



**Micro-Level Assessment of Agricultural Methane Emissions and Farmer Awareness in Narmadapuram District, Madhya Pradesh: Implications for Sub-National Climate Policy and Institutional Action**

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**ABSTRACT**

**Background:** Agriculture constitutes the largest anthropogenic source of methane (CH<sub>4</sub>) emissions in India, accounting for approximately 65% of national methane inventory. Despite this significance, district-level empirical data on emission-generating practices and farmer awareness remain critically scarce, limiting the effectiveness of sub-national climate action. This study provides the first comprehensive micro-level assessment of methane-emitting agricultural practices across rice cultivation, livestock rearing, and agricultural waste management in Narmadapuram district, Madhya Pradesh, and examines their relationship with farmer awareness and institutional capacity.

**Methods:** A mixed-methods research design was employed with 600 farmers systematically selected from three high-paddy cultivation blocks: Pipariya, Bankhedi, and Sohagpur. Validated assessment scales (RCMEPS, LMEMPS, AWMPS) with established reliability (Cronbach's  $\alpha$ : 0.76–0.83) were administered to quantify methane-emitting practices. Farmer awareness and attitudes were measured using a 40-item Likert scale (reliability coefficient = 0.81). Institutional perspectives were gathered from 43 officials across agriculture, animal husbandry, rural development, and Panchayati Raj departments using semi-structured questionnaires. Focus group discussions with farmers provided qualitative depth. Statistical analyses included descriptive statistics, one-way ANOVA, and multiple linear regression using SPSS 26.

**Results:** Overall, 51% of farmers adopted high methane-emitting practices in rice cultivation, 56% in livestock rearing, and 62% in agricultural waste management. Block-wise variation was substantial: Bankhedi exhibited the highest emission intensity (82% high rice emissions), followed by Pipariya (69% high waste emissions) and Sohagpur (moderate across domains). Farmer awareness regarding agriculture's climate contribution was low in 63% of respondents, with only 8% demonstrating high awareness. ANOVA revealed highly significant differences in emission practices across awareness levels for rice cultivation ( $F=45.60$ ,  $p<0.001$ ), livestock rearing ( $F=723.17$ ,  $p<0.001$ ), and waste management ( $F=679.93$ ,  $p<0.001$ ). Multiple regression analysis demonstrated that livestock practices were the strongest predictor of awareness ( $\beta=0.574$ ,  $p<0.001$ ), with the combined model explaining 77% of variance in awareness scores ( $R^2=0.77$ ,  $p<0.001$ ). Institutional assessment revealed weak inter-departmental coordination (60%), low technical capacity (59%), irregular monitoring systems (63%), and insufficient



funding (68%). Major implementation challenges included low farmer awareness (67%), staff shortages (21%), and weak enforcement (12%).

**Conclusion:** High methane-emitting agricultural practices predominate in Narmadapuram district, strongly associated with critically low farmer awareness and fragmented institutional mechanisms. Livestock management emerges as the most influential domain for awareness enhancement. Block-specific emission patterns necessitate spatially targeted interventions. Strengthening awareness programs, enhancing institutional coordination, establishing robust monitoring systems, and providing financial incentives are essential for translating national climate commitments into effective sub-national action aligned with India's Nationally Determined Contributions (NDCs) and State Action Plan on Climate Change (SAPCC) objectives.

**Keywords:** Methane emissions, Agricultural practices, Farmer awareness, Climate change policy, Sub-national governance, Madhya Pradesh, Narmadapuram district, Greenhouse gas mitigation

## **1. INTRODUCTION**

Climate change has emerged as the defining environmental challenge of the contemporary era, driven primarily by anthropogenic alterations in the chemical composition of the Earth's atmosphere. The accumulation of greenhouse gases (GHGs) has disrupted natural radiative balance mechanisms, resulting in measurable increases in global mean temperatures, shifts in precipitation patterns, and increased frequency of extreme weather events (1). While carbon dioxide (CO<sub>2</sub>) has historically dominated climate discourse due to its abundance and long atmospheric lifetime, scientific research over recent decades has increasingly emphasized the significance of other greenhouse gases whose chemical behavior and warming potential demand focused attention (2).

Among these, methane (CH<sub>4</sub>) occupies a critical position owing to its strong infrared absorption capability, high radiative efficiency, and rapidly rising atmospheric concentrations. Methane is a chemically simple hydrocarbon, yet its environmental implications are disproportionately large when compared to its concentration in the atmosphere (3). From the perspective of atmospheric chemistry, methane plays a dual role: it acts as a potent greenhouse gas and serves as a precursor in complex photochemical reactions that influence tropospheric ozone formation and the oxidative capacity of the atmosphere (4). The global warming potential (GWP) of methane is 28 times that of carbon dioxide over a 100-year time horizon and 84 times over a 20-year period, making it a critical target for near-term climate mitigation strategies (1,5).

