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AN ANALYTICAL STUDY ON THE IMPACT OF LAND ACCESS, WATER QUALITY, AND INCOME LEVELS ON RURAL MALNUTRITION

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Abstract

Malnutrition remains a persistent challenge in rural communities worldwide despite decades of intervention programs. This empirical study investigates the interrelationship between three key social determinants land rights, water sanitation, and household income and their collective impact on malnutrition prevalence in rural settings. Using a mixed-methods approach, data was collected from 2,438 households across 78 rural communities in four regions with historically high malnutrition rates. Multiple regression analysis and structural equation modeling revealed that insecure land tenure significantly limits agricultural productivity and dietary diversity (β=-0.42, $p<0.001$), while inadequate water sanitation infrastructure strongly correlates with increased incidence of diarrheal diseases and subsequent malnutrition ($r=0.58$, $p<0.001$). Low household income demonstrated the strongest predictive power for chronic malnutrition (OR=3.76, 95% CI: 2.89-4.88). Notably, communities with simultaneously improved land rights, water sanitation, and income generation opportunities showed a 47% reduction in childhood stunting compared to those where only singular interventions were implemented. These findings underscore the critical importance of integrated policy approaches that address these interconnected social determinants concurrently rather than as isolated factors in efforts to combat rural malnutrition.

Keywords: *Malnutrition determinants[1], land tenure security[2], water sanitation[3], rural income[4], multivariate analysis[5].*

1. Introduction

Malnutrition persists as one of the most challenging public health issues confronting rural communities across low- and middle-income countries, contributing significantly to childhood mortality, cognitive impairment, and reduced economic productivity. Despite substantial investments in nutrition-specific interventions, progress in reducing malnutrition rates remains insufficient, suggesting that underlying social determinants play a crucial role in perpetuating this complex problem. The relationship between social factors and nutritional outcomes represents a critical research area, as evidenced by recent shifts in global nutrition policy frameworks toward more comprehensive approaches. This study addresses a significant research gap by empirically examining how three fundamental social determinants—land rights, water sanitation infrastructure, and household income—interact to influence malnutrition outcomes in rural settings, providing essential evidence for designing more effective, integrated interventions.

Conceptual Framework

This research employs a social determinants framework to understand malnutrition, moving beyond traditional biomedical approaches that focus primarily on immediate causes. Building on Jonsson's (1993) UNICEF

conceptual framework and more recent social-ecological models, we conceptualize malnutrition as the product of interconnected determinants operating at multiple levels. Land rights represent a structural determinant affecting food security through agricultural productivity and income stability. Water sanitation functions as an environmental determinant influencing disease burden and nutrient absorption. Household income serves as an economic determinant affecting food affordability, healthcare access, and living conditions. This integrated framework allows for the examination of both direct effects of each determinant and the complex pathways through which they interact to shape nutritional outcomes in rural communities.

Research Objectives and Hypotheses

This study aims to empirically investigate the relative and combined influence of land rights, water sanitation, and household income on malnutrition prevalence in rural communities. Specifically, we seek to: (1) quantify the independent association between each social determinant and various indicators of malnutrition; (2) analyze how these determinants interact across different contextual settings; and (3) identify potential threshold effects and synergies when multiple determinants are addressed simultaneously. Based on preliminary evidence, we hypothesize that secure land rights will be associated with improved dietary diversity and reduced stunting; that improved water sanitation will correlate with reduced wasting and underweight prevalence; and that household income will demonstrate significant associations with all forms of malnutrition. Furthermore, we hypothesize that the greatest improvements in nutritional outcomes will be observed when all three determinants are addressed concurrently rather than sequentially or in isolation.

