

Linking Socioeconomic Vulnerability with Mineral Exploration Opportunities for Local Development Planning in the Noun Division, Cameroon

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Abstract

Mineral exploration can create opportunities for employment, local procurement and livelihood diversification, but its contribution to development depends on existing socioeconomic conditions. This study examines socioeconomic vulnerability across the Noun Division, Cameroon, and its relationship with a previously finalized lithostructural exploration framework. A relative Socio-Economic Vulnerability Index (SEVI) was constructed for nine subdivisions using seven dimensions: education, health, potable water, electricity, housing, roads and markets. Ranking robustness was assessed through leave-one-dimension-out and hypothetical input-perturbation sensitivity analyses. SEVI values range from 0.039 in Fouban to 0.886 in Bangourain, with Bangourain, Massangam, Njimom and Malantouen exhibiting Very High vulnerability. Rankings remained stable across sensitivity scenarios (Spearman's $\rho = 0.95\text{--}1.00$). Within seven geophysically covered subdivisions, SEVI showed a strong positive association with structural intersection density ($\rho = 0.893$; exact $p = 0.0123$), whereas other structural-density associations were not statistically significant. This exploratory relationship neither demonstrates mineral deposits nor guarantees socioeconomic benefits. Rather, it identifies territories where future exploration could interact with infrastructure constraints, service deficits and land-dependent livelihoods. Integrating socioeconomic vulnerability into early-stage exploration planning can therefore support livelihood protection, community participation, infrastructure prioritization and inclusive local development.

Keywords: Socioeconomic vulnerability, Local development, Livelihoods, Mineral exploration, Spatial inequality, SEVI, Cameroon

1. Introduction

Mineral exploration and the possible development of mineral resources can create opportunities for employment, local procurement, income diversification and broader territorial development. However, the socioeconomic benefits associated with extractive activities are neither automatic nor spatially uniform. Empirical studies have shown that mineral development may stimulate local incomes and backward linkages through demand for labour, goods and services, while benefits can remain geographically concentrated and coexist with inequality or other distributional effects (Aragón and Rud, 2013; Loayza and Rigolini, 2016). These issues are particularly important in rural territories where livelihoods remain strongly connected to agriculture and other land-based activities, because new mineral-sector opportunities may interact with existing patterns of employment, land use and household livelihood diversification. Studies from sub-Saharan Africa have consequently emphasized the close relationships between farming, mineral activities and livelihood strategies rather than treating agricultural and mineral economies as independent sectors (Hilson, 2011; Bryceson and Jönsson, 2010).

This issue is particularly relevant in Cameroon, where employment remains dominated by informal activities, which strongly influences how future mineral-related opportunities could be absorbed by the local economy. Results from the Third Employment and Informal Sector Survey (EESI3) indicate that 86.6% of employment is located in the informal sector,

including 52.0% in non-agricultural informal activities and 34.7% in informal agriculture (INS, 2023a). The developmental implications of future mineral activities should therefore be considered in relation not only to formal employment creation, but also to existing informal employment and livelihood-diversification strategies. Such effects may also differ between population groups, as evidence from African mining regions indicates differentiated labour-market effects between men and women and shifts between agricultural and non-agricultural activities (Kotsadam and Tolonen, 2016). Socioeconomic vulnerability provides an additional dimension to this context. The Fifth Cameroon Household Survey (ECAM5) reported a national monetary poverty rate of 37.7% in 2022, with a marked rural–urban contrast (56.3% versus 21.6%) and a rate of 30.4% for the West Region (INS, 2023b). Although these regional statistics do not describe conditions within individual subdivisions of the Noun, they underline the importance of examining new economic opportunities against geographically differentiated pre-existing socioeconomic conditions.

Within the West Region, the Noun Division provides a particularly relevant setting for examining territorial socioeconomic vulnerability. Its local economy is strongly supported by agriculture and other rural activities, while development conditions are unevenly distributed among its nine subdivisions: Bangourain, Fouban, Foubot, Kouoptamo, Koutaba, Magba, Malantouen, Massangam and Njimom. A household-based study involving 400 representatives across the Division documented substantial spatial inequalities in socioeconomic opportunities, infrastructure and services, with Fouban and Foubot generally displaying comparatively stronger development conditions than several peripheral subdivisions (Tafuh et al., 2024). These contrasts indicate that the Noun should not be treated as a socioeconomically homogeneous territory and provide a strong basis for examining vulnerability at subdivision level.

Alongside these socioeconomic disparities, a previously completed geological investigation has established a heterogeneous lithostructural framework identifying several environments relevant to future mineral exploration in the Noun Division (Ndam Njikam et al., in press). To our knowledge, no previous study has related this geological framework to a systematic assessment of socioeconomic vulnerability at the sub-divisional scale, which represents the principal novelty of the present study. These environments are defined from the convergence of structural, magnetic, radiometric and geological evidence and represent targets for further investigation rather than demonstrated mineral deposits or economically exploitable resources. Importantly, the available airborne geophysical coverage does not encompass the entire Noun Division, which limits direct geological–socioeconomic comparison to the areas where both types of information are available. This geological framework nevertheless creates an opportunity to address a complementary territorial question: to what extent do areas of high socioeconomic vulnerability spatially coincide with environments relevant to future mineral exploration? This question is important because geological opportunity alone cannot determine whether future mineral activities would contribute to inclusive local development; potential benefits depend on existing livelihoods, infrastructure, skills, local economic linkages and institutional capacity (Aragón and Rud, 2013; Loayza and Rigolini, 2016).

Accordingly, this study has three objectives: (1) to construct a relative Socio-Economic Vulnerability Index (SEVI) for the nine subdivisions of the Noun Division using comparable indicators of education, health, potable water, electricity, housing, roads and markets; (2) to evaluate the robustness of the resulting territorial ranking through sensitivity analysis; and (3) within the available geophysical coverage, to examine the spatial relationship between socioeconomic vulnerability and independently mapped geological environments relevant to mineral exploration. Importantly, the analysis does not seek to predict mineral resources, mine development, future household income or the profitability of extraction. Rather, it aims to identify territories where future exploration could intersect with existing livelihood dependencies and development constraints, thereby providing an evidence-based basis for anticipating employment, infrastructure, local participation and livelihood-protection needs in territorial development planning.

2. Study Area and Socioeconomic Context

2.1 Geographical and Economic Setting

The Noun Division is located in the West Region of Cameroon and comprises nine subdivisions (Note 1): Bangourain, Foumban, Foubot, Kouoptamo, Koutaba, Magba, Malantouen, Massangam and Njimom, with Foumban serving as the divisional administrative centre (Tafuh et al., 2024). The territory combines urban and predominantly rural areas whose accessibility, economic activities and provision of basic services vary considerably between subdivisions. The geographical position of the Division, its administrative subdivision framework and its main topographic and drainage characteristics are presented in Figure 1. These territorial contrasts provide the geographical context for examining differences in livelihoods, infrastructure and socioeconomic conditions across the Division.

Physiographically, much of the Noun belongs to the Bamoun Plateau, where Precambrian crystalline basement rocks coexist with Cenozoic volcanic formations associated with the Cameroon Volcanic Line (Moundi et al., 2007; Wandji et al., 2008). Recent geophysical interpretation has further revealed a structurally heterogeneous basement and several geological environments considered relevant to regional mineral exploration (Ndam Njikam et al., in press). In the present study, this geological information is used only as a spatial framework for examining where future exploration opportunities may coincide with contrasting socioeconomic conditions.

The economy of the Noun remains strongly dependent on land-based activities. A household survey covering the nine subdivisions indicates that more than 80% of households depend on agriculture for their livelihoods, although agricultural activities differ spatially (Tafuh et al., 2024). Both food and cash crops are cultivated. Robusta coffee is particularly associated with Malantouen, Massangam and Magba, whereas Arabica coffee is more strongly represented in Koutaba, Foubot, Bangourain and Kouoptamo (Tafuh et al., 2024). Food-crop production is also important across several subdivisions, with Foubot occupying a particularly prominent position as an agricultural production and commercialization centre (Tafuh et al., 2024).

