Statistical Framework to enhance Disaster Resilience: An Empirical Cyclone Disaster Assessment Model

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Abstract

This research study delves into the critical dimension of social resilience within communities vulnerable to disasters, with a specific focus on the coastal areas of India. The study, conducted in cyclone-affected regions of Puri, emphasizes the significance of social resilience in effective disaster management. Through the analysis of 210 samples, we present a framework grounded in the exploration of bonding, bridging and linking social capital. While prior research acknowledges the need of social capital in enhancing resilience, this study contributes by quantitatively examining these relationships within the context of emerging disaster management frameworks. Utilizing structural equation modelling (SME) and statistical analysis, the research investigates how bonding, bridging and linking social capital impact disaster resilience.

The survey results analyzed with specialized software like AMOS, SPSS reveal compelling insights: all three forms of social capital—bonding, bridging and linking are positively associated with impacting disaster resilience. This study leads social resilience research by providing empirical evidence supporting the hypothesis that social resilience is positively influenced by bonding, bridging and linking social capital. This finding highlights the importance of building and maintaining strong social connections to enhance social resilience.

Keywords: Social resilience, disaster management, social capital, bonding, linking, structural equation modelling.

Introduction

Cyclones pose a great challenge to communities, especially those inhabiting vulnerable coastal areas like Puri, Odisha. In such areas, the performance of disaster management initiatives and community participation are crucial. Studies show that social capital has a key character in shaping the effectiveness of these actions[33]. In his definition of social capital, Akcomak[1] sees it as serving productive purposes within communities through collective norms, group dynamics, networks and trust.

Equally important, Shi[24] describes social capital as being composed of the attributes of social resilience that enhance societal efficiency through coordinated actions like trust norms and networks[3]. Social capital takes forms in terms such as bonding, bridging and linking with other people[7]. Bonding social capital refers to the collective cohesion within a group or community[3], rooted in shared moral values and trust, often reinforced through joint ventures and interaction among social groups. Linking social capital refers to associations with external entities and influential individuals that help in accessing resources and support[2].

Among many coastal areas with pastoralist communities, all these forms of social capital exist, although at different levels[22]. Disaster strikes often impact communities that have traditionally relied on informal social support mechanisms but possess strong bonding social capital and bridging relationships. This does not mean that such communities lack linking capital, but rather that it is limited due to their isolation from mainstream society[22]. Consequently, these dynamics of social capital are important for understanding resilience and community participation in cyclone events[7].

In fact, recent studies stress the merits of putting resources into preparedness for disasters and mitigation measures, pointing out prospective savings for international donors as well as safeguarding vulnerable communities[20]. Social capital is crucial for community resilience and coping mechanisms in disaster management strategies in Indian coastal vulnerable areas, enabling effective preparedness, response and recovery[3].

The study aims to explore the role of social capital as a primary component of social resilience in disaster-prone communities, employing statistical methods for analysis. The objectives of the study are: (1) To assess the relationship between social capital and social resilience through quantitative analysis, (2) To explore the influence of bonding, bridging and linking capital on social resilience within disaster-affected regions and (3) To provide empirical evidence supporting the hypothesis that social capital significantly influences social resilience.

Study Area

Cyclonic storms significantly impact India, particularly in vulnerable regions like Odisha, necessitating the development of robust disaster management frameworks to mitigate their devastating effects[3]. The historical trajectory of cyclones in the region, exemplified by the catastrophic Super Cyclones of 1999, underscores the urgent need for proactive measures to mitigate future disasters. Due to its location along the Bay of Bengal, Odisha is highly exposed to cyclonic disturbances that often escalate rapidly into severe storms with potential threats to lives, livelihoods and infrastructure. Despite impressive advances made in

preparedness and response to disasters, a comprehensive approach is still required because coastal communities remain exposed[22]. Stakeholders in Odisha can develop strategies to increase resilience to cyclone hazards, to minimize effects, to save lives, to reduce economic losses and to promote sustainable development in high-risk areas. Hence, it is crucial to understand the importance of indicators and parameters in making a framework to deal with a disaster situation[2,3].

Conceptual structure and Hypotheses

To conceptually show how people utilize social networks to clarify the societal effect of their livelihood in reaction to cyclones and disasters, we draw on the data on social capital theory. Adopting the interactive approach to social capital theory[29], our model suggests that the bonding, bridging and linking of social capital have a direct impact on social resilience, measuring the impact of cyclone disaster management planning. As seen in figure 1, this paradigm emphasizes how crucial social networks are for disaster prevention and management, which in turn, encourage successful disaster management initiatives in susceptible regions. We elucidate in detail the subtle relationship between forms of capital and disaster resilience[17].