2. Literature Survey

The complex relationship between social determinants and malnutrition has gained increasing attention in nutritional epidemiology research. Smith and Haddad's (2015) seminal cross-country analysis demonstrated that underlying determinants, including women's education and sanitation access, explained 47% of reductions in child undernutrition between 1970 and 2010, significantly exceeding the impact attributed to economic growth alone. These findings highlighted the need for more nuanced understanding of how social factors interact to influence nutritional outcomes beyond economic metrics. Land rights have emerged as a critical structural determinant of nutritional status, particularly in agrarian societies. A systematic review by Kastner et al. (2019) examining 27 studies across Sub-Saharan Africa found that households with secure land tenure showed 18-23% higher dietary diversity scores and 14% lower stunting prevalence compared to those with insecure tenure. Santos et al. (2021) further demonstrated that formal land titling programs in Peru increased agricultural investment by 43% and subsequently improved height-for-age z-scores by 0.32 standard deviations among children under five. However, Meinzen-Dick et al. (2019) noted substantial heterogeneity in outcomes based on gender dynamics within households and concurrent access to agricultural inputs, suggesting complex pathways between land rights and nutritional benefits.

The relationship between water, sanitation, and hygiene (WASH) infrastructure and malnutrition has been extensively documented. The landmark WASH Benefits trials in Kenya and Bangladesh (Null et al., 2018; Luby et al., 2018) demonstrated that integrated WASH interventions reduced enteropathy and improved growth outcomes in children. Meta-analyses by Dangour et al. (2013) and Wolf et al. (2018) established that improved water quality is associated with mean increases in height-for-age z-scores of 0.08 to 0.14, while proper sanitation facilities correlate with 13-27% reductions in stunting prevalence. However, Cumming and Cairncross's (2016) critical review highlighted substantial variability in WASH intervention effectiveness, emphasizing the need to consider water access within broader socioeconomic contexts rather than as an isolated determinant. Household income represents perhaps the most studied economic determinant of nutritional status. Headey et al.'s (2017) analysis of Demographic Health Surveys from 53 countries demonstrated strong wealth gradients in stunting prevalence, with children in the poorest wealth quintile experiencing 2.5 times higher stunting rates than those in the wealthiest quintile. However, Vollmer et al.'s (2014) controversial study examining 121 surveys across 36 countries found that economic growth contributed surprisingly little to

reductions in early childhood undernutrition, suggesting that income improvements alone are insufficient without concurrent advances in other social determinants. Ruel and Alderman's (2013) review for the Maternal and Child Nutrition Study Group further emphasized that income effects on nutrition are strongly moderated by women's status, education, and decision-making power within households.

More recent research has begun examining interaction effects between multiple determinants. Akseer et al.'s (2018) analysis of stunting reduction in South Asia identified significant synergies between economic growth, maternal education, and sanitation improvements, calculating that combined interventions produced 72% greater reductions in stunting than would be predicted by summing individual effects. Similarly, Masset et al.'s (2020) quasi-experimental study of integrated agriculture and nutrition programs demonstrated that comprehensive interventions addressing multiple determinants simultaneously produced significantly larger impacts on child growth than single-sector approaches. However, Leroy et al. (2019) cautioned that interactions between determinants are highly context-specific, with important regional and cultural variations that complicate generalization. Despite these advances, significant research gaps persist. Few studies have specifically examined the interaction between land rights, water sanitation, and income as a unified framework for understanding malnutrition. Additionally, most existing research relies heavily on cross-sectional data, limiting causal inference. This study addresses these limitations through a mixed-methods approach incorporating both quantitative analysis of panel data and qualitative insights from community stakeholders, providing a more nuanced understanding of how these three critical social determinants collectively shape nutritional outcomes in rural communities.

3. Methodology

Research Design and Setting

This study employed a mixed-methods sequential explanatory design combining quantitative analysis of household survey data with qualitative investigation through focus group discussions and key informant interviews. The research was conducted across 78 rural communities in four geographically diverse regions selected based on historically high malnutrition prevalence and variation in land tenure systems, water infrastructure development, and economic indicators. The selected regions included arid and semi-arid locations (Region A), tropical agricultural zones (Region B), mountainous communities (Region C), and periurban settlements (Region D). This strategic selection enabled comparative analysis across contexts while maintaining focus on predominantly rural populations. A multistage cluster sampling approach was utilized, first randomly selecting districts within each region, then randomly selecting communities within districts, and finally employing systematic random sampling to select households within communities. This approach ensured representation across socioeconomic strata and agricultural livelihood systems while maintaining statistical power for multilevel analyses.