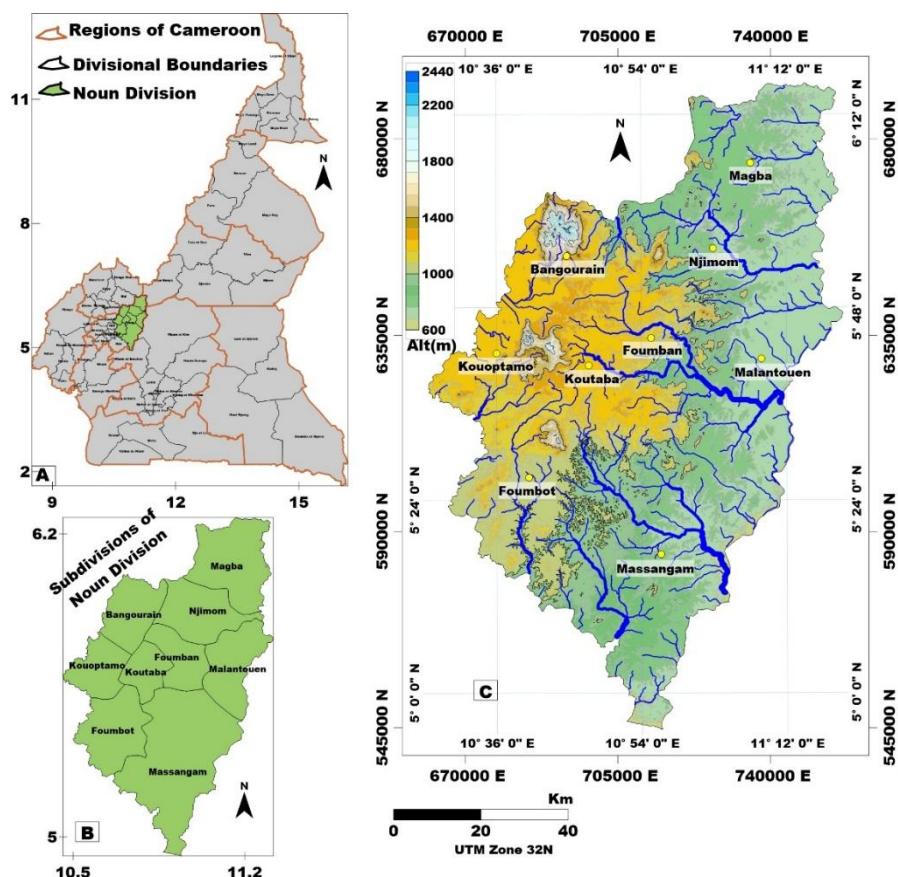


Figure 1. Location, administrative subdivisions and orohydrographic setting of the Noun Division, West Cameroon. (A) Location of the Noun Division within Cameroon; (B) the nine subdivisions considered in the socioeconomic analysis; and (C) topography and main drainage network

Livestock production, inland fishing and small-scale commercial activities complement crop agriculture and contribute to household livelihood diversification. Their importance varies geographically according to access to grazing land, water bodies, markets and transport infrastructure (Tafuh et al., 2024). Markets in Fouban and Foubot play particularly important roles in the circulation of agricultural products and other goods, while fishing and fish marketing contribute to local economic activity in areas associated with major water bodies, including the Magba sector (Tafuh et al., 2024). Together, these activities show that local livelihoods are organized around interconnected agriculture–livestock–fisheries–trade systems rather than crop farming alone.

This livelihood structure is central to the present analysis because any future mineral exploration would occur within territories where households already depend substantially on land, agricultural production, livestock, fisheries and local commercial networks. Potential employment, procurement or diversification opportunities therefore need to be considered alongside existing livelihood dependencies and territorial conditions rather than as an independent development pathway.

2.2 Livelihood Structure and Territorial Socioeconomic Disparities

Socioeconomic conditions are unevenly distributed across the Noun Division. Based on questionnaires administered to 400 household representatives across the nine subdivisions, Tafuh et al. (2024) documented spatial differences in agriculture, education, health, income and poverty, transport, housing, electricity, potable-water supply, markets and tourism. Fouban and Foubot generally occupied comparatively stronger positions in the local development structure, whereas several peripheral subdivisions displayed weaker combinations of infrastructure, basic services and economic opportunities.

The importance of territorially disaggregated socioeconomic information is also reflected in Cameroon's institutional planning framework. The 2021 Survey on the Socioeconomic Profiling of the 374 Councils and Urban Councils of Cameroon, implemented by the National Institute of Statistics (INS/MINEPAT), was designed to provide local-level information on socioeconomic conditions, public services and infrastructure (INS, 2022). Although its administrative units are not used as quantitative inputs to the present subdivision-level analysis, this national initiative illustrates the broader relevance of sub-regional socioeconomic profiling for local development planning.

Infrastructure and basic-service provision contribute strongly to these territorial differences. Road accessibility influences connections between rural production areas, markets, administrative centres and public services, while some peripheral areas experience greater transport constraints, particularly where secondary and rural roads deteriorate seasonally (Tafuh et al., 2024). Potable-water provision is also uneven, with formal treated-water networks more strongly represented in Fouban and Foubot and greater reliance on boreholes, wells and springs in several other subdivisions. Electricity shows a similar spatial differentiation: Fouban, Foubot, Koutaba and Magba occupy comparatively stronger positions in the dataset examined by Tafuh et al. (2024), whereas weaker conditions are reported for several other subdivisions. Together, these infrastructure and service disparities influence household living conditions, access to markets and services, and opportunities for livelihood diversification.

Education, health, housing and market access provide complementary dimensions of territorial inequality. Education and health services are not uniformly distributed across the Division, with a greater concentration of services around the principal urban centres, particularly Fouban (Tafuh et al., 2024). Housing conditions also vary, with comparatively more favourable conditions reported in Fouban and Foubot, while market access differentiates the capacity of producers and households to connect with commercial networks. These dimensions collectively reflect differences in human-development services, living conditions and economic connectivity rather than direct measures of household income or poverty.

Taken together, these conditions reveal a multidimensional pattern of territorial inequality across the Noun. Fouban and Foubot generally occupy comparatively favourable positions because of their concentration of services, infrastructure and economic activities, whereas several more peripheral subdivisions display weaker conditions across multiple

dimensions (Tafuh et al., 2024). Importantly, these differences represent relative territorial development conditions and should not be interpreted as direct measures of household poverty.

These documented disparities provide the socioeconomic basis for the multidimensional assessment developed in this study. The subsequent analysis focuses on seven comparable dimensions (education, health, potable water, electricity, housing, roads and markets) to characterize relative infrastructure-, service- and connectivity-related vulnerability across the nine subdivisions. The selection, normalization and aggregation of these dimensions into the Socio-Economic Vulnerability Index (SEVI) are described in Section 3.2.

3. Materials and methods

3.1 Data Sources and Analytical Framework

This study adopted a secondary-data and spatial-analysis approach organized in two successive stages. First, socioeconomic vulnerability was assessed across all nine subdivisions of the Noun Division—Bangourain, Fouban, Foubot, Kouoptamo, Koutaba, Magba, Malantouen, Massangam and Njimom. Second, the resulting socioeconomic pattern was compared with a previously finalized lithostructural exploration framework, developed independently of the socioeconomic analysis, within their common spatial extent. Because the available airborne geophysical coverage does not include Bangourain and Kouoptamo, this second stage was restricted to the seven covered subdivisions: Fouban, Foubot, Koutaba, Magba, Malantouen, Massangam and Njimom.

The principal socioeconomic dataset was derived from Tafuh et al. (2024), who investigated spatial inequalities in regional development across the Noun Division using information collected from 400 household representatives across the nine subdivisions. Their study considered several dimensions of local development, including education, health, potable water, electricity, housing, transport, markets, agriculture, income and poverty. Seven dimensions were retained for the present analysis: education, health, potable water, electricity, housing, roads and markets (Table 1). For each dimension, the published values represent the relative percentage distribution among the nine subdivisions, with each column summing to 100%. They should therefore be interpreted as relative territorial development shares rather than as percentages of households with access to the corresponding service or infrastructure. These published values constitute the quantitative input used to construct the SEVI.

Tafuh et al. (2024) adopted a quantitative and qualitative research design, reporting simple random sampling of 400 household representatives across the nine subdivisions. Their investigation combined questionnaire-based information with field observations and administrative data and employed descriptive and inferential statistical analyses. The subdivision-level socioeconomic indicators used to construct the SEVI were extracted from Table 4 of Tafuh et al. (2024), which reports the relative distribution of development dimensions across the nine subdivisions. However, the publication does not provide sufficient information on subdivision-specific sample allocation, indicator-level sampling uncertainty or measurement errors to reconstruct statistical confidence intervals for these inputs.

