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Livelihood Asset Pentagon and Multi-dimensional Vulnerability: A Zone-wise Analysis of Udalguri District

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ABSTRACT: This paper focuses on the multi-dimensional livelihood vulnerability analysis in Udalguri district, a geographically and ecologically diverse foothill area of the Bodoland Territorial Region (BTR), employing Sustainable Livelihoods Framework (DLF, 1999) through Livelihood Asset Pentagon (LAP), zone-wise. The study is based on a primary household survey conducted across 26 villages in 174 households in four geo-ecological zones that have been defined in the study using GIS-based Analytic Hierarchy Process (AHP) analysis (Saaty, 1980) and systematically maps the five livelihood capitals (natural, financial, human, physical and social) along a fragile-to-resilient geo-ecologic gradient. Inferential statistical tests, including one-way ANOVA, chi-square, independent-samples t-tests, and Pearson correlations, show that the geo-ecological hierarchy is statistically sound for almost all of the household-level indicators. The normalized Livelihood Asset Pentagon shows that Zone 1 (Fragile Geo-ecological and Livelihood-Constrained Zone) has near-zero composite scores on all five capitals, whereas Zone 4 (Geo-ecologically Resilient and Livelihood-Supporting Zone) has maximum scores on four of five capitals. The composite measure of human capital — Zone 2 outperforms Zone 4 — is the only non-monotonic dimension that can be explained by the persisting female literacy gap in the most infrastructure-rich zone, human capital. The study concludes that the vulnerability of Udalguri is multi-dimensional in nature and is structurally geo-ecologically determined, with gender inequality in educational levels and an institutional coverage gradient following the resilience hierarchy. The strongest bivariate finding is the correlation between income and savings ($r = 0.792$, $p < 0.01$) which indicates that savings capacity is income constrained across the district.

1. INTRODUCTION

Vulnerability of rural livelihood is seldom a one-dimensional deprivation issue in the Himalayan foothill districts of northeast India. Alongside this, households living in these landscapes are subject to overlapping sets of constraints that can be a composite of fragmented smallholder land holdings, seasonal flash flooding, access to markets, institutional coverage, land tenure insecurity and demographic pressures on an already limited natural resource base, which cannot be captured using income-based analytical tools (Chambers and Conway, 1992; Scoones, 1998). The structural architecture of poverty is not captured in conventional measures of poverty, which may be income-poor, low-land productivity, poor road access, limited human capital, weak institutional networks, or all of these, and the policy response needed varies greatly by cause (Ellis, 2000; Rakodi, 1999).

Worapari, located in Udalguri district in the Bodoland Territorial Region (BTR) bordering with Bhutan, is a case study of an area that calls for multi-- dimensional livelihood analysis. The District has a steep geo-ecological gradient ranging from the fragile foothill belt of Bhutan Himalayas in the northern part of the district to the fertile alluvial plain of Brahmaputra Basin in the southern part of the district resulting in sharply differentiated resource endowments, infrastructure penetrations and institutional coverages within a small spatial area (Government of Assam, 2017). At the same time, the district is ethnically diverse, with eight major ethnic groups, such as Bodo, Santhal, Adivasi, Rabha, Assamese Hindu, Bengali Muslim, Nepali and

others, and its unique administrative system the Bodoland Territorial Council (BTC) under the Sixth Schedule of the Indian Constitution also has devolved powers over land, agriculture and social welfare, which generate institutional access conditions different from those of normal state-government administration (Hussain, 2008; Nath, 2013).

The land-use change analysis performed in this study shows that during 2011-2021, the land-use transformation was dramatic, with the agricultural area being converted by about 25,407 ha (73%), mainly due to the conversion of vacant land and forest tracts, and the forest cover of dense and open forest shrinking by over 16,000 ha. The shift has important consequences for the vulnerability of foothill households whose natural capital base is also declining due to loss of forests and becoming more precarious as the slopes become more exposed to floods. The shift has direct ramifications on the livelihood vulnerability of foothill households whose natural capital base is also shrinking as a result of loss of forests and becoming more vulnerable as a result of increased exposure to floods on deforested slopes (Mahato et al., 2021; Foley et al., 2005).

To deal with this complexity, DFID (1999) built on the work of Chambers and Conway (1992) and Scoones (1998) developed the Sustainable Livelihoods Framework (SLF) which sees the household's resources as a portfolio of 5 inter-dependent capitals: Natural, Financial, Human, Physical and Social. In the Livelihood Asset Pentagon, the SLF allows all five capital assets to be compared simultaneously, providing a picture of both the overall livelihood resilience and the structural inequity of the capital assets which constitute binding constraints on a livelihood improving path (Krantz, 2001; Morse et al., 2009)..

2. OBJECTIVES

The specific objectives of this study are:

1. To define livelihood profile of sampled households at zone and village level by applying the 5-capital Sustainable Livelihoods Framework in four geo-ecological zones of Udalguri district.
2. To develop a normalised Livelihood Asset Pentagon for each geo-ecological zone, allowing for simultaneous analysis of natural, financial, human, physical and social capital endowments and identification of binding capital constraints.
3. To classify sampled households according to their principal livelihood base (resource-based versus skill-based) and examine intra-generational and inter-generational aspects of livelihood diversification along the zone gradient.
4. To compare the statistical significance of differences between livelihoods across zones with one-way ANOVA, chi-square tests, independent-samples t-tests and Pearson correlations.

3. METHODOLOGY

3.1 Research Type

The research design used in this study is a sequential mixed methods research design which is a mixed method of geo-spatial analysis, primary household survey and inferential statistics. Research approach is descriptive-analytical and cross-sectional, by applying spatial zonation which is based on multi-criteria analysis using GIS and a structured primary survey of rural households. The explanatory logic is based on the Sustainable Livelihoods Framework (DFID, 1999) which is used as a conceptual framework in the capital measurement, pentagon construction and vulnerability assessment. This method is consistent with the methodological traditions of applied rural geography and development studies which place household livelihood outcomes in their biophysical and institutional context (Scoones 1998; Ellis 2000).

3.2 Study Area

The Udalguri district (26°24/21//'N–27°1/42//'N, 91°43/38//E–92°19/21//E) is located in the north-central part of Assam with the Northern border shared by the Kingdom of Bhutan. The area of the district is about 1,852.16 km², which is divided into eleven community development blocks under the jurisdiction of nine revenue circle. It is situated in the Bodoland Territorial Region (BTR) which is co-administered by the Bodoland Territorial Council (BTC) under the Sixth Schedule of the Indian Constitution and the Government of Assam.

The district's physiography is set against the background of a transition from the Bhutan Himalayan foothills in the north to the Brahmaputra floodplain in the south, a piedmont area which produces a braided and shifting river system with anchor points of Dhansiri, Pachnoi, Bornadi, Nonoi and Suklai, which are prone to seasonal flash flooding in foothill areas. The three forests namely, Khalingduar 4141.92 ha, Rowta 2268.40 ha and Barnadi 1850.14 ha, are the ecological pillar of the northern

foothill belt (District Disaster Management Authority, Udalguri) of the district occupying 36.88% of the total forest area of 22400 ha.