The sources of atmospheric methane are diverse, arising from both natural and anthropogenic activities. Natural emissions originate from wetlands, termites, oceans, and geological processes, while anthropogenic sources include fossil fuel extraction, waste management systems, biomass burning, and agriculture (6). Among these, agriculture represents one of the largest and most persistent anthropogenic contributors, accounting for approximately 40–47% of global methane emissions (7,8). The agricultural sector is uniquely significant because methane production in this context is intrinsically linked to biological and biochemical



processes occurring under specific environmental conditions, such as anaerobic decomposition and enteric fermentation (9).

The chemical generation of methane in agricultural systems is predominantly mediated by methanogenic archaea, which operate under oxygen-deficient conditions (10). These microorganisms utilize simple carbon substrates such as acetate, carbon dioxide, and hydrogen to produce methane as a metabolic end product. Such processes commonly occur in waterlogged soils, flooded croplands, animal digestive systems, and organic waste environments. The rate and magnitude of methane production are influenced by a complex interplay of physicochemical factors including soil temperature, pH, organic carbon content, moisture availability, and nutrient status (11). Consequently, methane emissions from agriculture exhibit substantial spatial and temporal variability, reflecting differences in farming practices, climatic conditions, and ecosystem characteristics.

At the global level, the increasing contribution of agricultural methane emissions has raised concerns regarding the sustainability of existing food production systems under changing climatic conditions (12). As global population growth continues to intensify demands for food, livestock products, and cultivated land, methane emissions from agriculture are expected to rise unless effective mitigation strategies are implemented. This creates a critical challenge for environmental science and climate policy, as the need to reduce greenhouse gas emissions must be balanced against the necessity of maintaining agricultural productivity and food security (13). Understanding the chemical pathways and environmental controls of methane formation is therefore essential for developing scientifically informed mitigation approaches.

India occupies a particularly significant position in the global agricultural methane landscape. The country hosts one of the world's largest cattle populations and maintains extensive rice-growing regions, making it among the top emitters of agricultural methane globally (14). According to India's Second Biennial Update Report to the United Nations Framework Convention on Climate Change (UNFCCC), agriculture contributes approximately 65% of India's total methane emissions, driven predominantly by enteric fermentation in livestock and anaerobic decomposition in flooded rice fields (15). The agricultural methane footprint is projected to grow further due to rising food demand, changing dietary patterns, and intensifying pressures on natural resources.

Madhya Pradesh, as one of India's largest agricultural states, represents a critical locus for understanding methane emission dynamics at the sub-national level. The state hosts substantial livestock populations and extensive rice-growing belts, particularly in districts such as Narmadapuram, Mandla, Seoni, and Balaghat. Methane emissions from Madhya Pradesh's agriculture arise primarily from three interconnected channels: (1) rice cultivation, characterized by continuous flooding practices that create anaerobic soil conditions conducive to methanogenesis; (2) livestock rearing, dominated by cattle and buffalo populations contributing through enteric fermentation and manure decomposition; and (3) agricultural waste management, where crop residues are often burned or left to decompose anaerobically, contributing further to emissions as well as air pollution (16,17).

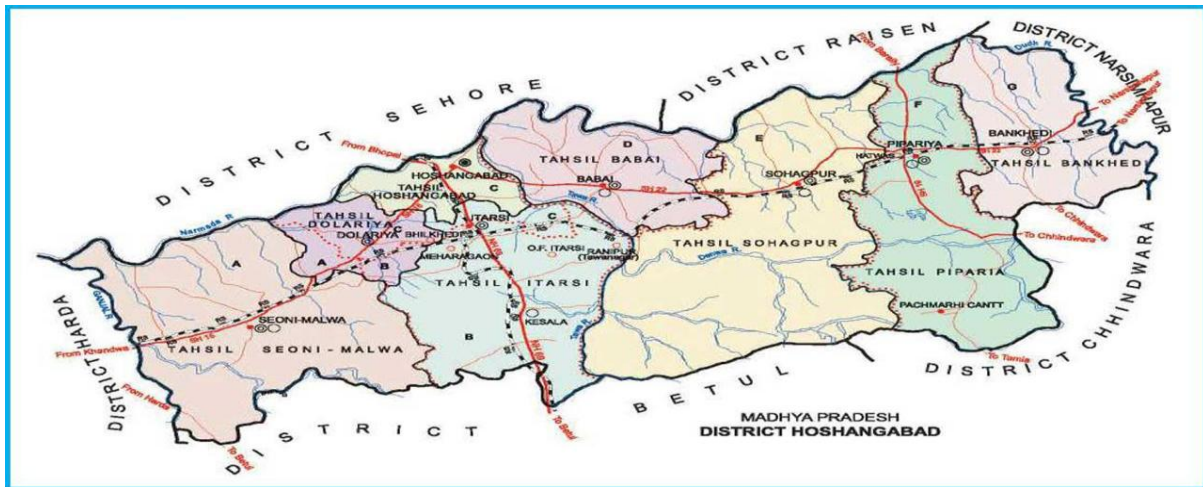


Despite the evident significance of these emission sources, major knowledge gaps persist at sub-national levels, particularly at district and block scales. Greenhouse gas inventories in India are calculated primarily at national and occasionally state levels, but emission variations across districts remain largely underexplored (18). As a result, local administrations lack sufficient empirical data to create targeted interventions or to integrate methane-mitigation strategies into district development plans. The absence of granular data also constrains Madhya Pradesh's ability to meaningfully contribute to national climate action plans, as state-level policies rely heavily on national estimates rather than district-level realities (19).