Consequently, the present study treats these values as published secondary-data estimates and explicitly distinguishes the reproducibility of the proposed analytical framework from the accuracy and representativeness of the underlying observations. The reliability of any resulting SEVI assessment remains conditional on the quality and comparability of the input data.

Additional contextual information was obtained from the 2021 Survey on the Socioeconomic Profiling of the 374 Communes and Urban Communes of Cameroon, produced by the National Institute of Statistics (INS). This national dataset was designed to support local development assessment at council level and includes information related to public services, infrastructure and socioeconomic conditions (INS, 2022). It was used as an institutional and contextual reference for local-scale socioeconomic profiling and was not numerically combined with the subdivision-level data of Tafuh et al. (2024) in the construction of the SEVI.

Table 1. Published subdivision-level relative development shares retained for the construction of the Socio-Economic Vulnerability Index (SEVI)

Subdivision	Education (%)	Health (%)	Potable water (%)	Electricity (%)	Housing (%)	Roads (%)	Markets (%)
Massangam	7	11	11	6	3	5	4
Bangourain	7	9	2	5	5	7	7
Foumban	28	24	25	24	27	20	20
Foumbot	16	2	21	20	22	19	26
Kouoptamo	7	14	4	8	6	10	10
Koutaba	13	14	13	14	12	12	12
Magba	6	10	6	12	11	11	11
Malantouen	10	15	8	7	4	5	4
Njimom	6	1	10	4	10	11	6
Total	100	100	100	100	100	100	100

Source: Values represent the relative percentage distribution of each development dimension among the nine subdivisions, with each column summing to 100%. They are not household access rates. Source: adapted from Tafuh et al. (2024).

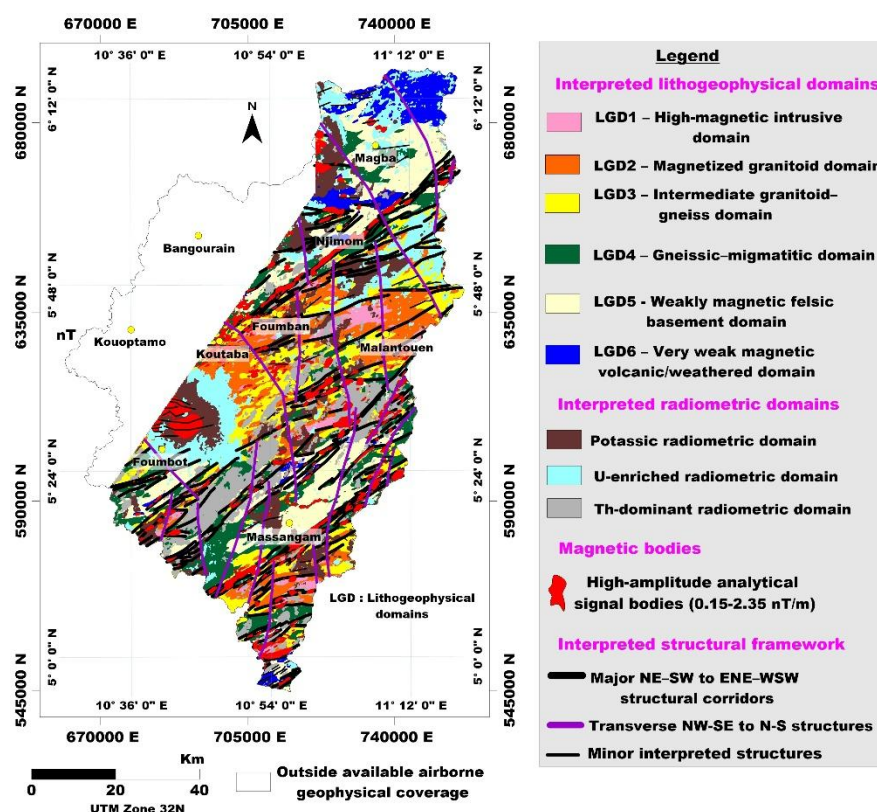


Figure 2. Integrated lithostructural framework used to characterize mineral exploration opportunities in the Noun Division, showing interpreted lithogeophysical domains, radiometric domains, high-amplitude magnetic bodies, major NE–SW to ENE–WSW structural corridors and transverse NW–SE to N–S structures. Modified from Ndam Njikam et al. (in press)

The mineral-exploration component was derived from the lithostructural framework developed by Ndam Njikam et al. (in press), based on integrated airborne magnetic and radiometric interpretation supported by geological and orohydrographic information. This framework was fully developed and finalized before the construction of the SEVI and the subsequent geological–socioeconomic comparison. Consequently, the geological interpretations were not influenced by, or adjusted to match, the socioeconomic vulnerability results. Although one author of the present study is also a co-author of the geological publication, this authorship overlap does not alter the chronological and methodological separation of the two analyses. The geological study has been accepted for publication in *Geosystem Engineering* and is currently in press. The original airborne geophysical datasets were not reprocessed in the present study; instead, the previously established geological framework was used as a separate spatial evidence layer for comparison with socioeconomic vulnerability (Fig. 2). The original airborne datasets were not reprocessed in the present study; instead, the previously interpreted framework was used as an independent spatial layer for comparison with socioeconomic vulnerability.

The analytical workflow therefore maintained socioeconomic vulnerability and mineral-exploration information as distinct components. The SEVI was first constructed and evaluated independently across all nine subdivisions (Section 3.2). Only thereafter was it compared spatially with the exploration framework within the seven subdivisions for which comparable geophysical information is available (Section 3.3). No combined socioeconomic–geological index was constructed.

3.2 Construction of the Socio-Economic Vulnerability Index (SEVI)

A composite-index approach was used to summarize the multidimensional socioeconomic differences among the nine subdivisions of the Noun Division. Composite indicators are particularly useful when several variables describe complementary dimensions of a broader phenomenon but cannot be directly compared or aggregated because of differences in scale and interpretation. Their construction requires explicit decisions regarding indicator selection, normalization, directionality, weighting and aggregation (OECD/European Union/EC-JRC, 2008).

Seven dimensions were retained from the subdivision-level socioeconomic information reported by Tafuh et al. (2024): education, health, potable water, electricity, housing, roads and markets (Table 1). These dimensions provide comparable information for all nine subdivisions and represent complementary aspects of basic services, infrastructure, living conditions and economic connectivity. For each dimension, the published values represent the relative percentage distribution of the corresponding development dimension among the nine subdivisions, with each column summing to 100%. They are therefore interpreted as relative territorial development measures rather than as direct household access rates. Agriculture and tourism were excluded because they primarily describe productive or sectoral characteristics whose relationship with socioeconomic vulnerability is not necessarily unidirectional. The published income/poverty dimension was also excluded because it is not reported as a directly comparable subdivision-level monetary poverty rate. The resulting seven dimensions therefore provide a conceptually coherent basis for constructing a relative, infrastructure- and service-based socioeconomic vulnerability index.

Because socioeconomic information is available for the entire Noun Division, the SEVI was calculated for all nine subdivisions, independently of the more restricted spatial extent used for the subsequent geological–socioeconomic comparison. Because higher published values for the seven selected dimensions correspond to comparatively more favourable territorial conditions, the indicators were first standardized as positive development measures. For each subdivision i and indicator j , min–max normalization was applied using Equation (1):

$$D_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \quad (1)$$

where D_{ij} is the normalized development score for subdivision i and indicator j ; x_{ij} is the original percentage value reported in Table 1 for indicator j for subdivision i ; and $\min(x_j)$ and $\max(x_j)$ are respectively the minimum and maximum observed values of

indicator j across the nine subdivisions. Here, $i = 1, \dots, 9$ identifies the subdivisions and $j = 1, \dots, 7$ identifies the selected socioeconomic dimensions. Equation (1) transforms each indicator to a common dimensionless scale ranging from 0 to 1 while preserving its relative ordering. Min–max normalization is widely used in composite-indicator construction to place variables on a comparable scale prior to aggregation (OECD/European Union/EC-JRC, 2008).

