Household-level land fragmentation and food security implications of land consolidation in the Terai region of Nepal: A case study of Lakshmaniya Rural Municipality

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https://doi.org/10.51867/ajernet.7.2.93

ABSTRACT

Agricultural land fragmentation remains a major constraint to efficient farming in Nepal, where many agricultural households operate several small and spatially separated parcels rather than a single compact holding. Theory of Land Fragmentation and Farm Efficiency anchored this research. This study assessed household-level land fragmentation and its food-security implications in selected settlements of Lakshmaniya Rural Municipality in the Terai region of Nepal. This study adopted a cross-sectional household-level analytical research design. The target population consisted of agricultural households operating land parcels in the selected settlements. A settlement-wise random household survey was conducted among 396 sampled households from 12 settlements using a structured questionnaire. Fragmentation was measured using parcel-based indicators, including parcel count, average parcel size, parcels per hectare, and land per capita. The analysis used descriptive statistics, cross-tabulation, chi-square tests, Cramér's V, ordered logistic regression, and a simple land-consolidation scenario. The results showed a mean family size of 6.90 persons, a mean parcel count of 5.88, and a mean operated land area of 0.78 ha, with 47.73% of households falling into the high-fragmentation class. Food sufficiency and irrigation status were significantly associated with fragmentation class, whereas self-reported productivity perception was not. After controlling for operated area and family size, higher parcels per hectare were associated with lower odds of being in a better food-sufficiency category, while larger operated area was associated with higher odds. Under the one-parcel consolidation scenario, mean parcel count declined from 5.88 to 1.00, average parcel size increased from 1,190.71 m² to 7,845.81 m², and parcels per hectare decreased from 10.28 to 3.43. These findings suggest that land consolidation could substantially reduce operational fragmentation and create more favourable conditions for efficient farm management and improved household food security. Therefore, local governments and land-management agencies should prioritize participatory land-consolidation pilot programs in highly fragmented settlements, supported by updated cadastral information, irrigation improvement, farm-road access, mechanization support, and farmer-centered implementation mechanisms.

Keywords: Land Consolidation, Land Fragmentation, Food Security, Food Sufficiency, Nepal

I. INTRODUCTION

Agricultural land fragmentation refers to a condition in which a farm holding is divided into several spatially separated parcels that are often small, scattered, and irregular in shape. It has long been recognized as a major constraint to efficient agricultural development because it increases management complexity, raises travel and labour requirements, complicates irrigation and input delivery, and limits the effective use of machinery and improved farming technologies (Demetriou et al., 2013; Niroula & Thapa, 2005). Fragmented landholding systems may also contribute to reduced food production, increased farming costs, land disputes, and higher transaction costs associated with agricultural land management (Air & Ghimire, 2016).

Land consolidation is widely considered an important land-management approach for reducing the negative effects of farmland fragmentation. It involves the readjustment, reallocation, or reorganization of fragmented and scattered land parcels into fewer, larger, and more operationally efficient units to improve agricultural productivity and land-use efficiency (de Vries, 2022). In practice, land consolidation may include parcel reallocation, voluntary land exchange, cooperative block farming, or other locally acceptable institutional arrangements depending on socio-economic conditions, land tenure patterns, and farmers' willingness to participate (Thapa & Niroula, 2008; Pun et al., 2024).

In Nepal, agricultural land fragmentation remains a persistent land-management challenge. It is mainly driven by inheritance-based subdivision, demographic pressure, declining average landholding size, limited non-farm employment opportunities, and weakly coordinated land-use planning. Previous studies have shown that the

continuous subdivision of land among heirs has increased parcel numbers and reduced operational farm efficiency (Thapa & Niroula, 2008; Paudel et al., 2013). Evidence from Nawalparasi also indicates that fragmented holdings increase labour demand, field-management burden, and inefficiency in the use of farm inputs and equipment (Dhakal & Khanal, 2018). Similarly, the increasing conversion and fragmentation of agricultural land have been identified as important challenges for food security in Nepal (Paudel et al., 2013).

The policy relevance of land consolidation in Nepal is reflected not through a single stand-alone consolidation law, but through a broader framework of land-use and land-management legislation. Existing legal and regulatory provisions related to land survey, land ownership, land use, and land management provide an institutional basis for controlling fragmentation, promoting planned land use, and supporting area-based development interventions in designated locations (Government of Nepal, 1963, 1964, 2019, 2022). These provisions create an important legal context within which consolidation-oriented planning and implementation can be discussed.

Although detailed cadastral parcel geometry allows more advanced measurement of land fragmentation, many empirical studies continue to use parcel-based indicators when the available data are collected through household surveys rather than parcel maps. Commonly used indicators include parcel count, holding size, average parcel size, and size-adjusted fragmentation intensity measures such as parcels per hectare (Demetriou et al., 2013). International evidence further suggests that land fragmentation can reduce farm productivity and technical efficiency, while larger and more compact operational parcels may improve agricultural performance (Rahman & Rahman, 2009; Looga et al., 2018).

Despite the recognized importance of this issue, household-level empirical evidence linking land fragmentation, food sufficiency, irrigation status, productivity perception, and potential land consolidation outcomes remains limited in the Terai region of Nepal. This study therefore focuses on selected settlements of Lakshmaniya Rural Municipality and assesses household-level land fragmentation using parcel-based indicators. It also examines the association of fragmentation with food sufficiency, irrigation status, and productivity perception, and evaluates a simple land-consolidation scenario to discuss its possible implications for operational efficiency and household food security.

1.2 Research Objectives

The main objective of this study is to assess household-level land fragmentation and examine the potential role of land consolidation in improving farm management and household food security in selected settlements of Lakshmaniya Rural Municipality, Nepal. Specifically, the study measures land fragmentation using parcel-based indicators, classifies households according to fragmentation level and settlement-wise variation, examines the association of fragmentation with food sufficiency, irrigation status, and productivity perception, and evaluates the potential effect of land consolidation in reducing operational fragmentation.

II. LITERATURE REVIEW

2.1 Theoretical Review

This study is guided by the theoretical relationship between land fragmentation, farm operational efficiency, and household food security. Land fragmentation occurs when a farm holding is divided into several small and spatially separated parcels, which increases travel time, labour demand, field-management difficulty, and transaction costs in agricultural production (Niroula & Thapa, 2005; Demetriou et al., 2013). Fragmented holdings may also reduce the efficiency of irrigation management, input application, and mechanized farming, thereby affecting overall agricultural performance (Dhakal & Khanal, 2018).

From the perspective of farm efficiency, the physical structure of landholdings directly influences agricultural operation and productivity. Larger and more compact parcels are generally associated with easier farm management, better access to irrigation, lower movement costs, and improved use of agricultural technologies. In contrast, small and scattered parcels create operational inefficiencies and may reduce productivity and technical efficiency (Rahman & Rahman, 2009; Looga et al., 2018). Therefore, parcel count, average parcel size, parcels per hectare, and land per capita can be used as practical indicators to assess household-level land fragmentation.

Land consolidation provides a theoretical solution to the problems created by fragmentation. It involves the reorganization, readjustment, or reallocation of scattered land parcels into fewer and larger operational units to improve land-use efficiency and agricultural performance (de Vries, 2022). In Nepal, land consolidation has also been discussed as a possible strategy to reduce the negative impacts of inheritance-based land subdivision and improve the operational structure of agricultural holdings (Thapa & Niroula, 2008; Pun et al., 2024).

Based on this theoretical understanding, the present study assumes that higher land fragmentation may negatively affect farm management and household food sufficiency, while land consolidation may improve operational conditions by reducing parcel numbers and increasing average parcel size.

2.1.1 Theory of Land Fragmentation and Farm Efficiency

The theory of land fragmentation and farm efficiency explains that the structure of agricultural landholdings influences the efficiency of farm operations. When households operate many small and scattered parcels, farming becomes more time-consuming and costlier because farmers must move between plots, manage separate boundaries, arrange irrigation separately, and apply inputs across dispersed fields (Niroula & Thapa, 2005; Demetriou et al., 2013). Such conditions reduce the efficiency of labour, irrigation, and mechanization.