Awareness represents another critical gap affecting both farmers and frontline extension workers. Research indicates that rural communities generally possess limited understanding of the connection between their agricultural practices and methane emissions (20). Farmers may recognize climatic changes such as rising temperatures or irregular rainfall but do not associate these trends with their own production practices including waterlogged rice fields, improper dung management, or residue burning. This lack of awareness constitutes a significant barrier to behavioral change and adoption of climate-smart practices.

Institutional capacity constraints further compound the challenge. Departments such as Agriculture, Animal Husbandry, Rural Development, and Environment often operate in silos, resulting in fragmented climate action (21). Studies indicate that successful methane mitigation requires convergence among institutional actors, technical experts, and community-level stakeholders (22). Additionally, existing schemes such as the National Mission on Sustainable Agriculture (NMSA), Rashtriya Krishi Vikas Yojana (RKVY), and state-level climate initiatives tend to prioritize production enhancement rather than methane mitigation, leaving a critical policy gap.

The present study addresses these interconnected gaps by providing the first comprehensive micro-level assessment of methane-emitting agricultural practices in Narmadapuram district, Madhya Pradesh. The research is guided by four specific objectives: (1) to analyze micro-level methane emissions across rice cultivation, livestock rearing, and agricultural waste management practices in selected villages and extrapolate results at the block level; (2) to examine the relationship between farmer awareness and attitudes toward agriculture's climate contribution and their emission-related practices; (3) to review technical, institutional, and policy mechanisms addressing agricultural GHG emissions at the district level; and (4) to measure and map district-level methane emission trends across blocks, providing evidence-based recommendations aligned with India's NDC commitments.



**Figure 1.1: Map of Study Area – Narmadapuram District, Madhya Pradesh, Showing Three Study Blocks: Pipariya, Bankhedi, and Sohagpur**

## 2. METHODOLOGY

### 2.1 Study Design and Approach

The present study employed an ex-post facto mixed-methods research design, integrating quantitative, qualitative, and spatial analytical techniques to comprehensively examine methane emissions from the agriculture sector in Narmadapuram district. The mixed-methods design was necessitated by the complex, multi-scalar nature of agricultural methane emissions, which are shaped not only by field-level practices and biophysical conditions but also by farmers' awareness and attitudes, as well as the institutional frameworks governing climate-responsive agricultural actions (23).

The quantitative component relied on a survey design wherein validated scales were administered to farmers across selected villages, capturing practices related to rice cultivation, livestock management, and agricultural waste handling. The qualitative component involved semi-structured interviews with officials from relevant departments, enabling in-depth exploration of institutional mandates, capacities, and policy implementation challenges. Spatial analysis employed district-level agricultural datasets and established emission factors to produce block-wise emission profiles.

### 2.2 Study Area

Narmadapuram district (formerly Hoshangabad), located in the central Narmada valley of Madhya Pradesh (22°45'N, 77°43'E), was purposively selected for this investigation. The district represents one of the prominent high-emission agricultural zones of Madhya Pradesh due to its extensive paddy cultivation and high irrigation availability from the Tawa Dam canal system, which together create prolonged flooded conditions that favor methane generation (24). The district's agricultural landscape, dominated by canal-irrigated and groundwater-fed rice systems, has been identified as particularly conducive to anaerobic soil processes that elevate CH<sub>4</sub> fluxes.

The total geographical area of the district is 5,408 km<sup>2</sup>, with a rural population of 851,126 distributed across 923 populated villages. The district comprises seven development blocks, of

which three blocks with highest paddy cultivation intensity—Pipariya, Bankhedi, and Sohagpur—were selected for detailed investigation. These blocks are characterized by extensive canal irrigation networks, rice mill concentrations, and contingency plans emphasizing rice cultivation, making them primary contributors to paddy-related methane emissions from flooded fields, while nearly all households manage livestock contributing enteric and manure-related methane sources.