Under Equation (1), $D_{ij} = 0$ corresponds to the least favorable observed condition among the nine subdivisions for indicator j , whereas $D_{ij} = 1$ corresponds to the most favorable observed condition. Because the objective is to measure socioeconomic vulnerability rather than development performance, the normalized development scores were subsequently inverted using Equation (2):

$$V_{ij} = 1 - D_{ij} \quad (2)$$

where V_{ij} represents the normalized vulnerability score of subdivision i for indicator j , and D_{ij} is the normalized development score obtained from Equation (1). Consequently, V_{ij} also ranges from 0 to 1, but its interpretation is reversed: values approaching 0 indicate comparatively favourable conditions and therefore lower relative vulnerability, whereas values approaching 1 indicate comparatively unfavourable conditions and greater relative vulnerability. This directional harmonization ensures that all seven indicators contribute to the composite index in the same conceptual direction, an important requirement in composite-indicator construction (OECD/European Union/EC-JRC, 2008).

Equal weights were assigned to the seven vulnerability dimensions. The Socio-Economic Vulnerability Index for each subdivision was calculated as the arithmetic mean of its seven normalized vulnerability scores using Equation (3):

$$SEVI_i = \frac{1}{7} \sum_{j=1}^7 V_{ij} \quad (3)$$

where $SEVI_i$ is the Socio-Economic Vulnerability Index for subdivision i , V_{ij} is the normalized vulnerability score of subdivision i for dimension j , and $j = 1, \dots, 7$ represents the seven dimensions included in the index. Equation (3) can therefore be written explicitly in terms of the seven components as Equation (4):

$$SEVI_i = \frac{V_{Edu,i} + V_{Health,i} + V_{Water,i} + V_{Electricity,i} + V_{Housing,i} + V_{Roads,i} + V_{Markets,i}}{7} \quad (4)$$

where $V_{Edu,i}$, $V_{Health,i}$, $V_{Water,i}$, $V_{Electricity,i}$, $V_{Housing,i}$, $V_{Roads,i}$ and $V_{Markets,i}$ denote the normalized vulnerability scores for subdivision i associated respectively with education, health, potable water, electricity, housing, roads and markets.

Equal weighting was preferred because no independently validated empirical or expert-based evidence was available to justify assigning systematically greater importance to any one of the seven dimensions in the Noun context. Alternative data-driven weighting approaches, such as principal component analysis (PCA), could have been considered; however, with only

nine territorial units, such weights would be strongly dependent on the statistical structure of this small dataset and would not necessarily reflect the substantive importance of the original socioeconomic dimensions. PCA-based weighting was therefore not adopted. The procedure instead provides a transparent and reproducible baseline in which each dimension contributes $1/7$, or approximately 14.29%, to the composite index. This choice should not be interpreted as evidence that the seven dimensions are intrinsically equally important to household welfare; rather, it avoids introducing differential weights that could not be independently justified. Equal weighting is an established option in composite-indicator construction when there is no defensible basis for assigning differential weights, provided that the assumption is explicitly stated and its robustness is assessed (OECD/European Union/EC-JRC, 2008). Given the normalization and aggregation procedures defined in Equations (1)–(4), the theoretical range of the resulting index is expressed by Equation (5):

$$0 \leq SEVI_i \leq 1 \quad (5)$$

where $SEVI_i$ denotes the composite socioeconomic vulnerability score for subdivision i . Values approaching 1 indicate greater relative socioeconomic vulnerability within the nine-subdivision comparison, whereas values approaching 0 indicate comparatively more favourable conditions across the seven selected dimensions. The SEVI is therefore not a direct measure of household poverty, income, welfare or individual deprivation. Rather, it provides a relative territorial measure of socioeconomic vulnerability based on the selected infrastructure-, service- and living-condition dimensions.

For cartographic and descriptive purposes, the continuous SEVI was divided into five equal-interval vulnerability classes: Very Low (0.00–0.20), Low (>0.20–0.40), Moderate (>0.40–0.60), High (>0.60–0.80), and Very High (>0.80–1.00). Equal intervals were retained because the index has a fixed theoretical range from 0 to 1 and only nine territorial units are compared. The classification was used to facilitate cartographic representation and descriptive interpretation, whereas the continuous $SEVI_i$ values were retained for quantitative comparison and subdivision ranking.

To evaluate whether the resulting territorial ranking was disproportionately influenced by any single dimension, a leave-one-dimension-out sensitivity analysis was performed. The reference SEVI defined by Equation (3) was recalculated seven times, each time excluding one of the seven component dimensions and assigning equal weights to the six remaining dimensions. Each alternative ranking was then compared with the reference nine-subdivision ranking using Spearman's rank correlation coefficient, calculated using Equation (6):

$$\rho = 1 - \frac{6 \sum_{i=1}^n d_i^2}{n(n^2-1)} \quad (6)$$

where ρ is Spearman's rank correlation coefficient; d_i is the difference between the rank of subdivision i in the reference SEVI and its rank in a given leave-one-dimension-out scenario; and n is the total number of subdivisions included in the comparison, with $n = 9$ in the present study. Under Equation (6), values of ρ approaching 1 indicate strong preservation of the reference territorial ranking after removal of a given dimension, whereas progressively

lower values indicate greater sensitivity of the ranking to that dimension (Spearman, 1904). This procedure was used to evaluate the robustness of the relative territorial ranking rather than to identify causal determinants of socioeconomic vulnerability. The resulting SEVI values, vulnerability classes and sensitivity outcomes are reported in Section 4. To further assess the sensitivity of the SEVI to uncertainties in the secondary socioeconomic inputs, a complementary scenario-based perturbation analysis was designed. Two hypothetical perturbation levels ($\pm 5\%$ and $\pm 10\%$) were considered for the seven published development indicators. For each scenario, the original subdivision-level values were independently perturbed using multiplicative factors randomly drawn from a uniform distribution within the specified bounds. Because the published indicators represent relative territorial shares summing to 100% for each dimension, the perturbed values were subsequently rescaled to preserve this constraint. Min–max normalization was then recalculated across the nine subdivisions, followed by the same inversion, equal-weight aggregation and vulnerability classification procedures used for the reference SEVI. For each perturbation level, 10,000 simulations were specified to examine variations in SEVI values, territorial ranks and vulnerability classes relative to the reference results. This analysis was intended to evaluate the numerical sensitivity of the proposed framework to plausible hypothetical changes in the published inputs, rather than to estimate actual sampling errors or statistical confidence intervals, which cannot be reliably derived from the available secondary data.

3.3 Spatial Integration of Socioeconomic Vulnerability and Mineral Exploration Opportunities

Spatial comparison was performed in a Geographic Information System (GIS) while maintaining socioeconomic vulnerability and mineral-exploration information as distinct analytical components. The continuous SEVI value and corresponding vulnerability class were assigned to each subdivision polygon, producing a socioeconomic layer covering all nine subdivisions. The exploration framework was represented independently by the principal lithostructural and geophysical elements interpreted by Ndam Njikam et al. (in press). No numerical mineral-prospectivity score was generated, and the SEVI was not mathematically combined with a geological index.

Because the airborne geophysical framework does not cover Bangourain and Kouoptamo, the geological–socioeconomic comparison was restricted to the common spatial coverage comprising Fouban, Foubot, Koutaba, Magba, Malantouen, Massangam and Njimom. For each of these seven subdivisions, the area intersected by the available geophysical coverage was calculated and used as the denominator for normalizing the structural indicators. This procedure prevented differences in geophysical coverage area among subdivisions from being interpreted directly as differences in structural occurrence.

Two categories of interpreted structures were retained as simple quantitative descriptors of the exploration framework: major structural corridors and transverse structures. Each structural dataset was intersected with the seven subdivision polygons within the common geophysical coverage, and the lengths of the resulting segments were calculated in kilometres and summed by subdivision. Major-structure density (D_M) and transverse-structure density

(D_T) were then calculated as: $D_M = \frac{L_M}{A}$ and $D_T = \frac{L_T}{A}$; where L_M and L_T are respectively the cumulative lengths (km) of major and transverse structures within the geophysically covered portion of a subdivision, and A is its geophysically covered area (km²). Both indicators are expressed in km/km².