In contrast, consolidated and compact landholdings support better farm planning, easier input application, improved irrigation management, and greater suitability for mechanized farming. Studies have shown that land fragmentation can reduce productivity and technical efficiency, while larger and more operationally efficient parcels can improve agricultural performance (Rahman & Rahman, 2009; Looga et al., 2018). Therefore, land consolidation is theoretically expected to reduce operational fragmentation and create favourable conditions for improved farm management, productivity, and household food security (de Vries, 2022; Pun et al., 2024).

2.2 Empirical Review

2.2.1 Measurement of Land Fragmentation

Several studies have measured land fragmentation using parcel-based and spatial indicators. Demetriou et al. (2013) emphasized that land fragmentation can be measured through parcel number, parcel size, parcel shape, distance between parcels, and holding structure. However, in many household-level studies where detailed cadastral geometry is not available, simple parcel-based indicators are commonly used. These include parcel count, total holding size, average parcel size, parcels per hectare, and land per capita.

Niroula and Thapa (2005) identified land fragmentation as a major agricultural problem in South Asia and highlighted its negative consequences for farm efficiency. Similarly, Thapa and Niroula (2008) noted that land subdivision through inheritance has increased parcel numbers and reduced the operational efficiency of agricultural holdings in Nepal. These findings support the use of parcel-based indicators for examining household-level fragmentation, especially in areas where farm parcels are small, scattered, and managed under traditional landholding systems.

2.2.2 Land Fragmentation and Agricultural Outcomes

Land fragmentation can influence agricultural outcomes through its effects on farm management, irrigation access, input use, and labour allocation. Paudel et al. (2013) reported that agricultural land fragmentation and land conversion are important challenges for food security in Nepal. Fragmented holdings may reduce the efficiency of cultivation by increasing travel time, complicating irrigation layout, and limiting the effective use of farm machinery and improved technologies.

International evidence also supports the negative relationship between land fragmentation and farm performance. Rahman and Rahman (2009), in a study of rice producers in Bangladesh, found that land fragmentation negatively affected productivity and technical efficiency. Similarly, Looga et al. (2018) reported that land fragmentation was one of the determinants affecting agricultural farm productivity in Estonia. These studies suggest that fragmentation can have implications for agricultural productivity, household food sufficiency, and farm efficiency.

2.2.3 Land Consolidation and Productivity Gains

Land consolidation has been widely discussed as a strategy to reduce the negative effects of land fragmentation. De Vries (2022) described land consolidation as a process that reorganizes fragmented parcels into more efficient land units to improve land-use management and agricultural production. Consolidation can reduce the number of parcels, increase average parcel size, improve farm accessibility, and create better conditions for irrigation and mechanization.

In the context of Nepal, Thapa and Niroula (2008) discussed alternative options for land consolidation and emphasized the importance of local participation and institutional feasibility. More recently, Pun et al. (2024) highlighted that farmers' preferences and willingness are important factors in farmland consolidation. These studies suggest that land consolidation should not be viewed only as a technical land readjustment process, but also as a social and institutional intervention requiring farmer acceptance, policy support, and locally suitable implementation mechanisms.

2.2.4 Research Gap

The reviewed literature shows that land fragmentation is a major agricultural and land-management problem in Nepal and other countries. Previous studies have examined its causes, consequences, and possible solutions, including land consolidation. However, household-level empirical evidence linking parcel-based fragmentation

indicators with food sufficiency, irrigation status, productivity perception, and consolidation scenarios remains limited in the Terai region of Nepal.

This study addresses this gap by assessing household-level land fragmentation in selected settlements of Lakshmaniya Rural Municipality. It measures fragmentation using parcel-based indicators, classifies households by fragmentation level, examines the association of fragmentation with food-security-related outcomes, and evaluates a simple land-consolidation scenario to understand its potential contribution to reducing operational fragmentation.

III. METHODOLOGY

3.1 Research Design

This study adopted a cross-sectional household-level analytical research design. The design was appropriate because the study assessed the existing condition of agricultural land fragmentation and examined its association with selected household-level agricultural and food-security-related variables at a single point in time. The household was used as the unit of analysis because landholding size, parcel count, family size, food sufficiency, irrigation status, and productivity perception were recorded at the household level. The study used quantitative methods to measure land fragmentation through parcel-based indicators and to examine its relationship with selected agricultural outcomes. In addition, a simple land-consolidation scenario was applied to evaluate the potential structural improvement in landholding conditions after reducing operational parcel fragmentation.

3.2 Study Area

The study was conducted in selected settlements of Lakshmaniya Rural Municipality, located in the Terai region of Nepal, as shown in Figure 1. According to the Population Census 2021, Lakshmaniya Rural Municipality covers an area of 30.66 square kilometers and has a total population of 31,881 with 6,301 households. The municipality is adjacent to Janakpur Sub-Metropolitan City, and agriculture is one of the major occupations of the local population.

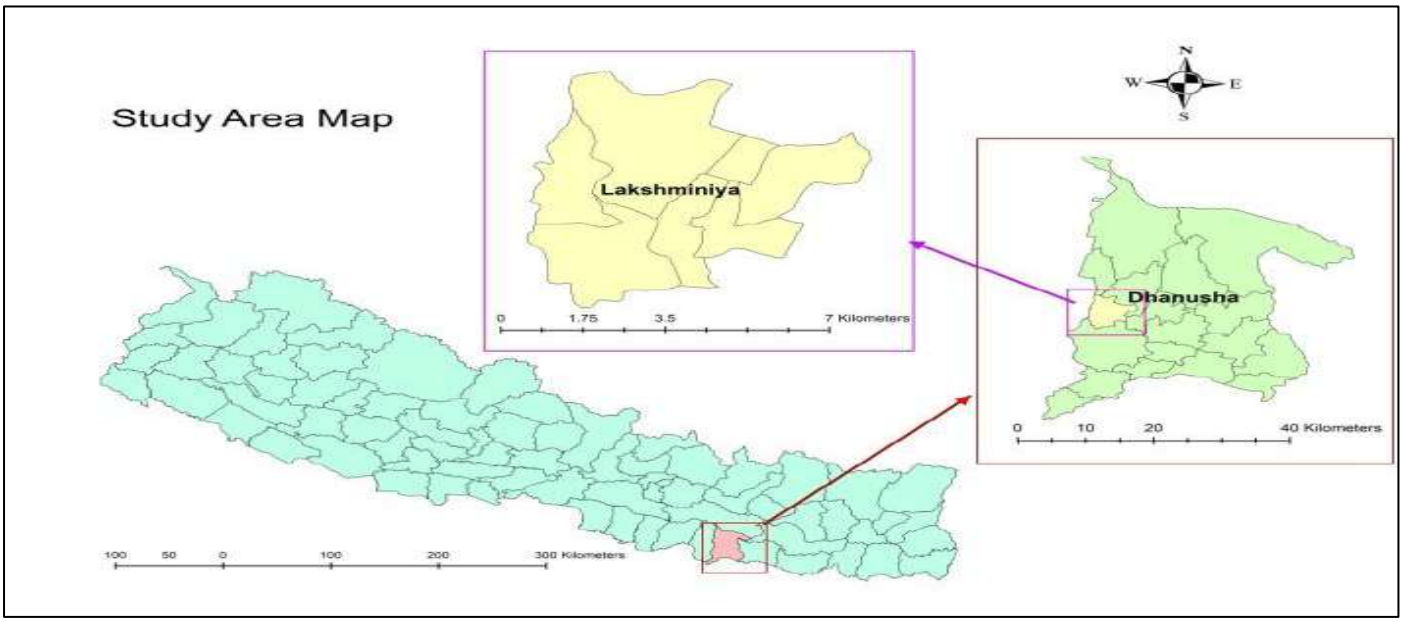

Figure 1

Study area map of Lakshmaniya Rural Municipality

3.3 Target Population

The target population of this study consisted of all agricultural households in the selected settlements of Lakshmaniya Rural Municipality. Since agriculture is the dominant occupation in the study area, the households of the selected settlements were considered relevant for assessing household-level land fragmentation, landholding structure, food sufficiency, irrigation status, and productivity perception. Therefore, the study focused on agricultural households operating land parcels within the selected settlements.

