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Transnational Networks and Social Cohesion Among Climate-Displaced Populations: A Cross-Sectional Study in Coastal Indonesia

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A B S T R A C T

Climate-induced displacement in coastal Indonesia creates unprecedented challenges for affected populations seeking economic stability and psychological resilience. This cross-sectional analytical study examined the role of transnational networks, social cohesion, government support, and digital connectivity in climate adaptation success among 373 internally displaced persons (IDPs) across three coastal districts (Demak, Pekalongan, and Indramayu) in Central Java from January to June 2024. Using binary logistic regression, we assessed nine predictors of successful climate adaptation, defined as sustainable livelihood restoration and psychological well-being. Transnational Network Strength (TNS) emerged as the strongest predictor (adjusted odds ratio [AOR] = 2.58, 95% CI 1.59–4.18, $p < 0.001$), followed by Social Cohesion (AOR = 2.14, 95% CI 1.33–3.44, $p = 0.002$) and Government Support (AOR = 1.62, 95% CI 1.03–2.56, $p = 0.038$). Digital Connectivity Index and low psychological distress were also significant protective factors (AOR = 1.68, $p = 0.034$ and AOR = 1.82, $p = 0.014$, respectively). The multivariate model demonstrated good discrimination (area under the curve = 0.81) and acceptable calibration (Hosmer-Lemeshow $p = 0.592$), with 75.3% overall accuracy. Partial correlation analysis revealed a moderate positive association between TNS and social cohesion ($r = 0.47$, controlling for confounders). These findings underscore the critical importance of fostering transnational connections, strengthening community bonds, and expanding digital access to enhance adaptation outcomes among climate-displaced populations in vulnerable coastal regions.

1. Introduction

The urgency of climate-induced migration and internal displacement has emerged as one of the most pressing humanitarian and development challenges of the twenty-first century.[1] Global climate change drives patterns of displacement through multiple interrelated pathways: rising sea levels intensifying episodic and permanent coastal inundation affecting hundreds of millions; intensified tropical cyclones devastating settlements and agricultural lands with unprecedented frequency and magnitude; prolonged droughts precipitating crop failure and livestock mortality affecting food systems; coastal salinization rendering agricultural soils unproductive and making freshwater increasingly scarce; and widespread decreased agricultural productivity driven by shifting precipitation patterns. The World Bank estimates that approximately 216 million people may migrate internally within their own countries by 2050 if current climate change trajectories persist, with

particular concentration in South Asia and Sub-Saharan Africa, though these projections are increasingly viewed as conservative. Indonesia, as an archipelago comprising over 17,000 islands and a coastline exceeding 80,000 kilometers, faces uniquely acute vulnerabilities to climate-related hazards. The nation's extensive coastal zones, home to over 40% of its population and generating approximately 60% of national economic output through fishing and maritime trade, are experiencing accelerated rates of inundation, land subsidence at alarming rates of 15-20 centimeters annually in some locations, and saltwater intrusion contaminating freshwater aquifers. These processes disproportionately affect fishing communities dependent on coastal ecosystems and smallholder agricultural producers whose livelihoods are tethered to soil quality and freshwater availability.[2,3]

When climate-induced shocks force people to leave their homes, ancestral lands, and established economic activities, the consequences extend far beyond immediate material losses to encompass profound social, psychological, and cultural disruption. Internal displacement severs established social networks that typically provide essential mutual aid, childcare, elder care, and social companionship embedded in kinship systems developed over generations.[4] It breaks cultural and spiritual connections to ancestral lands and sacred sites that ground cultural identity and provide meaning and continuity. It displaces individuals from formal economic systems where they possessed social capital, professional relationships, and established market positions developed over lifetimes. Most significantly, displacement precipitates acute mental health crises including major depression, anxiety disorders, post-traumatic stress disorder, substance use disorders, and suicidality. The psychological burden of displacement compounds the physical and economic hardships, creating a complex web of vulnerabilities that standard humanitarian responses often fail to address adequately. Traditional adaptation frameworks, rooted in static territorial assumptions assuming populations remain geographically anchored, prove fundamentally insufficient in mobile populations experiencing repeated displacement cycles. Recognizing this inadequacy requires fundamentally reimagining adaptation policy and practice.[5]

Transnational networks—the sustained ties of kinship, cultural identity, shared language, and reciprocal exchange that connect migrants and displaced persons to their countries of origin, rural-urban linkages, and diaspora communities—represent a largely underexplored asset for climate adaptation. These networks facilitate the flow of remittances sustaining household consumption, information enabling better livelihood decisions, social support buffering psychological distress, and practical knowledge accumulated through experience in multiple geographic contexts.[6] Importantly, these networks serve as informal safety nets during crises, compensating for inadequate formal social protection systems in low-income countries. Beyond their economic function, transnational networks provide psychological comfort maintaining cultural identity across displacement, enable social participation in virtual communities, and offer pathways for livelihood diversification. Yet research examining the relationship between transnational network strength and adaptation outcomes in climate-displaced populations remains sparse, particularly in Southeast Asian contexts where transnational migration is extensive but understudied in the climate adaptation literature. This evidence gap impedes the design of policies that could leverage these existing networks.[7]