Major–transverse structural intersections were additionally generated to characterize locations where the two structural sets cross. Intersection features were converted to individual point records and checked for coincident duplicates before counting by subdivision. The number of distinct intersections was subsequently normalized by the corresponding geophysically covered area according to: $D_I = \frac{N_I}{A} \times 100$; where N_I is the number of distinct major–transverse intersections and A is the geophysically covered subdivision area. D_I is expressed as intersections per 100 km².

These structural indicators were used only as supporting descriptors of the spatial relationship between socioeconomic vulnerability and the independently interpreted exploration framework. Lithogeophysical domains, radiometric domains and high-amplitude magnetic bodies were retained in the cartographic comparison to provide geological context, but were not converted into additional subdivision-level scores. No composite geological-opportunity index was constructed. The final integration was therefore interpreted as a spatial coincidence analysis rather than as a causal or predictive model linking socioeconomic vulnerability to mineral occurrence. Bangourain and Kouoptamo were classified only socioeconomically and were not assigned geological favourability because comparable airborne geophysical information is unavailable for these areas.

To complement the descriptive spatial comparison, a non-parametric Spearman rank correlation analysis was performed to quantify the associations between socioeconomic vulnerability and the three structural indicators across the seven subdivisions covered by the geophysical dataset. The continuous SEVI values were separately correlated with major-structure density (km/km²), transverse-structure density (km/km²), and major–transverse intersection density (intersections/100 km²). Spearman's rank correlation coefficient (ρ), previously defined in Equation (6), was used to assess monotonic associations without requiring normally distributed variables. Given the small sample size ($n = 7$) and the absence of tied ranks, two-sided exact permutation tests were performed by considering all 7! (5,040) possible permutations of the subdivision ranks. Statistical significance was assessed at a nominal threshold of $p < 0.05$, with an additional Bonferroni-adjusted threshold of $p < 0.0167$ to account for the three comparisons. The analysis was designed as an exploratory assessment of subdivision-level associations, without assuming causal relationships between socioeconomic vulnerability and geological characteristics.

4. Results and Interpretations

4.1 Spatial Distribution of Socioeconomic Vulnerability

The Socio-Economic Vulnerability Index (SEVI) reveals marked territorial contrasts among

the nine subdivisions of the Noun Division (Table 2; Fig. 3). SEVI values range from 0.039 in Foubman to 0.886 in Bangourain, indicating a broad gradient of relative socioeconomic vulnerability across the study area. Four subdivisions are classified as Very High vulnerability: Bangourain (SEVI = 0.886; rank 1), Massangam (0.861; rank 2), Njimom (0.839; rank 3) and Malantouen (0.822; rank 4). Together, these subdivisions occupy the upper part of the vulnerability ranking and form extensive areas of comparatively high socioeconomic vulnerability in the northern, eastern and southern sectors of the Division.

Two subdivisions fall within the High vulnerability class: Kouoptamo (SEVI = 0.767; rank 5) and Magba (0.712; rank 6). Koutaba occupies an intermediate position, with a SEVI of 0.562 and is the only subdivision classified as Moderate vulnerability. At the lower end of the distribution, Foubot records a SEVI of 0.307 and is classified as Low vulnerability, whereas Foubman has the lowest SEVI (0.039) and is the only subdivision classified as Very Low vulnerability (Table 2).

The spatial pattern shown in Figure 3 therefore comprises four Very High, two High, one Moderate, one Low and one Very Low vulnerability subdivision. High and Very High SEVI values are not confined to a single contiguous part of the Noun Division but occur across several peripheral and large territorial units, whereas the lowest values are concentrated around Foubman and Foubot. The continuous SEVI values and their associated classes thus highlight substantial relative socioeconomic differentiation among the nine subdivisions. These classes represent relative territorial vulnerability within the Noun Division and should not be interpreted as official poverty or deprivation thresholds.

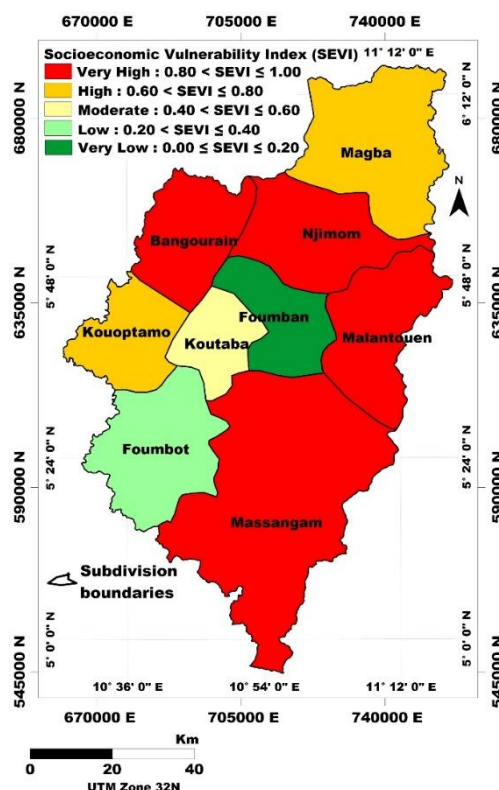


Figure 3. Spatial distribution of the Socio-Economic Vulnerability Index (SEVI) across the

nine subdivisions of the Noun Division, West Cameroon. SEVI values were derived from seven socioeconomic dimensions and classified into five relative vulnerability levels from Very Low to Very High

Table 2. Socio-Economic Vulnerability Index (SEVI), vulnerability classes and relative ranking of the nine subdivisions of the Noun Division

Subdivision	SEVI	Vulnerability class	Rank
Bangourain	0.886	Very High	1
Massangam	0.861	Very High	2
Njimom	0.839	Very High	3
Malantouen	0.822	Very High	4
Kouoptamo	0.767	High	5
Magba	0.712	High	6
Koutaba	0.562	Moderate	7
Foumbot	0.307	Low	8
Foumban	0.039	Very Low	9

Note: SEVI values range from 0 to 1, with higher values indicating greater relative socioeconomic vulnerability within the Noun Division. Vulnerability classes were defined as: Very Low ($0.00 \leq \text{SEVI} \leq 0.20$), Low ($0.20 < \text{SEVI} \leq 0.40$), Moderate ($0.40 < \text{SEVI} \leq 0.60$), High ($0.60 < \text{SEVI} \leq 0.80$), and Very High ($0.80 < \text{SEVI} \leq 1.00$). These classes represent relative territorial vulnerability among the nine subdivisions and do not correspond to official poverty or deprivation thresholds.

4.2 Robustness of the Socioeconomic Vulnerability Ranking

The leave-one-dimension-out sensitivity analysis indicates that the relative socioeconomic ranking of the nine subdivisions is highly stable when individual SEVI dimensions are successively excluded (Table 3). Spearman's rank correlation coefficients between the reference SEVI ranking and the seven leave-one-dimension-out rankings range from 0.9500 to 1.0000. The lowest correlations are obtained when either the health or potable-water dimension is excluded ($\rho = 0.9500$), whereas exclusion of education, electricity, housing or roads produces identical coefficients of $\rho = 0.9833$. Removing the markets dimension does not alter the subdivision ranking ($\rho = 1.0000$).

Overall, all seven coefficients remain at or above 0.95, showing that the territorial ordering obtained from the reference SEVI is not dependent on any single component dimension. The slightly greater changes associated with the exclusion of health and potable water indicate that these dimensions contribute somewhat more to differences in the relative ordering of subdivisions than the other individual components. Nevertheless, the consistently high rank correlations demonstrate that the main spatial pattern of socioeconomic vulnerability is robust to the removal of any one of the seven dimensions considered.

Table 3. Leave-one-dimension-out sensitivity analysis of the Socio-Economic Vulnerability Index (SEVI) ranking across the nine subdivisions of the Noun Division

Sensitivity scenario	Spearman's ρ with reference SEVI ranking	Ranking stability
Without Education	0.9833	Very high
Without Health	0.9500	Very high
Without Potable Water	0.9500	Very high
Without Electricity	0.9833	Very high
Without Housing	0.9833	Very high
Without Roads	0.9833	Very high
Without Markets	1.0000	Complete
Minimum ρ	0.9500	Very high overall stability

Note: Each sensitivity scenario recalculates the SEVI after excluding one socioeconomic dimension and assigning equal weights to the six remaining dimensions. Spearman's rank correlation coefficient (ρ) compares the resulting subdivision ranking with the reference seven-dimensional SEVI ranking. A value approaching 1 indicates strong preservation of the original territorial ranking.