3.4 Sampling Techniques and Sample Size

A settlement-wise random sampling technique was used to select households for the study. First, 12 settlements of Lakshmaniya Rural Municipality were considered for household-level data collection. Then, sample

households were selected randomly from each settlement to ensure representation of different localities within the study area. The final sample consisted of 396 households from Dohair, Kumharouda, Bagewa, Sohani, Gajariya, Sinurjoda, Bhangaha, Nikal, Bainigama, Aligesawa, Sapahi, and Baniniya settlements, as shown in Table 1 and Figure 2. The sample size was considered adequate for examining household-level land fragmentation patterns, settlement-wise variation, and the association of fragmentation with food sufficiency, irrigation status, and productivity perception.

Table 1

Distribution of Sampled Households by Settlement

S.N.	Settlement	Number of households	Percentage (%)
1	Dohair	20	5.05
2	Kumharouda	26	6.57
3	Bagewa	38	9.60
4	Sohani	61	15.40
5	Gajariya	25	6.31
6	Sinurjoda	40	10.10
7	Bhangaha	42	10.61
8	Nikal	37	9.34
9	Bainigama	29	7.32
10	Aligesawa	19	4.80
11	Sapahi	34	8.59
12	Baniniya	25	6.31
Total		**396**	**100.00**

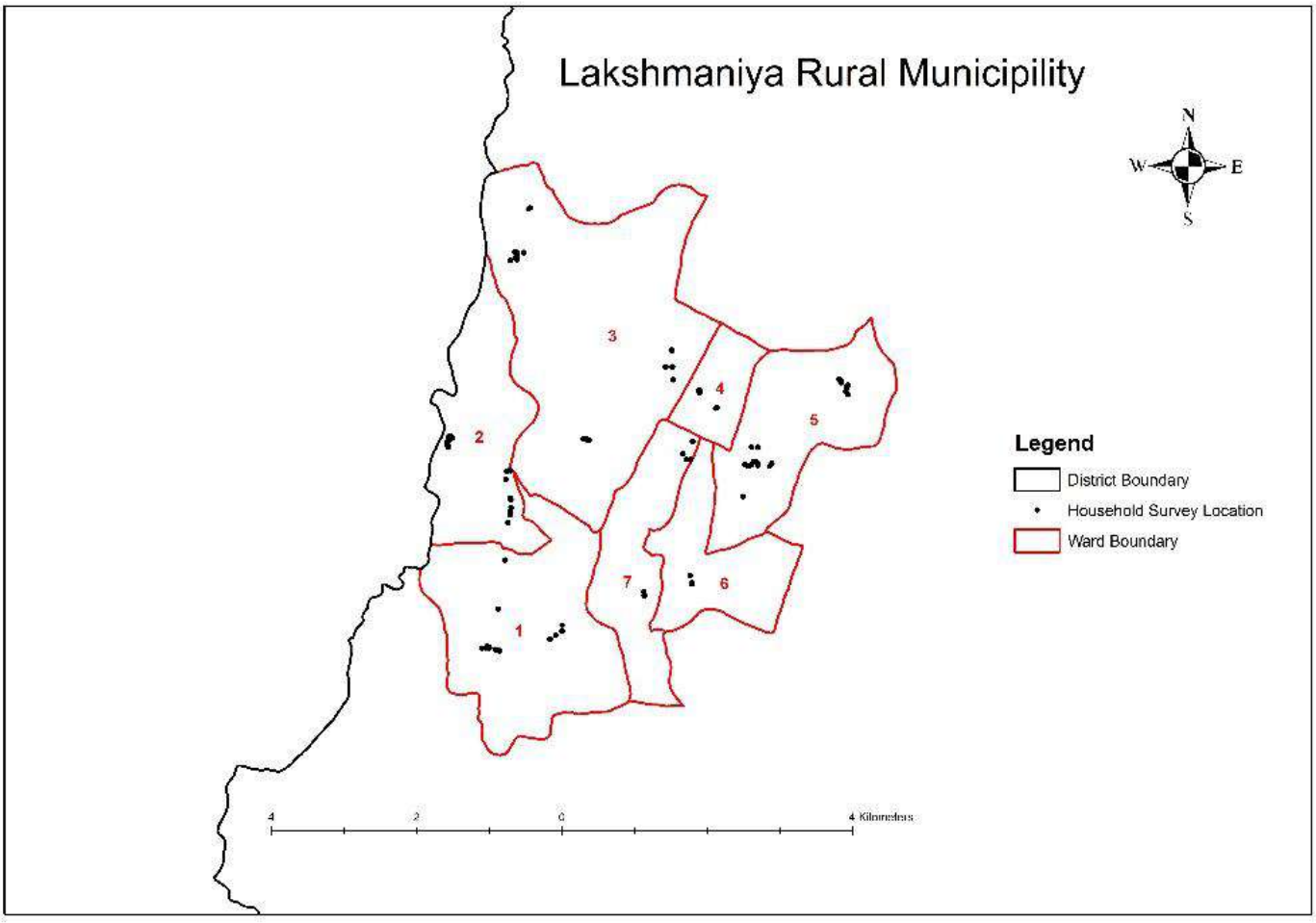

Figure 2

Distribution of Sampled Households by Settlement

3.5 Data Collection Tools and Procedures

Primary data were collected through a household survey using a structured questionnaire. The questionnaire was designed to collect information on household characteristics, landholding structure, parcel count, total operated land area, family size, irrigation status, food sufficiency, and productivity perception. After data collection, the dataset was checked for completeness, consistency, and accuracy. Settlement names and categorical responses were standardized. Land area values were harmonized into square meters and hectares. After data cleaning, derived variables such as average parcel size, parcels per hectare, land per capita, fragmentation class, and consolidation scenario indicators were calculated.

3.6 Data Analysis

The data were analyzed using descriptive statistics, cross-tabulation, chi-square tests of independence, Cramér's V, ordered logistic regression, and a simple land-consolidation scenario. The analysis was designed to address the four research objectives of the study. First, descriptive statistics were used to summarize household characteristics and land-fragmentation indicators. Mean, standard deviation, minimum, and maximum values were calculated for family size, parcel count, total operated land area, average parcel size, parcels per hectare, and land per capita. Settlement-wise mean values were also calculated to examine variation in fragmentation patterns across the sampled settlements.

Land fragmentation was measured using parcel-based indicators. Parcel count was defined as the total number of parcels operated by a household. Average parcel size was calculated by dividing total operated land area by the number of parcels:

$$\text{APS} = \frac{\text{Total operated land area}}{\text{Number of parcels}}$$

Parcels per hectare was calculated as:

$$\text{PPH} = \frac{\text{Number of parcels}}{Total\ operated\ land\ area\ in\ hectares}$$

Land per capita was calculated as:

$$\text{LPC} = \frac{\text{Total operated land area}}{Household\ family\ size}$$

Households were classified into three parcel-count-based fragmentation categories. Households operating 1 to 2 parcels were classified as low fragmentation, those operating 3 to 5 parcels as medium fragmentation, and those operating more than 5 parcels as high fragmentation. A parcels-per-hectare-based classification was also prepared, but because its distribution was highly skewed, parcel-count-based fragmentation class was used as the main grouping variable, while parcels per hectare was retained as a size-adjusted fragmentation indicator.Cross-tabulations were prepared to examine the distribution of selected categorical agricultural outcomes across fragmentation classes. In this analysis, parcel-count-based fragmentation class was used as the independent grouping variable, while food sufficiency, irrigation status, and productivity perception were used as dependent categorical variables.

