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Landscapes and Extractive Livelihood Lock-In: A Spatial Macro Psychological Analysis of Slow-Onset Environmental Degradation, Collective Efficacy, and Communal Disorganization in the Bangka Belitung Archipelago, Indonesia

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geographical psychology, solastalgia, slow-onset disaster, extractive livelihood lock-in, collective efficacy, Bangka Belitung

Abstract

Slow-onset environmental degradation associated with open-pit tin mining and coastal ecosystem deterioration has transformed ecological conditions and livelihoods in extractive island regions. However, environmental psychology research has predominantly emphasized individual cognitive responses and acute disasters, providing limited understanding of how ecological degradation and extractive economic dependence interact to shape community-level psychosocial vulnerability. Drawing on geographical psychology, solastalgia, the risk perception paradox, and collective efficacy theory, this study examined the relationships among ecological stressors, extractive economic dependence, collective efficacy, and communal social disorganization in Bangka Belitung Islands Province, Indonesia. A nonreactive, macroecological research design integrated geospatial and administrative secondary data from 40 rural subdistricts (309 villages), with seven urban subdistricts included for comparison. Fifteen standardized indicators were used to construct four formative variables. Data were analyzed using two-stage formative partial least squares structural equation modeling (PLS-SEM), moderated regression analysis, Johnson–Neyman analysis, and spatial autocorrelation techniques. The findings revealed positive associations between communal disorganization and ecological degradation ($\beta = 0.537$, $p = 0.0002$) and extractive economic dependence ($\beta = 0.552$, $p = 0.0016$), whereas collective efficacy demonstrated a negative association ($\beta = -0.537$, $p = 0.0002$). The model explained 51.51% of the variance in communal disorganization. Extractive dependence significantly moderated the relationship between ecological stressors and communal disorganization ($\beta = 0.311$, $p = 0.0372$). Spatial analysis identified significant positive autocorrelation (Moran's $I = 0.437$, $p = 0.0002$), indicating geographically clustered vulnerability. These findings support integrated strategies combining ecological restoration, livelihood diversification, and strengthened community institutions.

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INTRODUCTION

Large-scale extractive activities and prolonged coastal ecosystem degradation have contributed to a contemporary ecological crisis characterized by gradual, cumulative environmental deterioration that often falls outside conventional emergency response frameworks (Maccarrone et al., 2024; Plaisance, 2026; Wu & Wan, 2024). This phenomenon is commonly described as a slow-onset disaster. Unlike sudden-onset hydrometeorological or geological disasters, which can cause extensive physical destruction within minutes or days, slow-onset disasters progressively undermine ecological carrying capacity over years or decades, potentially exceeding ecosystems' capacity for recovery. In Indonesia, this phenomenon is particularly evident in Bangka Belitung Islands Province, an archipelagic region covering approximately 16,690.13 km² that has experienced more than three centuries of alluvial tin mining on land and in coastal waters. Open-pit mining, offshore dredging operations, and artisanal mining activities have contributed to the formation of numerous abandoned mining pits, locally known as kolong, which may accumulate groundwater or acidic mine drainage. These activities have also contributed to secondary forest fragmentation, mangrove ecosystem degradation, and extensive areas of degraded land. Reported environmental impacts include the loss or degradation of approximately 64,567.34 hectares of mangrove ecosystems and approximately 170,391 hectares of degraded and critically degraded land, representing more than 10.2% of the province's land area. In Central Bangka Regency, critically degraded land reportedly accounts for 17.22% of the total area, coinciding with exposure to flooding, coastal inundation, and shoreline erosion in several settlements. These changes in land morphology, hydrological processes, and coastal sediment dynamics have implications not only for ecosystem functioning but also for the livelihoods, place-based identities, ecological resilience, and long-term well-being of communities across the archipelago.

Despite the extensive spatial scale of post-mining environmental degradation and coastal ecosystem deterioration, important theoretical and methodological gaps remain in environmental psychology and disaster risk reduction research. Environmental psychology has frequently emphasized individual-level cognitive and behavioral frameworks, including the Theory of Planned Behavior and Value–Belief–Norm Theory, which examine how attitudes, subjective norms, perceived behavioral control, personal values, and normative beliefs shape environmental behavior. Although these frameworks provide valuable insights, their explanatory capacity may be constrained in communities where behavioral choices are strongly influenced by structural inequalities, extractive economic dependence, and limited alternative livelihood opportunities. These constraints are particularly relevant in resource-dependent communities in the Global South, where economic vulnerability may restrict individuals' capacity to respond to environmental risks. Similarly, disaster psychology has often focused on psychological responses to sudden-onset disasters, leaving the long-term implications of gradual ecological deterioration for social cohesion, community functioning, and psychosocial well-being comparatively underexamined. Furthermore, self-report questionnaires administered in areas affected by natural resource conflicts may be susceptible to social desirability bias, particularly when respondents are reluctant to disclose interpersonal tensions or economically sensitive involvement in mining activities. Addressing these limitations requires a broader socioecological and geographical psychology perspective that integrates

spatial environmental indicators with aggregated administrative and census data. A nonreactive macroecological approach can help identify geographic associations between environmental degradation, structural socioeconomic conditions, and indicators of community-level social vulnerability. Nevertheless, such analyses must distinguish area-level associations from individual psychological experiences to avoid ecological fallacies and unsupported cross-level inferences.

Understanding the potential psychosocial implications of chronic environmental degradation requires consideration of the relationships among landscape transformation, place attachment, and community well-being. Communities experiencing prolonged mining-related disturbance and coastal ecosystem deterioration may encounter disruptions to the environmental conditions that support their livelihoods, cultural identities, and sense of belonging. The concept of solastalgia describes distress associated with unwanted environmental changes affecting a person's home environment while that person continues to reside there. Within a broader geographical framework, landscape degradation may therefore be examined as a contextual condition potentially associated with community-level psychosocial vulnerability. Another relevant concept is shifting baseline syndrome, which describes the gradual normalization of deteriorating environmental conditions as successive generations adopt increasingly degraded ecological states as their reference points. In mining-dependent communities, continued exposure to abandoned mining areas, sediment-affected waterways, and declining coastal ecosystem quality may influence perceptions of environmental change and acceptable ecological conditions. However, the normalization of environmental degradation should not automatically be interpreted as psychological adaptation or reduced environmental concern. The risk perception paradox further suggests that awareness of environmental hazards does not necessarily translate into protective behavior. In extractive economies, this discrepancy may reflect structural constraints, including dependence on mining income, limited financial resources, inadequate access to alternative employment, and insufficient opportunities for occupational transition. Consequently, environmental risk awareness and livelihood dependence must be considered jointly when examining the structural conditions associated with community vulnerability.