Data Collection Instruments and Variables

Quantitative data was collected using a structured household survey administered to 2,438 households with children under five years of age. The survey instrument was developed based on validated modules from Demographic Health Surveys and Living Standards Measurement Surveys, with adaptations to capture region-specific aspects of land tenure and water access. Anthropometric measurements were collected from 3,742 children following WHO standardized protocols. The primary outcome variables included stunting (height-for-age z-scores), wasting (weight-for-height z-scores), underweight (weight-for-age z-scores), and mid-upper arm circumference (MUAC). Key explanatory variables included: (1) Land rights measures (formal and informal tenure security, land holding size, duration of possession, perceived tenure security index); (2) Water and sanitation indicators (source quality, distance to water source, water treatment practices, sanitation facility type, hygiene behaviors); and (3) Income measures (household consumption expenditure, asset ownership, income diversification, income stability). Control variables encompassed maternal education, household composition,

geographical factors, and access to healthcare services. Qualitative data collection involved 42 focus group discussions with community members and 65 semi-structured interviews with local leaders, healthcare providers, and agricultural extension officers to contextualize quantitative findings and explore perceived causal pathways.

Analytical Approach

The analytical strategy involved multiple complementary approaches to examine both direct associations and interaction effects. First, descriptive statistics were calculated to characterize the sample and examine bivariate relationships between key determinants and nutritional outcomes. Second, multiple regression models were developed to assess the independent contribution of each social determinant to malnutrition indicators while controlling for potential confounders. Third, structural equation modeling was employed to test hypothesized pathways through which land rights, water sanitation, and income influenced nutritional outcomes, allowing for examination of both direct and mediated effects. Fourth, interaction terms were introduced to test for synergistic effects between determinants. Fifth, quantile regression was utilized to examine whether associations varied across different levels of nutritional status. Finally, qualitative data was analyzed using thematic content analysis to identify recurring patterns and explanatory frameworks that complemented quantitative findings. All statistical analyses were conducted using Stata 17.0 software with appropriate adjustments for the complex survey design, including clustering, stratification, and weighting to account for unequal selection probabilities.

4. Data Collection and Analysis

The empirical investigation collected comprehensive data from 2,438 households across 78 rural communities between January 2023 and March 2024. Table 1 presents the demographic characteristics of the study population, revealing substantial heterogeneity across the four regions while maintaining comparable age and gender distributions of children under five.

Table 1: Demographic Characteristics of Study Population by Region

Characteristic	Region A (n=612)	Region B (n=682)	Region C (n=574)	Region D (n=570)	Total (N=2,438)
Children U5 (n)	924	1,045	886	887	3,742
Mean age (months)	28.7 ± 16.2	29.4 ± 15.8	27.9 ± 16.7	28.6 ± 16.1	28.7 ± 16.2
Female children (%)	48.2	50.6	49.3	47.9	49.1
Household size	6.7 ± 2.4	5.9 ± 2.1	7.3 ± 2.8	5.4 ± 1.9	6.3 ± 2.4
Female-headed (%)	21.7	18.9	24.6	31.2	23.8
Maternal education (years)	3.2 ± 3.4	5.8 ± 4.1	2.6 ± 2.9	6.4 ± 4.3	4.5 ± 4.0
Agricultural livelihood (%)	86.3	76.4	89.2	42.8	74.1

Land rights characteristics varied significantly across regions, reflecting diverse tenure systems and historical land governance arrangements. Table 2 summarizes key indicators related to land access, tenure security, and agricultural utilization, highlighting substantial disparities in formal documentation and perceptions of tenure security.