Chi-square tests of independence were applied to examine whether fragmentation class was significantly associated with food sufficiency, irrigation status, and productivity perception. In addition, a chi-square test was also used to examine the association between holding-size class and fragmentation class, because holding size was considered an important confounding factor in the relationship between fragmentation and food sufficiency. The chi-square statistic was calculated as:

$$\chi 2 = \sum \frac{(O-E)2}{E}$$

Where O is the observed frequency and E is the expected frequency under the null hypothesis of independence. A statistically significant chi-square result indicates that the observed distribution across categories differs from what would be expected if no association existed.To complement the chi-square test, Cramér's V was reported as a measure of effect size in order to indicate the strength of the observed association. Cramér's V was calculated as:

$$\text{V} = \sqrt{\frac{\chi 2}{n(k-1)}}$$

Where $\chi 2$ is the chi-square statistic, n is the total sample size, and k is the smaller number of rows or columns in the contingency table. Values closer to 0 indicate weaker association, whereas values closer to 1 indicate stronger association (Agresti, 2013). Continuous fragmentation indicators were compared across low, medium, and high parcel-count-based fragmentation classes using descriptive group-wise comparison. The variables compared included parcel count, total operated area, average parcel size, parcels per hectare, and land per capita. This comparison was used to examine how landholding characteristics varied among different fragmentation classes. Since the fragmentation classes were based on parcel count, the comparison helped explain the differences between operational complexity and size-adjusted fragmentation intensity.

In addition, an ordered logistic regression model was fitted to examine the food-security implication of fragmentation while accounting for household landholding size and family size. The dependent variable was the five-level household food-sufficiency category, treated as an ordered outcome ranging from lower to higher levels of food sufficiency. The explanatory variables included parcels per hectare, total operated area, and family size. This model was chosen because food sufficiency has a natural ranking, making ordinal regression more appropriate than ordinary linear regression (McCullagh, 1980). The model was expressed as:

$$\log\left(\frac{P(Y>j)}{P(Y\geq j)}\right) = \alpha_j + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$$

Where Y is the ordered food-sufficiency category, j is the cumulative threshold, α_j is the threshold-specific intercept, and X1, X2, and X3 represent parcels per hectare, total operated area, and family size, respectively. Odds ratios were obtained as:

$$OR = e^{\beta}$$

An odds ratio greater than 1 indicates that the predictor increases the odds of being in a better food-sufficiency category, while an odds ratio below 1 indicates that the predictor decreases those odds. Finally, a simple land-consolidation scenario was developed. Under this scenario, all parcels operated by each household were assumed to be reorganized into one operational unit. Based on this assumption, post-consolidation parcel count, average parcel size, parcels per hectare, percentage reduction in parcel count, and percentage increase in average parcel size were calculated. This scenario did not represent an actually implemented consolidation program; rather, it was used as a conceptual simulation to estimate potential structural improvement in landholding conditions. All statistical tests were interpreted at the 5% significance level, and p-values below 0.05 were considered statistically significant.

3.7 Ethical Considerations

Ethical considerations were maintained during the study. Respondents were informed about the purpose of the household survey, and their participation was treated as voluntary. The information collected from households was used only for academic and research purposes. Personal identification of respondents was not disclosed in the analysis or reporting. Data were analyzed and presented in aggregated form to maintain confidentiality. The study also respected the local context and avoided any interpretation that could negatively affect individual households or communities.

IV. FINDINGS & DISCUSSION

4.1 Household and Landholding Characteristics

Descriptive statistics in Table 2 show that the sampled households had a mean family size of 6.90 persons. The mean parcel count was 5.88 parcels per household, while the mean operated land area was 0.78 ha. The mean average parcel size was 1,190.71 m², and the mean parcels-per-hectare value was 10.28. These statistics indicate that agricultural landholdings in the study area are commonly divided into several relatively small parcels rather than being operated as single compact holdings.

Table 2

Descriptive Statistics of Key Land Fragmentation Indicators

Variable	N	Mean	SD	Minimum	Maximum
Family size	396	6.90	1.32	4.00	12.00
Parcel count	396	5.88	4.50	1.00	45.00
Total land area (ha)	396	0.78	0.96	0.03	10.16
Average parcel size (m²)	396	1190.71	818.98	135.45	10158.93
Parcels per hectare	396	10.28	6.12	0.98	73.83
Land per capita (ha/person)	396	0.11	0.13	0.00	1.27

This finding supports the first objective of the study, which was to measure household-level land fragmentation using parcel-based indicators. The observed landholding pattern is consistent with Niroula and Thapa (2005), who reported land fragmentation as a major agricultural problem in South Asia. It also supports Thapa and Niroula (2008), who explained that inheritance-based land subdivision has increased parcel numbers and reduced operational farm efficiency in Nepal.

4.2 Fragmentation Classes and Settlement-Wise Variation

Using parcel-count-based classification, 47.73% of households were in the high-fragmentation class, 32.32% were in the medium-fragmentation class, and 19.95% were in the low-fragmentation class, as shown in Table 3. This shows that nearly half of the sampled households operated more than five parcels, confirming that land fragmentation is a major land-management issue in the study area.

Table 3

Distribution of Households by Parcel-Count-Based Fragmentation Class

Fragmentation class	Number of households	Percentage (%)
Low	79	19.95
Medium	128	32.32
High	189	47.73

The parcels-per-hectare-based classification showed that 89.90% of households were in the high-fragmentation category, as shown in Table 4. However, this distribution was highly skewed. Therefore, parcel-count-based fragmentation class was used as the main grouping variable, while parcels per hectare was retained as a supporting size-adjusted indicator.

Table 4

Distribution of Households by PPH-Based Fragmentation Class

PPH class	Number of households	Percentage (%)
Low	4	1.01
Medium	36	9.09
High	356	89.90

Settlement-wise comparison in Table 5 showed meaningful internal variation in fragmentation structure. Bainigama recorded the highest mean parcel count, with 9.00 parcels per household, whereas Bhangaha recorded the highest mean parcels per hectare, with 13.69. Sinurjoda had the largest mean operated area, 1.27 ha, but also showed a relatively high parcels-per-hectare value of 12.54. This indicates that even relatively large holdings can remain operationally fragmented.

Table 5

Settlement-Wise Fragmentation Indicators

Settlement	N	Mean parcel count	Mean area (ha)	Mean APS (m^2)	Mean PPH	Mean LPC (ha/person)
Dohair	20	5.00	0.73	1220.70	9.41	0.10
Kumharouda	26	6.12	0.84	1141.44	9.67	0.11
Bagewa	38	6.63	1.01	1255.35	9.35	0.14
Sohani	61	5.20	0.58	1032.55	10.14	0.08
Gajariya	25	8.00	1.21	1401.95	8.02	0.17
Sinurjoda	40	7.68	1.27	1788.35	12.54	0.18
Bhangaha	42	3.21	0.34	883.95	13.69	0.05
Nikal	37	4.81	0.54	1060.60	10.11	0.08
Bainigama	29	9.00	1.19	1299.48	8.00	0.16
Aligesawa	19	8.53	1.03	1122.34	9.37	0.15
Sapahi	34	4.59	0.59	1134.37	10.12	0.10
Baniniya	25	4.12	0.46	1048.49	10.11	0.07

This finding supports the second objective of the study, which was to classify households by fragmentation level and examine settlement-wise variation. The result agrees with Paudel et al. (2013), who noted that land subdivision, demographic pressure, and agricultural land conversion have contributed to increasing land fragmentation in Nepal. It also supports Dhakal and Khanal (2018), who found that fragmented landholdings increase field-management burden and inefficiency in agricultural operations.

