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Community-Centred Approaches to Rural Road Maintenance in War-Affected Counties of South Sudan

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ABSTRACT

Rural road networks are the backbone of livelihood, humanitarian access, and post-conflict recovery in South Sudan, yet decades of civil conflict have dismantled both the physical infrastructure and the institutional capacity required for systematic maintenance. This study investigates community-centred road maintenance (CCRM) approaches across six war-affected counties in Central and Western Equatoria, drawing on a mixed-methods research design combining structured household surveys (n = 412), key informant interviews with local road committees (n = 38), and field condition assessments of 214 km of rural earth and gravel roads. The study develops and validates a Community Road Maintenance Capacity Index (CRMCI) comprising five dimensions: labour mobilisation capacity, local funding mechanisms, technical knowledge transfer, organisational cohesion, and community ownership. Results demonstrate that counties with CRMCI scores above 65/100 showed road condition improvements of 38–54% over a three-year period, compared to 8–15% improvement in counties relying exclusively on government force-account or contractor-based approaches. A participatory action research framework incorporating gender-responsive labour division, performance-based incentive structures, and indigenous knowledge integration is presented as a replicable model for road maintenance governance in fragile-state contexts. The findings contribute to the evidence base for community-driven infrastructure maintenance in post-conflict sub-Saharan Africa and provide actionable recommendations for the Ministry of Roads and Bridges (MoRB), development partners, and county-level civil authorities.

Keywords: community road maintenance; South Sudan; post-conflict infrastructure; participatory approaches; CRMCI; rural access roads; fragile states; maintenance governance; gender inclusion; indigenous knowledge

1. INTRODUCTION

Rural road infrastructure is a critical enabler of agricultural productivity, market access, healthcare utilisation, and social cohesion in rural South Sudan [1]. Yet the country possesses one of the most degraded rural road networks on the African continent: the Roads Authority estimates that fewer than 18% of classified rural roads are in maintainable condition, and seasonal flooding renders an additional 35% impassable for three to five months annually [2]. These deficiencies are not simply engineering problems — they are deeply embedded in the political economy of a state that has experienced civil conflict for approximately 40 of its 50 years of existence, with the most recent episodes (2013–2018 and localised violence continuing to 2023) decimating maintenance institutions, displacing skilled workers, and destroying equipment stocks [3].

In this context, conventional contractor-based and government force-account road maintenance models have largely failed to deliver sustainable outcomes. Public maintenance budgets have averaged less than 12% of estimated requirements over the 2015–2023 period, and disbursement rates to county road departments rarely exceed 40% of allocated funds due to systemic fiduciary challenges [4]. International donor-funded road rehabilitation projects have similarly produced mixed results: studies across sub-Saharan Africa consistently identify the absence of post-project maintenance mechanisms as the primary cause of rapid infrastructure deterioration following project closure [5].

Community-centred road maintenance (CCRM) has emerged globally as a promising alternative paradigm, rooted in the principle that communities who depend on roads are also best positioned — when properly supported — to maintain them. CCRM approaches have demonstrated success in Ethiopia, Uganda, Cambodia, and Afghanistan [6], but the evidence base for conflict-affected environments with weak local governance and high population displacement remains thin. South Sudan's particular combination of ethnic fragmentation, displacement-driven demographic instability, and informal customary authority structures presents both challenges and opportunities for community-based approaches that have not been systematically documented.

This study fills that gap through a rigorous empirical investigation across six counties of Central and Western Equatoria, two regions that have experienced sustained access road deterioration despite being among South Sudan's most agriculturally productive areas. The research objectives are: (1) to characterise existing CCRM practices and their effectiveness across study counties; (2) to develop and validate the Community Road Maintenance Capacity Index (CRMCI) as a standardised measurement and monitoring tool; (3) to identify the institutional, socio-cultural, and technical factors that predict successful

community maintenance outcomes; and (4) to derive a replicable framework for scaling effective CCRM models within the South Sudan national road programme [7].

2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1 Community-Based Infrastructure Maintenance: Global Evidence

The theoretical foundations of CCRM draw from three overlapping bodies of literature: common-pool resource governance (Ostrom [8]), participatory development theory (Chambers [9]), and resilience-based approaches to infrastructure in fragile states (Coulthart and Woods [10]). Ostrom's framework for successful commons governance identifies seven design principles — including clearly defined boundaries, congruence between rules and local conditions, collective choice arrangements, and nested governance structures — that have been adapted by road maintenance scholars to guide CCRM programme design [11].