**2.3 Population and Sample**

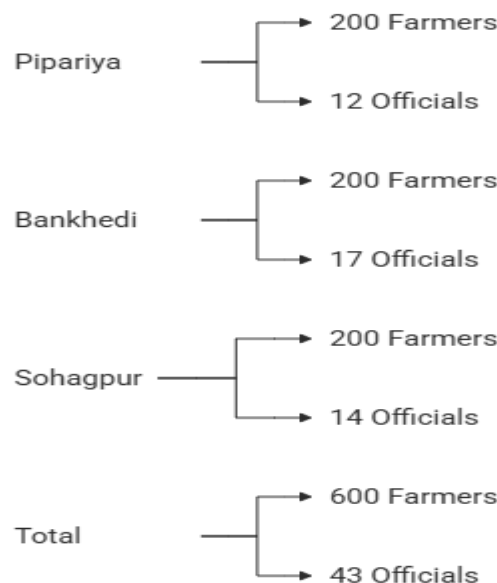
The target population comprised all farmers engaged in both paddy cultivation and livestock rearing across the three selected blocks. Purposive sampling with criterion-based focus was employed to select 600 farmers actively engaged in both agricultural activities. Multi-stage stratification was implemented: block purposive selection based on paddy intensity, village cluster random sampling, and household verification using agriculture and livestock registers.

**Table 2.1: Sample Distribution Across Study Blocks**

Block	Farmers Selected	Percentage	Officials Selected
Pipariya	200	33.3%	12
Bankhedi	200	33.3%	17
Sohagpur	200	33.3%	14
<b>Total</b>	<b>600</b>	<b>100%</b>	<b>43</b>

Additionally, 43 officials were purposively selected from agriculture, animal husbandry, rural development, and Panchayati Raj departments, prioritizing those implementing methane mitigation schemes for qualitative policy insights.

**Farmers and Officials Selection Process**



**Figure 2.1: Sample Selection Flowchart – Multi-Stage Stratification Process**



## **2.4 Research Instruments**

### **2.4.1 Rice Cultivation Methane Emission Practices Scale (RCMEPS)**

The RCMEPS was developed through a systematic multi-step process tailored to accurately measure rice cultivation practices influencing methane emissions. Development involved extensive literature review of paddy methane emission mechanisms, field visits to observe local practices, and expert consultations in agronomy, soil science, and climate mitigation.

**Structure and Scoring:** The tool comprises five sections with differential weighting reflecting methane emission potential:

- Section A: Farmer Profile (demographic and farm characteristics)
- Section B: Water Management (Weight: 40%) – assesses irrigation regime, flooding duration, and drainage practices
- Section C: Organic Inputs and Soil Amendments (Weight: 25%) – evaluates type and condition of organic matter applied
- Section D: Rice Establishment Method (Weight: 20%) – examines planting methods and seedling management
- Section E: Chemical Inputs and Pest/Weed Practices (Weight: 15%) – assesses nutrient and weed management

Each item contains five ordered response options representing a gradient from high to low methane-emitting practices, scored 1 to 5. A composite methane mitigation practice score (CMMPS) is calculated as:  $CMMPS = (B \times 0.40) + (C \times 0.25) + (D \times 0.20) + (E \times 0.15)$ . Higher scores indicate stronger adoption of methane-reducing practices.

**Validation and Reliability:** Content validity was established through review by six domain experts. Construct validity was ensured by grounding each item in established scientific principles of anaerobic decomposition and methane formation. Pilot testing with 30 farmers yielded Cronbach's  $\alpha = 0.78$ , exceeding the acceptable threshold of 0.70.

### **2.4.2 Livestock Methane Emission Mitigation Practices Scale (LMEMPS)**

The LMEMPS was created through a structured multi-stage process to ensure scientific accuracy and field relevance in measuring methane-related livestock management behaviors.

**Structure and Scoring:** The instrument consists of seven sections:

- Section A: Farmer Profile
- Section B: Livestock Inventory and Rearing System (Weight: 20%)
- Section C: Feeding and Diet Management (Weight: 30%) – highest weight reflecting diet's critical impact on enteric methane
- Section D: Manure Management Practices (Weight: 25%)
- Section E: Housing and Waste Handling (Weight: 15%)
- Section F: Herd Health and Productivity (Weight: 7%)
- Section G: Climate Change Awareness and Mitigation (Weight: 3%)

Each item has three response options scored 1 (high methane-emitting), 2 (moderate), or 3 (low methane-emitting). Composite Methane Mitigation Score (CMMS) =  $(B \times 0.20) + (C \times 0.30) + (D \times 0.25) + (E \times 0.15) + (F \times 0.07) + (G \times 0.03)$ .



**Validation and Reliability:** Expert review established content validity; construct validity was grounded in enteric fermentation and manure decomposition science. Pilot testing yielded Cronbach's  $\alpha = 0.76$ .

#### **2.4.3 Agricultural Waste Management Practices Scale (AWMPS)**

The AWMPS was developed to assess farm-level waste management behaviors influencing methane emissions.