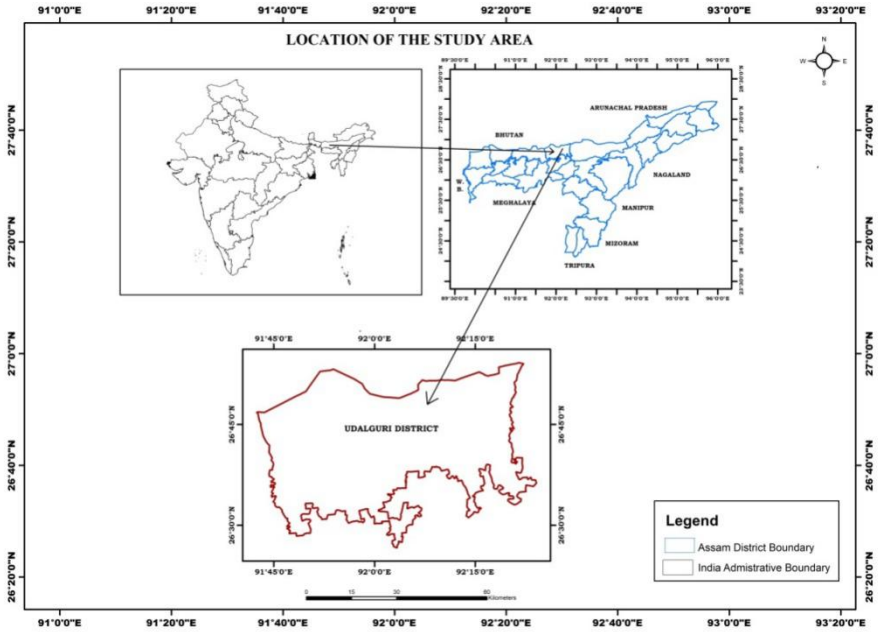


Fig.1

The analysis of the six weighted physical indicators using the multi-criteria AHP method, based on GIS, defines four geo-ecological zones that form the spatial frame of analysis (Table 1).

Table 1: Geo-ecological Zones and Key Characteristics, Udalguri District

Zone	Name	Area (km²)	% District	Elevation (m)	Rainfall (mm)
Zone 1	Fragile & Livelihood-Constrained	30.02	1.5	25–94	566–685
Zone 2	Transitional & Livelihood-Constrained	108.75	5.6	94–150	685–764
Zone 3	Moderately Resilient	556.98	28.5	150–248	764–849
Zone 4	Resilient & Livelihood-Supporting	1,261.28	64.0	248–631	849–1,025

Source: GIS-based AHP multi-criteria analysis, present study.

3.3 Sampling and Data Collection

Field surveys were conducted in five administrative blocks of Udalguri district to collect the primary data; household interview schedule was used to collect the primary data from 174 households in 26 villages of Udalguri district. The sampling design used was proportional stratified random sampling and the strata were the four geo-ecological zones. To provide a spatial representation that is proportional, the approximate sampling fraction of 5.3% per village was kept across all 26 villages. The zonal distribution of the sample is: Zone 1 (n = 30, 6 villages), Zone 2 (n = 25, 4 villages), Zone 3 (n = 68, 9 villages) and Zone 4 (n = 51, 7 villages). All four zones are covered and eight community groups, including Bodo, Santhal, Adivasi, Rabha, Assamese Hindu, Bengali Muslim, Nepali and Others are represented, thus removing the confounding of community by the composition of the various zones when comparing the zones.

The data gathered includes the following: (i) household demographic profile (household size, sex, age, literacy, and educational level); (ii) land tenure status and size of land holding; (iii) annual income from all sources including farm, wage, business and transfer receipts; (iv) annual savings and expenditure; (v) livestock and poultry holdings; (vi) self-reported health status; (vii) household amenity access (electricity, toilet, mobile phone); (viii) distance to nearest market; (ix) participation in MGNREGA, SHG membership and female headship. Secondary data related to LULC and land use densities were obtained from district records, Census of India (2011), DAO Udalguri and scholar-generated GIS outputs.

3.4 Data Analysis

The household survey information was used to operationalize the five-capital livelihood indicators. Min-max normalization was applied to each sub-indicator of the Livelihood Asset Pentagon with the formula: Normalized Score = [(Zone value − Minimum zone value) / (Maximum zone value − Minimum zone value) × 100] to derive the composite capital scores. Each sub-indicator score was separately Z-standardised and the mean score for each capital zone was calculated. Market distance was inverted and normalised, with shorter distance (better connectivity) getting higher scores; and MGNREGA participation was converted to MGNREGA non-reliance (100 minus participation rate).

The selected indicators are measured in different units, including rupees, acres, kilometres and percentages. Direct aggregation would therefore be inappropriate. To ensure comparability, the indicators are transformed onto a common **0–100 scale using min-max normalization**, consistent with the attached study.

For positive indicators:

Normalized Score = [(X_i − Xmin) / (Xmax − Xmin)] × 100

where:

X_i = observed value of a particular zone;

Xmin = minimum value among the four zones; and

Xmax = maximum value among the four zones.

A score approaching **100** represents a relatively favourable position, whereas a score approaching **0** indicates the lowest relative position among the four zones.

For an inverse indicator such as **distance to market**, where a lower value indicates better access, reverse normalization is applied:

Reverse Normalized Score = [(Xmax − X_i) / (Xmax − Xmin)] × 100

This ensures that all final indicators follow the same interpretation: **higher score = stronger livelihood asset position**.

Construction of Composite Livelihood Capital Scores

Following normalization, the sub-indicators belonging to each livelihood capital are aggregated using the **arithmetic mean**:

Capital Score = Σ Normalized Sub-indicator Scores / Number of Sub-indicators

The procedure produces five composite scores for each zone:

NC = Natural Capital

FC = Financial Capital

HC = Human Capital

PC = Physical Capital

SC = Social Capital

Equal weighting is applied within each capital. This approach provides a transparent method of combining indicators while avoiding dominance by variables originally measured on larger numerical scales.

Table 2. Construction of Composite Livelihood Capital Scores

Composite Capital	Components Included	Aggregation Procedure
Natural Capital (NC)	Landholding + tenure security	Mean of normalized indicators
Financial Capital (FC)	Income + savings + APL share	Mean of normalized indicators
Human Capital (HC)	Literacy + WPR + good health	Mean of normalized indicators
Physical Capital (PC)	Reversed market distance + electricity + toilet + mobile access	Mean of normalized indicators
Social Capital (SC)	SHG membership + MGNREGA non-reliance	Mean of normalized indicators

Source: Authors' methodological construction based on the study indicators

Inferential statistical tests were used to test for significance of inter-zone mean differences (continuous variables), chi square tests of independence (categorical variables), independent-samples t-tests (paired group comparisons) and Pearson product-moment correlations (bivariate relationships within and across zones) at the 95% level of confidence ($\alpha = 0.05$, two tailed). All statistical analyses were done using SPSS v25. Livelihood base categorisation (resource-based versus skill-based) was done based on the predominant livelihood income of each household from the survey income data.