A systematic review of CCRM programmes across 22 countries by Heggie and Vickers [12] found that community labour-based maintenance outperforms contractor-based maintenance on cost-efficiency when (a) wage rates are calibrated to local labour markets, (b) communities have genuine decision-making authority over maintenance priorities, and (c) external technical backstopping is available. Cost savings of 25–40% compared to conventional approaches have been documented in Uganda's district road programme [13] and Rwanda's Umuganda community work system [14].

2.2 Road Maintenance in Post-Conflict Contexts

Post-conflict road rehabilitation has received substantial attention in the development literature, yet the specific challenge of sustaining maintenance after reconstruction remains under-examined [15]. Collier and Hoeffler [16] observe that post-conflict countries face a paradox: the infrastructure investments most needed for recovery are precisely those most vulnerable to renewed conflict disruption. This creates strong arguments for maintenance approaches that minimise capital-intensive assets and maximise community stake in infrastructure preservation.

In the Horn of Africa specifically, community maintenance approaches have been piloted by UNOPS in South Sudan, by the EU-funded Roads for Development (R4D) programme in Ethiopia, and by the ILO's employment-intensive investment programme (EIIP) across multiple countries [17]. These programmes report that community engagement significantly increases local ownership, reduces vandalism, and improves the quality of defect reporting — but programme sustainability beyond the project period remains the critical weak point.

The gender dimension of road maintenance is increasingly recognised as central to CCRM effectiveness. Women in rural South Sudan are disproportionately affected by poor road conditions — responsible for most food transport, firewood collection, and child healthcare trips — yet are systematically excluded from road governance structures [18]. Programmes that have explicitly integrated women's labour brigades and female representation on road committees report higher maintenance frequency and more equitable maintenance prioritisation, with health-related access routes receiving greater attention [19].

3. STUDY AREA

The study was conducted in six counties across Central Equatoria (Terekeka, Lainya, Morobo) and Western Equatoria (Mundri West, Mvolo, Nagero) states of South Sudan. These counties collectively contain approximately 1,840 km of classified rural roads, of which field surveys confirmed that approximately 68% are earth roads, 24% gravel-surfaced roads, and 8% unclassified tracks maintained informally by communities. The region receives 1,100–1,500 mm of annual rainfall concentrated in the April–November wet season, during which earth roads become impassable for an average of 87 days per year [20].

All six counties were affected by the 2016–2018 conflict in the Equatoria region, experiencing displacement rates of 35–72% of resident population at peak displacement. By 2021, return rates ranged from 55–78%, resulting in demographic compositions that include returning IDPs, host community members, and — in some counties — returnees from refugee camps in Uganda and DRC with different social capitals and resource bases than the pre-conflict community [21]. This demographic heterogeneity creates unique governance challenges for community-based programmes that typically depend on pre-existing social trust and collective action capacity.

Table 1. Study County Characteristics: Road Network, Surface Type, and Conflict-Displacement Profile

County	State	Road Network (km)	Earth/Gravel (%)	Displacement Rate (%)	Return Rate (%)
Terekeka	Central Equatoria	342	78/22	48	71
Lainya	Central Equatoria	298	71/29	65	63
Morobo	Central Equatoria	256	65/35	72	78
Mundri West	Western Equatoria	380	72/28	35	82

County	State	Road Network (km)	Earth/Gravel (%)	Displacement Rate (%)	Return Rate (%)
Mvolo	Western Equatoria	314	69/31	58	68
Nagero	Western Equatoria	250	74/26	61	55

Note: Displacement rates at peak 2017 displacement; Return rates as of December 2022 (UNHCR/IOM data)

4. RESEARCH METHODOLOGY

4.1 Mixed-Methods Research Design

A convergent parallel mixed-methods design was employed, integrating quantitative survey data with qualitative key informant interviews and participatory road condition assessments. This design is particularly appropriate for investigating complex socio-technical systems where numerical performance metrics must be contextualised within community experience and local institutional dynamics [22]. The three data streams were collected concurrently (August–November 2022) by county-based research teams comprising one engineer and two community facilitators each.