The complementary input-perturbation analysis confirmed the overall numerical stability of the SEVI under the two hypothetical uncertainty scenarios (Table 4). With $\pm 5\%$ perturbations, the original nine-subdivision ranking was preserved in 99.24% of the 10,000 simulations, and all vulnerability classes remained unchanged. Under the $\pm 10\%$ scenario, the complete ranking was preserved in 84.44% of simulations, while all nine vulnerability classes were simultaneously maintained in 94.82%. The median Spearman rank correlation with the reference ranking was 1.000 under both scenarios, with 2.5th–97.5th percentile ranges of 1.000–1.000 and 0.983–1.000, respectively. The limited ranking changes primarily involved subdivisions with relatively similar reference SEVI values. These findings indicate that the territorial pattern is generally stable under the specified hypothetical perturbations, although they do not quantify the actual measurement or sampling uncertainty of the secondary socioeconomic data.

Table 4. Sensitivity of the Socio-Economic Vulnerability Index (SEVI) to hypothetical perturbations of the socioeconomic input data

Sensitivity indicator	$\pm 5\%$ scenario	$\pm 10\%$ scenario
Number of simulations	10,000	10,000
Median Spearman's ρ with reference ranking	1.000	1.000
Spearman's ρ , 2.5th–97.5th percentiles	1.000–1.000	0.983–1.000
Simulations preserving all nine original ranks (%)	99.24	84.44
Simulations preserving all nine original vulnerability classes (%)	100.00	94.82

Note: The perturbations were hypothetical multiplicative variations applied to the published socioeconomic inputs, followed by rescaling each indicator to a total of 100% and recalculating min–max normalization and SEVI. Percentile ranges describe the simulated sensitivity distributions and do not represent statistical confidence intervals for the original data.

4.3 Spatial Relationship between Socioeconomic Vulnerability and Mineral Exploration Opportunities

The spatial comparison between socioeconomic vulnerability and the lithostructural exploration framework was restricted to the common geophysical coverage shown in Figure 4. Seven subdivisions were therefore included: Foumban, Foumbot, Koutaba, Magba,

Malantouen, Massangam and Njimom. Bangourain and Kouoptamo remained part of the nine-subdivision SEVI assessment but were not included in the geological comparison because comparable airborne geophysical information is unavailable for these areas. Within the common coverage, vulnerability ranges from Very Low in Fouban to Very High in Massangam, Malantouen and Njimom (Fig. 4A).

Within the common coverage, the three Very High-vulnerability subdivisions (Massangam, Malantouen and Njimom) also display comparatively substantial structural evidence relevant to mineral exploration (Fig. 4B; Table 5). Njimom records the highest major-structure density (0.441 km/km^2) and the highest major-transverse intersection density ($2.700 \text{ intersections/100 km}^2$). Massangam records the highest transverse-structure density (0.104 km/km^2), together with a major-structure density of 0.305 km/km^2 and $2.389 \text{ intersections/100 km}^2$. Malantouen also shows comparatively high major- and transverse-structure densities (0.246 and 0.101 km/km^2 , respectively) and an intersection density of $2.656 \text{ intersections/100 km}^2$.

However, the spatial relationship is not uniform across the seven subdivisions, warranting caution in the interpretation of the spatial coincidence described above. Magba, classified as High vulnerability, has a relatively low major-structure density (0.126 km/km^2) but an intersection density of $2.030 \text{ intersections/100 km}^2$. Koutaba, classified as Moderate vulnerability, records the lowest major-structure density (0.112 km/km^2) but $1.979 \text{ intersections/100 km}^2$. Foubot and Fouban, classified respectively as Low and Very Low vulnerability, show lower intersection densities of 1.059 and $0.693 \text{ intersections/100 km}^2$. These differences indicate that socioeconomic vulnerability and structural indicators do not vary in a simple one-to-one manner across the study area.

Table 5. Socioeconomic vulnerability and selected structural indicators within the common geophysical coverage of the Noun Division

Subdivision	SEVI	Vulnerability class	Geophysically covered area (km^2)	Major-structure density (km/km^2)	Transverse-structure density (km/km^2)	Major-transverse intersections (n)	Intersections (n/100 km^2)
Fouban	0.038961	Very Low	433.126	0.237	0.099	3	0.693
Foubot	0.307270	Low	660.914	0.250	0.046	7	1.059
Koutaba	0.561862	Moderate	252.633	0.112	0.043	5	1.979
Magba	0.711895	High	1,034.646	0.126	0.075	21	2.030
Malantouen	0.822421	Very High	753.068	0.246	0.101	20	2.656
Massangam	0.861208	Very High	2,177.052	0.305	0.104	52	2.389
Njimom	0.838514	Very High	592.593	0.441	0.071	16	2.700

Note: Structural lengths and intersection counts were normalized by the geophysically covered area of each subdivision to account for differences in the spatial extent available for geological comparison. Bangourain and Kouoptamo are not included because comparable airborne geophysical information is unavailable within these subdivisions. Structural indicators characterize spatial association with the interpreted exploration framework and are not measures of mineral resources or economic potential.

Table 6. Spearman rank correlations between the Socio-Economic Vulnerability Index (SEVI) and structural indicators across the seven geophysically covered subdivisions

Structural indicator	Spearman's ρ	Exact two-sided p-value	Significant at adjusted threshold
Major-structure density (km/km ²)	0.5714	0.2000	No
Transverse-structure density (km/km ²)	0.4643	0.3024	No
Major–transverse intersection density (intersections/100 km ²)	0.8929	0.0123	Yes

Note: Correlations were calculated using continuous SEVI values and structural indicators for the seven subdivisions with comparable geophysical coverage ($n = 7$). Two-sided exact permutation p-values were obtained from all 5,040 possible rank permutations. Statistical significance was evaluated at $p < 0.05$, with a Bonferroni-adjusted threshold of $p < 0.0167$ for the three comparisons. These associations do not establish causality or mineral prospectivity.

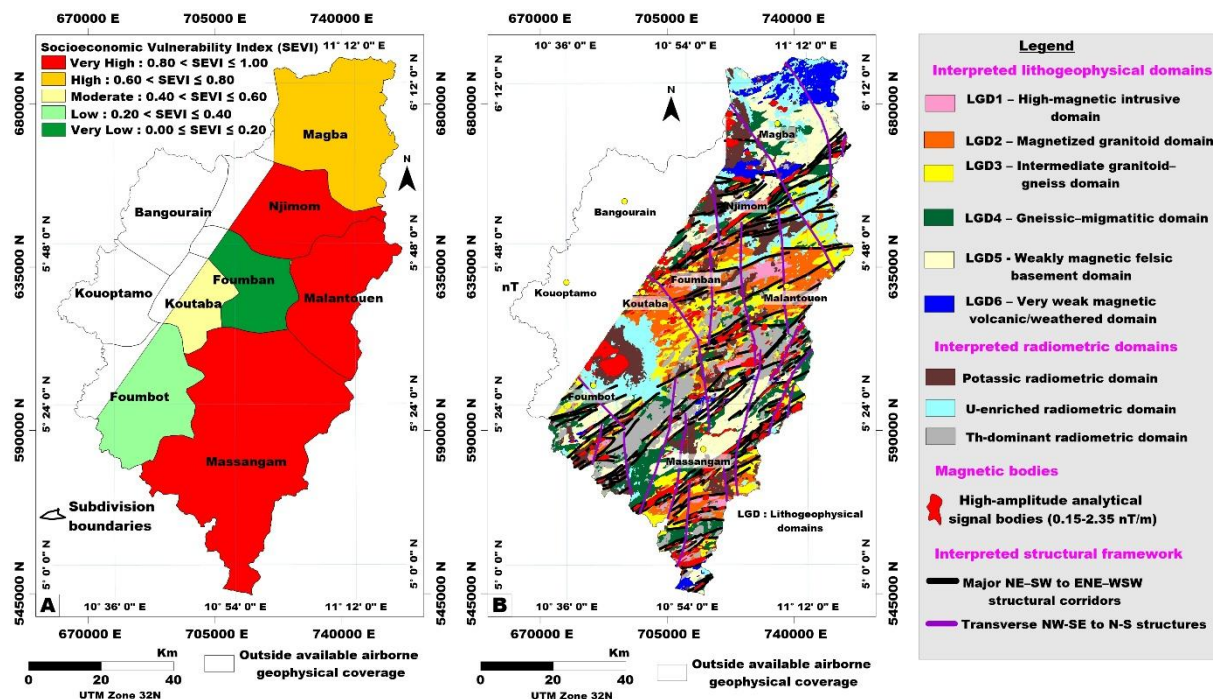


Figure 4. Spatial comparison of socioeconomic vulnerability and the mineral exploration framework within the common geophysical coverage of the Noun Division. (A) SEVI classes for the seven subdivisions intersected by the airborne geophysical coverage. (B) Simplified lithostructural exploration framework showing lithogeophysical and radiometric domains, high-amplitude magnetic bodies, and major and transverse structures. Bangourain and Kouoptamo lie outside the comparable geophysical coverage and are therefore not included in this spatial comparison. Geological framework modified from Ndam Njikam et al. (in press)