The tension between ecological sustainability and livelihood security provides a theoretical basis for examining extractive economic dependence as a potential moderator of the relationship between landscape degradation and communal social disorganization. Social Disorganization Theory emphasizes how structural disadvantages, residential instability, and weakened social networks may undermine communities' capacity to maintain social organization and informal social control. In extractive regions, prolonged environmental degradation may coincide with livelihood insecurity, competition over mining territories and fishing grounds, interpersonal conflicts, and declining access to ecosystem services. Where local economies depend heavily on mining activities and opportunities for nonextractive employment remain limited, extractive livelihood lock-in may intensify the association between ecological stressors and indicators of communal vulnerability. Conversely, communities with more diversified economic structures may possess greater adaptive capacity to respond to environmental deterioration. Collective efficacy theory offers a complementary perspective by emphasizing social cohesion and residents' shared willingness to intervene for the common good. Community cooperation, accessible public spaces, institutional capacity,

and effective local dispute resolution may provide structural conditions that support collective action and social resilience. At the subdistrict level, indicators of village development, community infrastructure, and local institutional capacity may serve as indirect proxies for these conditions. However, such indicators should not be treated as direct measurements of collective efficacy without adequate theoretical justification and construct validation.

These theoretical considerations raise several interconnected research questions concerning the spatial distribution of ecological stressors, extractive economic dependence, collective efficacy, and communal social disorganization across subdistricts in Bangka Belitung Islands Province. First, it is necessary to examine whether post-mining land degradation and coastal environmental vulnerability are associated with higher levels of community-level social disorganization. Second, the study considers whether extractive economic dependence is independently associated with communal vulnerability and whether it strengthens the relationship between ecological stressors and social disorganization. Third, the analysis investigates whether structural indicators representing collective efficacy are associated with lower levels of communal vulnerability. Finally, the study examines whether the geographic distribution of social disorganization exhibits significant spatial autocorrelation and whether identifiable clusters emerge across the mining-intensive areas of Bangka Island and the comparatively less mining-dependent areas of Belitung Island. Addressing these questions may provide a more integrated understanding of how ecological degradation and socioeconomic dependence correspond to geographically differentiated patterns of community vulnerability. Such evidence is relevant to the development of environmental restoration and disaster risk reduction policies that incorporate social and institutional considerations alongside biophysical rehabilitation.

Accordingly, this study aimed to examine the associations between landscape degradation, extractive economic dependence, collective efficacy, and communal social disorganization at the subdistrict level in Bangka Belitung Islands Province. Specifically, it sought to assess the direct relationships between ecological stressors and social disorganization and between extractive economic dependence and social disorganization. It also investigated whether extractive economic dependence moderated the association between ecological stressors and communal vulnerability, including the identification of conditional significance thresholds. Furthermore, the study examined whether structural indicators representing collective efficacy were negatively associated with social disorganization. Spatial analysis was conducted to assess global and local spatial autocorrelation and identify geographic concentrations of relatively high and low communal vulnerability. By integrating these objectives, the research sought to clarify how environmental degradation, economic structures, and community-level institutional conditions were associated with spatial variations in social vulnerability across the archipelago.

This study sought to contribute to environmental psychology, disaster research, and socioecological scholarship by examining the structural conditions associated with environmental degradation and community-level vulnerability in an extractive archipelagic setting. Theoretically, it extended discussions of solastalgia, environmental risk perception, extractive livelihood dependence, and collective efficacy by considering their relevance to geographically aggregated indicators of social vulnerability. Methodologically, the research combined two-stage formative partial least squares structural equation modeling (PLS-SEM),

moderated regression analysis using the Johnson–Neyman technique, and spatial autocorrelation analysis to investigate relationships among ecological, economic, and institutional indicators. This integrated approach was intended to provide complementary evidence regarding structural associations, conditional relationships, and geographic clustering. From a practical perspective, the findings may inform geographically targeted environmental restoration, livelihood diversification, and community resilience initiatives. They may also assist local governments and disaster management authorities in identifying areas where ecological rehabilitation should be accompanied by economic transition programs and strengthened community institutions. Ultimately, the study provides an empirical basis for considering environmental sustainability, livelihood security, and community-level social resilience as interconnected priorities in the management of extractive landscapes.

METHOD

Research Design and Spatial Analysis Unit

This study employed a cross-sectional ecological design at the regional level, integrating social ecometrics (Sampson et al., 1997) and geographical psychology (Rentfrow et al., 2008; Oishi, 2014). A nonreactive approach using official administrative records and archived geospatial data was adopted to minimize potential social desirability bias and reporting reluctance associated with individual self-report surveys in extractive mining communities. To reduce the risk of ecological fallacy (Robinson, 1950), all constructs were operationalized and interpreted at the subdistrict level as aggregated structural characteristics of the socioecological environment, including landscape degradation associated with potential solastalgia, extractive economic dependence, structural proxies for collective efficacy, and communal social disorganization. These indicators were not interpreted as measures of individual psychological conditions or clinical diagnoses.

The study covered Bangka Belitung Islands Province, Indonesia, located east of Sumatra between 104°50′–109°30′ E and 0°50′–4°10′ S, with a land area of approximately 16,690.13 km². The primary units of analysis comprised all 40 rural subdistricts encompassing 309 administratively designated villages across six regencies: Bangka (n = 8), Belitung (n = 5), South Bangka (n = 8), Central Bangka (n = 6), West Bangka (n = 6), and East Belitung (n = 7). Seven urban subdistricts in Pangkalpinang City, comprising 42 urban villages (kelurahan), were considered separately as an urban comparison group because they lacked rural village administrative units and corresponding Developing Village Index (Indeks Desa Membangun [IDM]) scores. The selection of subdistricts as the spatial units of analysis accounted for the modifiable areal unit problem (MAUP; Openshaw, 1984), as regency-level aggregation would have obscured local variations in coastal and mining-related environmental conditions. Subdistricts also provided a suitable administrative scale for integrating data on policing, primary health care, and inter-village development coordination. The administrative dataset was reported to have complete coverage, with no missing observations.