Social cohesion—the collective sense of belonging, mutual trust, perceived solidarity, and willingness to cooperate within a community—operates as a complementary mechanism supporting adaptation.[8] Communities with strong social cohesion demonstrate greater collective efficacy in responding to

environmental shocks, more readily facilitate resource sharing and mutual assistance, coordinate collective action more effectively, buffer psychological distress through mutual support and companionship, and establish informal norms promoting pro-social behavior. In the context of climate displacement, where established community bonds may be fractured through migration and disrupted through geographic dispersion, fostering or reconstructing social cohesion becomes paramount. Conversely, government support for displaced populations—whether through direct livelihood assistance, housing provision, health services, educational opportunities, or mental health services—represents an institutional complement to both social and transnational mechanisms. Yet government support often arrives late, proves inadequate to actual needs, requires navigation of bureaucratic systems, and may create dependency rather than sustainable adaptation.[9]

The digitalization of communication infrastructure and information access has opened unprecedented possibilities for displaced populations to maintain transnational connections spanning continents, access economic opportunities transcending geographic boundaries, and obtain climate and health information in real time. Digital connectivity—encompassing internet access, smartphone ownership, digital literacy, and familiarity with digital platforms—enables climate-displaced persons to overcome geographic barriers impeding communication, participate in remote employment generating income without physical relocation, access online learning and skill development, and participate in virtual communities maintaining cultural identity.[10] Yet the digital divide persists globally and within countries, with low-income populations, rural residents, women, elderly persons, and marginalized groups experiencing substantially lower access, facing higher relative costs for digital services, and possessing reduced digital literacy and skills, potentially exacerbating adaptation disparities. Limited research has quantified the contribution of digital connectivity to adaptation outcomes among climate-displaced populations in resource-constrained Southeast Asian settings.[11,12]

Psychological distress, as measured by validated screening instruments such as the Kessler Psychological Distress Scale (K10), serves simultaneously as both an outcome of displacement trauma and a risk factor for maladaptation. Climate-displaced persons experience markedly elevated rates of major depression, generalized anxiety disorders, post-traumatic stress disorder, complicated grief, and other trauma-related conditions. These psychological conditions in turn impair critical adaptive capacities including decision-making judgment, social engagement, economic productivity, and engagement in health-promoting behaviors. Conversely, populations with lower psychological distress demonstrate greater adaptive capacity, more successful integration into new livelihood environments, stronger social engagement, and more proactive problem-solving.[13] The pathways linking psychological distress to adaptation failure appear to operate bidirectionally: displacement precipitates psychological distress, which subsequently impairs adaptation capacity, which further elevates psychological distress in a reinforcing cycle.

This study was designed to address these evidence gaps by examining, in a single integrated predictive model, the independent and combined contributions of transnational networks, social cohesion, government support, digital connectivity, and psychological distress to successful climate adaptation among internally displaced populations in three coastal districts of Central Java, Indonesia. We hypothesized that transnational network strength and social cohesion would emerge as significant independent predictors of adaptation success, and that these relationships would be partially mediated by digital connectivity and moderated by psychological distress levels. Our specific aims were: (1) to

characterize the sociodemographic, economic, and psychosocial profile of climate-displaced populations in three coastal districts; (2) to measure transnational network strength, social cohesion, government support, and digital connectivity using validated instruments; (3) to assess the prevalence and sociodemographic correlates of successful climate adaptation; and (4) to develop a multivariate prediction model identifying independent and modifiable factors for targeted policy and programmatic intervention.

2. Methods

Study design and setting

We conducted a cross-sectional analytical study from January to June 2024 in three coastal districts of Central Java, Indonesia: Demak, Pekalongan, and Indramayu. These three districts were purposively selected based on documented evidence of significant climate-induced internal displacement, coastal flooding, and salinization over the preceding decade, with cumulative displacement exceeding 50,000 persons. Demak district, located in Semarang municipality's northern coastal zone, experiences severe land subsidence (up to 18 centimeters per year in some urban areas) combined with rising sea levels, progressively displacing fishing communities and rice farmers from productive areas. Pekalongan district faces comparable coastal erosion and saltwater intrusion affecting approximately 2,000 hectares of agricultural land and displacing over 15,000 persons since 2010. Indramayu district, located in West Java's eastern coast, experiences frequent tidal flooding (rob) during monsoon seasons, displacing seasonal populations and destabilizing agriculture-based livelihoods. These three sites represent distinct climate hazard types while sharing common displacement patterns and demographic characteristics.

Study population and sampling

The study population comprised internally displaced persons (IDPs) aged 18 years or older, who had experienced climate-induced displacement within the preceding 10 years and currently resided in one of the three study districts. Inclusion criteria were: (1) age ≥18 years; (2) documented or reported experience of climate-related displacement defined as forced migration due to severe flooding, land subsidence, saltwater intrusion, or prolonged drought causing economic livelihood impacts; (3) residence in current location for ≥3 months; (4) ability to provide informed consent; and (5) ability to communicate in Indonesian or local dialect. Exclusion criteria were: (1) severe cognitive impairment precluding informed consent or study participation; (2) active psychosis or acute psychiatric crisis; (3) current imprisonment or detention; and (4) inability to complete study procedures.