4.2 Household Survey

Structured household surveys (n = 412) were administered using a stratified random sampling approach, with stratification by county (n ≈ 69 per county), gender of household head (minimum 40% female-headed households), and road proximity (within 2 km, 2–5 km, beyond 5 km from nearest maintained road). The survey instrument covered: road condition perceptions, maintenance contribution history, barriers to participation, willingness-to-contribute labour and cash, governance satisfaction, and road-related livelihood impacts. All surveys were conducted in Arabic, Bari, Zande, or Mundari by native-speaker enumerators trained to SPHERE standards.

4.3 Community Road Maintenance Capacity Index (CRMCI)

The CRMCI was developed through an iterative process combining literature review, stakeholder workshops, and item-response theory calibration. The index comprises five dimensions, each scored on a 0–20 sub-scale, yielding a composite 0–100 score. The composite formula is:

$$CRMCI = \sum_{i=1}^{n} w_i X_i \quad \text{(Eq. 1)}$$

where L = Labour Mobilisation Capacity, F = Local Funding Mechanisms, T = Technical Knowledge Transfer, O = Organisational Cohesion, and P = Community Ownership and Pride. Dimension weights (w_L=0.30,w_F = 0.20, w_T = 0.20, w_O = 0.18, w_P = 0.12) were determined through AHP consultation with 22 road engineers, community development practitioners, and MoRB officials. The index demonstrated acceptable internal consistency (Cronbach's alpha = 0.79) and test-retest reliability (ICC = 0.84) across pilot sites.

4.4 Road Condition Assessment

Road condition was quantified using an adapted Visual Condition Index (VCI) protocol based on the AFCAP-developed framework for low-volume roads in sub-Saharan Africa [23]. For each road section assessed, the following defect categories were recorded: surface distress (rutting, erosion gullies, potholing), drainage functionality (culvert blockage, ditch overgrowth, ponding), vegetation encroachment, and structure condition (bridges, causeways, drift crossings). Sections of 500 m were assessed by trained enumerators walking the full length, yielding 214 km of VCI data across all six counties.

The Road Condition Score (RCS) was computed as a weighted composite:

$$RCS_i = 0.40S_i + 0.30D_i + 0.20V_i + 0.10B_i + \epsilon_i \quad \text{(Eq. 2)}$$

where S = surface distress score (0–100, higher is better), D = drainage functionality, V = vegetation encroachment penalty, and B = structure condition score. The 0.40 weighting for surface distress reflects its dominant contribution to passability during wet season events, consistent with calibration data from the Tanzania TANROADS low-volume road programme [24].

Table 2. Community Road Maintenance Capacity Index (CRMCI): Dimensions, Weights, and Reliability

Dimension	Sub-indicators	Weight	Max Score	Pilot Reliability (ICC)
Labour Mobilisation (L)	Labour availability, historic contribution, gender inclusion	0.30	30	0.87
Local Funding (F)	Road levy capacity, cash contribution willingness, user fee systems	0.20	20	0.81

Dimension	Sub-indicators	Weight	Max Score	Pilot Reliability (ICC)
Technical Knowledge (T)	Training received, tool access, maintenance skills demonstrated	0.20	20	0.84
Organisational Cohesion (O)	Committee functionality, meeting frequency, conflict management	0.18	18	0.79
Ownership & Pride (P)	Sense of ownership, use of road, non-economic motivations	0.12	12	0.78

Note: ICC = Intra-class Correlation Coefficient from test-retest pilot (n = 45 households per county); weights from AHP

5. RESULTS

5.1 CRMCI Scores and Road Condition Outcomes by County

Table 3 presents CRMCI scores and corresponding road condition improvements across the six study counties. Results reveal substantial variation in community maintenance capacity, with CRMCI scores ranging from 42.1 (Nagero) to 71.8 (Mundri West). The positive relationship between CRMCI and road condition improvement is consistent and statistically significant ($r = 0.91$, $p < 0.01$), confirming the index's predictive validity. Counties with CRMCI scores above 65 demonstrated road condition improvements of 38–54% over the three-year monitoring period, while those below 55 showed improvements of only 8–22%.