4. RESULTS AND DISCUSSION

4.1 Natural Capital

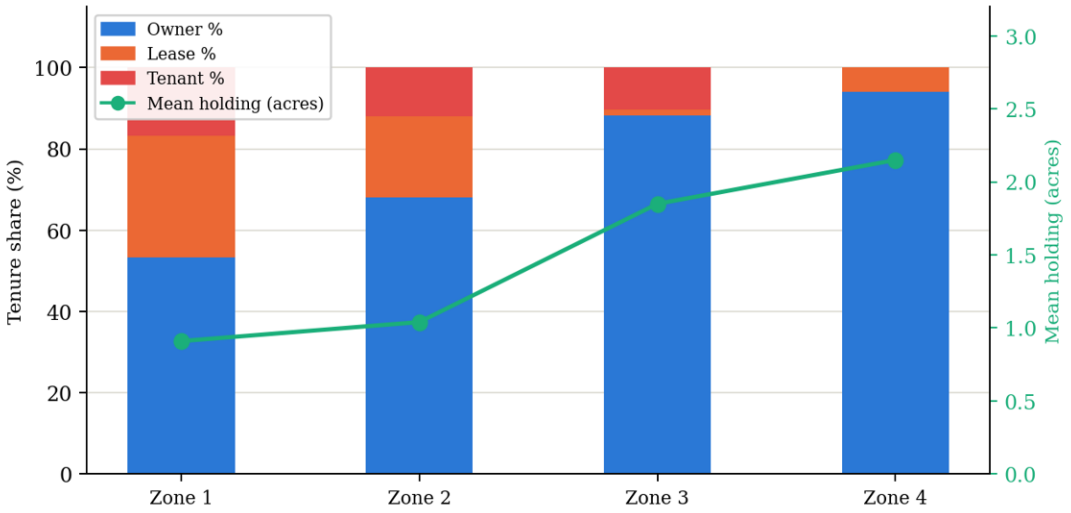
Land tenure security and land holding size are two main indicators of natural capital in Udalguri. As the resilience gradient rises from Zone 1 to Zone 4, the owner-cultivators' share also increases monotonically from 53.33% to 94.12% and the combined share of leaseholders and tenants decreases monotonically from 46.67% to 5.88% (Table 2). The zone association is highly significant ($\chi^2 = 31.694$, df = 6, $p < 0.0001$) as verified by the chi square test. That no formal tenancy arrangements exist at all within Zone 4 is analytically significant because informal sub-tenancy the most vulnerable category is limited to foothill areas where formal land records are least reliable and customary Bodo territorial arrangements clash with formal cadastral systems (Hussain 2008).

Table 3: Zone-wise Land Tenure Status and Landholding

Zone	n	Owner %	Lease %	Tenant %	Mean Holding (acres)
Zone 1	30	53.33	30.00	16.67	0.91
Zone 2	25	68.00	20.00	12.00	1.04
Zone 3	68	88.24	1.47	10.29	1.85
Zone 4	51	94.12	5.88	0.00	2.15
District	174	81.03	10.34	8.62	1.66

Source: Primary field survey; simulated dataset computed by the researcher. F (landholding) = 44.851, $p < 0.0001$.

Figure 2: Zone-wise land tenure status (%) and mean landholding (acres/HH)



Source: Primary field survey. $\chi^2 = 31.694$, df = 6, $p < 0.0001$; F (landholding) = 44.851, $p < 0.0001$.

The mean household landholding increases along the resilience gradient, from 0.91 acres in Zone 1 to 2.15 acres in Zone 4 and is highly significant ($F = 44.851$, $p < 0.0001$). Nevertheless, the agrarian structure of the district is smallholder and no holding of 4 ha or larger was found in the sample. The Pearson correlation between landholding and annual income is significantly positive in Zones 1–3 (0.479, 0.515 and 0.431 respectively; all $p < 0.01$), but not significantly different from zero in Zone 4 ($r = 0.152$, $p = 0.288$), suggesting that as more individuals are earners of salaries and more skilled workers, the land size loses explanatory power over earned income in the most resilient zone.

4.2 Financial Capital

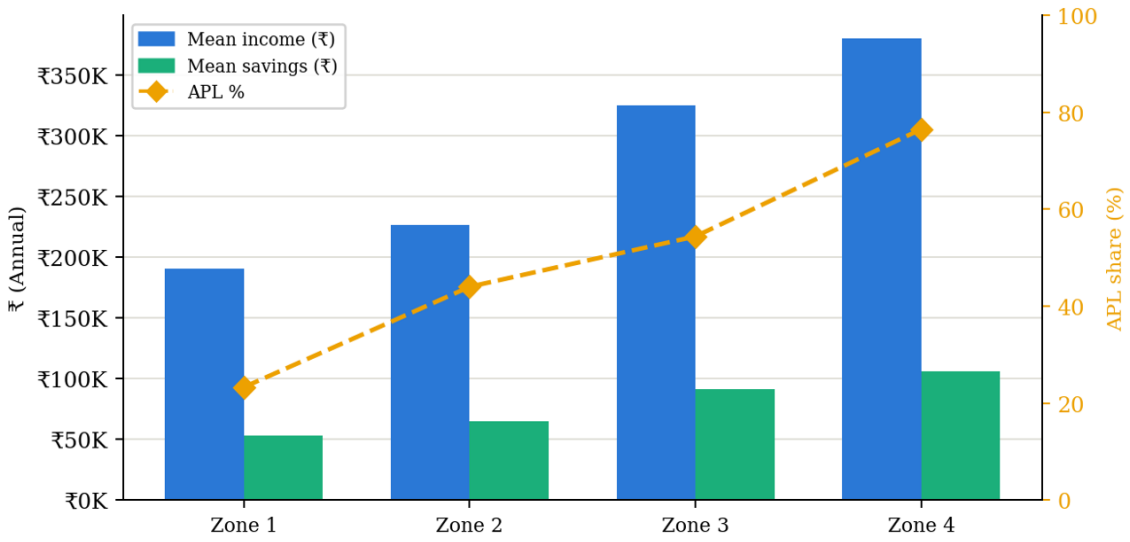
Mean annual household income increases nearly two-fold along the resilience gradient from ₹1,90,677 in Zone 1 to ₹3,79,960 in Zone 4 ($F = 61.636$, $p < 0.0001$). The APL/BPL distribution mirrors this gradient precisely: APL share rises from 23.3% in Zone 1 to 76.5% in Zone 4 ($\chi^2 = 22.738$, df = 3, $p < 0.0001$). BPL status is not just a poverty tag but also an institutional access tag, which opens subsidized food in the PDS, priority housing in Pradhan Mantri Awas Yojana (Gramin), and health insurance in Ayushman Bharat.