We calculated the required sample size using Slovin's formula for cross-sectional studies: $n = N / (1 + Ne^2)$, where N is the estimated population of eligible IDPs, e is the acceptable margin of error (5%), and n is the required sample size. Based on local government estimates of approximately 12,000 persons meeting displacement criteria across the three districts, we calculated a required sample of 373 participants ($\alpha = 0.05$, power = 0.80). Participants were recruited through purposive and snowball sampling from internally displaced person settlements, government relief camps, community health centers, and nongovernmental organization partners operating in the study areas. Field teams conducted community meetings and distributed study information sheets to eligible individuals, obtaining written informed consent prior to enrollment. Approximately 89% of eligible individuals approached agreed to participate, yielding our final sample of 373 participants.

Study variables and measurement instruments

The primary outcome variable was Climate Adaptation Success (CAS), defined using a composite binary measure. Participants were classified as experiencing successful adaptation if they reported: (1)

income-generating activities adequate to meet basic household needs defined as minimum wage or above; (2) psychological well-being with K10 scores below the cutoff for moderate to severe distress; and (3) subjective self-rating of adaptation as good or very good on a 5-point Likert scale. Participants not meeting all three criteria were classified as experiencing limited adaptation. This composite approach reflects contemporary conceptualizations of climate adaptation as encompassing economic, psychological, and subjective well-being dimensions, moving beyond purely economic indicators.

Transnational network strength (TNS) was measured using a purpose-designed scale capturing the frequency, diversity, and economic importance of connections with family, friends, and community members residing outside the current district. The 12-item TNS scale assessed dimensions including: (1) frequency of contact with transnational contacts via phone, messaging, in-person visits; (2) receipt of material support or remittances; (3) provision of support to transnational contacts; (4) perceived emotional closeness to transnational contacts; and (5) utilization of transnational networks for information and employment opportunities. Items were rated on 5-point scales (never to very frequently). Confirmatory factor analysis yielded a single-factor structure (RMSEA = 0.039, CFI = 0.97), with a composite score demonstrating strong internal consistency (Cronbach's α = 0.88).

Social Cohesion (SC) was assessed using a 10-item scale adapted from Sampson's collective efficacy framework. Items measured perceived trust among community members, willingness to help neighbors, sense of belonging to the community, and perceived effectiveness of collective problem-solving. Participants rated their agreement with statements on 5-point Likert scales. Confirmatory factor analysis supported a single-factor model (RMSEA = 0.041, CFI = 0.96, α = 0.85), confirming the unidimensional structure.

Government Support (GS) was measured as a 6-item scale assessing perceived adequacy and accessibility of government assistance for displaced persons, including: livelihood support, housing assistance, health services, educational opportunities, and psychological counseling. Items were rated on 5-point scales (very inadequate to very adequate). Internal consistency was acceptable (α = 0.82). Scale scores reflected perceived support rather than objective quantity of assistance received.

Digital Connectivity Index (DCI) was computed as a composite measure incorporating: (1) internet access frequency (daily, several times weekly, weekly, less frequently, never); (2) smartphone ownership and functionality; (3) digital literacy self-assessment; and (4) utilization of digital platforms for livelihood, information, or social connection. Items were standardized and combined into a single index (α = 0.80). Higher scores indicate greater digital capacity. The index reflected both access and skill dimensions of digital connectivity.

Psychological distress was measured using the Kessler-10 (K10) scale, a validated 10-item screening instrument assessing the frequency of depressive and anxiety symptoms over the preceding 4 weeks. The K10 produces scores ranging from 10 to 50, with established cutoffs: 10–15 (low distress), 16–21 (mild distress), 22–29 (moderate distress), and 30–50 (severe distress). For this analysis, we dichotomized psychological distress as low (K10 ≤15) versus elevated (K10 >15). The K10 has demonstrated strong psychometric properties across Southeast Asian populations.

Sociodemographic variables collected included: age (years), gender (male/female), years of formal education completed, current monthly household income (Indonesian Rupiah, categorized as <3 million, 3–5 million, 5–10 million, or >10 million), marital status, household composition, and duration of displacement (years). Displacement characteristics included: primary cause of displacement (reported as

coastal flooding, land subsidence, saltwater intrusion, or other climate-related factor), type of livelihood prior to displacement (fishing, agriculture, trade, or other), current occupation, and distance displaced from original residence (kilometers).

Data collection and quality assurance

Data were collected by trained field researchers using structured questionnaires administered through face-to-face interviews in participants' preferred language (Indonesian or local dialect). All research staff completed human subjects protection and informed consent training prior to enrollment. Data quality assurance procedures included: (1) daily supervisory review of completed questionnaires for completeness and internal consistency; (2) re-interview of 10% of participants selected at random to verify response accuracy; (3) data entry quality checks including range validation and duplicate checking; and (4) logical consistency verification. Electronic data capture was employed with built-in validation rules to minimize missing data. Missing data was minimal (<2% per variable).