4.3 Association between Land Fragmentation and Food Sufficiency

Food sufficiency was used as a dependent variable, while parcel-count-based fragmentation class was used as the independent grouping variable. The cross-tabulation showed that food sufficiency differed strongly across fragmentation classes. Low-fragmentation households were mainly concentrated in the three-month and six-month food-sufficiency categories, whereas highly fragmented households were more concentrated in the twelve-month and surplus-sale categories, as shown in Table 6 and Figure 3.

Table 6

Fragmentation Class and Food Sufficiency

Food sufficiency category	Low	Medium	High	Total
Three months	32	2	1	35
Six months	39	56	7	102
Nine months	5	46	21	72
Twelve months	3	19	64	86
More than 12 months / surplus sale	0	3	95	98
Missing	0	2	1	3

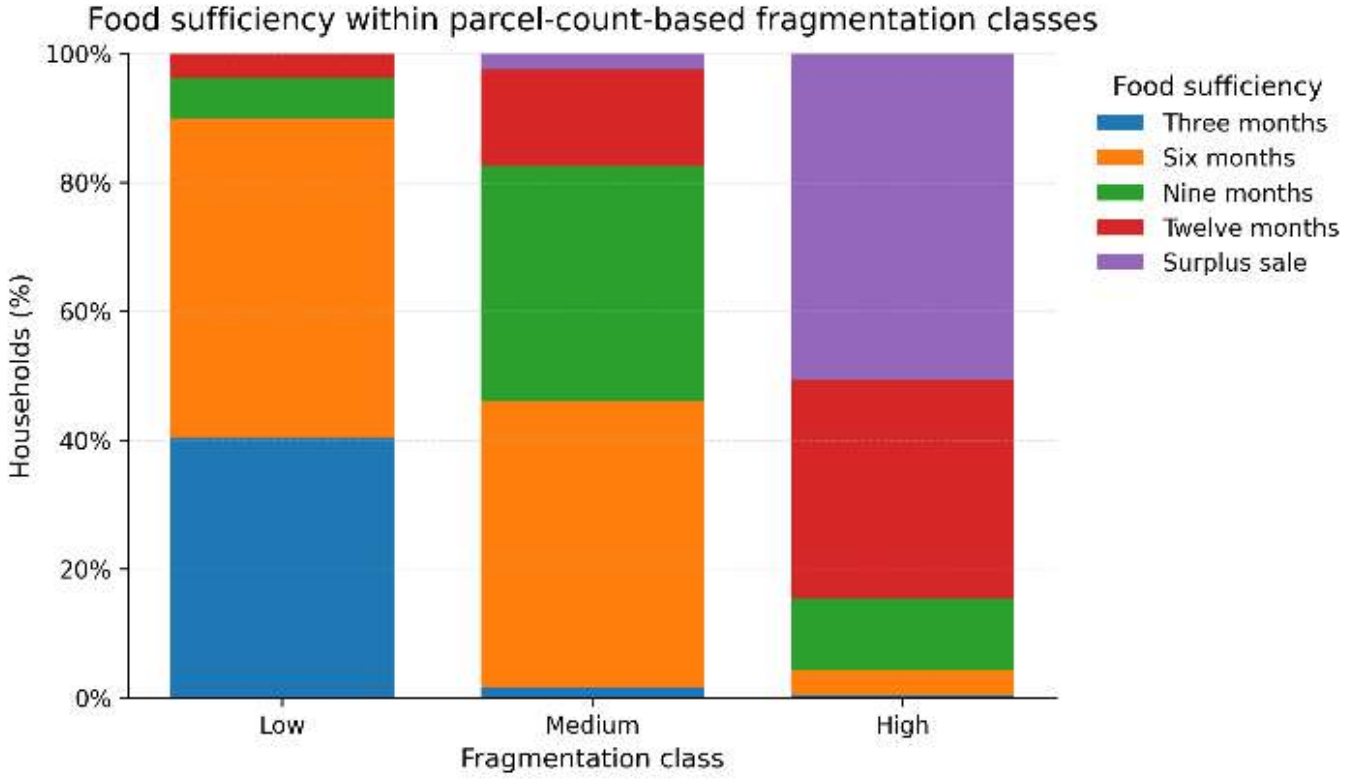

Figure 3

Food Sufficiency by Parcel-Count-Based Fragmentation Classes

At the descriptive level, this pattern appears counterintuitive because higher fragmentation is generally expected to reduce farm efficiency. However, this result can be explained by the fact that many highly fragmented households also operated larger total land areas. Therefore, parcel count alone does not fully explain food sufficiency unless the effect of total operated area is also considered. The chi-square test showed a statistically significant association between fragmentation class and food sufficiency, with $\chi^2 = 338.80$, df = 10, and $p < 0.001$. The effect size was strong, with Cramér's V = 0.654. This indicates that household food sufficiency differed substantially across fragmentation classes. This finding supports Paudel et al. (2013), who identified land fragmentation and agricultural land conversion as important challenges for food security in Nepal. However, the present finding also shows that food sufficiency should not be interpreted from parcel count alone because total landholding size can mask the negative effect of fragmentation.

4.4 Association between Land Fragmentation and Irrigation Status

Irrigation status was used as another dependent categorical variable, while parcel-count-based fragmentation class was used as the independent variable. The results in Table 7 and Figure 4 showed that tube well or pump irrigation was the dominant irrigation source across all fragmentation classes, followed by partly available canal irrigation. Fully available canal irrigation was limited in the sample.

Table 7

Fragmentation class and Irrigation Status

Irrigation status	Low	Medium	High	Total
Tube well / pump	46	83	143	272
Canal partly available	26	32	35	93
Canal fully available	1	3	0	4
Missing	6	10	11	27