Data Sources and Procedures for Spatial-Socioeconomic Mergers

This study integrates five government archive data repositories and official geospatial databases through a spatial-socioeconomic data fusion procedure. The first data source is the aggregate microdata of the Village Potential Data Collection (PODES) 2024 (BPS, 2024) and

the Development Village Index (IDM) of the Ministry of Villages and Rural Development (IDM) (2016, 2019), which provides environmental (IKL), economic (IKE), and social (IKS) resilience parameters in 309 villages in 40 sub-districts, as well as the geographical typology of seaside villages. The second data source includes a geospatial database on land degradation and coastal hazards sourced from the National Critical Land Determination Decree of the Ministry of Environment and Forestry (DLHK Bangka Belitung Islands, 2023), coastal mangrove ecosystem mapping (BPS Bangka Belitung Islands Province, 2023), the 2025 Indonesian Disaster Risk Index (IRBI) from the BNPB InaRISK portal (2025), as well as records of hydrometeorological and coastal disaster events (BPS Bangka Belitung Islands Province, 2022a).

The third data source is the sectoral database from the One Data Indonesia (SDI) portal of the Bangka Belitung Islands Province, including the distribution of Mining Business Licenses (IUP) of the Energy and Mineral Resources Service as well as the capture fisher population and the value of marine fisheries production of the Marine and Fisheries Service. The fourth data source is the National Socio-Economic Survey (Susenas KOR) for estimating the prevalence of health complaints in the past month, morbidity rate, and poverty depth index (P1), which is combined with crime statistics from the Bangka Belitung Islands Regional Police regarding crime risk per 100,000 population. All geospatial data were extracted using the Zonal Statistics technique at the boundaries of the sub-district administrative polygons and combined relationally based on the standard area code of the four-digit BPS district (19.01–19.71) and the six-digit sub-district (19.01.01–19.71.07).

Operationalization of Constructs and Preparation of Formative Composite Indices

Given that each theoretical construct in this study is formed by a combination of objective structural indicators that capture different facets of socio-ecological reality, all latent variables are operationalized as formative composite constructs (Hair et al., 2019). For each raw indicator in sub-district i and indicator j in construct k, indicators that have a semantic direction opposite to the construct definition are first aligned with their polarity (e.g. finite index inversion 1 - x or reciprocal ratio 1/x), then transformed into a Z-score standard score (M = 0, SD = 1) and aggregated into a standardized composite score.

The operational mapping of 15 formal secondary data indicators into four macro-psychological constructs is presented in detail in Table 1.

Table 1. Macro-Psychological Variable Operationalization Matrix from Official

Macro Constructs & Roles	Theoretical Foundations	Indicator Code & Official Source	Macro-Psychological Rationalization
Land & Coastal Degradation Stressors (Z_X) [Major Exogenous]	Geographical Psychology (Rentfrow et al., 2008); Solastalgia (Albrecht et al., 2007)	• z_x1: IKL Inversion (IDM Indicator 51–53) • z_x2: Hydrometeorological Disaster (PODES Block V/VI) • z_x3: IRBI Score (InaRISK BNPB 2025) • z_x4: Critical Land Intensity (Decree of the	Represents the intensity of slow changes in the landscape of solastalgia: accumulation under mines, water pollution by tailings, and coastal abrasion that suppresses the carrying capacity of living spaces.

		Ministry of Environment and Forestry)	
Extractive Economic Dependence (Z_M) [Structural Moderator]	Risk Perception Paradox (Wachinger et al., 2013); Trapped Populations (Black et al., 2011)	• z_m1: IKE Inversion (IDM Indicator 39–50) • z_m2: IUP Density per 10k People (SDI ESDM) • z_m3: Vulnerability of Fishermen's Catch Value (DKP) • z_m4: Poverty Depth Burden P1 (Susenas)	Measure the degree of livelihood lock-in and socio-economic immobility of residents due to mining monocultures and traditional capture fisheries.
Collective Efficacy & Social Capital (Z_C) [Buffer]	Collective Efficacy Theory (Sampson et al., 1997); Socioecological Buffer (Oishi, 2014)	• z_c1: Village Adaptive Capacity (IDM 16–24, 27, 54) • z_c2: Dispute Resolution (Police Clearance Rate) • z_c3: District Social Resilience Index (IKS)	It reflects the capacity of communal social regulation, the cohesion of citizens' mutual cooperation, village institutional preparedness, and the effectiveness of conflict resolution as an antidote to horizontal tensions.
Social Disorganization & Communal Distress (Z_Y) [Principal Endogenous]	Social Disorganization Theory (Sampson et al., 1997); Somatic Solastalgia (Albrecht et al., 2007)	• z_y1: SME Inversion & Social Friction (IDM 25–30; PODES) • z_y2: Health Complaints for a Month (Susenas R1102) • z_y3: Morbidity/Pain Rate (Susenas R1103) • z_y4: Crime Risk per 100k Inhabitants (Babel Police)	Objective manifestations of macro-psychological vulnerability of the region: erosion of social cohesion, surge in somatic-health complaints of citizens, morbidity, and risk of disruption of law and crime order.

Source: Original data/source attribution requires author verification.

Note: All indicators have been aligned with the direction of polarity and standardized into Z-score (M = 0, SD = 1) in the population of N = 40 rural sub-districts (309 villages) of Bangka Belitung Islands Province.

Statistical Analysis Strategies and Spatial Econometrics

Data analysis was carried out through four structured stages using a Python computing environment (NumPy, SciPy, and Pandas, random seed = 42). The first stage was the evaluation of the formative measurement model (Outer Model Assessment) through a multicollinearity test using the Variance Inflation Factor (VIF) with a strict VIF threshold of < 3.3 (Hair et al., 2019), as well as the significance test of weights and formative loads through nonparametric bootstrapping as many as 5,000 replications.