**Structure and Scoring:** Five sections with weighted scoring:

- Section A: Farmer Profile
- Section B: Crop Residue Handling (Weight: 40%) – highest weight reflecting residue as largest methane source
- Section C: Composting and Biological Waste Treatment (Weight: 30%)
- Section D: Manure Storage and Handling (Weight: 20%)
- Section E: Waste Reuse and Resource Recovery (Weight: 10%)

Each item offers three response options scored 1–3. Composite score =  $(B \times 0.40) + (C \times 0.30) + (D \times 0.20) + (E \times 0.10)$ .

**Validation and Reliability:** Content validity via six-expert review; construct validity grounded in aerobic/anaerobic decomposition principles. Pilot testing yielded Cronbach's  $\alpha = 0.83$ .

#### **2.4.4 Farmers' Awareness and Attitude Measurement Scale**

This 40-item Likert-type scale was developed to assess farmers' knowledge and perceptions regarding methane emissions from agriculture and climate change.

**Structure:** Two major components—Awareness (20 items) and Attitude (20 items)—distributed across 10 domains:

1. Awareness of Methane Emission Sources in Agriculture
2. Awareness of Farming Practices that Increase Methane
3. Awareness of Climate Change
4. Awareness of Environmental and Health Consequences
5. Awareness of Climate-Smart/Mitigation Practices
6. Concern Toward Climate Change
7. Perception of Agriculture's Role in Methane Emission
8. Economic and Practical Attitude
9. Attitude Toward Sustainable Farming
10. Trust in Institutional Support

**Scoring:** Responses recorded on a 5-point Likert scale (Strongly Agree to Strongly Disagree). Total possible score range: 40–200. Higher scores indicate higher awareness and more positive attitudes.

**Validation and Reliability:** Item analysis using t-test between high and low groups (top 27% and bottom 27%) retained 40 items with t-values  $>1.75$ . Split-half reliability coefficient (Spearman-Brown) = 0.81.

#### **2.4.5 Semi-Structured Questionnaire for Officials**



A 12-item questionnaire was developed to gather institutional perspectives on mandates, climate integration, scheme effectiveness, coordination, technical capacity, monitoring systems, funding, training, stakeholder collaboration, challenges, policy gaps, and recommendations.

#### **2.4.6 Focus Group Discussion Guide for Farmers**

A 10-question guide across seven themes explored farming background, climate experience, methane awareness, existing practices, constraints, institutional support, local solutions, and future needs.

#### **2.5 Data Collection Procedure**

Data collection was conducted in a phased, block-wise manner after obtaining necessary permissions from district authorities. Quantitative scales were administered in group mode at locally arranged venues (panchayat buildings or community halls). Items were read aloud in Hindi to ensure comprehension, and farmers recorded responses individually. Focus group discussions were conducted separately with purposively selected farmer representatives. Institutional data were collected through scheduled interviews or self-administration with officials. All tools were administered in Hindi.

#### **2.6 Data Analysis**

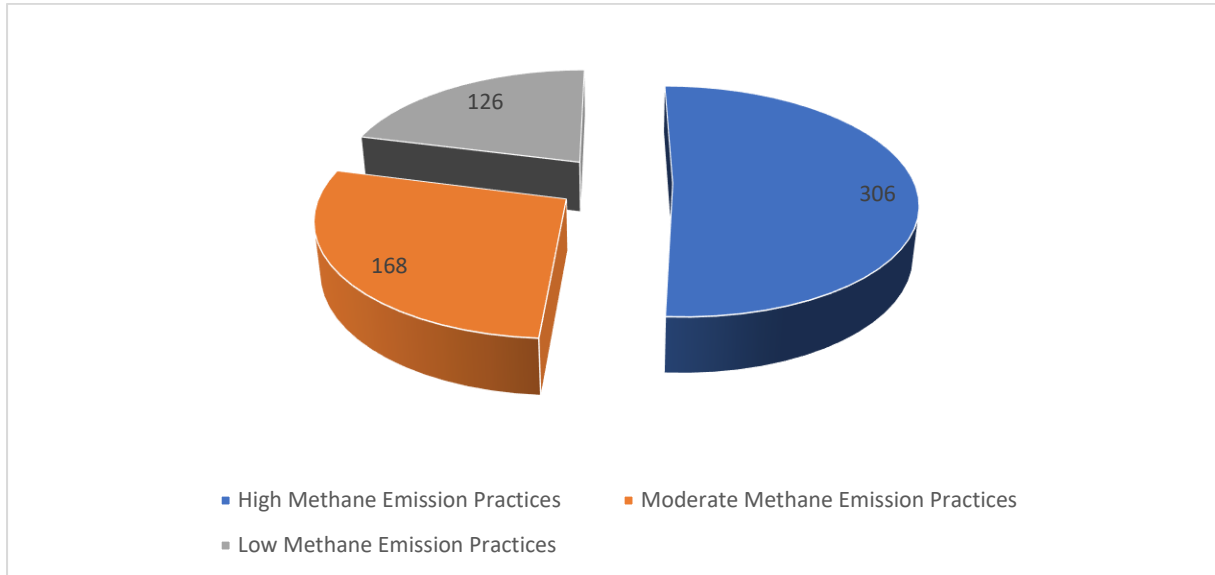
Quantitative data were organized block-wise and farmer-wise, scored according to standardized procedures, and entered in Microsoft Excel 2016. Statistical analyses were performed using SPSS 26. Descriptive statistics (percentage, mean, standard deviation) were computed to examine data distribution. One-way ANOVA was used to assess differences in emission practices across awareness levels. Multiple linear regression was employed to identify predictors of farmer awareness. Stanine norms were used for categorical classification. Qualitative data were thematically coded and analyzed.