Social capital in disaster resilience: Social capital theory, with its application to crisis management, emphasizes the importance of linkages within social networks[26,36]. From a network viewpoint, social capital is a critical resource that enables effective resource mobilization and inter-organizational exchange during crises[31]. Social capital, particularly in disaster-prone countries facing resource shortages, allows communities to get crucial commodities at below-market costs, to increase their resilience[24]. In crisis management, bonding social capital is critical for creating cohesiveness and collaboration within tightly knit communities[5]. This type of social capital builds trust and reciprocity among individuals, allowing for successful collective action during times of crisis[30].

Furthermore, bridging social capital broadens networks beyond immediate circles, providing access to a variety of resources and skills critical for disaster response and recovery[15].
Furthermore, linking social capital promotes interactions with external organizations such as government agencies, non-governmental organizations (NGOs) and other formal institutions. These links allow communities to get access to extra resources, information and support, enhancing their ability to face the complex difficulties provided by disasters[27].

Bonding social capital and enhancing disaster resilience: Bonding social capital, defined as networks of people with a common identity and inward-looking interactions, is critical for increasing social impact. Bonding social capital within communities, particularly during disasters like cyclones, builds trust and collaboration among individuals, allowing for quick resource mobilization and collaborative action. This is demonstrated by close-knit ties inside family-owned enterprises, where bonding social capital fosters unity and similar aims, eventually improving organizational scalability[19].

Bonding social capital, particularly in tight-knit neighborhoods or indigenous tribes, is crucial in cyclone-prone areas for demonstrating resilience through collaborative preparedness, resource sharing and mutual assistance. This bonding allows local NGOs to quickly mobilize volunteers and resources, thereby enhancing social impact and its importance in disaster management and community resilience-building initiatives.

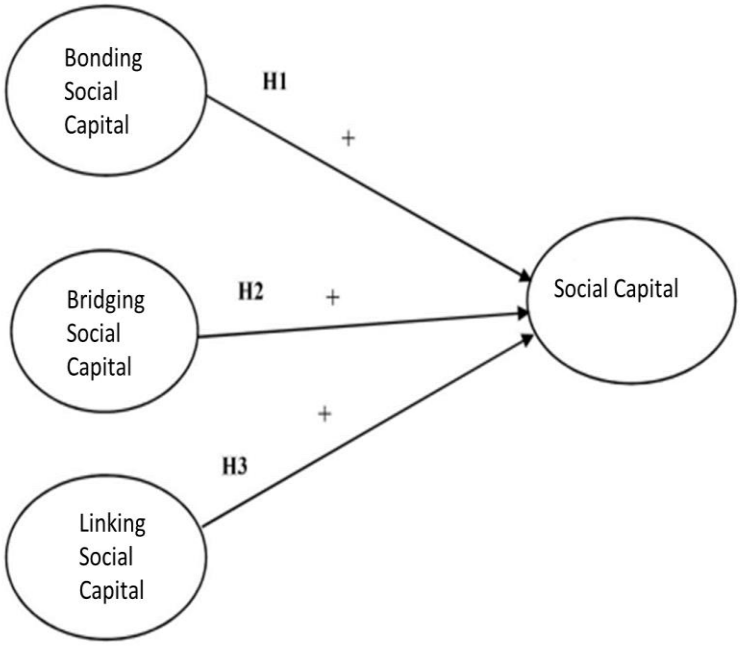

Figure 1: Study model

H1: Bonding capital is positively linked with enhancing Social Capital

Bridging Social Capital and enhancing disaster resilience: Bridging social capital, as opposed to bonding capital, promotes outward-looking connections inspired by shared interests or collaborative actions that benefit all parties[16]. Members of bridging social capital networks engage in social contacts, reciprocity and trust with businesses and outside organizations and they hold equal power positions[16,18]. In crisis management, bridging social capital is crucial because it boosts resilience and makes response and recovery efforts more successful. Bridging social capital, for instance, makes it easier for different stakeholders including residents, non-governmental organizations and government agencies to collaborate in cyclone-prone areas and produces coordinated catastrophe preparation and response strategies[17].

Bridging social capital enhances community resilience during cyclone disasters by facilitating resource exchange and skill sharing among stakeholders. Collaborative relationships between local governments and humanitarian organizations facilitate evacuation plans, relief supplies and assistance. Access to external resources enhances adaptive capacity and recovery efficiency during disasters.