The second stage is the testing of structural models (Inner Model) and Moderated Regression Analysis (MRA) using the Two-Stage Approach to estimate the full structural equation together with the conditional simple slopes analysis and the Johnson-Neyman light flood threshold test (Bauer & Curran, 2005) to map the limit of moderator values at which the impact of ecological stressors transitions from insignificant to statistically significant. The third stage is the construction of a spatial weighting matrix (W) using the k-Nearest Neighbors (k = 4) method based on Haversine geodesic distances between sub-districts with line standardization to test global spatial autocorrelation (Global Moran's I with 4,999 Monte Carlo permutations) and local autocorrelation (Local Indicators of Spatial Association / LISA;

Anselin, 1995) to detect hotspot and coldspot clusters.

RESULTS AND DISCUSSION

Spatial Distribution and Typology of Degradation and Psychosocial Areas

Cross-regional comparative descriptive analysis of 40 rural sub-districts (309 villages) and 7 urban sub-districts in the Bangka Belitung Islands Province showed a sharp socio-ecological polarity between the Bangka Island and Belitung Island clusters (Table 2). The areas in the onshore and coastal tin mining corridors of Bangka Island—especially in Central Bangka Regency (n = 6 sub-districts, 56 villages) and Bangka Regency (n = 8 sub-districts, 62 villages)—recorded severe landscape degradation pressures as well as the highest rates of social disorganization and communal distress in the province (Z_Y scores reached +1,267 and +1,065 respectively). On the other hand, the Belitung Island cluster (Belitung and East Belitung Regencies) displayed a very solid environmental resilience profile (IKL reached 0.679 and 0.690) which was supported by social capital and a very strong community collective efficacy (Z_C score reached +0.650 in Belitung and +1.627 in East Belitung), thus succeeding in suppressing communal distress to the lowest level (-1.158 in Belitung).

Table 2. Spatial Distribution, Descriptive Statistics of the Building Village Index, and Composite Construct Typology per Regency/City (N = 47 Districts, 393 Villages/Urban Villages)

Regency/City	n Kec (Village)	IKL_kec	IKE_kec	IKS_kec	Stressor (Z_X)	Economics (Z_M)	Efficacy (Z_C)	Distracted (Z_Y)
Bangka Regency	8 (62/19)	0,636	0,614	0,776	-0,069	+0,220	-0,599	+1,065
Belitung Regency	5 (42/7)	0,679	0,613	0,798	-1,596	+1,448	+0,650	-1,158
South Bangka Regency	8 (50/3)	0,668	0,590	0,768	+0,604	-0,447	+0,171	-0,724
Central Bangka Regency	6 (56/7)	0,665	0,643	0,771	+1,083	-0,617	-0,952	+1,267
West Bangka Regency	6 (60/6)	0,630	0,602	0,760	-0,802	-0,935	-0,916	-0,715
East Belitung Regency	7 (39/0)	0,690	0,659	0,819	+0,288	+0,557	+1,627	-0,036
Rural Sub-Total	40 (309/42)	0,660	0,619	0,781	0,000	0,000	0,000	0,000
Pangkalpinang City	7 (0/42)	— (Urban)	— (Urban)	— (Urban)	—	—	—	—

Source: Original data/source attribution requires author verification.

Note: IKL = Environmental Resilience Index; IKE = Economic Resilience Index; IKS = Social Resilience Index (Kemendesa PDTT). The scores of Z_X, Z_M, Z_C, and Z_Y are standardized composite scores.

The crossover between the Land-Coastal Degradation Stressor (Z_X) and Community Collective Efficacy Resilience (Z_C) groups 40 rural sub-districts into four regional typology quadrants. Quadrant IV (High Degradation – Low Resilience / Solastalgia Crisis Zone; n = 12 sub-districts) includes Koba, Pangkalan Baru, Simpang Katis, Sungai Selan, Namang, Lubuk Besar, Sungailiat, Puding Besar, Mentok, Payung, Pulau Besar, and Pongok Islands which

recorded the highest average communal distress in the province (+0.589 SD). Quadrant I (High Degradation – High Resilience / Resilient Adaptation Zone; n = 9 sub-districts) includes Manggar, Damar, Dendang, Simpang Pesak, Toboali, Lepar Pongok, Air Gegas, Simpang Rimba, and Tukak Sadai where high environmental stressor pressure is successfully mitigated by strong collective efficacy so that communal distress remains at negative values (-0.356 SD). Quadrant II (Low Degradation – High Resilience / Ecotourism Zone; n = 8 sub-districts) covers all sub-districts on Belitung Island that recorded the lowest communal distress (-0.911 SD). Finally, Quadrant III (Low Degradation – Low Resilience / Latent Vulnerability Zone; n = 11 sub-districts) in Bangka and West Bangka experienced positive distress (+0.311 SD) due to the fragility of local institutional efficacy.

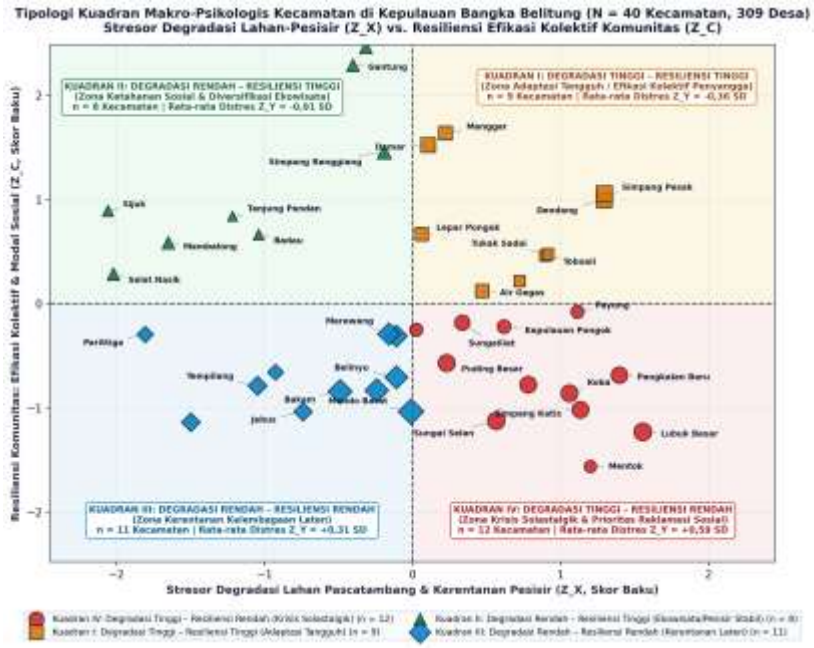

Figure 1. Plot of Distribution of Regional Typology Quadrants: Land-Coastal Degradation Stressors (Z_X) vs. Community Collective Efficacy Resilience (Z_C) in 40 Rural Districts in Bangka Belitung Islands Province