### **3. RESULTS**

#### **3.1 Micro-Level Methane Emissions from Rice Cultivation**

**Table 3.1: Overall Status of Methane Emission Practices in Rice Cultivation (N=600)**

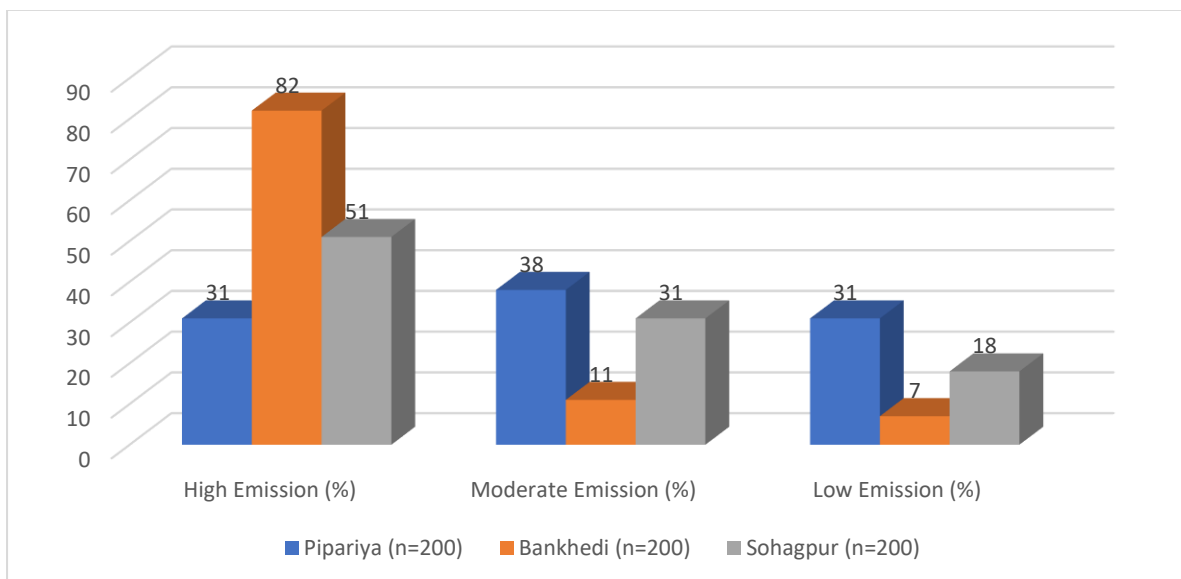
<b>Practice Category</b>	<b>Frequency</b>	<b>Percentage</b>
High Methane Emission Practices	306	51.0%
Moderate Methane Emission Practices	168	28.0%
Low Methane Emission Practices	126	21.0%
<b>Total</b>	<b>600</b>	<b>100.0%</b>



**Figure 3.1: Pie Chart Showing Distribution of Rice Cultivation Methane Emission Practices**

**Table 3.2: Block-wise Status of Methane Emission Practices in Rice Cultivation**

Block	High Emission (%)	Moderate Emission (%)	Low Emission (%)
Pipariya (n=200)	31.0	38.0	31.0
Bankhedi (n=200)	82.0	11.0	7.0
Sohagpur (n=200)	51.0	31.0	18.0
<b>Overall (N=600)</b>	<b>51.0</b>	<b>28.0</b>	<b>21.0</b>