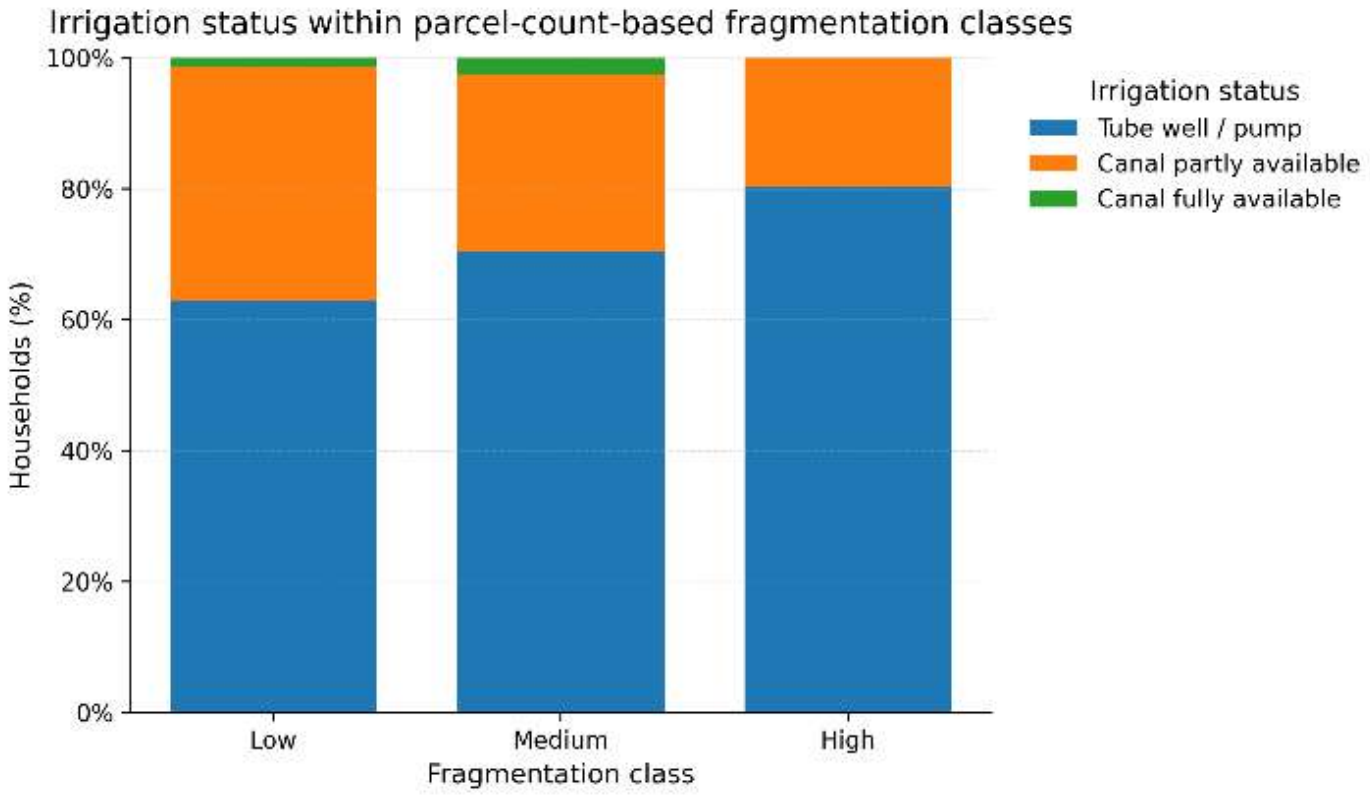

Figure 4

Irrigation Status by Parcel-Count-Based Fragmentation Class

The chi-square test showed a statistically significant association between fragmentation class and irrigation status, with $\chi^2 = 12.72$, df = 6, and p = 0.048. However, the effect size was small, with Cramér's V = 0.127. This indicates that irrigation status varied by fragmentation class, but the strength of association was weak. This weak association may be because irrigation access depends not only on parcel fragmentation but also on local infrastructure, groundwater availability, canal coverage, physical parcel location, and household investment capacity. Nevertheless, the finding supports the argument that fragmented landholdings may complicate irrigation planning and field-level water management. This is consistent with Dhakal and Khanal (2018), who reported that fragmented landholdings create field-management difficulties and inefficiency in agricultural input use.

4.5 Association between Land Fragmentation and Productivity Perception

Productivity perception was used as another dependent categorical variable, while parcel-count-based fragmentation class was used as the independent variable. The results in Table 8 showed that most households across all fragmentation classes rated productivity as fair. Only a small number of households reported productivity as good or very good.

Table 8

Fragmentation Class and Productivity Perception

Productivity perception	Low	Medium	High	Total
Poor	1	2	0	3
Fair	76	121	174	371
Good	2	3	9	14
Very good	0	1	6	7
Missing	0	1	0	1

From Table 9, the chi-square test showed no statistically significant association between fragmentation class and productivity perception, with $\chi^2 = 10.77$, df = 8, and p = 0.215. The effect size was also weak, with Cramér's V = 0.117. This indicates that self-reported productivity perception did not differ significantly across fragmentation classes. This result suggests that productivity perception may not be sensitive enough to capture the actual productivity effect of land fragmentation. Farmers may report productivity based on general experience rather than measured crop yield, labour cost, input use, or net farm income. Therefore, although land fragmentation may affect operational efficiency, its effect may not be clearly reflected in perception-based productivity responses. This finding partly differs from Rahman and Rahman (2009) and Looga et al. (2018), who found that land fragmentation can reduce productivity and farm efficiency. The difference may be due to the type of productivity variable used in this study, as this study used self-reported productivity perception rather than measured crop-output or farm-income data.

4.6 Summary of Chi-Square Association Tests

The chi-square tests show that the relationship between land fragmentation and agricultural outcomes varied by variable. Food sufficiency had a strong and statistically significant association with fragmentation class. Irrigation status had a statistically significant but weak association. Productivity perception was not significantly associated with fragmentation class.

Table 9

Summary of Chi-Square Association Tests

Outcome	Test	Statistic (χ^2)	df	p-value	Interpretation	Effect size (Cramér's V)
Food sufficiency	Chi-square	338.80	10	<0.001	Significant	0.654
Irrigation status	Chi-square	12.72	6	0.048	Significant	0.127
Productivity perception	Chi-square	10.77	8	0.215	Not significant	0.117

Among the three dependent variables, food sufficiency was most strongly related to fragmentation class. Irrigation status was related to fragmentation class only weakly, while productivity perception did not show a statistically meaningful relationship.

4.7 Continuous Fragmentation Indicators by Fragmentation Class

Continuous fragmentation indicators were compared across low, medium, and high fragmentation classes. Mean parcel count increased from 1.72 in the low-fragmentation class to 3.66 in the medium-fragmentation class and 9.13 in the high-fragmentation class, as shown in Table 10. This confirms that the classification successfully separated households by parcel number. Mean operated area also increased across fragmentation classes, from 0.17 ha in the low-fragmentation group to 0.39 ha in the medium-fragmentation group and 1.31 ha in the high-fragmentation group. This shows that households with more parcels often also operated larger total land areas.

In contrast, mean parcels per hectare decreased from 14.20 in the low-fragmentation class to 10.51 in the medium-fragmentation class and 8.49 in the high-fragmentation class. This indicates that parcel count and parcels per hectare measure different dimensions of fragmentation. Parcel count reflects operational complexity, while parcels per hectare reflects fragmentation intensity relative to landholding size. Therefore, both indicators should be interpreted together when assessing land fragmentation.

Table 10

Continuous Fragmentation Indicators by Parcel-Count Class

Fragmentation class	N	Mean parcel count	Mean area (ha)	Mean APS (m^2)	Mean PPH	Mean LPC (ha/person)
Low	79	1.72	0.17	1105.91	14.20	0.03
Medium	128	3.66	0.39	1048.61	10.51	0.06
High	189	9.13	1.31	1322.39	8.49	0.18

This finding supports Demetriou et al. (2013), who emphasized that land fragmentation should be measured using multiple indicators rather than a single measure. The present result shows that a household may have many parcels but also a larger total holding size. Therefore, parcel count and parcels per hectare should be interpreted together.

4.8 Holding-Size Effect and Additional Chi-Square Test

A key analytical issue in this dataset is that highly fragmented households often also operated larger total land areas. This was examined by comparing holding-size class with parcel-count-based fragmentation class. The low-fragmentation group was dominated by very small holdings, while the high-fragmentation group contained a large concentration of holdings above 1.0 ha, as shown in Table 11 and Figure 5. This means that households classified as highly fragmented by parcel count were not necessarily poorer in landholding size. Many of them had more parcels because they operated more land.

Table 11

Holding-Size Class by Parcel-Count-Based Fragmentation Class

Holding-size class	Low	Medium	High	Total
Small (<0.25 ha)	74	19	1	94
Medium(0.25–1.0 ha)	3	107	77	187
Large (>1.0 ha)	2	2	111	115