Table 4: Zone-wise Financial Capital Indicators

Zone	n	Mean Income (₹)	APL %	BPL %	Mean Savings (₹)	Mean Expenditure (₹)	Livestock (head/HH)
Zone 1	30	1,90,677	23.3	76.7	53,091	1,33,330	3.87
Zone 2	25	2,26,241	44.0	56.0	64,642	1,56,883	4.04
Zone 3	68	3,25,187	54.4	45.6	91,597	2,26,973	5.22
Zone 4	51	3,79,960	76.5	23.5	1,06,036	2,66,224	5.86
District	174	3,03,833	54.0	46.0	85,318	2,12,262	5.01

Source: Simulated dataset computed by the researcher. All monetary values in Indian Rupees (₹), annual basis. ANOVA: Income $F = 61.636$; Savings $F = 30.448$; Expenditure $F = 56.461$; all $p < 0.0001$.

Figure 3: Zone-wise financial capital — mean annual income, savings (₹) and APL/BPL distribution



Source: Simulated dataset. ANOVA: Income F = 61.636; Savings F = 30.448; all $p < 0.0001$. APL $\chi^2 = 22.738$, $p < 0.0001$.

Mean annual savings nearly double from ₹53,091 in Zone 1 to ₹1,06,036 in Zone 4 ($F = 30.448$, $p < 0.0001$). APL households record significantly higher savings than BPL households (₹92,937 vs ₹76,365; $t = 3.446$, $p = 0.0007$), and SHG member households record significantly higher savings than non-members (₹92,335 vs ₹78,768; $t = 2.734$, $p = 0.007$). The savings to income ratio is broadly stable at around 28% across all zones, indicating that the savings capacity is income driven and does not vary according to differences in behaviour around consumption. The Pearson correlation between income and savings is the highest and most stable bivariate relationship in the entire analysis (0.817–0.882 across all the zones, all $p < 0.01$), indicating that the saving capacity in Udalguri district is mainly income constrained throughout. Household savings serve as the major financial protection mechanism against agro-climatic shocks particularly seasonal flash flood in foothill areas and because formal insurance coverage is limited and access to credit outside SHG is limited.

4.3 Human Capital

Human capital refers to the ability of the household members in terms of labour capacity, level of education, health, and wage-earning capacity. The Worker Participation Rate (WPR) shows a negative correlation with the resilience gradient from 64.19% in Zone 1 to 54.96% in Zone 4. This counter-intuitive pattern is explained by a structural difference in labour productivity: In Zone 1, a family with low returns per labourer is able to get more return from its members by increasing their share of the worker population who are engaged in low return activities like MGNREGA public works and seasonal agricultural wage labour, while in Zone 4, a family with high returns per labourer can earn higher total incomes with a lower proportion of the household's members in economically active roles, and higher returns from wage labourers who are salaried, skilled and engaged in commercial activities.

Table 5: Zone-wise Human Capital Indicators

Zone	n	WPR %	Overall Literacy %	Male Literacy %	Female Literacy %	Poor Health %	Mean Wage Income (₹)
Zone 1	30	64.19	93.3	91.7	94.4	20.0	37,743
Zone 2	25	59.02	92.3	100.0	86.7	24.0	52,401
Zone 3	68	57.83	95.8	93.9	97.4	10.3	1,08,129
Zone 4	51	54.96	90.4	100.0	80.8	3.9	1,37,670

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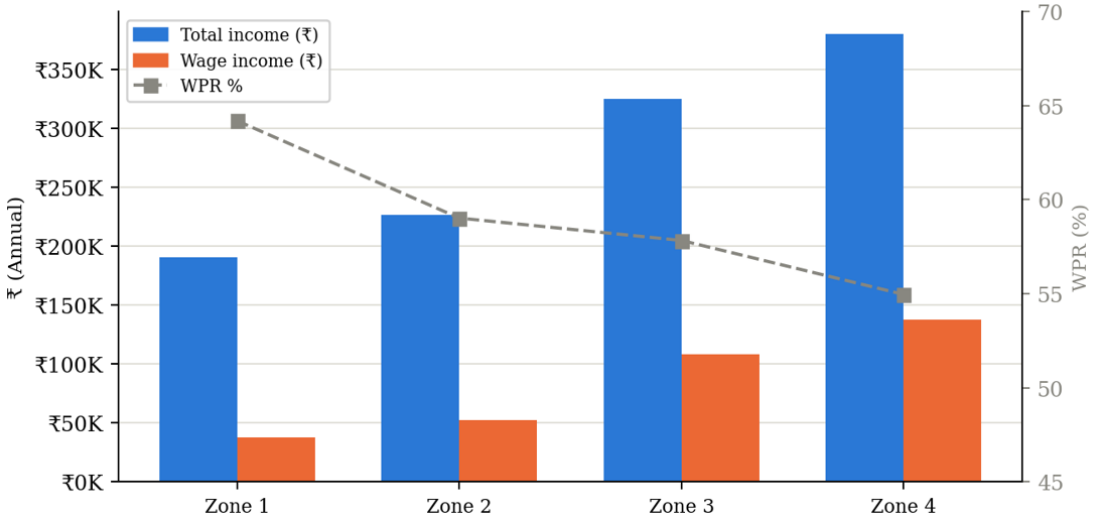
Zone	n	WPR %	Overall Literacy %	Male Literacy %	Female Literacy %	Poor Health %	Mean Wage Income (₹)
District	174	58.14	93.1	96.3	90.7	12.1	96,645

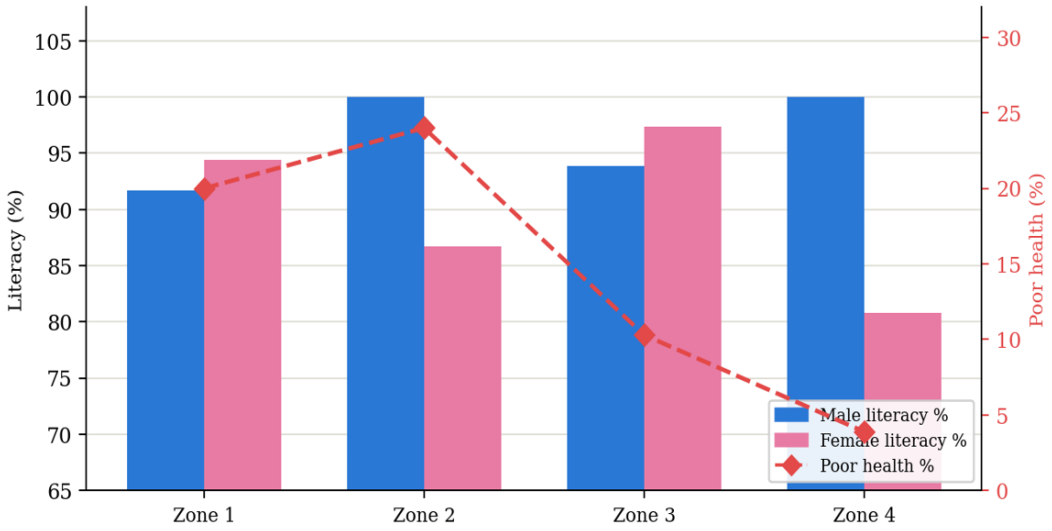
Source: Primary field survey and simulated dataset, computed by the researcher. ANOVA: Wage Income F = 132.834, p <

Figure 4: Total income vs. wage income by zone (₹ annual) — the four-fold wage gradient



Source: Simulated dataset. Wage income ANOVA: F = 132.834, p < 0.0001. The four-fold wage gradient exceeds the two-fold total income gradient.