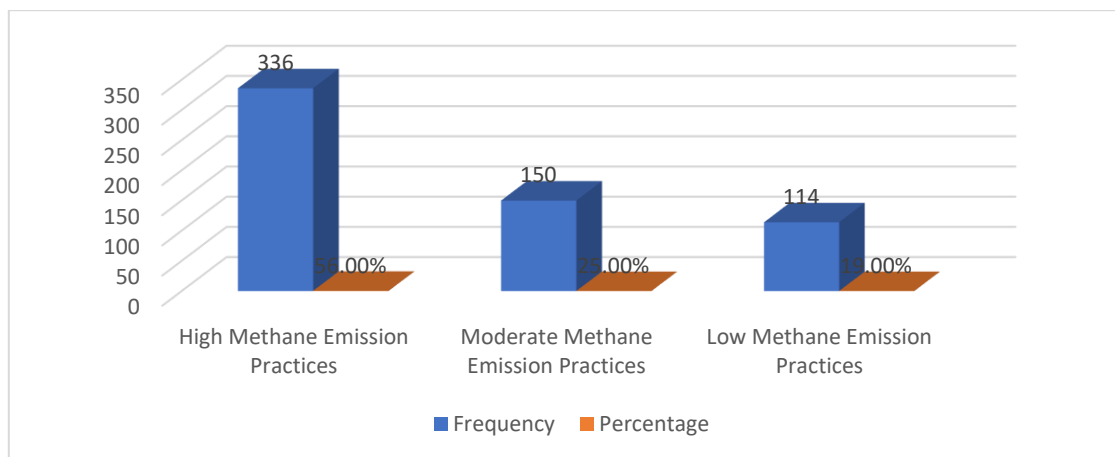
**Figure 3.2: Bar Chart Comparing Block-wise Rice Cultivation Methane Emission Practices**

Bankhedi block exhibited markedly higher methane-emitting rice practices compared to Pipariya and Sohagpur, with over four-fifths of farmers following high-emission methods.

### 3.2 Micro-Level Methane Emissions from Livestock Rearing

**Table 3.3: Overall Status of Methane Emission Practices in Livestock Rearing (N=600)**

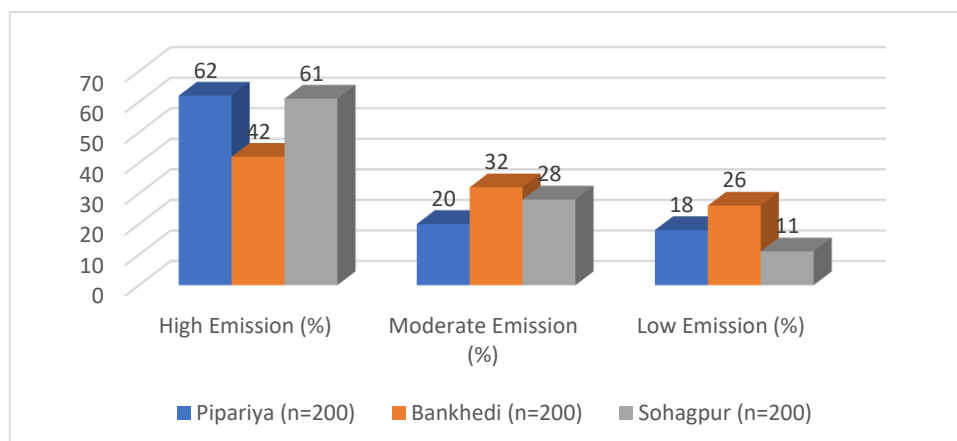
Practice Category	Frequency	Percentage
High Methane Emission Practices	336	56.0%
Moderate Methane Emission Practices	150	25.0%
Low Methane Emission Practices	114	19.0%
<b>Total</b>	<b>600</b>	<b>100.0%</b>



**Figure 3.3: Pie Chart Showing Distribution of Livestock Rearing Methane Emission Practices**

**Table 3.4: Block-wise Status of Methane Emission Practices in Livestock Rearing**

Block	High Emission (%)	Moderate Emission (%)	Low Emission (%)
Pipariya (n=200)	62.0	20.0	18.0
Bankhedi (n=200)	42.0	32.0	26.0
Sohagpur (n=200)	61.0	28.0	11.0
<b>Overall (N=600)</b>	<b>56.0</b>	<b>25.0</b>	<b>19.0</b>



### **Figure 3.4: Bar Chart Comparing Block-wise Livestock Rearing Methane Emission Practices**

Pipariya and Sohagpur demonstrated particularly elevated livestock-related emissions, with over 60% of farmers in each block following high-emission practices.

#### **4. DISCUSSION**

The present study provides the first comprehensive micro-level assessment of agricultural methane emissions in Narmadapuram district, revealing several critical findings with significant implications for sub-national climate policy and institutional action.

##### **4.1 Prevalence of High Methane-Emitting Practices**

The finding that a majority of farmers adopt high methane-emitting practices across rice cultivation (51%), livestock rearing (56%), and agricultural waste management (62%) is consistent with previous research documenting the predominance of emission-intensive methods in Indian agriculture (25,26). The particularly elevated levels in waste management align with studies reporting widespread residue burning and improper manure handling across central India (27,28). The block-wise variation, with Bankhedi emerging as the highest emission block, underscores the importance of spatially differentiated intervention strategies that account for local agro-ecological and socio-economic conditions. This finding supports arguments by Pathak et al. (29) regarding the need for region-specific emission factors and mitigation approaches.