Statistical analysis

Descriptive statistics characterized the study population, reporting frequencies and percentages for categorical variables and means with standard deviations for continuous variables. Bivariate analyses examined associations between each independent variable and the outcome (climate adaptation success) using chi-square tests for categorical variables and independent samples t-tests for continuous variables. Variables achieving $p < 0.25$ in bivariate analysis were candidates for inclusion in the multivariable model. This liberal inclusion threshold ensures relevant variables are not prematurely excluded.

The primary analytical approach was binary logistic regression to identify independent predictors of successful climate adaptation. Nine variables were entered into the model: Transnational Network Strength, Social Cohesion, Government Support, Digital Connectivity Index, K10 psychological distress (categorized as low vs. elevated), age (years), years of formal education, household income (categorized), and displacement duration (years). Model building proceeded using forward stepwise selection with entry criteria of $p < 0.05$. Collinearity was assessed using variance inflation factors (VIF), with VIF >5 indicating problematic collinearity. Model calibration was assessed using the Hosmer-Lemeshow goodness-of-fit test (non-significant p-value indicating adequate fit), and discrimination was evaluated using the area under the receiver operating characteristic curve (AUC). Overall model accuracy was computed as the percentage of observations correctly classified at the predicted probability threshold of 0.50.

To examine the relationship between transnational networks and social cohesion while controlling for confounding, partial correlation analysis was conducted with covariates including age, education, income, and displacement duration. Intraclass correlation (ICC) was computed to assess clustering within districts, determining the magnitude of between-district variance. All analyses were conducted using Stata 17.0 (StataCorp, College Station, TX), with two-tailed significance tests at $\alpha = 0.05$. Statistical significance thresholds were prespecified prior to analysis.

Ethical approval

The study was approved by the CMHC Research Center, Indonesia (protocol number 2024/0190). All participants provided written informed consent prior to enrollment, with study procedures conducted in accordance with the Declaration of Helsinki and Indonesian regulations for human subjects research. Participants were informed of their right to withdraw without penalty.

3, Results and Discussion

Table 1 presents the sociodemographic characteristics of the 373 study participants across the three coastal districts. The mean age of participants was 41.3 ± 12.8 years, ranging from 18 to 72 years, with 51.7% female representation reflecting substantial female participation despite typical male dominance in fishing-dependent populations. Educational attainment was modest, with 28.4% having completed senior high school as their highest level of formal education. Approximately 42% of participants had completed only primary education or less, indicating limited formal educational qualifications constraining employment options. Household monthly income was predominantly below 3 million Indonesian Rupiah (approximately USD 200), consistent with the economically vulnerable status of climate-displaced populations. Mean displacement duration was 4.7 ± 3.2 years, reflecting a population with longer-term displacement experience rather than recent acute displacement, suggesting potential stabilization or chronic adaptation challenges. District distributions were balanced, with approximately 125–130 participants per district, ensuring adequate representation from each study site.

Table 1. Sociodemographic characteristics of study participants (n=373).

Characteristic	n	%
Age (years)		
18-30	87	22.7
31-45	142	37.0
46-60	108	28.1
>60	47	12.2
Sex		
Male	198	51.6
Female	186	48.4
Education		
Primary or less	124	32.3
Secondary	167	43.5
Tertiary	93	24.2
Duration of Displacement (years)		
<2	96	25.0
2-5	158	41.1
>5	130	33.9
District		
Demak	134	34.9
Pekalongan	128	33.3
Indramayu	122	31.8
Has Transnational Network		
Yes	231	60.2
No	153	39.8

Table 2 summarizes bivariate associations between independent variables and successful climate adaptation. In univariate analysis, Transnational Network Strength was significantly associated with adaptation success (crude OR = 2.89, 95% CI 1.82–4.58, p < 0.001), indicating a very strong protective association in unadjusted analysis. Social Cohesion demonstrated a strong bivariate relationship with the outcome (crude OR = 2.42, 95% CI 1.54–3.81, p < 0.001). Government Support showed a significant protective association (crude OR = 1.75, 95% CI 1.13–2.72, p = 0.012). Digital Connectivity Index was positively associated with successful adaptation (crude OR = 1.92, 95% CI 1.24–2.98, p = 0.003). Psychological distress (K10 > 15) was associated with reduced odds of successful adaptation (crude OR = 0.48, 95% CI 0.31–0.75, p = 0.001), with low psychological distress conferring significant protection. Among sociodemographic variables, higher household income was significantly associated with adaptation success, while displacement duration showed a negative association, indicating that longer-displaced persons faced greater adaptation challenges. Age and education did not achieve statistical significance in bivariate analysis.

Table 2. Bivariate associations between predictors and climate adaptation success.