The Spearman rank correlation analysis revealed positive but contrasting associations between socioeconomic vulnerability and the three structural indicators across the seven subdivisions (Table 6). The strongest association was observed between SEVI and major–

transverse intersection density ($\rho = 0.8929$, exact two-sided $p = 0.0123$), which was statistically significant at both the nominal 0.05 threshold and the Bonferroni-adjusted threshold of 0.0167. By comparison, major-structure density showed a moderate positive association with SEVI ($\rho = 0.5714$, $p = 0.2000$), whereas transverse-structure density exhibited a weaker positive association ($\rho = 0.4643$, $p = 0.3024$). Neither of these latter associations was statistically significant. The results therefore indicate that the subdivision-level relationship between socioeconomic vulnerability and structural characteristics varies according to the indicator considered, with the clearest positive rank association involving structural intersection density.

Figure 4B further shows that the structurally characterized sectors occur within a heterogeneous geological setting comprising several lithogeophysical and radiometric domains and locally high-amplitude magnetic bodies. These features provide the broader mineral-exploration context established by Ndam Njikam et al. (in press). In the present analysis, however, they are used as contextual geological evidence rather than combined into a numerical prospectivity score. Taken together, the spatial comparison and correlation results identify a particularly pronounced association between high socioeconomic vulnerability and structural intersection density, alongside more variable relationships with major- and transverse-structure densities. This pattern is especially apparent in Njimom, Massangam and Malantouen, where Very High socioeconomic vulnerability coincides with comparatively substantial structural evidence relevant to future mineral exploration. These findings describe territorial associations and do not demonstrate the presence of mineral deposits or imply that exploration will necessarily lead to mine development or socioeconomic improvement.

5. Discussion

The SEVI results reveal pronounced territorial inequalities in socioeconomic vulnerability across the Noun Division. The contrast between the comparatively low vulnerability of Fouban and Foubot and the much higher vulnerability observed in Bangourain, Massangam, Njimom and Malantouen is consistent with the broader spatial inequalities previously documented in the Division. Tafuh et al. (2024) identified Fouban and Foubot as comparatively better positioned in terms of regional development, whereas several peripheral subdivisions displayed weaker conditions across basic services, infrastructure and economic connectivity. The present analysis extends these observations by integrating seven comparable dimensions into a single relative measure. The resulting pattern shows that territorial vulnerability in the Noun is multidimensional and spatially differentiated, reflecting the cumulative occurrence of disadvantages across several dimensions rather than a deficit in any single service or infrastructure category.

The comparatively favourable position of Fouban is consistent with its role as the divisional administrative centre and with the concentration of services and infrastructure reported there. Foubot also occupies a relatively favourable position and functions as an important agricultural production and commercialization centre, supported by its accessibility and market connections (Tafuh et al., 2024). In contrast, the high SEVI values recorded in Bangourain, Massangam, Njimom and Malantouen reflect the cumulative effect of

comparatively weaker conditions across several of the education, health, potable-water, electricity, housing, road and market dimensions included in the index. These differences should not be interpreted as direct measurements of household poverty or income deprivation. Rather, the SEVI identifies territories where multiple infrastructure-, service- and connectivity-related disadvantages coincide relative to the other subdivisions of the Noun Division.

This territorial differentiation is especially important in a setting where livelihoods remain strongly dependent on agriculture and other land-based activities. More than 80% of the households surveyed by Tafuh et al. (2024) were reported to depend on agriculture for livelihood sustenance, while crop production, livestock, fisheries and small-scale trade contribute in different combinations across the subdivisions. Socioeconomic vulnerability in the Noun must therefore be understood not only in terms of access to basic services and infrastructure, but also in relation to the conditions that enable households to maintain and diversify existing livelihood systems. Weak transport connectivity, limited service provision and restricted market access can constrain the ability of households to diversify economic activities or benefit from new opportunities. This livelihood context is particularly relevant when considering future exploration because any new activity would enter an already occupied and economically active rural landscape rather than an unused territorial space.

The leave-one-dimension-out analysis provides additional confidence in the territorial ranking. Spearman correlations between the reference SEVI ranking and the alternative rankings remain between 0.95 and 1.00, showing that the principal ordering of the subdivisions is highly stable when any single dimension is removed. The slightly larger ranking changes observed after excluding health or potable water do not alter this overall conclusion. The SEVI pattern therefore does not depend strongly on one particular component, which is important because composite indicators can be sensitive to indicator selection and weighting choices (OECD/European Union/EC-JRC, 2008). The robustness analysis nevertheless validates the stability of the ranking rather than the causal importance of the individual socioeconomic dimensions. The complementary input-perturbation analysis provides further evidence of numerical stability under the specified hypothetical uncertainty scenarios (Table 4). The complete subdivision ranking was preserved in 99.24% and 84.44% of simulations under the $\pm 5\%$ and $\pm 10\%$ scenarios, respectively, while vulnerability classifications remained largely unchanged. These results complement the leave-one-dimension-out analysis by showing that the main territorial pattern is not only relatively insensitive to the exclusion of individual dimensions but also generally stable under the simulated variations in the published socioeconomic inputs. However, this numerical stability should not be confused with empirical validation of the original measurements.

The spatial comparison with the mineral exploration framework adds a complementary territorial dimension to the socioeconomic analysis. Within the available geophysical coverage, Massangam, Malantouen and Njimom combine Very High socioeconomic vulnerability with comparatively substantial structural evidence relevant to future mineral exploration (Tables 5 and 6; Fig. 4). The quantitative analysis strengthens this observation by revealing a strong positive rank association between SEVI and major–transverse structural

intersection density, whereas the associations with major- and transverse-structure densities are weaker and not statistically significant. This contrast suggests that the spatial distribution of structural intersections provides a more consistent subdivision-level correspondence with socioeconomic vulnerability than the overall abundance of individual structural sets. However, structural intersections represent geological features potentially relevant to exploration, not confirmed mineralization, and there is no established mechanism by which structural density would directly determine socioeconomic vulnerability. The significance of the observed association is therefore territorial rather than causal: some of the subdivisions characterized by greater infrastructure- and service-based vulnerability also contain structural features that may warrant further geological investigation. This overlap highlights the importance of considering existing socioeconomic constraints when planning future exploration activities, without assuming that mineral deposits, economically viable resources or subsequent development benefits have been demonstrated.

This spatial coincidence has implications for how future exploration is approached from a local-development perspective. Exploration activities may generate demand for labour, transport, accommodation, supplies and other local services, although the scale and duration of such effects can differ substantially from those associated with mine development. Evidence from established resource-producing regions shows that broader extractive-sector benefits are neither automatic nor spatially uniform: local income and consumption effects depend on labour-market linkages, local economic structures and the capacity of households, businesses and institutions to participate in emerging opportunities (Aragón and Rud, 2013; Loayza and Rigolini, 2016). Employment effects may also differ between men and women and between formal and informal economic activities (Kotsadam and Tolonen, 2016). These studies concern contexts that are generally more advanced than the exploration stage considered in the Noun, but they underscore a relevant principle: geological opportunity alone should not be equated with inclusive local development.