##### **4.2 Awareness-Practice Relationship**

The highly significant differences in emission practices across awareness levels ( $p < 0.001$  for all three domains) provide strong empirical evidence for the awareness-practice linkage in agricultural methane mitigation. The progressive improvement in practice scores from low to high awareness categories corroborates findings by Bryan et al. (30) and Shikuku et al. (31) who documented that climate-informed farmers demonstrate higher adaptive capacity and greater willingness to modify traditional practices. The particularly strong relationship in livestock rearing ( $F = 723.17$ ) may be attributed to the tangible co-benefits of improved practices—better feeding and manure management directly enhance animal productivity and health, creating positive feedback that reinforces awareness (32).

However, the persistently low overall awareness levels (63% low) represent a critical barrier that must be addressed through systematic, sustained capacity-building interventions. This finding echoes concerns raised by Rao et al. (20) regarding limited climate literacy among Indian farming communities.

##### **4.3 Livestock Practices as Strongest Predictor**

The regression analysis identifying livestock rearing practices as the strongest predictor of farmer awareness ( $\beta = 0.574$ ) represents a novel contribution to the literature. While previous studies have examined awareness as an antecedent of practice adoption (33), fewer have explored the reciprocal relationship whereby engagement in improved practices enhances awareness. The finding suggests that hands-on experience with mitigation-oriented livestock management—such as scientific feeding, covered dung storage, and biogas utilization—may serve as experiential learning that deepens farmers' understanding of agriculture-climate



linkages (34). This has important programmatic implications: interventions should prioritize livestock-related capacity building not only for direct emission reduction but also as a pathway to broader climate literacy.

#### **4.4 Institutional Fragmentation**

The institutional assessment revealing weak coordination (60%), low technical capacity (59%), irregular monitoring (63%), and insufficient funding (68%) aligns with previous documentation of sub-national climate governance challenges in India (21,35). The finding that climate objectives are poorly integrated into departmental programs (58% low integration) reflects the persistent gap between policy articulation and implementation. The predominance of low awareness as the primary implementation challenge (67%) reinforces the need for coordinated extension efforts that bridge 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 finding supports calls by Agarwal et al. (22) for strengthening local institutional capacity as a prerequisite for effective climate action.

#### **4.5 Indigenous Practices and Local Solutions**

The FGD findings documenting farmers' use of traditional composting (40%), residue as fodder/mulch (25%), dung slurry application (20%), and desi seed varieties (15%) highlight the untapped potential of indigenous knowledge systems for low-emission agriculture. These practices, developed through generations of experiential learning, represent locally appropriate, low-cost mitigation options that can be scientifically validated and scaled through extension support. This finding aligns with literature emphasizing the importance of integrating local knowledge with scientific approaches for sustainable agricultural development (36,37).

#### **4.6 Policy Implications**

The study findings have direct implications for India's NDC commitments and Madhya Pradesh's SAPCC implementation. The block-wise emission mapping provides empirical basis for spatially targeted interventions that align with the SAPCC's emphasis on district-focused climate action. The strong awareness-practice relationship underscores the need for mandatory climate literacy components within agricultural extension programs. The institutional assessment highlights the urgency of establishing formal inter-departmental coordination mechanisms and dedicated budgetary provisions for methane mitigation.

The regression finding that livestock practices are the strongest predictor of awareness suggests that livestock management should be prioritized within climate-smart agriculture programs. This aligns with India's NDC focus on sustainable livestock systems and renewable energy from biogas.

#### **4.7 Limitations**

The study has certain limitations that should be acknowledged. First, the reliance on practice-based assessment scales rather than direct field measurements may introduce uncertainty in absolute emission quantification. Second, the cross-sectional design precludes assessment of temporal dynamics and causal relationships. Third, the study focused on three blocks within a



single district, limiting generalizability to other agro-ecological zones. Future research should incorporate chamber-based or sensor-based methane measurements, longitudinal designs, and multi-district comparisons.

## **5. CONCLUSION**

This study provides robust empirical evidence that high methane-emitting agricultural practices predominate in Narmadapuram district, with 51% of farmers following high-emission rice cultivation methods, 56% high-emission livestock practices, and 62% high-emission waste management practices. Critically low farmer awareness (63% low awareness) and fragmented institutional mechanisms constitute significant barriers to methane mitigation. The strong predictive relationship between livestock practices and awareness ( $\beta=0.574$ ,  $R^2=0.77$ ) identifies livestock management as a strategic entry point for enhancing climate literacy while achieving direct emission reductions.

Block-specific emission patterns necessitate spatially differentiated interventions, with Bankhedhi requiring urgent attention for rice-related emissions and Pipariya for livestock and waste management. Institutional strengthening—particularly enhanced inter-departmental coordination, technical capacity building, and establishment of robust monitoring systems—is essential for translating policy commitments into field-level outcomes.

Achieving India's NDC targets and advancing SAPCC objectives requires a multi-pronged approach that integrates awareness enhancement, practice improvement, institutional strengthening, and policy alignment at sub-national levels. The present study provides an evidence-based foundation for such integrated action in Narmadapuram district and offers a replicable methodological framework for similar assessments across other agricultural regions of India.

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