Note. The size of the circle represents the magnitude of Social Disorganization and Communal Distress (Z_Y). The vertical and horizontal dotted lines mark the average provincial population (Z = 0.00 SD) that divides the sub-districts into four socio-ecological regimes: Quadrant I (High Degradation–High Resilience, n = 9), Quadrant II (Low Degradation–High Resilience, n = 8), Quadrant III (Low Degradation–Low Resilience, n = 11), and Quadrant IV (High Degradation–Low Resilience, n = 12).

Evaluation of Formative Measurement Models (Outer Model)

The testing of the formative measurement model proved the fulfillment of convergent validity and the absence of multicollinearity in all research constructs (Table 3). The correlation between the Equal Weighting and Principal Component Analysis composites reached r = 0.835 to 0.998 ($p < 0.0001$). All 15 formative indicators had an Outer VIF value ranging from 1.005 to 2.024 (with a tolerance value of 0.494–0.995), well below the critical VIF threshold of < 3.3 (Hair et al., 2019). At the level of the structural model (Inner Model), the value of inter-construct multicollinearity was also very low: VIF(Z_X) = 1.201; VIF(Z_M) = 1.888;

VIF(Z_X×M) = 1.492; and VIF(Z_C) = 1.158. A bootstrapping test of 5,000 samples confirmed that 14 of the 15 indicators had a significant bivariate charge at $p < 0.01$ (t_Boot between 2.75 to 24.70).

Table 3. Evaluation of Formative Measurement Models: Multicollinearity Diagnostics (VIF), Composite Weights, and Bootstrap Significance Tests (B = 5,000)

Construct & Indicator Code	Indicator Description	VIF Outer	Weight EW	PCA Weights	Loading (r)	t_Boot (p-val)
Construct X: Ecological Stressors	**Inner VIF = 1,201**	—	—	—	—	—
• z_x1_degradasi_ikl_kec	Environmental Index Inversion	1,147	0,250	0,270	+0,437	+4.70 (p<.001)
• z_x2_bencana_hidro	Flood/Abrasion Occurrence	1,416	0,250	0,347	+0,491	+4.15 (p<.001)
• z_x3_skor_irbi	InaRISK Disaster Risk Score	1,057	0,250	0,007	+0,618	+7.95 (p<.001)
• z_x4_intensitas_lahan_kritis	Critical Land Intensity of the Ministry of Environment and Forestry	1,482	0,250	0,376	+0,113	+0.99 (Retain PCA)
Construct M: Economic Dependency	Inner VIF = 1,888	—	—	—	—	—
• z_m1_monokultur_ike	Economic Resilience Inversion	1,005	0,250	0,004	+0,422	+3.81 (p<.001)
• z_m2_intensitas_iup	IUP Density per 10k Population	2,024	0,250	0,467	+0,775	+6.77 (p<.001)
• z_m3_kerentanan_nelayan	Inversion of Fishermen's Catch Value	1,028	0,250	0,067	+0,468	+4.89 (p<.001)
• z_m4_kemiskinan_ekstraktif	Poor Depth P1 × IKE	2,000	0,250	0,462	+0,701	+7.05 (p<.001)
Construct C: Collective Efficacy	Inner VIF = 1.158	—	—	—	—	—
• z_c1_kapasitas_adaptif	Village Adaptive Capacity Score	1,544	0,333	0,337	+0,732	+7.78 (p<.001)
• z_c2_penyelesaian_sengketa	Police Clearance Rate (%)	1,254	0,333	0,261	+0,662	+14.39 (p<.001)
• z_c3_ketahanan_sosial	Village Social Capital Index	1,847	0,333	0,401	+0,875	+24.70 (p<.001)
Construct Y: Disorganization & Distension	Primary Endogenous	—	—	—	—	—
• z_y1_erosi_kohesi	Inversion of Social Resilience & Friction	1,181	0,250	0,333	+0,382	+3.36 (p<.001)
• z_y2_keluhan_kesehatan	Prevalence of Pain Complaints in a Month	1,573	0,250	0,054	+0,813	+19.42 (p<.001)
• z_y3_morbiditas_susenas	Breast Disease Morbidity Rate	1,589	0,250	0,375	+0,343	+2.75 (p<.01)
• z_y4_risiko_kriminalitas	Crime Risk per 100k Lives	1,450	0,250	0,238	+0,612	+6.88 (p<.001)

Source: Original data/source attribution requires author verification.

Note: N = 40 rural sub-districts. All VIF values were below the strict threshold of 3.3 (Hair et al., 2019). The PCA weight of critical land was maintained for the validity of the construct content.

Testing of Structural Models and the Moderation Effect of Hostage Livelihood

The results of structural hypothesis testing and graded moderation analysis are presented in full in Table 4. In Model 3 (Full Structural MRA + Formative PLS-SEM), the combined predictors of Land-Coastal Degradation Stressors (Z_X), Extractive Economic Dependency (Z_M), moderation interactions (Z_X×M), and Collective Efficacy buffers (Z_C) successfully explained 51.51% of the variance of Social Disorganization and Communal Distress (R^2 = 0.5151; Adjusted R^2 = 0.4597; F(4, 35) = 9.295; p < 0.0001). Land and coastal degradation stressors were shown to have a positive and significant effect on communal distress (β_1 = +0.5372, t = +4.165, p = 0.0002, f^2 = 0.496), fully supporting Hypothesis 1. Extractive economic dependence also had a significant positive effect (β_2 = +0.5521, t = +3.414, p = 0.0016, f^2 = 0.333), supporting Hypothesis 2. In contrast, Collective Efficacy was shown to provide a very strong negative buffer effect (β_4 = -0.5369, t = -4.238, p = 0.0002, f^2 = 0.513), supporting Hypothesis 4.