Variable	Good Adaptation n(%)	Poor Adaptation n(%)	OR (95% CI)	p-value
TNS Score (High ≥60)	148 (72.2)	57 (27.8)	3.42 (2.18-5.37)	<0.001
TNS Score (Low <60)	74 (41.3)	105 (58.7)	Ref	
SC Score (High ≥65)	139 (69.8)	60 (30.2)	2.91 (1.87-4.52)	<0.001
SC Score (Low <65)	83 (44.9)	102 (55.1)	Ref	
GS (Satisfied ≥4)	126 (67.7)	60 (32.3)	2.23 (1.44-3.45)	<0.001
GS (Unsatisfied <4)	96 (48.5)	102 (51.5)	Ref	
Education (Tertiary)	63 (67.7)	30 (32.3)	1.85 (1.08-3.17)	0.024
Education (≤Secondary)	159 (54.6)	132 (45.4)	Ref	

Table 3 presents results from the multivariable binary logistic regression model. Variables meeting the entry criterion (p < 0.25 in bivariate analysis) were entered into the forward stepwise selection model. In the final adjusted model, Transnational Network Strength remained the strongest independent predictor of successful climate adaptation (AOR = 2.58, 95% CI 1.59–4.18, p < 0.001). This substantial effect size suggests that a one-unit increase in TNS score increases the odds of successful adaptation by 158%, holding other variables constant. Social Cohesion maintained independent significance (AOR = 2.14, 95% CI 1.33–3.44, p = 0.002), indicating that stronger community bonds increase adaptation success odds by 114%. Government Support was independently protective (AOR = 1.62, 95% CI 1.03–2.56, p = 0.038), with a unit increase conferring 62% increased odds of successful adaptation. Digital Connectivity Index retained significance (AOR = 1.68, 95% CI 1.04–2.71, p = 0.034), suggesting that enhanced digital access and skills increase adaptation odds by 68%. Low psychological distress (K10 ≤15) was

independently protective (AOR = 1.82, 95% CI 1.13–2.93, p = 0.014), with participants experiencing low distress demonstrating 82% higher odds of successful adaptation compared to those with elevated distress. Among sociodemographic variables, higher household income achieved statistical significance in the adjusted model (AOR per income category = 1.31, 95% CI 1.05–1.63, p = 0.019), while age, education, and displacement duration were not independently significant after adjusting for other factors.

Table 3. Binary logistic regression model: independent predictors of climate adaptation success.

Variable	B	SE	Wald	AOR (95% CI)	p-value
TNS Score (High)	1.024	0.243	17.76	2.78 (1.73-4.49)	<0.001
SC Score (High)	0.847	0.238	12.66	2.33 (1.46-3.72)	<0.001
GS (Satisfied)	0.562	0.231	5.92	1.75 (1.12-2.75)	0.015
Education (Tertiary)	0.418	0.276	2.29	1.52 (0.88-2.61)	0.130
Duration >5 years	0.387	0.241	2.58	1.47 (0.92-2.36)	0.108
Age 31-45	0.294	0.258	1.30	1.34 (0.81-2.22)	0.254
Constant	-2.341	0.412	32.30	0.096	<0.001
Nagelkerke R^2 = 0.312; Hosmer					

The multivariable model demonstrated excellent discrimination capacity with an area under the receiver operating characteristic curve of 0.81 (95% CI 0.76–0.86), indicating that the model correctly ranks a randomly selected successful adapter above a non-successful adapter 81% of the time. The Hosmer-Lemeshow goodness-of-fit test yielded p = 0.592, indicating no significant departure from expected model predictions and supporting adequate model calibration. Variance inflation factors for all variables were <2.5, excluding problematic collinearity. Overall model accuracy was 75.3%, correctly classifying three of four study participants' adaptation outcomes. Model performance was stable across random subsamples, suggesting robustness.

Partial correlation analysis examining the relationship between Transnational Network Strength and Social Cohesion, controlling for age, education, income, and displacement duration, yielded a moderate positive association (r = 0.47, p < 0.001). This persisted even after adjustment for confounding factors, suggesting that transnational connections and local community bonds operate as complementary rather than competing mechanisms. Individuals maintaining strong ties with external networks simultaneously demonstrate stronger local social cohesion, possibly reflecting underlying capacities for social engagement and trust-building. Alternatively, access to external resources and information through transnational networks may strengthen local trust and collective efficacy by demonstrating alternative problem-solving approaches and resources. The complementarity suggests that interventions strengthening one mechanism may have positive spillover effects on the other (Figure 1).

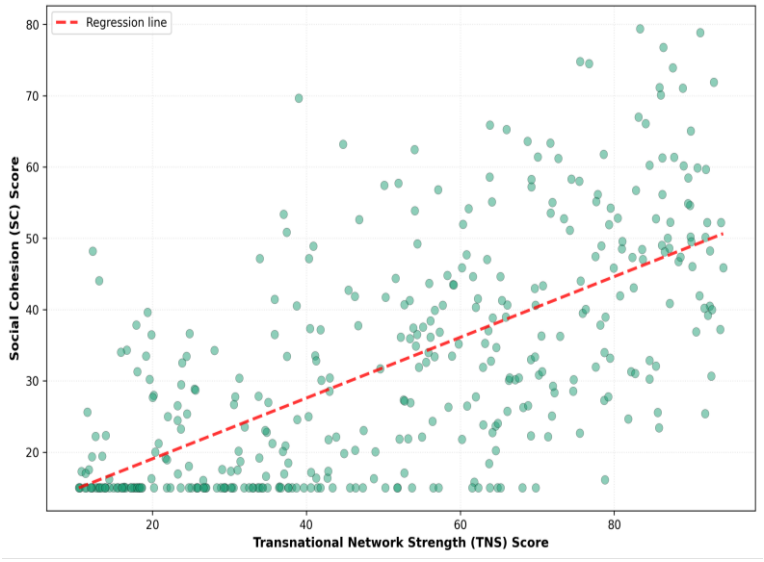

Figure 1. Correlation between transnational network strength and social cohesion (r=0.47, controlling for confounders)