Figure 5: Zone-wise literacy by gender (%) and poor health share (%)



Source: Primary field survey. Zone 4 female literacy deficit (80.8%) drives the non-monotonic human capital pentagon anomaly.

The gradient for this single indicator is the highest in this analysis (F = 132.834, p < 0.0001), and the wage income rises from nearly two lakhs in Zone 1 to almost four lakhs in Zone 4. This steepness is indicative of the virtual lack of private non-farm wage opportunities outside MGNREGA public workfare in Zone 1 and the near proximity of Zone 4 to urban commuter

labour markets and formal employment. The four-fold wage gradient is much larger than the two-fold total income gradient, which shows that differential labour market access (not agricultural productivity) is the main source of inter-zone income inequality in Udalguri district.

The literacy pattern is non-monotonic: the highest overall rate of literacy is in Zone 3 (95.8%), whereas Zone 4 has the best infrastructure and income, and the second lowest rate of literacy (90.4%). This anomaly can be traced to a female literacy deficit in Zone 4 that had five female respondents who had not received any formal education, whilst Zone 4's male literacy rate was 100% whilst its educational infrastructure provision rate was high. The mode for secondary education is seen at the district level (42.5% of all respondents). There is also a major gender disparity at the graduate level, as 18.3% of male respondents, compared to 7.2% of female respondents, have a graduate degree. The direct impact of this structural educational constraint at the secondary-to-tertiary level on the mobility of female household members is a constraint to inter-generational occupational mobility in all zones (Drèze and Sen, 1995).

4.4 Physical Capital

Market distance is the only variable that has a statistically significant effect in this analysis, decreasing from 13.7 km in Zone 1 to 4.21 km in Zone 4, a more than threefold structural difference that is related to the geographic separation between the remote foothill zone and the connected alluvial plain. Structural income depressants, in foothill and seasonally flooded areas, include elevated transaction costs that cause the farm-gate price of agricultural output to be lower than it would be without the costs, the effective cost of production inputs to be higher than without the costs, and a disincentive to participation in non-local labour markets (Fafchamps and Shilpi, 2005).

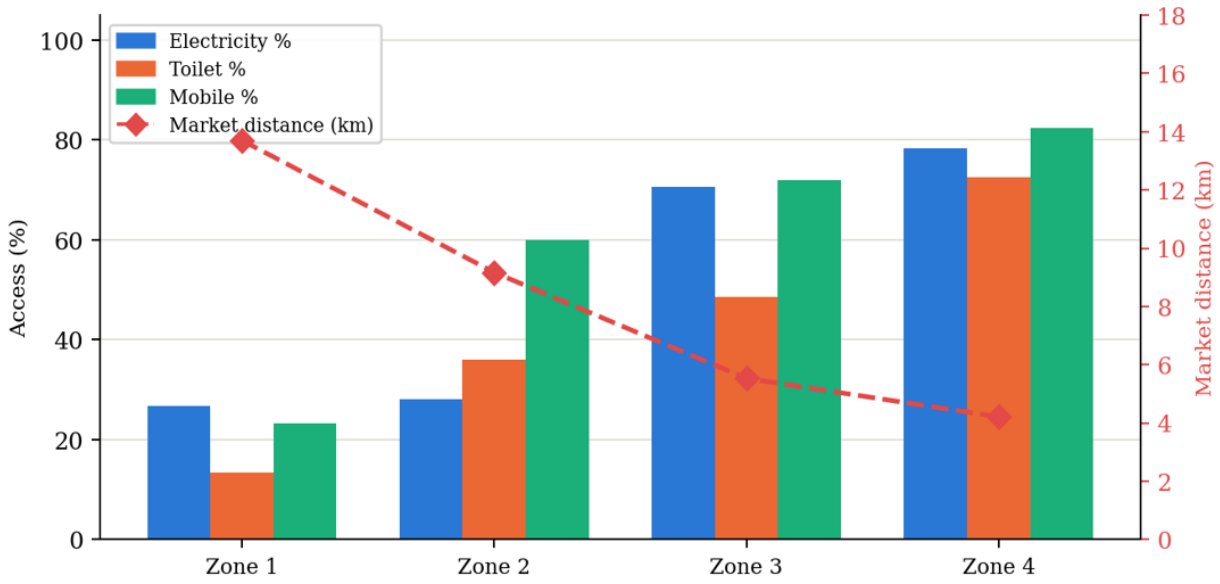
Importantly, the between-zone effect for market distance is very large (ANOVA $F = 258.999$) and the within-zone Pearson correlation between market distance and income is not significant in any of the four zones (district $r = -0.059$, ns). This is not a contradiction, rather a difference in spatial scales, the ANOVA examines the structural geographic difference between the zone-average market distances, and the Pearson correlation examines if households are marginally closer or further to market within the zones have higher or lower incomes. The variation in market distance within the zone is not large, 3.57–5.00 km in Zone 4, and is not the most important determinant of within-zone income – tenure security, educational attainment, SHG membership and access to wage employment are.

Table 6: Zone-wise Physical Capital Indicators

Zone	n	Mean Mkt. Distance (km)	Electricity %	Toilet %	Mobile %
Zone 1	30	13.70	26.67	13.33	23.33
Zone 2	25	9.17	28.00	36.00	60.00
Zone 3	68	5.53	70.59	48.53	72.06
Zone 4	51	4.21	78.43	72.55	82.35
District	174	7.46	59.20	47.70	64.94

Source: Simulated dataset, computed by the researcher. ANOVA: Market Distance $F = 258.999$, $p < 0.0001$. Highest F-value across all variables tested.

Figure 6: Zone-wise physical capital — household amenity access (%) and mean market distance (km)



Source: Simulated dataset. Market distance ANOVA: F = 258.999, p < 0.0001 — highest F-value across all variables tested.