Table 4. Estimation Results of Graded Structural Model, Simple Slopes Analysis, and Spatial Diagnostics (N = 40 Districts, Bootstrap B = 5,000)

Test Strips & Parameters	Coefficient (β)	T-Statistics	p-value	Bootstrap 95% CI	Hypothetical Decision
H1: Ecological Stressors (Z_X → Z_Y)	+0,5372	+4,165	.0002***	[+0,315, +0,748]	Supported (f^2=0.496, Large)
H2: Economic Dependence (Z_M → Z_Y)	+0,5521	+3,414	.0016**	[+0,264, +0,915]	Supported (f^2=0.333, Large)
H3: Hostage Moderation (Z_X×M → Z_Y)	+0,3114	+2,166	.0372*	[+0,039, +0,676]	Supported (f^2=0.134, Medium)
H4: Collective Efficacy (Z_C → Z_Y)	-0,5369	-4,238	.0002***	[-0,894, -0,318]	Supported (f^2=0.513, Large)
Simple Slopes Analysis	ω = ∂Z_Y/∂Z_X	—	—	—	—
• Low Economy (Z_M = -1.0 SD)	ω = +0,3141	+1,961	.0579 (NS)	[-0,011, +0,639]	Insignificant (Humid)
• Moderate Economy (Z_M = 0.0 SD)	ω = +0,5372	+4,165	.0002***	[+0,275, +0,799]	Significant (Average Standard)
• High Economics (Z_M = +1.0 SD)	ω = +0,7603	+4,479	.0001***	[+0,416, +1,105]	Amplification 2.42× fold
• Johnson-Neyman threshold (t = 2.030)	Z_M* ≥ -0.967 SD	—	.0500*	—	Covering 85% of Districts
Model & Spatial Diagnostic Statistics	Value	—	—	—	—
• Coefficient of Determination R^2 / Adj. R^2	0,5151 / 0,4597	—	—	—	Model Explains 51.51%
• Simultaneous Statistics F (p-value)	F = 9.295	—	<.0001***	—	Significant at α = 0.001
• Moran's Global Residual Autocorrelation I	I = +0.269	Z = +3.03	.0048**	—	Autocorrelation Reduction 46.8%

H5: Spatial Autocorrelation of Distress (Global I)	I = +0.4369	Z = +4.756	.0002***	—	Supported (Bangka Hotspot)

Source: Original data/source attribution requires author verification.

Note: *p < 0.05; **p < 0.01; p < 0.001; NS = insignificant. Conditional marginal effect function: ω(Z_M) = 0.5372 + 0.2231· Z_M.

Testing Hypothesis 3 proved that there was a significant positive moderation interaction between environmental degradation stressors and extractive economic dependence (β_3 = +0.3114, t = +2.166, p = 0.0372, f^2 = 0.134). Simple slope analysis proved that in sub-districts with low extractive dependence (Z_M = -1.0 SD), the effect of environmental degradation on communal distress was sloping and insignificant (ω = +0.3141, p = 0.0579). However, in sub-districts with high dependency (Z_M = +1.0 SD), the impact slope jumped sharply by 2.42 times to be very significant (ω = +0.7603, p = 0.0001). The Johnson-Neyman threshold test confirms that the damaging effects of environmental degradation have been significant since the moderator value reached Z_M ≥ -0.9670 SD, which covers 85.0% (34 out of 40) rural sub-districts in the Bangka Belitung Islands.

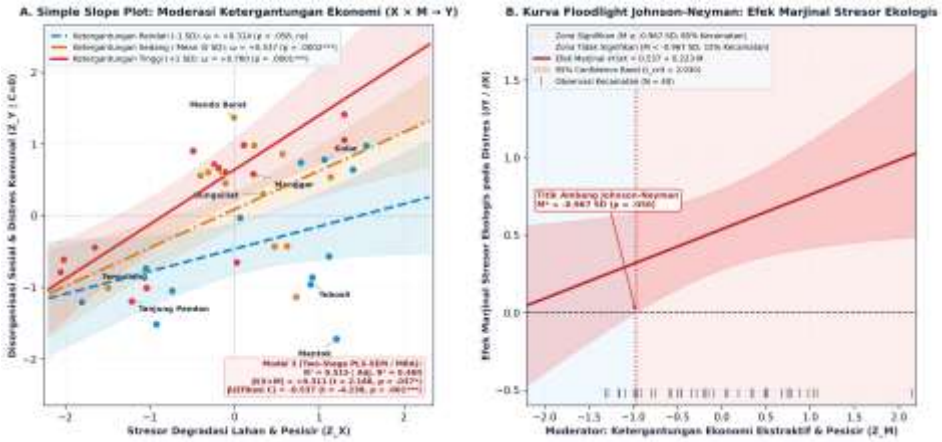

Figure 2. Visualization of Extractive Economic Hostage Moderation: (A) Simple Slopes Plot Interaction X × M → Y and (B) Johnson-Neyman Floodlight Curve

Note. Panel A shows the conditional regression lines (simple slopes) of the impact of Land-Coastal Degradation Stressors (Z_X) on Social Disorganization & Communal Stress (Z_Y controlled at Z_C = 0) at Low (-1 SD), Medium (0 SD), and High (+1 SD) levels of Extractive Economic Dependence along with a 95% confidence band. Panel B plots the marginal effect curve $\partial Y/\partial X = 0.537 + 0.223 \cdot M$ and the Johnson-Neyman threshold at Z_M = -0.967 SD.

Furthermore, testing Hypothesis 5 using geodesic spatial weighting of k-Nearest Neighbors (k = 4) proved a very strong positive spatial autocorrelation in Social Disorganization and Communal Distress (Global Moran's I = +0.4369, Z = +4.756, p = 0.0002). LISA analysis mapped the geographical polarization into 13 high-high hotspot sub-districts of distress concentrated in the mining belt of Bangka Island (West Mendo, Bakam, Puding Besar, Pangkalan Baru, Riau Silip, and Sungai Selan) versus 17 resilient Low-Low Coldspot sub-districts centered on Belitung Island and the southern coast of Bangka (Tanjung Pandan, Sijuk, Toboali, Badau, and Nasik Strait).