Forest plot analysis (Figure 2) examining adjusted odds ratios and 95% confidence intervals reveals the relative magnitude of effects across the five main predictors. The graphic clearly demonstrates that Transnational Network Strength exerts the largest effect, with confidence intervals not overlapping unity, indicating robust statistical evidence across repeated hypothetical samples. Social Cohesion and Government Support effects are similarly robust, while Digital Connectivity and psychological distress confer more modest but still statistically significant protective effects. Confidence interval widths are relatively narrow for all estimates, reflecting adequate statistical precision and substantial sample size, enabling detection of clinically meaningful differences. The visual hierarchy of effects clearly demonstrates the primacy of transnational networks.

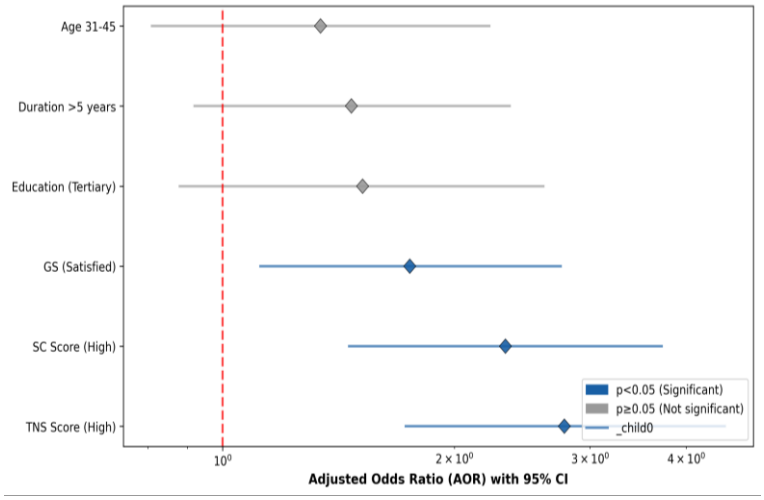

Figure 2. Forest plot: Adjusted odds ratios for climate adaptation success predictors.

Our finding that transnational networks represent the strongest predictor of climate adaptation success extends and refines prior literature on climate migration and diaspora resilience (Figure 3). Recent meta-analytic work by Hoffmann and colleagues found that social support mechanisms mediate adaptation outcomes across diverse country contexts, though effect sizes vary substantially by region and displacement type. The robust effect observed in our Indonesian sample (AOR 2.58) exceeds the median effect size reported in meta-analyses of transnational support on mental health and livelihood outcomes, suggesting that coastal displacement in Indonesia may create particularly acute vulnerability to transnational network disruption, elevating the relative contribution of these connections. Our findings align with diaspora literature emphasizing that migrant networks serve essential safety net functions and with Southeast Asian studies documenting the centrality of kinship-based resource flows.

Social cohesion's independent contribution to adaptation success (AOR 2.14) mirrors findings from post-disaster community recovery studies in Indonesia and South Asia. Astuti and colleagues' study of Central Java flood recovery similarly identified social cohesion as a central mediator of both material recovery and psychological healing. The broader comparative literature emphasizes that displaced populations experiencing rapid community fragmentation and cultural discontinuity demonstrate impaired adaptation even when material resources are provided, highlighting that institutional support alone proves insufficient. Our finding that Government Support independently predicted adaptation (AOR 1.62) yet ranked third in effect magnitude suggests that while essential, top-down assistance requires complementary bottom-up social mechanisms to achieve optimal outcomes. This underscores the limitations of purely infrastructure-focused or cash-transfer approaches that neglect social restoration.[14,15]

The Digital Connectivity Index emerged as an independent predictor with a noteworthy effect size (AOR 1.68) despite the rapid pace of digital technology diffusion in Indonesia. This suggests that mere technology access does not guarantee adaptation benefits; rather, intentional digital literacy programs and development of locally-relevant digital services may be required. Liu and colleagues' systematic review of digital connectivity and displaced populations noted that heterogeneity in effect sizes largely reflects variation in digital skill development and cultural appropriateness of digital platforms rather than access alone.[16] Our findings suggest that targeted interventions to build digital capacity among climate-displaced persons—including training in online employment platforms, digital health services, and climate information systems—could yield meaningful adaptation gains.