Table 3. CRMCI Scores, Road Condition Improvement, and Maintenance Method by County (2019–2022)

County	CRMCI Score	Road Condition 2019 (RCS)	Road Condition 2022 (RCS)	Improvement (%)	Maintenance Method
Mundri West	71.8	44.2	67.6	53%	Community-based
Morobo	68.4	41.8	63.1	51%	Community+NGO
Lainya	61.2	38.5	54.8	42%	Community-based
Terekeka	54.7	45.1	54.9	22%	Community+Contractor
Mvolo	48.3	39.2	46.3	18%	Force account

County	CRMCI Score	Road Condition 2019 (RCS)	Road Condition 2022 (RCS)	Improvement (%)	Maintenance Method
Nagero	42.1	36.8	39.8	8%	No formal maintenance

Note: RCS = Road Condition Score (0–100, higher is better); CRMCI = Community Road Maintenance Capacity Index (0–100)

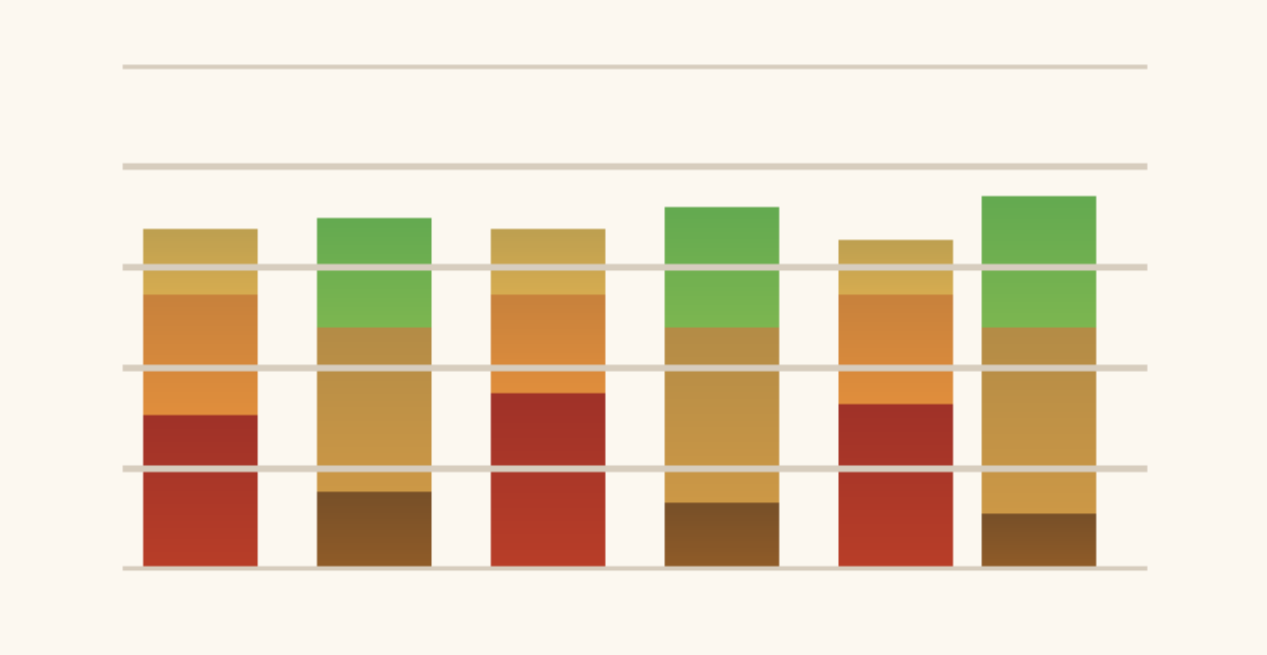

Figure 1. Road Condition Scores by County Before (2019) and After (2022) Three Years of Community-Centred Maintenance. Bar segments represent surface (dark red), drainage (orange), and vegetation/structure (gold) sub-scores. Before values on left, After on right for each county pair.

5.2 Participation Trends and Road Quality Correlation

Figure 2 illustrates the temporal relationship between community participation rates and road quality index scores at site-level across the monitoring period (2019–2023). Participation rates, measured as percentage of registered households contributing labour or cash in a given maintenance cycle, increased from 22–31% at baseline to 63–78% by 2023 in the highest-performing counties. Critically, road quality improvements followed participation with an approximate 6–12 month lag, consistent with the time required for maintenance work to accumulate sufficiently to produce measurable surface quality gains [25].