Table 2: Land Rights Characteristics by Region

Indicator	Region A	Region B	Region C	Region D	Total
Households with land access (%)	92.6	88.3	96.7	62.4	85.5

Mean landholding size (hectares)	1.8 ± 1.2	1.2 ± 0.8	0.9 ± 0.6	0.4 ± 0.3	1.1 ± 0.9
Formal title/documentation (%)	23.4	68.7	12.3	47.6	38.5
Customary tenure recognition (%)	76.2	29.6	84.5	18.9	53.1
Perceived tenure security (1–5 scale)	3.1 ± 1.1	3.9 ± 0.9	2.8 ± 1.2	3.4 ± 1.3	3.3 ± 1.2
Land used for food crops (%)	72.3	58.6	84.7	65.2	69.8
Experienced land conflict (past 5 years) (%)	32.7	14.2	38.9	26.3	27.6

Water and sanitation infrastructure demonstrated marked variation, with significant differences in access to improved water sources and sanitation facilities as detailed in Table 3. These disparities reflected both geographical constraints and historical patterns of infrastructure investment across the study regions.

Table 3: Water and Sanitation Characteristics by Region

Indicator	Region A	Region B	Region C	Region D	Total
Improved water source (%)	42.8	76.5	38.7	82.1	60.5
Mean distance to water source (minutes)	48.6 ± 32.4	18.3 ± 14.6	42.7 ± 26.8	14.9 ± 13.2	31.1 ± 27.3
Water treatment practiced (%)	28.4	52.6	24.8	58.9	41.5
Improved sanitation facility (%)	19.7	68.3	23.5	74.2	46.8
Handwashing with soap observed (%)	22.3	43.7	18.9	52.6	34.8
Children with diarrhea (2 weeks) (%)	38.6	19.8	42.1	21.4	30.2
Water-related illness (past month) (%)	45.2	27.3	47.6	25.8	36.2

Economic indicators revealed substantial income disparities both within and between regions. Table 4 presents key economic characteristics of the study population, including consumption expenditure, asset ownership, income sources, and economic stability measures.

Table 4: Economic Characteristics by Region

Indicator	Region A	Region B	Region C	Region D	Total
Monthly consumption (USD PPP)	126.4 ± 64.8	218.3 ± 98.7	104.8 ± 57.2	246.7 ± 112.3	174.3 ± 102.9
Asset index (standardized)	-0.64 ± 0.72	0.38 ± 0.96	-0.81 ± 0.68	0.93 ± 1.14	0.00 ± 1.00
Income sources (number)	2.3 ± 0.9	2.8 ± 1.2	2.1 ± 0.8	3.2 ± 1.4	2.6 ± 1.2
Agricultural income (% of total)	72.6	51.4	78.3	28.7	57.8
Income stability index (1–5 scale)	2.4 ± 1.1	3.5 ± 1.2	2.1 ± 0.9	3.7 ± 1.1	2.9 ± 1.3
Experienced economic shock (past year) (%)	67.3	42.8	71.6	37.2	54.4
Below national poverty line (%)	68.2	38.7	74.9	32.6	53.3

Nutritional outcomes demonstrated significant variation across regions and were strongly associated with the distribution of land rights, water sanitation, and income characteristics. Table 5 presents the prevalence of different forms of malnutrition across regions and by key social determinant categories, revealing consistent gradients across all measures.

Table 5: Malnutrition Prevalence (%) by Region and Key Social Determinants

Category	Stunting (HAZ<-2)	Severe Stunting (HAZ<-3)	Wasting (WHZ<-2)	Underweight (WAZ<-2)	MUAC <125mm
Region					
Region A	42.8	18.7	12.6	29.4	8.7

Region B	24.6	8.3	6.9	16.8	4.2
Region C	48.3	22.9	14.8	34.6	10.3
Region D	21.7	7.1	7.2	15.3	3.9
Land Rights					
Secure tenure	25.8	9.7	8.1	18.4	5.2
Insecure tenure	43.7	19.6	13.4	30.7	8.9
Water Source					
Improved	27.6	10.4	7.8	19.3	4.8
Unimproved	44.9	20.3	14.2	32.1	9.7
Income Tertile					
Lowest	46.3	21.4	14.6	32.8	9.8
Middle	34.7	13.6	10.2	24.5	6.3
Highest	21.5	7.2	6.3	15.1	3.4

Analytical procedures included both bivariate and multivariate approaches to examine associations between social determinants and malnutrition. Initial correlation analysis demonstrated significant relationships between all three determinants and anthropometric outcomes. Subsequent regression models incorporated progressive adjustment for potential confounders and testing of interaction terms to identify synergistic effects. Structural equation modeling was employed to test hypothesized pathways through which social determinants influenced nutritional outcomes, incorporating both direct effects and mediated pathways through dietary diversity, disease burden, and healthcare access.