This distinction is especially relevant in the Noun, where future exploration would interact with existing agriculture–livestock–fisheries–trade systems rather than enter an economically empty landscape. Access to land, roads and local services is already closely connected to household livelihoods, meaning that future exploration-related activities could generate new economic opportunities while also interacting with existing land uses and livelihood dependencies. In Very High-vulnerability subdivisions such as Massangam, Malantouen and Njimom, the local-development significance of exploration would therefore depend partly on the extent to which residents and local enterprises can participate in employment, procurement, training and service opportunities without undermining existing livelihood systems. The spatial coincidence identified in this study should consequently be viewed as a basis for territorial planning and anticipatory socioeconomic assessment, rather than as evidence that mineral exploration will necessarily reduce vulnerability.

The results also illustrate the importance of distinguishing the absence of comparable geological information from low exploration interest. Bangourain, which records the highest SEVI in the Division, and Kouoptamo, classified as High vulnerability, could not be included in the geological comparison because they lie outside the available airborne geophysical

coverage. Their absence from Figure 4B and Table 5 is therefore strictly a data-coverage limitation and should not be interpreted as evidence of unfavourable geology or low mineral-exploration interest. Additional geoscientific information would be required before these two subdivisions could be assessed on the same basis as the seven covered subdivisions.

Several limitations should be considered when interpreting this study and are discussed below in approximate order of importance. First, the SEVI is a relative composite index constructed from published subdivision-level development shares and therefore measures territorial differences within the Noun rather than absolute household deprivation, monetary poverty or individual household vulnerability. Second, equal weighting was adopted for transparency because no defensible empirical basis was available for assigning different weights to the seven dimensions. Although the leave-one-dimension-out analysis demonstrates strong ranking stability, the index remains dependent on the dimensions and secondary data available for this study. An additional limitation concerns the dependence of min–max normalization on the observed extreme values within a relatively small set of nine subdivisions. Although the input-perturbation analysis indicates substantial stability under the hypothetical $\pm 5\%$ and $\pm 10\%$ scenarios (Table 4), these results should not be interpreted as evidence that the original socioeconomic measurements are free from sampling or reporting errors. Rather, they demonstrate the numerical behaviour of the proposed analytical framework under explicitly defined input variations. The framework remains reproducible and transferable to other territories, but the reliability of its application necessarily depends on the quality, representativeness and comparability of the underlying socioeconomic data. Third, subdivision-level aggregation masks socioeconomic heterogeneity within each subdivision and does not capture household perceptions, gender-specific vulnerability, land tenure, income trajectories or the actual capacity of particular groups to participate in future exploration-related opportunities. Higher-resolution household and community data would therefore be required for project-level planning. Finally, the geological comparison identifies structural and geophysical environments relevant to exploration rather than proven mineral deposits, resources, reserves or economically viable projects. No inference regarding future mine development, profitability or direct household income effects can be made from the present analysis. The statistical assessment of the geological–socioeconomic relationship is also constrained by the small number of subdivisions with comparable geophysical coverage ($n = 7$). Although the association between SEVI and structural intersection density remains statistically significant after adjustment for the three comparisons, this result should be interpreted cautiously because the observations are spatially aggregated, the subdivisions differ substantially in size, and the analysis does not account for potential spatial dependence or unmeasured territorial characteristics. Furthermore, the correlations describe associations between subdivision-level socioeconomic conditions and interpreted structural indicators rather than relationships between individual households and mineral occurrences. The observed association should therefore be considered exploratory and requires confirmation using finer-scale socioeconomic information and additional geological investigations. The geological–socioeconomic comparison also relies on a previously finalized geological framework from a study that shares one co-author with the present work. Although the

geological interpretation preceded the SEVI analysis and was not modified in response to its results, the two publications are not independent in authorship. The geological study has been accepted for publication in *Geosystem Engineering* (Ndam Njikam et al., in press), but independent verification of its detailed results will be facilitated by the availability of the published article and supporting materials.

Despite these limitations, the main contribution of this study is to bring socioeconomic vulnerability into the spatial context of mineral exploration at an early stage, before any demonstrated mine-development trajectory exists. Geological investigations can indicate where further exploration may be technically justified, whereas socioeconomic analysis can identify territories where infrastructure constraints, service deficits and livelihood dependencies require particular attention. Considering these dimensions together provides a basis for anticipating where future exploration may encounter the greatest local-development challenges and where early planning could be most valuable. In the Noun Division, progression towards more advanced exploration should therefore be accompanied by finer-scale socioeconomic assessment, stakeholder engagement and specific investigation of land use and tenure, livelihood dependence, local skills, infrastructure needs, gender-differentiated conditions and realistic opportunities for local procurement and employment. The purpose is not to assume that mineral exploration will generate development, but to ensure that geological opportunities are evaluated within the socioeconomic realities of the territories in which they occur.

6. Conclusion

This study examined socioeconomic vulnerability across the Noun Division of West Cameroon and subsequently compared its spatial distribution with a previously finalized lithostructural framework relevant to mineral exploration. The Socio-Economic Vulnerability Index (SEVI), constructed from seven dimensions related to education, health, potable water, electricity, housing, roads and markets, reveals pronounced territorial inequalities across the nine subdivisions. Bangourain, Massangam, Njimom and Malantouen exhibit the highest relative vulnerability, whereas Foumban and Foubot occupy the least vulnerable positions. The leave-one-dimension-out analysis confirmed substantial ranking stability (Spearman's $\rho = 0.95\text{--}1.00$), while the complementary input-perturbation analysis preserved the complete territorial ranking in 99.24% and 84.44% of simulations under the hypothetical $\pm 5\%$ and $\pm 10\%$ scenarios, respectively. These findings support the numerical robustness of the SEVI under the tested scenarios, although the reliability of its application remains conditional on the quality of the underlying socioeconomic data.

Within the available airborne geophysical coverage, Massangam, Malantouen and Njimom combine Very High socioeconomic vulnerability with comparatively substantial structural evidence relevant to mineral exploration. The quantitative assessment across the seven covered subdivisions reveals a strong positive association between SEVI and major–transverse structural intersection density (Spearman's $\rho = 0.8929$; exact two-sided $p = 0.0123$), whereas the associations with major- and transverse-structure densities are weaker and not statistically significant. This finding strengthens the territorial comparison by demonstrating that the

observed correspondence varies among structural indicators. Nevertheless, the association remains exploratory and does not establish a causal relationship, confirm mineral deposits or economically viable resources, or imply that future exploration and mine development would automatically reduce socioeconomic vulnerability. Rather, it identifies territories where potential exploration activities could intersect with existing infrastructure and service constraints and land-dependent livelihood systems, highlighting the importance of anticipatory and inclusive local development planning.

The main contribution of this study is therefore to show how socioeconomic vulnerability can be incorporated into the territorial assessment of mineral exploration opportunities at an early stage. The results indicate that geological opportunity and local development conditions should not be considered independently. Where exploration advances, attention to existing livelihoods, land use, infrastructure and service needs, local skills, employment and procurement opportunities, and community participation should begin before any mine-development trajectory is assumed. In territories strongly dependent on agriculture and other land-based activities, such anticipatory planning is particularly important for identifying both opportunities for livelihood diversification and potential interactions with existing livelihood systems.

Overall, the proposed framework provides a transferable approach for identifying territories where socioeconomic vulnerability and mineral exploration opportunities spatially coincide, while maintaining a clear distinction between exploration-relevant geological evidence and demonstrated economic mineral potential. Higher-resolution household and community surveys are now needed to examine land use and tenure, livelihood dependence, local skills, gender-differentiated conditions, perceptions and the capacity of households and local enterprises to participate in future exploration-related opportunities. Additional geoscientific information is also required for Bangourain and Kouoptamo, which could not be included in the geological comparison because of the absence of comparable airborne geophysical coverage. Combining these finer-scale socioeconomic assessments with subsequent geological investigations would provide a stronger basis for inclusive and territorially informed planning as mineral exploration progresses in the Noun Division.

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Author contributions

Tourere Zenabou, Poutouochi Mongapna Arouna, Ntieche Adamou, Ismaila Amadu, and Mohamed Moustapha Ndam Njikam contributed to data processing, data analysis, interpretation of the results, and manuscript preparation. All authors contributed to the critical revision of the manuscript, read and approved the final version, and agreed to its submission for publication.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

Not applicable. This study relied on previously published, aggregated socioeconomic data and existing geological and geophysical information. No new research involving human participants or identifiable personal data was conducted.

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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Notes

Note 1. In Cameroon, an arrondissement is a third-level administrative unit, broadly corresponding to a sub-prefecture and generally associated with a council area.