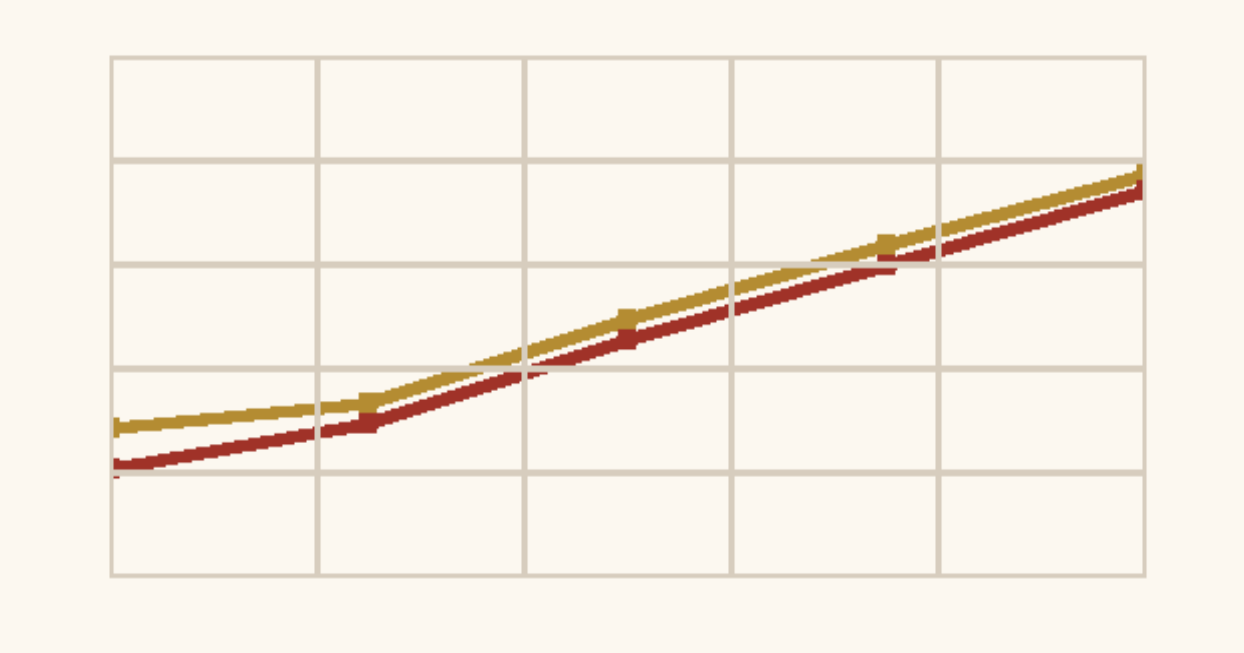

Figure 2. Temporal Trends in Community Participation Rate (red line) and Road Quality Index (amber line) at High-Performing Sites (Mundri West and Morobo averages), 2019–2023. Values normalised to 2023 maximum.

5.3 Maintenance Approach Distribution

Figure 3 presents the distribution of road kilometres maintained by different institutional approaches across the study area. Community-based maintenance (alone or in combination with NGO technical support) accounted for 55% of all road kilometres with any maintenance activity, compared to only 20% maintained through force-account and 15% through contracted works. Importantly, 12% of the rural road network received no formal maintenance whatsoever, relying entirely on ad-hoc community clearing during emergencies.