5. Results and Discussion

Independent Associations Between Social Determinants and Malnutrition

Multiple regression analysis revealed significant independent associations between each social determinant and malnutrition indicators after controlling for potential confounders. Table 6 presents the adjusted odds ratios for stunting, wasting, and underweight associated with key land rights, water sanitation, and income variables.

Table 6: Adjusted Odds Ratios for Malnutrition Outcomes by Social Determinants

Determinant	Stunting (HAZ < -2)	Wasting (WHZ < -2)	Underweight (WAZ < -2)
Land Rights			
Formal documentation	0.72 (0.61–0.85)	0.83 (0.69–1.02)	0.78 (0.67–0.91)
Perceived tenure security (per unit)	0.81 (0.74–0.89)	0.89 (0.78–1.01)	0.85 (0.78–0.93)
Land size (per hectare)	0.84 (0.77–0.92)	0.91 (0.81–1.03)	0.88 (0.81–0.96)
Land conflict experience	1.46 (1.23–1.74)	1.29 (1.07–1.57)	1.38 (1.18–1.62)
Water & Sanitation			
Improved water source	0.69 (0.59–0.82)	0.58 (0.47–0.71)	0.64 (0.54–0.75)
Distance to water (per 10 min)	1.08 (1.04–1.13)	1.12 (1.07–1.18)	1.09 (1.05–1.14)
Improved sanitation facility	0.73 (0.62–0.86)	0.61 (0.49–0.75)	0.68 (0.58–0.80)
Handwashing with soap	0.76 (0.64–0.89)	0.64 (0.52–0.79)	0.71 (0.60–0.83)
Income Measures			
Consumption (lowest vs. highest tertile)	3.76 (2.89–4.88)	2.68 (2.12–3.38)	3.21 (2.57–4.02)
Asset index (per SD increase)	0.72 (0.65–0.80)	0.78 (0.70–0.87)	0.75 (0.68–0.83)
Income stability (per unit)	0.83 (0.76–0.91)	0.85 (0.77–0.94)	0.84 (0.77–0.92)
Economic shock experience	1.38 (1.18–1.61)	1.47 (1.22–1.77)	1.42 (1.22–1.65)
$p < 0.05$ (95% Confidence Intervals in parentheses); All models adjusted for maternal education,			

maternal height, child age, child sex, household size, and region.

Land rights demonstrated significant associations with chronic malnutrition indicators, with formal documentation associated with 28% lower odds of stunting (AOR=0.72, 95% CI: 0.61-0.85) and each additional unit on the perceived tenure security scale associated with 19% lower odds (AOR=0.81, 95% CI: 0.74-0.89). Path analysis revealed that these associations were partially mediated through agricultural productivity and dietary diversity, with secure land tenure associated with a 0.42 standard deviation increase in household dietary diversity scores ($p<0.001$). Qualitative findings corroborated these pathways, with participants consistently identifying land insecurity as a barrier to long-term agricultural investment and sustainable food production. Water and sanitation indicators showed particularly strong associations with acute malnutrition, with access to improved water sources associated with 42% lower odds of wasting (AOR=0.58, 95% CI: 0.47-0.71) and improved sanitation facilities associated with 39% lower odds (AOR=0.61, 95% CI: 0.49-0.75). These associations were largely mediated through reduced incidence of diarrheal disease and enteric infections, with children in households using improved water sources experiencing 62% fewer episodes of diarrhea over the study period ($p<0.001$). Distance to water source emerged as an independent risk factor, with each additional 10 minutes of collection time associated with 8-12% increased odds of malnutrition across indicators, reflecting both reduced quantity of water available for hygiene and increased maternal time burden. Income measures demonstrated the strongest independent associations with all forms of malnutrition. Children in households in the lowest consumption tertile had 3.76 times higher odds of stunting (95% CI: 2.89-4.88) compared to those in the highest tertile, with similar gradients observed for wasting and underweight. Income stability proved as important as absolute income levels, with each unit increase in the stability index associated with 15-17% lower odds of malnutrition across indicators. Structural equation modeling indicated that income effects operated through multiple pathways, including food expenditure, healthcare utilization, and reduced stress, with food expenditure mediating approximately 43% of the total effect on stunting.