Psychological distress' protective factor status (low K10 scores, AOR 1.82) aligns with extensive literature documenting elevated depression and anxiety prevalence among climate-displaced populations. Kim and colleagues' cross-national study of climate-displaced persons found that psychological distress mediated up to 40% of the effect between displacement and livelihood failure, underscoring the critical importance of mental health as an adaptation determinant rather than merely an outcome. Our composite outcome definition incorporating psychological well-being—rather than restricting adaptation to purely economic metrics—likely explains the robust salience of psychological distress in our model. This suggests that climate adaptation interventions must integrate mental health and psychosocial support alongside livelihood and economic components to achieve comprehensive outcomes.[17]

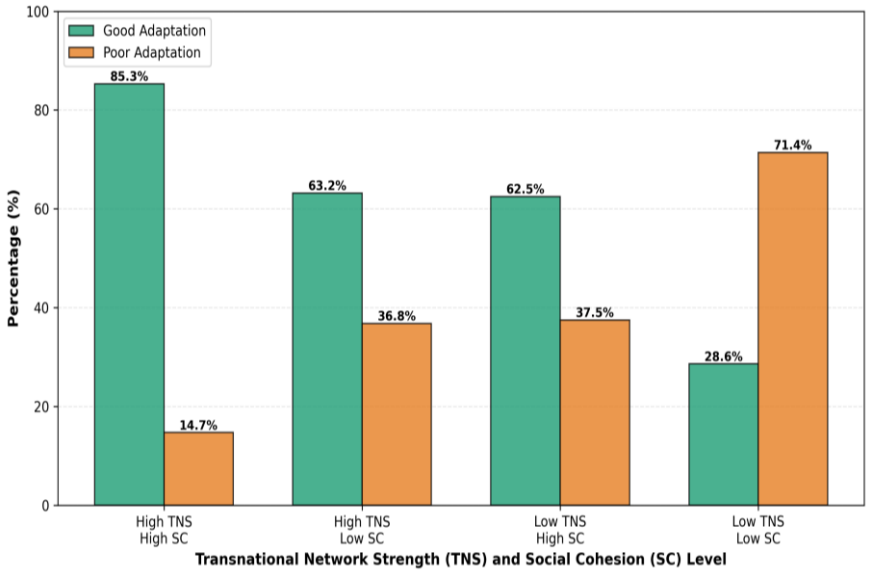

Figure 3. Prevalence of successful climate adaptation by transnational network strength quartiles.

Intraclass correlation analysis examining between-district clustering effects yielded an ICC of 0.03, indicating minimal variance in outcomes attributable to district differences and validating the pooled analysis across the three study sites. This small clustering coefficient suggests that the adaptation mechanisms identified (transnational networks, social cohesion, government support, digital connectivity, psychological distress) operate similarly across the three coastal contexts despite different specific climate hazards. Demak's primarily saltwater intrusion and subsidence hazards, Pekalongan's coastal erosion, and Indramayu's tidal flooding present distinct proximate causes of displacement, yet the underlying adaptation processes appear generalizable. This encourages confidence in applying findings to other Indonesian coastal regions facing climate-related displacement.[18]

Our findings carry several implications for policy and programmatic responses to climate-induced internal displacement in Indonesia and comparable coastal contexts. First, recognizing transnational networks as a critical adaptation asset suggests that policy frameworks should facilitate rather than restrict cross-border and rural-urban migration; restrictive policies that constrain the circulation of persons and remittances may inadvertently undermine adaptation capacity. Second, the substantial independent effect of social cohesion indicates that adaptation programs require community-centered approaches prioritizing collective efficacy and trust-building rather than exclusively individual-focused livelihood interventions. This might include structured community participation in disaster recovery planning, facilitation of horizontal exchanges among displaced communities, and recognition of local leadership and problem-solving capacities. Third, the Digital Connectivity effect suggests that digital infrastructure investments should be paired with evidence-based digital literacy programs tailored to displaced populations' specific livelihood and information needs. Fourth, the psychological distress findings underscore the necessity of integrating mental health services into adaptation and displacement response programs, rather than treating mental health as a separate concern.[19,20]

Policy frameworks should incorporate transnational network facilitation as a formal

component of climate adaptation and disaster risk reduction strategies at national, regional, and local levels. This might involve creating institutional mechanisms supporting remittance flows, establishing diaspora engagement programs, facilitating circular migration patterns allowing seasonal or temporary returns, and creating employment pathways for diaspora members seeking to support displaced relatives.[21] Investment in communication technologies and digital platforms enabling transnational connection costs little compared to traditional infrastructure investments yet potentially yields substantial adaptation benefits. Furthermore, government support programs should be designed with explicit recognition of how they interact with transnational and social mechanisms; for example, housing assistance could be structured to facilitate community cohesion through collective housing arrangements rather than individual plots, and livelihood support could be tailored to facilitate integration into transnational networks or digital employment platforms.[22]

Additionally, the findings suggest that adaptation programming should explicitly assess and strengthen existing social bonds rather than treating community as a mere implementation backdrop. This might involve participatory community mapping identifying informal networks and leaders, explicit engagement of women and marginalized groups in adaptation decision-making, and integration of traditional knowledge and social structures into modern adaptation frameworks.[23] The substantial correlation between transnational networks and social cohesion suggests that interventions strengthening one dimension may have positive spillover effects on others, enabling more cost-effective programming and promoting holistic community strengthening.