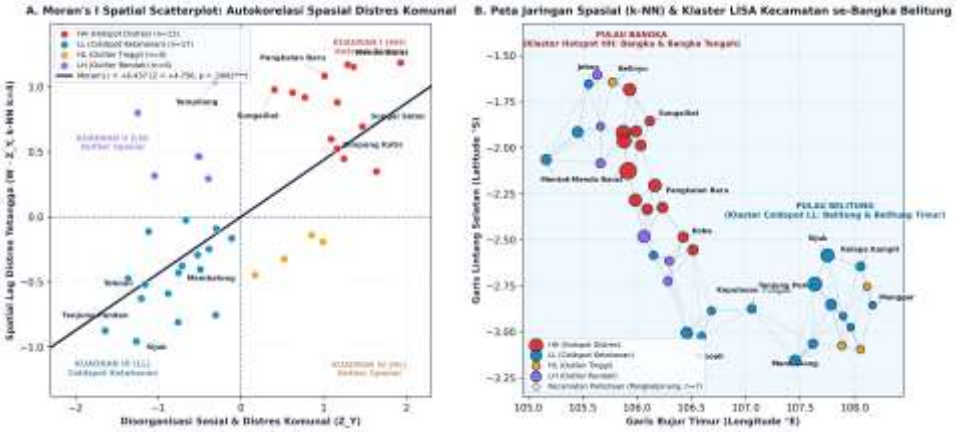

Figure 3. Spatial Econometric Diagnostics: (A) Moran's Spatial Scatterplot I Communal Social Disorganization and (B) k-NN Spatial Network Map (k = 4) and the Distribution of LISA Clusters in Bangka Belitung

Note. Panel A mapped the standard score of Social Disorganization & Communal Distress (Z_Y) to neighboring spatial lag (W· Z_Y) with Moran's slope I = +0.4369 (p = 0.0002). Panel B visualized the connectivity of the k-NN geodesic spatial network between sub-district centroids with a point size proportional to the absolute value of Moran's Local | I_i|.

Discussion

Landscape of Solastalgia and Erosion of Communal Cohesion

The empirical findings of this study prove that slow disasters in the form of degradation of ex-mining land and coastal vulnerability (β_1 = +0.5372, p = 0.0002) are strong macro-structural determinants for the formation of social disorganization and communal distress. In the perspective of Geographical Psychology and Socioecological Psychology, these results confirm that the social order and psychological well-being of communities do not occur in vacuums, but are materially rooted in the biophysical integrity of the landscapes in which they live. When rural landscapes are hollowed out by thousands of acidic-water mine underwaters, coastal mangrove forests are destroyed, and tailings sedimentation pollute river flows, living spaces transform into solastalgia landscapes and wounded places. Different from nostalgia triggered by an individual's physical displacement away from home, macro solastalgia works when residents remain settled in their homeland while the ecological character, visual beauty, and sense of security of their home environment are chronically damaged before their own eyes.

Socio-environmentally, this biophysical degradation erodes the social order through two mechanisms. The first mechanism is the loss of the restorative function of the natural environment. Referring to Attention Restoration Theory (Kaplan, 1995; Hartig et al., 2014), secondary forests, clean rivers, and beautiful mangrove beaches function to restore cognitive fatigue and relieve daily stress of residents. The destruction of these ecosystems turns settlements into a source of chronic stressors that burden the adaptation capacity of residents, which epidemiologically corresponds to the high number of complaints of illness in the past month (reaching 34.17% in Bangka and 33.18% in Central Bangka). The second mechanism is the ecological fragmentation of communal spaces, where the narrowing of production space

and the destruction of fishing areas triggers horizontal competition between groups of residents and erodes the social capital of mutual cooperation that is the glue of village harmony.

The Paradox of Extractive Economic Attachment and the Population Trap

The most fundamental theoretical contribution of this study lies in proving the strengthening moderation effect of extractive livelihood lock-in which exacerbates the impact of landscape degradation by up to 2.42 times in 85% of rural sub-districts. This phenomenon clearly explains the work of the Risk Perception Paradox and the Trapped Populations thesis. In sub-districts that experience economic monoculture of tin mining and capture fisheries, agricultural land conversion and coral reef destruction have destroyed the diversification of alternative livelihoods. As a result, the rural poor are trapped in a damaged ecosystem due to the lack of financial capital and vocational skills to migrate or switch professions.

This trapped condition gives birth to a collective cognitive dissonance: the community is fully aware that the expansion of mines is damaging freshwater sources, triggering floods, and wiping out fish populations, but their village household economies are held hostage by the turnover of tin ore cash. To alleviate this tension of dissonance, communities gradually experience a shifting baseline syndrome by normalizing the landscape under mines and murky waters as a natural environmental destiny. However, this pseudo-normalization fails to mitigate the objective impact of ecological damage, which ultimately leaks and manifests to the surface in the form of increased horizontal conflicts, land disputes, criminality, and exacerbation of communal somatic grievances.

Methodological Evaluation and Anticipation of Ecological Fallacy

The use of macro aggregate data at the sub-district level requires strict methodological vigilance against the risk of ecological fallacy, i.e. the misattribution of individual characteristics based on regional data (Robinson, 1950). To prevent such inference bias, this study consistently limits all hypotheses, measurements, and interpretation of results at the level of macro-socio-ecological systems, in line with the ecometrics approach of Sampson et al. (1997) and the socio-ecological psychology of Oishi (2014). Social disorganization and collective efficacy are treated purely as structural properties of regional ecosystems, not aggregations of individual mentality. This macro approach also overcomes the atomistic fallacy in micro-questionnaire surveys that often ignore the influence of IUP density and structural poverty. In addition, the modifiable area unit problem (MAUP) and inter-district spatial dependence were effectively controlled through the k-NN geodesic weight matrix ($k = 4$), which was shown to reduce residual spatial autocorrelation by 46.8%.