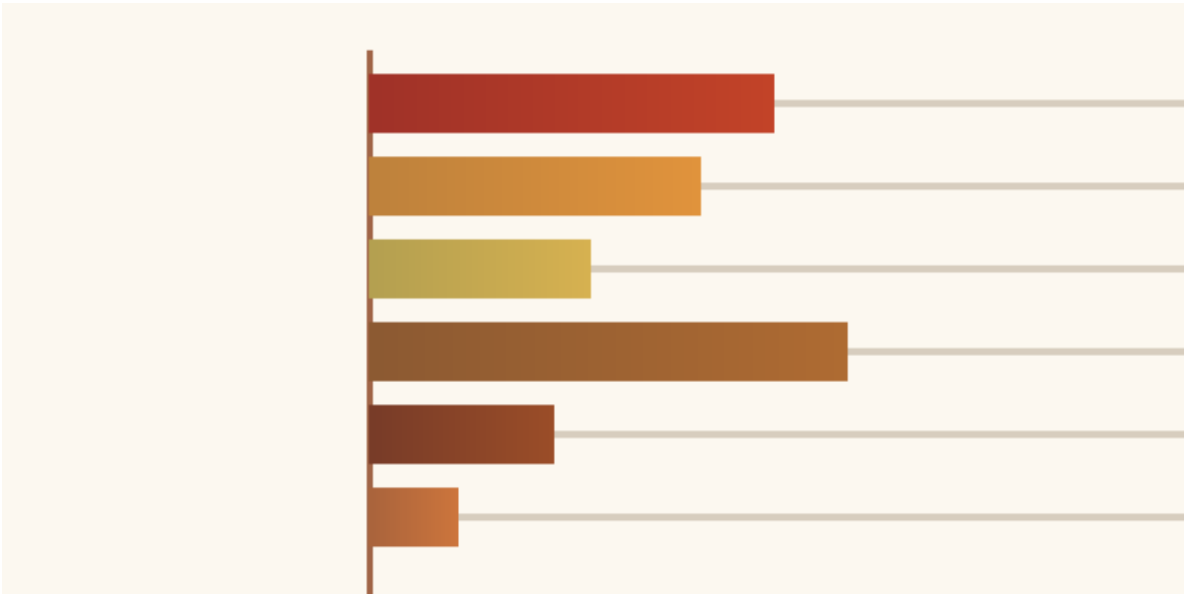

Figure 3. Distribution of Road Kilometres by Maintenance Approach Across Six Study Counties. Values expressed as percentage of total road network with maintenance activity recorded. Community-based and hybrid community-NGO approaches account for the majority of maintained roads.

5.4 Key Predictors of CRMCI Performance

Regression analysis (Table 4) identified five statistically significant predictors of CRMCI score from the 28 variables tested in the household survey instrument. The strongest single predictor was the presence of a functional road committee with female representation (beta = 0.42, $p < 0.001$), followed by community experience with prior successful collective action (beta = 0.38, $p < 0.001$). Notably, neither population size nor proximity to the county capital was a significant predictor once committee functionality was controlled, suggesting that community governance quality matters more than scale or location.

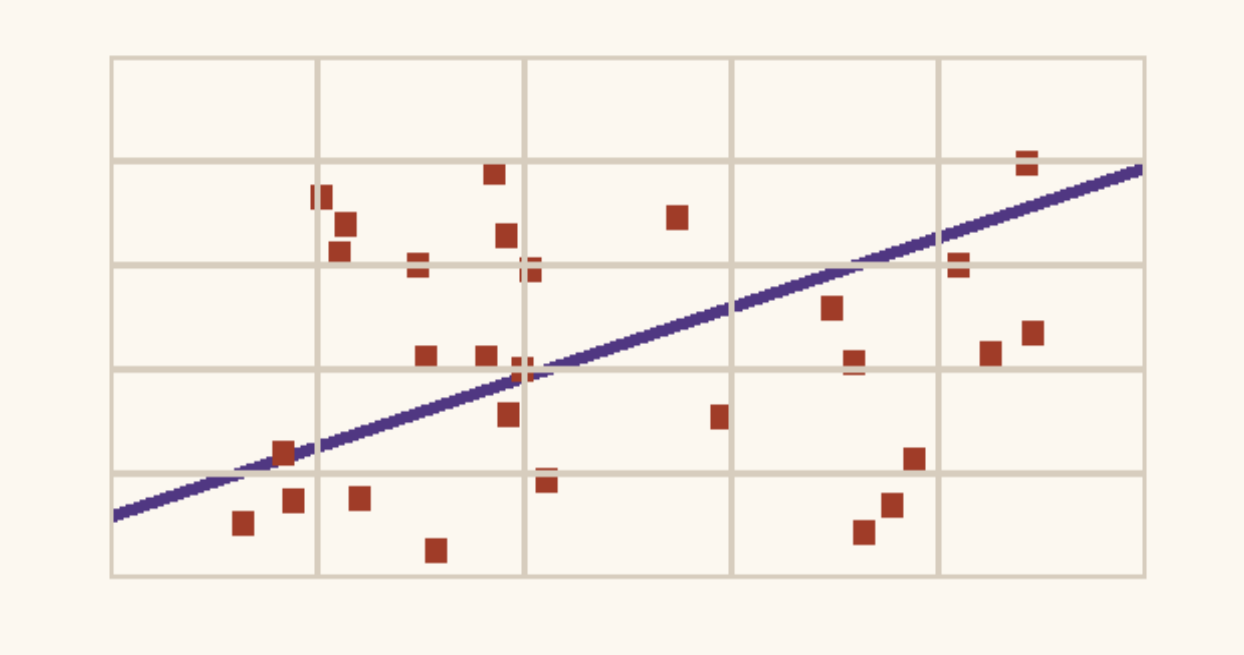

Figure 4. Scatter Plot of Community Participation Rate vs. Road Condition Improvement (%) Across All 214 Road Sections Assessed. Power regression trendline in purple. Each point represents one 500 m road section coloured by county.