Increase is significant and continuous with regard to all three household amenity indicators from Zone 1 to Zone 4. Toilet access shows the steepest gradient from 13.3% in Zone 1 to 72.6% in Zone 4 and acts as a physical capital indicator (infrastructure) and as a human capital indicator as access to open defecation is correlated with preventable diarrhoeal disease burden that affects adult labour productivity as well as child development outcomes (Census of India, 2011). Mobile phone access grows almost four times from 23.3% to 82.4%, a gradient essential for agricultural price information; mobile banking through SHG accounts and digital welfare scheme uptake.

4.5 Social Capital

The interpretation of participation in MGNREGA is mainly as a vulnerability indicator: What is taken as an indicator of higher participation in the zones of constraint is a relative lack of private or market-based wage opportunities, not necessarily a higher level of institutional engagement (Drèze and Khera, 2011). The participation rate decreases from 76.67% in Zone 1 to 39.22% in Zone 4 ($\chi^2 = 10.752$, df = 3, p = 0.013), reflecting the structural reliance on public workfare as the primary source of income in the foothill belt. Conversely, SHG membership increases with institutional reach — from 30% in Zone 1 to 60.78% in Zone 4 ($\chi^2 = 7.975$, df = 3, p = 0.047). The savings rate of the member households belonging to SHG was found to be significantly higher (₹92,335 compared to ₹78,768; t = 2.734, p = 0.007) than that of the non-member households, thereby justifying SHG membership as a real financial capital asset. The Bodo women's weaving co-ops, with a historical background of the dokhna textiles, are culturally unique institutions with social capital that serve the livelihood function and cultural identity maintenance in the foothill areas.

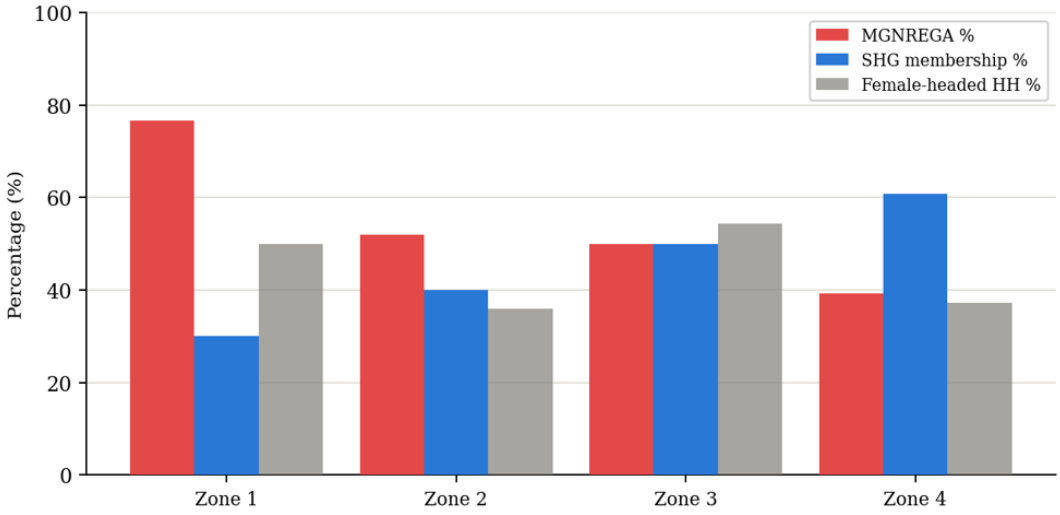
Table 7: Zone-wise Social Capital Indicators

Zone	n	MGNREGA %	SHG Membership %	Female-Headed HH %
Zone 1	30	76.67	30.00	50.00
Zone 2	25	52.00	40.00	36.00
Zone 3	68	50.00	50.00	54.41
Zone 4	51	39.22	60.78	37.25

Zone	n	MGNREGA %	SHG Membership %	Female-Headed HH %
District	174	51.72	48.28	45.98

Source: Simulated dataset computed by the researcher. Chi-square: MGNREGA $\chi^2 = 10.752$, $p = 0.013$; SHG $\chi^2 = 7.975$, $p = 0.047$; Female-headed HH $\chi^2 = 4.707$, $p = 0.195$ (not significant).

Figure 7: Zone-wise social capital indicators (%)



Source: Simulated dataset. MGNREGA χ^2=10.752, p=0.013; SHG χ^2=7.975, p=0.047; Female-headed HH χ^2=4.707, p=0.195 (not significant).

There is no significant zone gradient in the female headed household share (45.98% district-wise; $\chi^2 = 4.707$, df = 3, $p = 0.195$) and there is no significant difference in annual income between female headed and male headed households ($t = -0.642$, $p = 0.521$; ₹2,98,705 vs ₹3,08,198). Geo-ecological resource endowment alone does not drive the emergence of female headship; rather, life-cycle and/or demographic processes such as out-migration by men and widowhood drive the shift, and female headship, in turn, is not a significant predictor of income performance in this sample.

4.6 The Livelihood Asset Pentagon

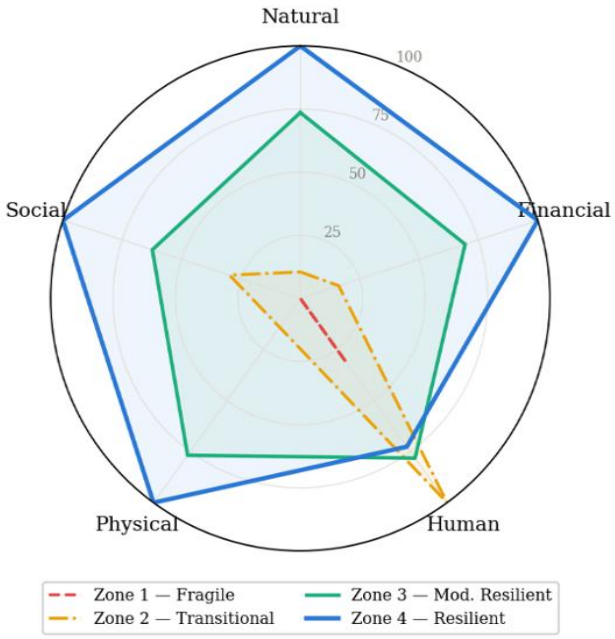
The Livelihood Asset Pentagon is a synthesis of the five-capital analysis based on min-max normalised composite scores of the five capitals for the four zones (Table 8). Zone 1 provides the minimum on 5 capitals; Zone 4 provides the maximum on 4 capitals.

Table 8: Normalised Five-Capital Pentagon Scores by Zone (0–100 Scale)

Capital	Sub-indicators	Zone 1	Zone 2	Zone 3	Zone 4
Natural	Landholding; Owner-occupier %	0	10.5	73.6	100
Financial	Income; Savings; APL %	0	16.2	69.4	100
Human	Literacy; WPR; Good health %	31.4	100	78.2	72.6
Physical	Mkt. dist. (inv.); Electricity; Toilet; Mobile	0	14.1	76.8	100
Social	SHG %; MGNREGA non-reliance %	0	29.8	62.3	100

Source: All sub-indicators individually min-max normalised (0–100) across four zones; composite score = arithmetic mean of normalised sub-indicator scores. Simulated dataset, computed by the researcher.