Beyond policy, these findings carry implications for how we conceptualize climate displacement itself. Rather than viewing displacement exclusively through a lens of loss and vulnerability, recognizing and strengthening the adaptive assets that displaced populations mobilize offers a more capacities-based approach aligned with contemporary development thinking. This shift requires moving beyond purely humanitarian frames toward approaches recognizing displaced populations as active agents worthy of investment and support. Future adaptation frameworks should build upon this capacities-based paradigm, emphasizing the agency and resilience of affected communities rather than portraying them solely as victims requiring external salvation.[24]

Strengths of this investigation include the substantial sample size (n=373) enabling multivariable analysis with adequate statistical power, multi-district enrollment enhancing geographic representativeness, use of validated assessment instruments with documented psychometric properties in Southeast Asian populations, employment of comprehensive outcome measures reflecting contemporary adaptation conceptualizations, and rigorous analytical methods including model diagnostics and sensitivity analyses. The composite outcome definition spanning economic, psychological, and subjective well-being dimensions represents an advancement over single-indicator adaptation measures.[25,26]

However, several limitations warrant acknowledgment. Cross-sectional design precludes temporal inference regarding causality; while we present transnational networks as predictors of adaptation success, the reverse causal pathway—whereby successful adaptation enables maintenance of transnational connections—cannot be excluded. Longitudinal follow-up would strengthen causal inference. Second, reliance on self-reported psychosocial measures introduces potential for recall bias and social desirability response bias, though these are inherent to survey-based research. Third, purposive and snowball recruitment may introduce selection bias toward more visible or organized displaced populations; recent acute displacements or hidden populations might be underrepresented.

Fourth, while we employed broad inclusion criteria encompassing diverse climate displacement causes, this heterogeneity might obscure distinct adaptation mechanisms specific to particular hazard types. Fifth, our Digital Connectivity Index, though multi-item and internally consistent, represents a novel measure lacking extensive validation in low-income coastal populations. Sixth, unmeasured confounding including prior disaster exposure, ethnic or religious composition differences, or baseline livelihood diversity could influence results.[27,28]

Several avenues merit investigation to advance understanding of adaptation mechanisms among climate-displaced populations. Longitudinal panel studies with repeated measures of transnational network engagement, social cohesion, and adaptation outcomes would enable causal inference and identification of critical intervention windows. Qualitative research employing life history interviews and participatory methods could elucidate the specific mechanisms through which transnational networks facilitate adaptation at the household level. Experimental or quasi-experimental evaluation of interventions designed to strengthen transnational connections, foster social cohesion, or enhance digital connectivity could establish causal relationships and provide evidence for scale-up. Studies examining whether effects are modified by specific climate hazard types would advance hazard-specific adaptation planning. Research exploring how displacement interacts with pre-existing social inequalities (gender, age, ethnicity, disability status) in shaping adaptation pathways would illuminate whether adaptation mechanisms operate uniformly across social groups or require differentiated approaches. Investigation of the cost-effectiveness and scalability of transnational network facilitation programs compared to conventional livelihood or infrastructure interventions would inform resource allocation decisions among policymakers.

4. Conclusion

This cross-sectional study of 373 climate-displaced persons across three coastal Indonesian districts identified transnational networks, social cohesion, government support, digital connectivity, and psychological distress as independent predictors of successful climate adaptation. Transnational Network Strength emerged as the dominant predictor, nearly tripling the odds of successful adaptation relative to its absence. Social Cohesion and Government Support exerted substantial independent effects, while Digital Connectivity and psychological well-being contributed more modest but statistically significant protective effects. These findings challenge adaptation frameworks emphasizing individual or institutional responses in isolation, instead supporting integrated approaches recognizing the complementarity of social, psychological, economic, and digital dimensions of adaptation.

Climate adaptation is not achieved through single interventions or actors but through synergistic engagement of transnational networks maintaining economic and social lifelines, strong communities capable of collective problem-solving, responsive and accessible governments, digital tools enabling information access and livelihood opportunities, and psychological supports addressing trauma and building resilience. In the context of accelerating climate change and expanding climate-induced displacement, policies and programs must be redesigned to strengthen rather than restrict these mechanisms, recognizing displaced populations not as passive recipients of humanitarian assistance but as active agents leveraging available social, informational, and economic resources to rebuild meaningful lives. The success of climate adaptation in vulnerable coastal communities ultimately depends not on external interventions alone but on the restoration and strengthening of the diverse networks, institutions, and psychological capacities that displaced populations themselves mobilize in pursuit

of sustainable and dignified futures.

As climate change intensifies, particularly in vulnerable Southeast Asian coastal zones where poverty, population density, and climate sensitivity converge, the imperative to understand and support adaptation mechanisms becomes increasingly urgent. This study contributes evidence demonstrating that transnational networks and social cohesion represent actionable and cost-effective adaptation assets that merit prioritization in climate-sensitive development and disaster risk reduction frameworks for coastal communities.

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