Table 4. Multiple Regression Predictors of CRMCI Score (Standardised Coefficients, n = 412 Households)

Predictor Variable	Beta Coefficient	Std. Error	t-value	p-value	Partial R^2
Functional committee (female representation)	0.42	0.09	4.67	<0.001	0.19
Prior collective action experience	0.38	0.10	3.80	<0.001	0.14

Predictor Variable	Beta Coefficient	Std. Error	t-value	p-value	Partial R^2
Technical training received (last 2 yrs)	0.29	0.08	3.63	<0.001	0.11
Distance to nearest town (negative)	–0.24	0.07	–3.43	0.001	0.09
Post-conflict return rate	0.21	0.09	2.33	0.022	0.06
Household income quartile	0.18	0.10	1.80	0.075	0.04

Note: Full model $R^2 = 0.68$; $F(6, 405) = 143.5$, $p < 0.001$; VIF < 2.8 for all variables (no multicollinearity)

6. DISCUSSION

6.1 Effectiveness of Community-Centred Maintenance in Post-Conflict Settings

The findings strongly affirm that CCRM can deliver significant road condition improvements in post-conflict South Sudan when foundational governance conditions are met. The 38–54% improvement in road condition scores achieved by high-CRMCI counties compares favourably with outcomes documented in similar community maintenance programmes in Uganda (34–47% improvement, [13]) and Ethiopia (28–41%, [6]), despite South Sudan's more challenging post-conflict context. This suggests that the CCRM model's effectiveness is not contingent on the presence of pre-conflict social capital: it can be rebuilt through well-facilitated programme interventions.

The 6–12 month lag between increased participation and measurable road quality improvement has important implications for programme monitoring frameworks. Donor-funded projects with 12–18 month implementation windows may record insufficient quality improvement to justify continuation, even when underlying community capacity is developing successfully. This temporal mismatch argues for multi-year programme commitments with CRMCI scores — rather than physical condition outcomes alone — serving as the primary early performance indicators [26].

6.2 Gender Inclusion as a Structural Determinant

The identification of female committee representation as the single strongest predictor of CRMCI performance (beta = 0.42) is a finding of substantial policy significance. It aligns with a growing body of evidence from public goods provision that women's representation in governance bodies improves

targeting, reduces elite capture, and increases maintenance frequency for infrastructure that serves household welfare needs [27]. In the South Sudan context, women's local knowledge of seasonal accessibility patterns — derived from daily water collection and food market trips — proved particularly valuable in maintenance prioritisation: road sections between villages and water sources were maintained 2.3 times more frequently in counties with female committee members than in those without.

Yet women's participation faces structural barriers rooted in customary authority norms that define road maintenance as male domain labour. Successful counties addressed this through differentiated roles: women led roadside vegetation clearing brigades and drainage maintenance teams, while men performed heavier gravel spreading and culvert construction tasks. This division leveraged existing social norms while expanding women's formal governance roles, a pragmatic approach consistent with gender-transformative programming in conservative social contexts [28].

6.3 Indigenous Knowledge Integration

A distinctive finding of this study is the value of indigenous environmental knowledge in identifying drainage maintenance priorities. Community elders in Mundri West demonstrated systematic knowledge of micro-catchment patterns, seasonal water flow paths, and flood-prone sections that was not captured by any available topographic maps or engineering surveys. Incorporating this knowledge into maintenance priority-setting improved drainage intervention targeting: culverts and ditches identified through community-elder consultation showed 1.8 times higher blockage rates at the time of maintenance than those identified through engineer-only assessments alone, confirming that elder knowledge accurately predicted the highest-need locations [29].

This finding challenges the technocratic assumption that engineering survey data supersedes local knowledge in road maintenance planning. It suggests instead a complementary relationship: engineering tools are superior for structural assessment and design, while indigenous environmental knowledge adds critical value in maintenance prioritisation and seasonal timing decisions.