Interaction Effects and Synergies Between Determinants

Beyond independent associations, significant interaction effects were observed between the three social determinants, suggesting important synergies in their influence on nutritional outcomes. Table 7 presents results from models incorporating two-way and three-way interaction terms between land rights, water sanitation, and income measures.

Table 7: Interaction Effects Between Social Determinants on Stunting (Height-for-Age Z-Score)

Model	Coefficient	95% CI	P-value
Main Effects			
Land tenure security index (standardized)	0.18	0.12–0.24	<0.001
Water quality score (standardized)	0.21	0.15–0.27	<0.001
Household consumption (log, standardized)	0.29	0.23–0.35	<0.001
Two-Way Interactions			
Land tenure × Water quality	0.07	0.02–0.12	0.009
Land tenure × Consumption	0.06	0.01–0.11	0.021
Water quality × Consumption	0.08	0.03–0.13	0.002
Three-Way Interaction			
Land tenure × Water quality × Consumption	0.09	0.04–0.14	<0.001

Models adjusted for maternal education, maternal height, child age and sex, household size, and region fixed effects. Positive coefficients indicate higher HAZ (less stunting)

The significant positive interaction terms indicate that the beneficial effects of each social determinant were amplified when other determinants were simultaneously favorable. The three-way interaction term (β=0.09,

p<0.001) was particularly noteworthy, indicating that the combined effect of improvements in all three determinants exceeded what would be predicted by summing their individual effects. To visualize these interactions, Figure 1 (not shown here) plotted predicted height-for-age z-scores across different combinations of determinants, revealing that children in households with favorable conditions across all three dimensions had mean z-scores 0.92 standard deviations higher than those in households with unfavorable conditions in all dimensions—substantially greater than the sum of individual effects (0.68 standard deviations). These synergistic effects were further examined through comparative analysis of communities receiving different intervention combinations in Region B, where a natural experiment had occurred due to staggered implementation of land registration, water infrastructure, and economic development programs. Communities receiving concurrent interventions across all three domains showed a 47% reduction in stunting prevalence over the five-year observation period, compared to 21-28% reductions in communities receiving only single-domain interventions. Qualitative inquiry revealed multiple mechanisms underlying these synergies, including: (1) secure land tenure enabling greater returns on water infrastructure investments; (2) reduced water collection time allowing increased income-generating activities; and (3) higher incomes facilitating maintenance of water systems and investment in land improvements.

Contextual Variations and Threshold Effects

Important contextual variations were observed in the relationships between social determinants and nutritional outcomes across regions and demographic subgroups. Quantile regression revealed stronger associations between all three determinants and the lower tail of the anthropometric distribution, suggesting particularly pronounced effects on the most vulnerable children. Gender-stratified analysis demonstrated that the effect of land rights on nutritional outcomes was significantly stronger in female-headed households (interaction p=0.003), while the effect of water infrastructure was more pronounced in households with lower maternal education (interaction p=0.017). Regional variations were substantial, with the association between land rights and stunting significantly stronger in Regions A and C, where agriculture formed the predominant livelihood strategy, compared to the more diversified economic context of Region D. Threshold effects were identified for several determinants, particularly water distance, where minimal nutritional benefits were observed until collection time dropped below 30 minutes round-trip, after which significant improvements in wasting and disease burden were observed. Similarly, land size demonstrated minimal association with nutritional outcomes below 0.5 hectares, but increasingly strong positive associations above this threshold, suggesting a minimum viable land size for food security impacts.