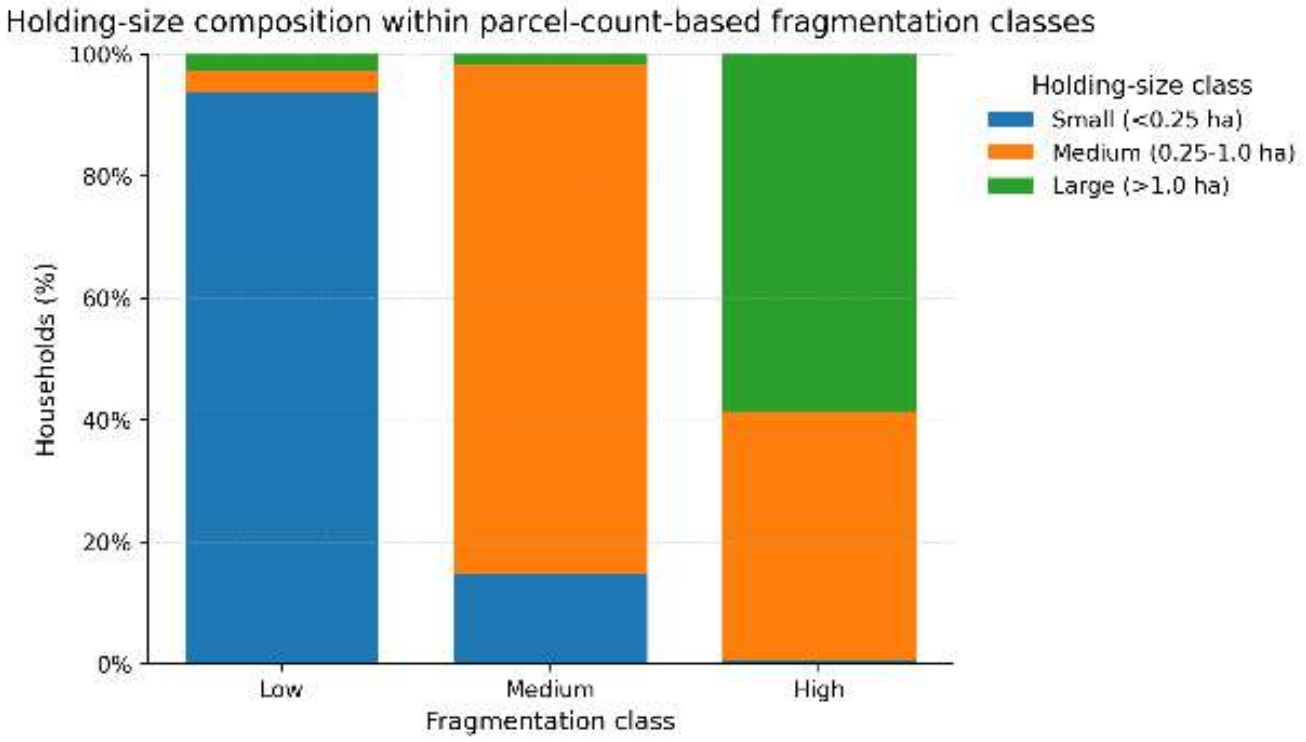

Figure 5

Holding-Size Composition within Parcel-Count-Based Fragmentation Classes

The chi-square test showed a very strong and statistically significant association between holding-size class and fragmentation class, with $\chi^2 = 388.77$, df = 4, and $p < 0.001$. The effect size was also strong, with Cramér's V = 0.701. This confirms that holding size and fragmentation class were strongly related in the study sample.

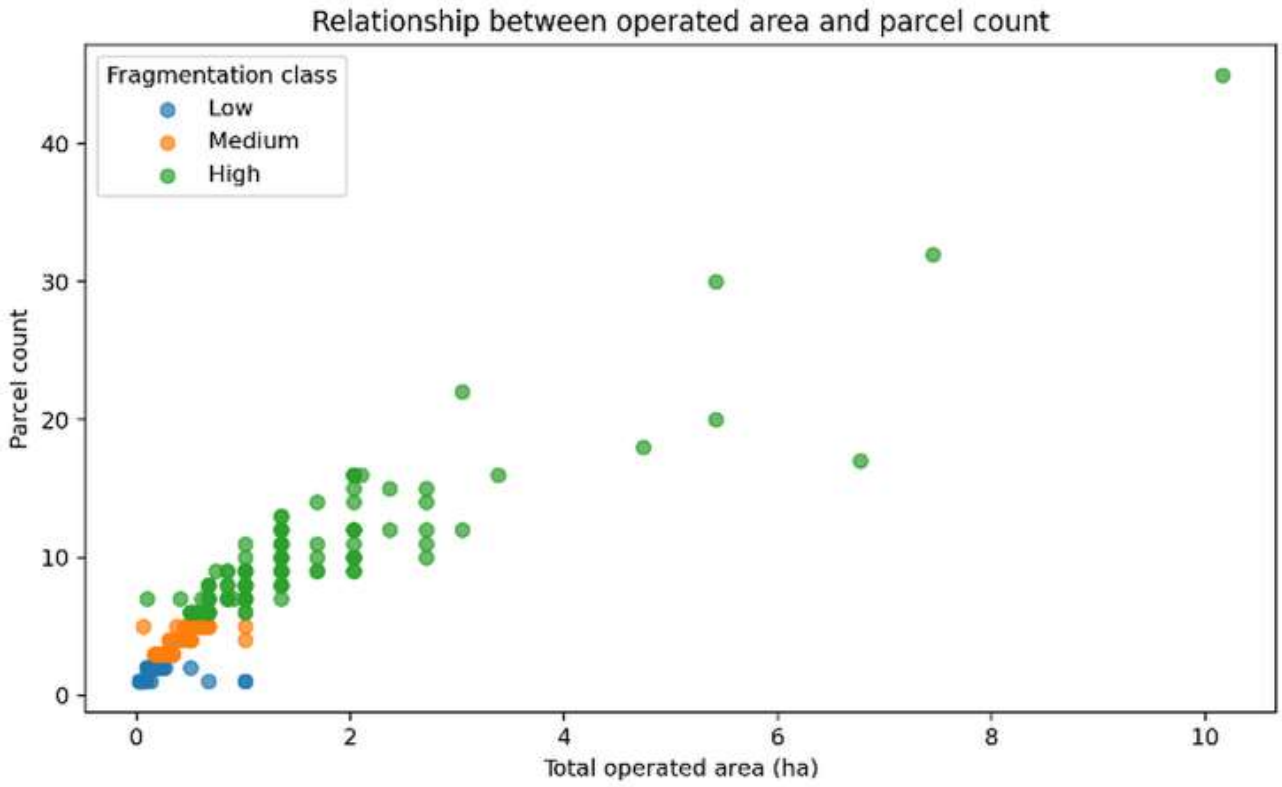

Figure 6
Relationship between Total Operated Area and Parcel Count

This result is important because it explains why highly fragmented households appeared to have better food sufficiency in the descriptive cross-tabulation. Their better food sufficiency was likely influenced by larger total operated land area, not by fragmentation itself. Therefore, a regression model was necessary to control for landholding size. Figure 6 further illustrates the positive relationship between total operated area and parcel count. This supports the interpretation that households with more parcels frequently also operated larger land areas. Therefore, simple cross-tabulations between fragmentation class and food sufficiency may be misleading unless holding size is considered.

4.9 Ordered Logistic Regression of Food Sufficiency

To further examine the food-security implication of fragmentation while accounting for holding size, an ordered logistic regression model was estimated. In this model, food sufficiency was used as the ordered dependent variable. The independent variables were parcels per hectare, total operated area, and family size. The result from Table 12 showed that parcels per hectare had a negative and statistically significant effect on food sufficiency. The coefficient for parcels per hectare was -0.092, with an odds ratio of 0.91 and $p = 0.003$. This means that higher fragmentation intensity reduced the odds of being in a better food-sufficiency category after controlling for total operated area and family size. Total operated area had a positive and statistically significant effect on food sufficiency. The coefficient was 4.152, with an odds ratio of 63.57 and $p < 0.001$. This indicates that households with larger operated land areas were more likely to report better food sufficiency. Family size was not statistically significant, with $p = 0.399$.

Table 12
Ordered Logistic Regression of Food Sufficiency

Predictor	Coefficient	Std. Error	Odds Ratio (OR)	95% CI	p-value
Parcels per hectare (PPH)	-0.092	0.032	0.91	0.86–0.97	0.003
Total operated area (ha)	4.152	0.415	63.57	28.16–143.52	<0.001
Family size	0.064	0.076	1.07	0.92–1.24	0.399

These findings clarify the relationship between land fragmentation and household food sufficiency. At the descriptive level, highly fragmented households appeared to have better food sufficiency because many of them also had larger landholdings. However, after controlling for operated area and family size, higher parcels per hectare

reduced the likelihood of better food sufficiency. This confirms that size-adjusted fragmentation intensity has a negative implication for household food security. This finding is consistent with Rahman and Rahman (2009), who found that land fragmentation negatively affects productivity and technical efficiency. It also supports Paudel et al. (2013), who linked agricultural land fragmentation with food-security challenges in Nepal.