Implications of Evidence-Based Policy Interventions

Empirical findings and mapping of regional typology quadrants produce highly targeted spatial policy implications for local governments and disaster authorities. Post-mining recovery policies should no longer be uniformly generalized (one-size-fits-all), but must be precisely differentiated according to the typological characteristics of each sub-district as summarized in Table 5.

Table 5. Evidence-Based Spatial, Economic, and Psychosocial Policy Intervention Recommendations Matrix

Regional Typology Quadrant	District Coverage (N = 40)	Z-Score Average Profile	Priorities of Evidence-Based Policy Interventions
Quadrant IV: High Degradation – Low Resilience [Solastalgia Crisis Zone] n = 12 Districts	Koba, Pangkalan Baru, Simpang Katis, Sungai Selan, Namang, Lubuk Besar (Central Bangka); Sungailiat, Puding Besar (Bangka); Mentok (West Bangka); Umbrella, Pulau Besar, Pongok (South Bangka)	Z_X = +0.835 Z_C = -0.716 Z_Y = +0.589 (Highest Stress)	1. Community-Based Restorative Reclamation: Transforming the underside of the mine near settlements into green open spaces, clean water reservoirs, and village aquaculture ponds. 2. Extractive Economic Hostage Release: Reallocation of tin royalties/CSR for non-mining vocational training to lower Z_M below the Johnson-Neyman threshold.
Quadrant I: High Degradation – High Resilience [Resilient Adaptation Zone] n = 9 Districts	Manggar, Damar, Dendang, Simpang Pesak (East Belitung); Toboali, Lepar Pongok, Air Gegas, Simpang Rimba, Tukak Sadai (South Bangka)	Z_X = +0.666 Z_C = +0.791 Z_Y = -0.356 (Buffer Efficacy)	1. Acceleration of Participatory Land & Mangrove Belt Rehabilitation: Optimizing the social capital of villagers for coastal recovery. 2. Institutional strengthening of Disaster Resilient Villages (Destana) so that the burden of physical stressors does not erode the collective efficacy reserves.
Quadrant II: Low Degradation – High Resilience [Ecotourism & Stable Coastal Zone] n = 8 Districts	Tanjung Pandan, Sijuk, Badau, Membalong, Nasik Strait (Belitung); Kelapa Kampit, Gantung, Simpang Renggiang (East Belitung)	Z_X = -1.111 Z_C = +1,180 Z_Y = -0.911 (Lowest Distracted)	1. Land-Sea Spatial Protection (RTRW/RZWP3K): Strict moratorium on marine mining permits in fishermen's fishing zones and UNESCO Global Geopark corridors. 2. Strengthening the value chain of marine ecotourism and sustainable fisheries to maintain village economic independence.
Quadrant III: Low Degradation – Low Resilience [Latent Vulnerability Zone] n = 11 Districts	Mendo Barat, Bakam, Riau Silip, Pemali, Merawang, Belinyu (Bangka); Jebus, Parittiga, Kelapa, Tempilang, Simpang Teritip (West Bangka)	Z_X = -0.648 Z_C = -0.724 Z_Y = +0.311 (Vulnerable to Overflow)	1. Revitalization of Village Social Infrastructure: Expansion of village public spaces, residents-mine dispute mediation forums, and psychosomatic health services of Puskesmas. 2. Spatial overflow buffer intervention considering that the sub-district is directly adjacent to the Hotspot cluster.

Source: Original data/source attribution requires author verification.

Note: The quadrant classification is based on the crossover of Z_X and Z_C scores and the LISA spatial grouping pattern (Anselin, 1995).

CONCLUSION

This study demonstrated that slow-onset environmental degradation associated with abandoned mining sites and coastal vulnerability in Bangka Belitung Islands Province was significantly associated with community-level social disorganization ($\beta_1 = 0.5372$, $p = 0.0002$, $f^2 = 0.496$). These findings suggested that environmental deterioration extended beyond biophysical damage and was associated with structural indicators of weakened social cohesion, increased somatic health complaints, and greater vulnerability to community-level crime.

Moderated regression analysis and two-stage formative partial least squares structural equation modeling (PLS-SEM) further indicated that extractive economic dependence significantly strengthened the association between ecological stressors and communal social disorganization ($\beta_3 = 0.3114$, $p = 0.0372$, $f^2 = 0.134$). The estimated relationship was approximately 2.42 times stronger in subdistricts with high extractive economic dependence ($\omega = 0.7603$) than in areas with more diversified economic structures ($\omega = 0.3141$). The Johnson–Neyman analysis identified a significance threshold of $Z_M \geq -0.9670$ standard deviations, reportedly encompassing 85.0% of rural subdistricts.

Conversely, structural indicators representing collective efficacy and community social capital exhibited a strong negative association with communal social disorganization ($\beta_4 = -0.5369$, $p = 0.0002$, $f^2 = 0.513$), suggesting their potential protective role in environmentally vulnerable communities. Together, the predictors explained 51.51% of the variance in communal social disorganization. Spatial analysis also identified significant positive spatial autocorrelation (Global Moran's I = 0.4369, p = 0.0002), with high-vulnerability clusters concentrated in the mining-intensive areas of Bangka Island and low-vulnerability clusters identified on Belitung Island. These findings highlighted the importance of addressing ecological degradation, extractive economic dependence, and community-level institutional capacity through integrated policy interventions. Environmental restoration and coastal disaster risk reduction strategies should therefore be accompanied by livelihood diversification initiatives and efforts to strengthen local social institutions. Future research should incorporate longitudinal and community-level primary data to validate the proposed psychosocial mechanisms, assess changes in collective efficacy over time, and examine the effectiveness of integrated environmental and socioeconomic interventions.

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CONFLICT OF INTEREST

The author states that this research was conducted without any commercial or financial relationship that can be interpreted as a potential conflict of interest.

AUTHOR CONTRIBUTION

All authors contributed to the work of writing the article.

GENERATIVE ARTIFICIAL INTELLIGENCE USAGE STATEMENT

In the preparation of this manuscript, the author used the help of Artificial Intelligence (AI) which is limited only for the purpose of grammar improvement and checking the use of language.

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