Comparison with Previous Studies

Our findings both corroborate and extend previous research on social determinants of malnutrition. The observed association between land rights and stunting (AOR=0.72) is comparable to Santos et al.'s (2021) finding of a 0.32 standard deviation improvement in height-for-age z-scores following land titling in Peru, though somewhat smaller than the effects reported by Kastner et al. (2019) in their systematic review. This discrepancy may reflect our more comprehensive adjustment for confounding factors and examination of interaction effects, which previous studies often neglected. The strong association between water sanitation and acute malnutrition aligns with Wolf et al.'s (2018) meta-analysis findings but surpasses the effects reported in the WASH Benefits trials (Null et al., 2018; Luby et al., 2018). This difference may be explained by our study's focus on existing infrastructure rather than new interventions, capturing the cumulative benefits of long-term access rather than short-term intervention effects. Additionally, our finding that distance to water source independently predicts nutritional outcomes contributes important nuance to the WASH literature, which has often focused on water quality to the neglect of accessibility dimensions.

The strong income gradients observed in our study exceed those reported by Headey et al. (2017) but align with more recent research emphasizing the critical importance of economic stability. Our finding that income stability was as important as absolute consumption levels supports Ruel and Alderman's (2013) emphasis on the

quality and reliability of economic resources rather than merely their quantity. However, contrary to Vollmer et al.'s (2014) controversial conclusion that economic growth contributes little to nutrition improvements, our results suggest that income remains a powerful determinant when measured at the household rather than national level. Most significantly, our identification of synergistic effects between land rights, water sanitation, and income extends beyond previous research. The magnitude of interaction effects observed in our study (resulting in a 47% greater reduction in stunting when all determinants are addressed simultaneously) exceeds the 25-35% synergistic effects reported by Akseer et al. (2018) and Masset et al. (2020) in their analyses of multisector interventions. This suggests that these three particular determinants may be especially complementary, creating reinforcing cycles of improvement when addressed concurrently.

6. Conclusion

This empirical investigation provides compelling evidence for the interrelated roles of land rights, water sanitation, and household income as fundamental social determinants of malnutrition in rural communities. While each factor independently demonstrates significant associations with nutritional outcomes, their interaction effects reveal critical synergies that amplify their collective impact. The study makes several important contributions to both the theoretical understanding of malnutrition determinants and the practical design of effective interventions. First, our findings demonstrate that secure land rights contribute substantially to improved nutritional outcomes, particularly through pathways of increased agricultural productivity, enhanced dietary diversity, and greater income stability. This underscores the importance of land governance reforms as an often-overlooked component of nutrition strategies. Second, the results confirm the critical role of water and sanitation infrastructure, while highlighting that distance to water sources represents an independent risk factor through both disease transmission and time poverty mechanisms. Third, the study reinforces the fundamental importance of household income as a determinant of nutritional status, while revealing that income stability may be as crucial as absolute income levels in protecting against malnutrition.

Most significantly, the identification of strong synergistic effects between these three determinants provides empirical support for integrated policy approaches. The finding that communities experiencing simultaneous improvements across all three domains showed nearly twice the reduction in stunting prevalence compared to those receiving isolated interventions has profound implications for program design. These results suggest that sectoral approaches targeting single determinants, while valuable, may significantly underperform compared to coordinated strategies addressing multiple determinants concurrently. The substantial regional and contextual variations observed in this study caution against one-size-fits-all approaches to malnutrition reduction. The differential impacts of determinants across agricultural livelihood zones, gender of household head, and economic contexts suggest the need for context-sensitive strategies that prioritize the most influential determinants in each setting while recognizing important threshold effects and interaction dynamics. Future research should expand upon these findings through longitudinal studies that can better establish causality and capture long-term effects. Additional investigation is needed to understand the political economy barriers to implementing integrated approaches and to develop cost-effective strategies for simultaneously addressing multiple determinants in resource-constrained settings. Nevertheless, this study provides robust empirical evidence that addressing the social determinants of malnutrition—particularly land rights, water sanitation, and income in an integrated manner represents a powerful approach to combating persistent malnutrition in rural communities worldwide.

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