), open dung dumping (25%), and residue burning/rotting (20%) as methane sources, demonstrating partial but incomplete understanding.
- **Barriers:** High cost (35%), lack of technical knowledge (25%), labor shortages (20%), and limited machinery access (15%) constrained adoption of improved practices.
- **Indigenous Practices:** Traditional composting (40%), residue use as fodder/mulch (25%), dung slurry application (20%), and desi seed varieties (15%) represented existing low-cost mitigation options.

4. DISCUSSION

4.1 Principal Findings

This study provides the first district-level empirical evidence linking farmer awareness to methane mitigation practices in central Indian agriculture. Four principal findings emerge: (1) high methane-emitting practices predominate across rice cultivation, livestock rearing, and waste management; (2) farmer awareness of agriculture–climate linkages is critically low, with only 8% demonstrating high awareness; (3) awareness strongly differentiates practice adoption, with highly aware farmers exhibiting substantially lower emission behaviors; and (4) livestock practices constitute the strongest predictor of awareness, explaining a major proportion of variance in farmer climate literacy.

4.2 Awareness–Practice Linkage

The highly significant differences in practice scores across awareness categories ($p<0.001$ for all domains) provide robust empirical support for the hypothesis that cognitive factors mediate adoption of climate-smart agricultural practices. This finding aligns with research from East Africa and Southeast Asia documenting that climate-informed farmers demonstrate greater adaptive capacity and willingness to modify traditional methods (13,18). However, the present study extends this literature by quantifying the strength of association across three distinct emission domains and identifying livestock management as the most influential pathway.

The particularly strong relationship in livestock rearing ($F=723.17$) may be explained by the tangible co-benefits of improved practices. Better feeding regimes, covered dung storage, and enhanced animal housing not only reduce methane emissions but directly improve milk yield, animal health, and household income—creating positive feedback that reinforces awareness (19,20). In contrast, methane reductions from modified rice cultivation (e.g., alternate wetting and drying) may be less immediately visible to farmers, potentially explaining the weaker (though still significant) association.

4.3 Livestock Practices as Awareness Driver

The regression finding that livestock practices are the strongest predictor of farmer awareness ($\beta=0.574$, contributing to $R^2=0.77$) represents a novel contribution with significant programmatic implications. While conventional extension models position awareness as an antecedent to practice adoption, the present results suggest a reciprocal relationship wherein engagement in improved practices—particularly livestock management—enhances climate literacy through experiential learning (21,22). Farmers who actively manage feeding, manure handling, and animal health may develop deeper understanding of biological processes and their environmental implications through daily observation and interaction with extension personnel.

This finding underscores the strategic importance of prioritizing livestock interventions within climate-smart agriculture programs. Beyond direct emission reductions, such interventions may serve as gateway practices that build farmer capacity for broader climate-responsive decision-making.

4.4 Spatial Heterogeneity and Targeted Interventions

Block-wise variation in emission patterns—Bankhedi's elevated rice emissions, Pipariya's high livestock and waste emissions, and Sohagpur's comparatively moderate profile—highlights the inadequacy of uniform, district-wide interventions. This spatial heterogeneity reflects differences in irrigation infrastructure, cropping intensity, livestock density, and perhaps extension coverage. The finding supports calls for spatially differentiated climate action planning that aligns with the SAPCC's emphasis on district-focused strategies (16,23). Bankhedi requires urgent attention to rice water management; Pipariya demands integrated livestock and residue management interventions.

4.5 Institutional Fragmentation

The institutional assessment revealing weak coordination (60%), low technical capacity (59%), and irregular monitoring (63%) mirrors findings from other Indian states and developing country contexts (24,25). Climate responsibilities remain inadequately integrated into departmental mandates, with officers reporting that climate concerns are addressed through isolated schemes rather than embedded into routine agricultural and rural development programs. The predominance of low farmer awareness as the primary implementation challenge (67%) reinforces the need for coordinated extension efforts that transcend departmental silos.

The convergence between identified gaps (lack of incentives, poor coordination, weak monitoring) and official recommendations (training, financial support, improved monitoring) suggests that stakeholders possess clear understanding of necessary reforms but face systemic constraints in implementation. This aligns with literature emphasizing that sub-national climate governance requires not only policy articulation but also institutional capacity building, resource allocation, and accountability mechanisms (26).

4.6 Policy Implications

The findings have direct implications for India's NDC commitments and Madhya Pradesh's SAPCC implementation. First, the strong awareness–practice linkage necessitates mandatory climate literacy components within agricultural extension programs, delivered through Krishi Vigyan Kendras (KVKs) and Agricultural Technology Management Agencies (ATMA). Second, the predictive primacy of livestock practices argues for prioritizing livestock management within climate-smart agriculture initiatives, aligning with NDC focus on sustainable livestock systems and biogas promotion. Third, block-specific emission profiles support spatially targeted interventions that optimize resource allocation. Fourth, institutional strengthening—particularly formal inter-departmental coordination mechanisms, dedicated budgetary provisions, and robust monitoring systems—is essential for translating policy commitments into field-level outcomes.

4.7 Limitations and Future Research

This study has limitations that should be acknowledged. The reliance on practice-based scales rather than direct flux measurements may introduce uncertainty in absolute emission quantification, though the scales demonstrate strong reliability and construct validity. The cross-sectional design precludes assessment of temporal dynamics and causal directionality. The focus on a single district, while providing depth, limits generalizability to other agro-ecological zones.

Future research should incorporate chamber-based or sensor-based methane measurements to validate practice-based indices, employ longitudinal designs to examine awareness–practice dynamics over time, extend the analysis to other districts and states, and conduct impact evaluations of specific interventions (e.g., alternate wetting and drying, improved feeding, biogas systems) on both emissions and farmer livelihoods.

5. CONCLUSION

This study demonstrates that high methane-emitting agricultural practices are pervasive in Narmadapuram district, with 51–62% of farmers employing emission-intensive methods across rice cultivation, livestock rearing, and waste management. Critically low farmer awareness (63% low) constitutes a fundamental barrier to mitigation, while the strong awareness–practice linkage ($p<0.001$ across domains) confirms that cognitive factors powerfully differentiate adoption behaviors. Livestock practices emerge as the strongest predictor of awareness ($\beta=0.574$), identifying this domain as a strategic entry point for enhancing climate literacy while achieving direct emission reductions.

Block-specific emission heterogeneity necessitates spatially differentiated interventions, with Bankhedi and Pipariya requiring prioritized attention. Institutional fragmentation—characterized by weak coordination, low technical capacity, and irregular monitoring—must be addressed through systemic reforms to enable effective sub-national climate governance.

Achieving India's NDC targets and advancing SAPCC objectives requires an integrated approach that combines awareness enhancement, practice improvement, institutional strengthening, and evidence-based policy alignment. The present study provides a replicable methodological framework and empirical foundation for such integrated action, contributing to the broader goal of climate-resilient, low-emission agricultural development in India.

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