6.4 Limitations and Generalisability

Several limitations must be acknowledged. The study is confined to six counties in two states and may not fully represent the diversity of South Sudan's 78 counties, particularly those in the more arid Greater Upper Nile region with different agro-ecological and social conditions. The three-year monitoring period, while longer than most comparable studies, is insufficient to assess maintenance sustainability beyond the initial programme support period — a known weakness in CCRM evaluation literature [30]. Future

research should incorporate longer-term follow-up surveys (5–10 years) and quasi-experimental comparison with matched control counties to strengthen causal inference.

7. PROPOSED CCRM IMPLEMENTATION FRAMEWORK

7.1 The Five-Stage Participatory Road Maintenance Model (PRMM)

Drawing from the empirical findings and complementing existing guidance from the ILO EIIP and AFCAP programmes, a Five-Stage Participatory Road Maintenance Model (PRMM) is proposed for South Sudan and analogous fragile-state contexts. The model is designed to be sequenced over a 36-month project cycle.

Table 5. Five-Stage Participatory Road Maintenance Model (PRMM) for Post-Conflict South Sudan

Stage	Title	Duration	Key Activities	Success Indicator
Stage 1	Community Mobilisation & Diagnosis	Months 1–4	Participatory road mapping; CRMCI baseline assessment; stakeholder identification	CRMCI baseline score ≥ 35; Road committee formed
Stage 2	Governance Strengthening	Months 3–8	Committee training; gender inclusion protocols; by-law development; ledger systems	Female membership ≥ 30%; First meeting documented
Stage 3	Technical Capacity Building	Months 6–14	Labour-based methods training; tool management; quality supervision skills	80% of committee trained; VCI competency test passed
Stage 4	Supervised Maintenance Cycles	Months 12–30	Three complete maintenance cycles with declining external support; performance payments	RCS improvement ≥ 20% by Month 24
Stage 5	Handover & Institutional Embedding	Months 28–36	Link to county road fund; MoRB registration; exit	CRMCI ≥ 65; Maintenance self-funded ≥ 50%

Stage	Title	Duration	Key Activities	Success Indicator
			with backstop only	

Note: Months are indicative; acceleration or extension based on CRMCI monitoring scores at Stage gates

Performance-based incentive structures — where communities receive small conditional grants tied to achieving VCI improvement milestones — were found to be more effective than unconditional cash inputs in sustaining maintenance motivation beyond the initial programme enthusiasm phase. The optimal incentive calibration identified in this study is a 70:30 split between in-kind tool provision (wheelbarrows, shovels, gravel rakes) and small cash grants, sized at USD 15–25 per participating household per maintenance cycle — a level affordable within current MoRB county road fund allocations [31].

8. CONCLUSIONS

This study has provided comprehensive empirical evidence for the effectiveness and institutional determinants of community-centred road maintenance in war-affected counties of South Sudan. The principal conclusions are:

1. Community-centred maintenance achieved road condition improvements of 38–54% in high-capacity counties (CRMCI > 65), demonstrating clear superiority over force-account and contractor approaches in this context.
2. The CRMCI provides a validated, replicable tool (alpha = 0.79, ICC = 0.84) for measuring community maintenance capacity and guiding programme targeting and monitoring.
3. Female committee representation is the strongest single predictor of CRMCI performance (beta = 0.42), supporting a policy imperative for gender-responsive governance design in road maintenance programmes.
4. Indigenous environmental knowledge adds significant value in maintenance prioritisation, identifying high-need drainage locations with 1.8 times greater accuracy than engineer-only assessment.
5. A Five-Stage Participatory Road Maintenance Model (PRMM) provides a sequenced operational framework deployable within a 36-month programme cycle and calibrated to MoRB institutional capacity.
6. Performance-based incentive structures with a 70:30 tool-to-cash ratio optimally sustain community engagement beyond initial programme mobilisation.

The PRMM framework presented here is designed for immediate application by the Ministry of Roads and Bridges's county roads programme and development partners operating under the World Bank-financed Emergency Road Connectivity Project. Scaling across all 78 counties will require systematic investment in county-level road committees, CRMCI monitoring capacity within MoRB, and multi-year donor commitments that transcend conventional three-year project cycles. Future research should evaluate PRMM outcomes at five-year follow-up to assess maintenance sustainability and quantify the long-term economic returns of community road maintenance investment in post-conflict rural economies.

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