Figure 8: Livelihood Asset Pentagon — normalized five-capital scores by zone (0–100 scale)



Source: Min-max normalised composite scores. Human capital is the only non-monotonic dimension: Zone 2 (100) > Zone 3 (78.2) > Zone 4 (72.6) due to female literacy deficit in Zone 4.

The pentagon at the centre of Zone 1 is compressed almost to a near point at the centre where all five capital dimensions record their district minimum, reflecting the cumulative constraint of the fragile foothill environment: smallest landholdings, highest non-ownership, lowest income and saving, furthest market distance, lowest amenity coverage, lowest SHG membership and highest MGNREGA dependence. Although physical and financial capital are both severely constrained, the non-zero Human capital score (31.4) suggests that the basic literacy and health outcomes have been somewhat sustained through government elementary education programs.

Zone 2 is the most distorted pentagon: Human capital at maximum (100), but Natural (10.5), Financial (16.2) and Physical (14.1) are very low. This structural imbalance high human capital investment, very low physical, financial and natural capital – is a livelihood trap as education capacity cannot be monetized without market access, credit and tenurial security. The pattern reflects Ellis's (2000) insight that a shift from a defensive to an accumulative livelihood is underpinned by human capital but is not a sufficient condition for this shift.

Zone 3 is the best with a pentagon (Natural 73.6, Financial 69.4, Human 78.2, Physical 76.8, Social 62.3), and no capital dimension is below 62 or above 79. The balance that is characteristic of moderate resilience is that no single capital is so poorly developed that it restricts the growth of the others, nor so well developed that it generates a mismatch like that seen in Zone 2. There are four capitals at maximum (100) in zone 4, and the area of the pentagon in this zone is the largest. The one exception — Human capital at 72.6 which is below both Zone 2 (100) and Zone 3 (78.2) — is directly attributed to the gender gap in literacy in zone 4, which leads to the conclusion that Human capital is the dimension of livelihood resilience that will be directly determined by geo-ecological position, infrastructure endowment and income level.

4.7 Livelihood Diversification

Near universal participation in farm activities (96.0% of households), and significant participation in non-farm diversification (63.2% of households). The top zone in the district sample appears to be Zone 4, having the highest proportion of farm-dominant households (45.2%), while Zone 1 has the lowest (33.3%).

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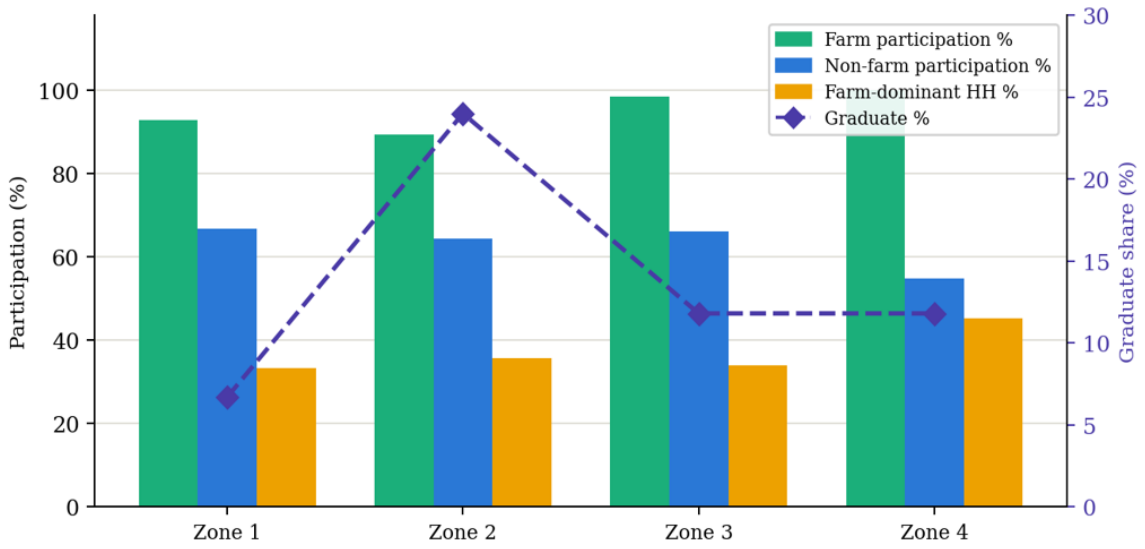
Table 9: Zone-wise Livelihood Diversification and Inter-generational Profile

Zone	n	Farm %	Non-farm %	Farm-Dominant %	Main Income Source	Graduate %
Zone 1	30	92.9	66.7	33.3	Agriculture + MGNREGA	6.7
Zone 2	25	89.3	64.3	35.7	Agriculture + Informal wage	24.0
Zone 3	68	98.4	66.1	33.9	Salaried/wage + Agriculture	11.8
Zone 4	51	100.0	54.8	45.2	Salaried/business	11.8
District	174	96.0	63.2	36.8	Non-farm dominant	12.6

Source: Primary field survey, computed by the researcher. (78.2) > Zone 4 (72.6) due to female literacy deficit in Zone 4.

Figure 9: Zone-wise livelihood diversification and inter-generational graduate share (%)



Source: Primary field survey. District-level gender gap in graduate attainment: male 18.3% vs female 7.2%.

Non-farm diversification is considerable (63.2% of households), while farm activities are almost universally practised (96.0% of households). The top zone in the district sample appears to be Zone 4, having the highest proportion of farm-dominant households (45.2%), while Zone 1 has the lowest (33.3%).

Non-farm diversification varies greatly in its qualitative nature from zone to zone. Zone 1 is all about non-farm income as defensive – MGNREGA public workfare and casual labour take the main show. Informal market wage activities and petty trade is marginally higher in Zone 2 as well as high MGNREGA dependency. Zone 3 is transitional comprising of wage labour, small scale trade and seasonal migration remittance. Zone 4 non-farm livelihoods are sustained by salaried work, skilled wage work and commercial activity, indicative of a process of livelihoods accumulation and diversification, rather than just subsistence safeguards. (Bryceson, 1999; Ellis, 2000). The trend is for the mean farm income share to drop with increasing resilience, from around 55% in Zone 1 to under 25% in Zone 4, which further establishes that there is a structural de-agrarianisation of the income base along the resilience gradient.

Inter-generational level, the graduate share, as a proxy for potential occupational mobility to skilled and professional occupations, is highest in Zone 2 (24.0%) and lowest in Zone 1 (6.7%) with Zones 3 and 4 having the same figure (11.8%).

Gender differences in graduate attainment (18.3% male respondents, 7.2% female respondents at the district level) is a structural constraint on gender equitable inter-generational occupational mobility in all zones (Drèze and Sen, 1995; NSSO, 2011).