4.10 Land Consolidation Scenario

A simple land-consolidation scenario was developed to assess the potential structural improvement in landholding conditions. Under this scenario, all parcels operated by each household were assumed to be reorganized into one operational unit. The results showed that mean parcel count decreased from 5.88 to 1.00, representing an 83.00% reduction. Mean average parcel size increased from 1,190.71 m² to 7,845.81 m². Mean parcels per hectare decreased from 10.28 to 3.43, representing a 66.63% reduction, as shown in Table 13 and Figure 7.

Table 13

Land Consolidation Scenario Summary

Indicator	Current mean	After consolidation	% change
Parcel count	5.88	1	-83.00
Average parcel size (m²)	1190.71	7845.81	558.92
Parcels per hectare	10.28	3.43	-66.63

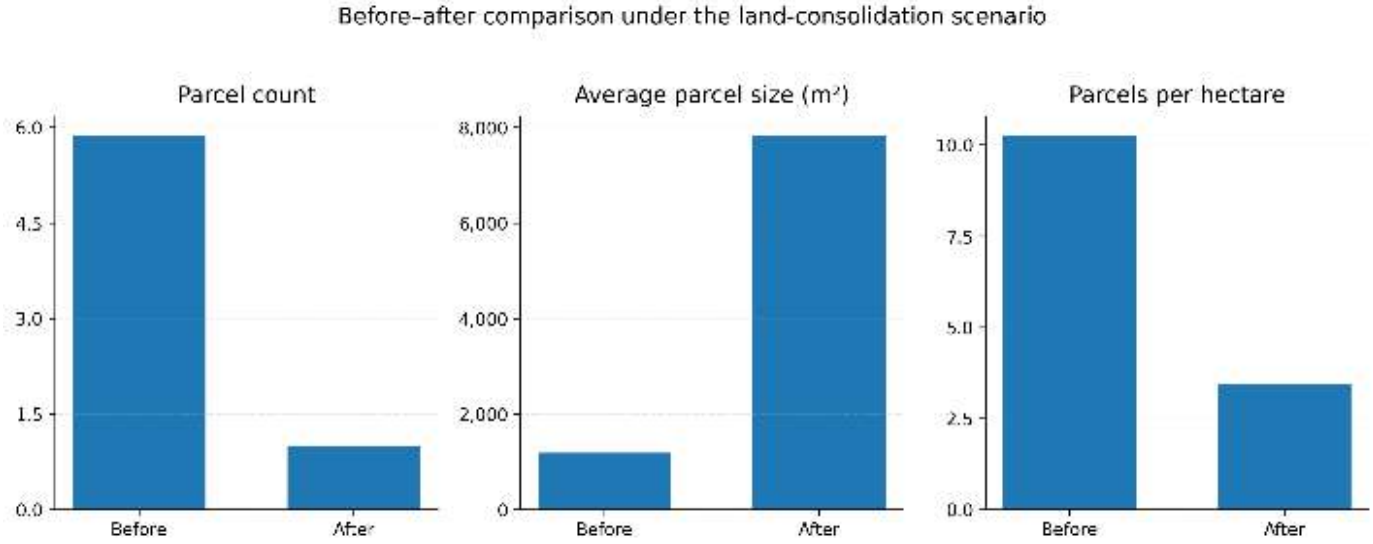

Figure 7

Before-After Comparison under the Land-Consolidation Scenario

These scenario results do not directly measure actual yield change. However, they clearly show that land consolidation could substantially reduce operational fragmentation and increase average parcel size. From a structural perspective, such changes could improve field accessibility, simplify irrigation layout, reduce movement between plots, and create more favourable conditions for mechanization and farm management. This finding supports de Vries (2022), who described land consolidation as a process for reorganizing fragmented parcels into more efficient land units. It also supports Thapa and Niroula (2008), who discussed land consolidation as a possible option for improving fragmented farm structures in Nepal. However, as Pun et al. (2024) emphasized, farmer willingness, local acceptance, institutional support, and socio-economic feasibility are essential for successful land consolidation.

4.11 Overall Discussion

Overall, the findings indicate that land fragmentation is a prominent feature of household agriculture in the selected settlements of Lakshmaniya Rural Municipality. The mean parcel count of 5.88 and the high proportion of households in the high-fragmentation class show that agricultural land is commonly managed through several scattered parcels rather than compact operational holdings. This pattern is consistent with earlier studies from Nepal, which have linked fragmentation to inheritance-based subdivision, declining holding size, and reduced operational efficiency (Niroula & Thapa, 2005; Thapa & Niroula, 2008).

The statistical analysis shows that food sufficiency and irrigation status were significantly associated with fragmentation class, whereas productivity perception was not. The strongest association was found between

fragmentation class and food sufficiency. However, the holding-size analysis showed that many highly fragmented households were also larger landholders. Therefore, the apparent advantage of highly fragmented households in food sufficiency was explained by their larger operated area.

The ordered logistic regression provided a clearer interpretation. It showed that greater fragmentation intensity, measured by parcels per hectare, reduced the odds of better food sufficiency after controlling for operated area and family size. This means that fragmentation has a negative implication for household food security when the effect of farm size is properly considered. The land-consolidation scenario demonstrated that reducing parcel dispersion could substantially improve the structural condition of farm holdings. Although the scenario does not prove actual productivity gains, it shows that consolidation could create better conditions for farm management, irrigation planning, mechanization, and agricultural efficiency. Therefore, land consolidation in the Terai should be understood not only as a cadastral or administrative intervention, but also as a practical strategy for improving agricultural land management and strengthening household food-security conditions.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

This study assessed household-level agricultural land fragmentation and its food-security implications in selected settlements of Lakshmaniya Rural Municipality in the Terai region of Nepal. The results confirmed that land fragmentation is substantial in the study area, with a mean parcel count of 5.88 parcels per household and nearly half of the sampled households falling into the high-fragmentation class. The study found clear settlement-wise variation in land fragmentation patterns. Some settlements had higher parcel counts, while others had higher parcels-per-hectare values. This indicates that land fragmentation varies not only by the number of parcels but also by total landholding size and settlement-level landholding structure.

The chi-square tests showed that fragmentation class was significantly associated with food sufficiency and irrigation status, but not with productivity perception. Food sufficiency showed the strongest association with fragmentation class. However, the holding-size analysis showed that many highly fragmented households also operated larger land areas. Therefore, food sufficiency could not be interpreted from parcel count alone. The ordered logistic regression showed that higher parcels per hectare reduced the odds of being in a better food-sufficiency category after controlling for total operated area and family size. This confirms that size-adjusted fragmentation intensity has a negative implication for household food security. In contrast, larger operated land area significantly increased the likelihood of better food sufficiency. The land-consolidation scenario showed that reorganizing multiple parcels into one operational unit could reduce mean parcel count from 5.88 to 1.00 and increase average parcel size from 1,190.71 m^2 to 7,845.81 m^2. Therefore, land consolidation has strong potential to reduce operational fragmentation and improve the structural condition of farm holdings in the study area.

5.2 Recommendations

Based on the findings, land fragmentation should be considered in local land-use planning, especially in settlements where households operate many small and scattered parcels. Pilot land-consolidation programs should be introduced in highly fragmented areas and linked with irrigation improvement, agricultural road access, mechanization support, and farmer-oriented planning. Fragmentation assessment should use both parcel count and parcels per hectare to capture operational complexity and size-adjusted fragmentation intensity. Farmer participation and local acceptance should be prioritized before implementation. Future studies should use cadastral parcel data, crop yield, farm income, labour cost, input use, and irrigation-efficiency data to measure the direct productivity gains from land consolidation.

Declaration of Interest

The authors declare that they do not have any known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding Declaration

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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