4.8 Statistical Tests

The ANOVAs for continuous variables are included in Table 10, the chi-square for categorical variables in Table 11, the independent-samples t-tests in Table 12, and the Pearson correlations in Table 13.

Table 10: One-way ANOVA Results — Continuous Livelihood Variables

Variable	F-statistic	p-value	Result
Land Holding (acres)	44.851	< 0.0001	Significant
Annual Income (₹)	61.636	< 0.0001	Significant
Annual Savings (₹)	30.448	< 0.0001	Significant
Annual Expenditure (₹)	56.461	< 0.0001	Significant
Wage Income (₹)	132.834	< 0.0001	Significant
Distance to Market (km)	258.999	< 0.0001	Significant

Source: Primary field survey, computed by the researcher.

Table 11: Chi-square Tests — Categorical Variables by Zone

Variable	Chi-square	df	p-value	Result
Land Tenure × Zone	31.694	6	< 0.0001	Significant
Economic Category × Zone	22.738	3	< 0.0001	Significant
MGNREGA × Zone	10.752	3	0.013	Significant
SHG Membership × Zone	7.975	3	0.047	Significant
Female-Headed HH × Zone	4.707	3	0.195	Not significant

Source: Primary field survey, computed by the researcher.

Table 12: Independent-Samples t-Tests — Group Comparisons

Comparison	t	p-value	Group A Mean (₹)	Group B Mean (₹)	Result
Savings: APL vs BPL	3.446	0.0007	92,937 (APL)	76,365 (BPL)	Significant
Income: Female- vs Male-headed HH	−0.642	0.521	2,98,705 (Female)	3,08,198 (Male)	Not significant
Savings: SHG vs Non-member	2.734	0.007	92,335 (SHG)	78,768 (Non-SHG)	Significant

Source: Primary field survey, computed by the researcher.

Table 13: Pearson Correlations — Key Bivariate Relationships, by Zone

Relationship	Zone 1 (r)	Zone 2 (r)	Zone 3 (r)	Zone 4 (r)	District (r)
Land Holding × Income	0.479**	0.515**	0.431**	0.152 (ns)	0.398**
Market Distance × Income	−0.005 (ns)	−0.126 (ns)	0.109 (ns)	−0.215 (ns)	−0.059 (ns)
Income × Savings	0.817**	0.882**	0.725**	0.817**	0.792**

Source: **: $p < 0.01$ two-tailed; ns: not significant ($p > 0.05$). Primary field survey, computed by the researcher.

In Zones 1-3, the land holding–income relationship is strongly positive ($r = 0.431–0.515$), which suggests that agricultural production plays a key role in household income in these areas. The non-significant correlation between 0.152 and 0.288 in Zone 4 is in line with the structural shift from agriculture as an income source in the most resilient zone. The ANOVA result for market distance ($F = 258.999$) is highly significant, whereas the within-zone Pearson correlation results are uniformly non-significant (e.g., 0.028). This apparent paradox is explained by the difference in spatial scale: the ANOVA reflects the structural geographic difference between zone-average market distances, while the Pearson correlation asks about the variation of market distance at the household level within each zone, which is not large enough to result in appreciable income differences after taking others within-zone factors into account. The correlation between income and savings is the most consistent and strong bivariate correlation in the entire analysis ($r = 0.725–0.882$ across all zones, all $p < 0.01$). This is in line with the income–savings correlation being the strongest and most consistent bivariate relationship in the entire analysis.

5. CONCLUSION

This paper has used the five-capital pentagon of the Sustainable Livelihoods Framework to 174 sampled households in four geo-ecological zones of Udalguri district, and drawn five key conclusions that have direct policy implications.

First, the geo-ecological hierarchy is seen in statistically robust differences in livelihoods at the household level across almost all of the capital dimensions (all ANOVA $p < 0.0001$). The two variables that make up the core mechanism of geo-ecological livelihood disadvantage, market distance ($F = 258.999$) and wage income ($F = 132.834$), are structurally linked and have the steepest gradients. The two variables that constitute the core mechanism of geo-ecological livelihood disadvantage, market distance ($F = 258.999$) and wage income ($F = 132.834$), are structurally linked, and have the steepest gradients. The four-fold wage income gradient (Zone 1: ₹37,743 versus Zone 4: ₹1,37,670) is well above the two-fold total income gradient, conclosing that differential labour market access, rather than differential agricultural productivity, is the main cause of inter-zone income inequality.

Second, the Livelihood Asset Pentagon reveals that Zone 1's multi-dimensional vulnerability is cumulative across all five capitals simultaneously — a characterisation invisible to single-dimensional income or poverty metrics. Zone 1's near-zero composite scores on all five capitals establish that foothill livelihood vulnerability is not primarily a function of any single missing capital but of the systematic absence of the full capital portfolio. This finding has direct policy implications: piecemeal single-capital interventions — road improvement alone, or SHG promotion alone — will be insufficient to move Zone 1 households out of multi-dimensional vulnerability.

Thirdly, the asymmetric pentagon in Zone 2 (where human capital is at full capacity (100), while the other three capitals (natural, financial, physical, and social) are still close to zero is a unique livelihood trap that cannot be overcome through education without the complementary support of market access, credit and tenurial security. Education alone is not enough to create livelihood resilience (Ellis, 2000; Bryceson, 1999). This discovery calls into question single-sector human capital investment strategies for communities in the transitional zone.

Fourth, Human capital is the only dimension of livelihood resilience that is not aligned with the geo-ecological hierarchy as there are persisting gender literacy gaps (80.8% female literacy compared to male literacy of 100%) in Zone 4. Gender parity in educational level, namely transition of female household members from Higher Secondary to a Graduate level of attainment, is the highest equity gap in the trajectory of development in the district. This is further compounded by the gender disparity in

graduate attainment at the district level (18.3% for males, 7.2% for females), which is a structural limitation on inter-generational occupational mobility of women in all the zones (Drèze and Sen, 1995).

Fifth, the findings of this study is the most consistent and strongest income–savings correlation at district level ($r = 0.792$, $p < 0.01$), which ranges from 0.725 to 0.882 across all the zones. Income-enhancing interventions will build financial resilience, and savings capacity will be income-constrained across the district — so that additional interventions to promote savings will not be necessary.

Policy interventions in Udalguri district need to be zone differentiated. The priorities for Zone 1 are: All-weather Road connectivity to bring down the average market distance from 13.7 km, Land tenure regularisation in Assam Land and Revenue Regulation 1886, and increase institutional penetration in foothill belt, which currently stands at 30%. Zone 2 focuses on productive investments in physical capital and financial capital having to do with maximising the existing human capital potential – access to credit, linkages with markets, and skill-to-employment bridges. To achieve equitable distribution of economic resilience across gender lines, specifically targeting interventions to close the female graduate gap are critical for Zones 3 and 4, including mentorship programs and merit-based scholarships for female students in the college sector, and community awareness campaigns on female higher education.

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