H2: Bridging capital is positively linked with enhancing Social Capital.

Linking social capital and enhancing disaster resilience: Linking social capital, typically seen as a distinct type of bridging social capital, spans many groups and connects individuals across different levels of power[21]. It describes relationships when there is underlying unequal power dynamics but where there is also mutual respect, trust and status equality. These networks consist of formalized relationships with foreign businesses, funding agencies, non-governmental organizations (NGOs) and government representatives. Linking social capital enhances the performance of social enterprises through supporting the business model, making financial resources more accessible and enabling the expansion of social impact, according to prior research[15,22].

Social capital is crucial for disaster management, especially in cyclone-prone areas. Institutional ties with government agencies, NGOs and community-based organizations improve resource mobilization, coordination and knowledge access, especially in rising economies.

H3: Linking capital is positively linked with enhancing Social Capital.

Research Model: We suggest a study model shown in figure 1 based on the literature on enhancing social capital for cyclone hazard resilience. This version shows how social capital bonds, bridges and links affect communities' ability to withstand cyclone catastrophes. The based variable is the level of resilience tested by using communities in the face of cyclone failures[17].

The hypothesis (H1) suggests that strong social bonds within communities such as familial ties or neighborhood networks, enhance community resilience to cyclones, contributing to better disaster preparedness, response and recovery efforts.

The second hypothesis (H2) suggests that fostering social capital among diverse stakeholders such as neighborhood authorities, agencies and NGOs, enhances collective action and resource mobilization competencies during cyclone events.

The third hypothesis (H3) suggests that integrating social capital into disaster management can enhance community resilience to cyclones by fostering institutional relationships with external entities, government bodies, global organizations and donor companies.

The overall objective of our research is to improve our understanding of the ways in which different types of extraordinary social capital interact to strengthen a community's resistance to cyclones and to offer practical data for preparedness and mitigation strategies.

Material and Methods

Structural Equation Modelling (SEM): In this study, we experimented with structural equation modelling (SEM), a strong multivariate statistical tool used to investigate and assess complicated causal linkages[6]. The two fundamental statistical techniques used in SEM are route analysis and confirmatory factor analysis (CFA). CFA measures latent psychological qualities whereas path analysis uses a route diagram to determine causal links between variables[4]. SEM analysis involved five logical steps: model formulation, identification, parameter estimate, model assessment and model change[4].

Sampling Procedure: The total population of the selected village is 8,770. For this study, a sample size was determined using a Z-score of 1.96, corresponding to a 95% confidence level. Assuming maximum variability, the proportion (P) was set at 0.5, with the complement (q) also being 0.5. A margin of error (d) of 5% was used which translates to 0.05. Based on these parameters, the calculated sample size was rounded up to 210 individuals (details given in table 1). This sample size represents a small fraction of the total number of rural households in the village. Data collection was conducted from June to September 2023.The data were collected from the households from June to September 2023.

The Likert scale was employed in the questionnaire administered to participants, facilitating the nuanced evaluation of responses on a five-point scale stating, 1for strongly disagree; 5 for strongly agree[17,28]. The data was carefully examined and analyzed using structural equation

modelling (SEM) methods which were carried out with the aid of statistical software such as SPSS and AMOS 23. By enabling confirmatory factor analysis and SEM stages, this approach guaranteed the study's findings' robustness and reproducibility[17].

Independent Variables - Bonding, Bridging and Linking: In our study focusing on cyclone disaster resilience, we utilized adapted scales[34] to measure bonding, bridging and linking social capital. Bonding social capital (BNSC), as shown in table 2, encapsulating cooperative relationships within communities, was assessed through an eight-item scale covering pre-, during- and post-disaster stages[28]. The analysis revealed moderate to high levels of bonding social capital across various disaster management phases with mean scores ranging from 3.82 to 4.26.

Bridging social capital (BRSC) scores indicate active participation and information sharing among stakeholders throughout the disaster continuum with mean scores ranging from 3.90 to 4.10. The study found that social capital (LSC) significantly influences disaster response and recovery efforts, with mean scores ranging from 3.78 to 4.15, indicating strong connections between communities and external entities. Four regulated (BBCS6, BCS7, LSC6 and LSC7) were eliminated due to their failure to meet the criteria.

Our findings underscore the importance of social capital in enhancing resilience and fostering collaborative efforts to mitigate the impact of cyclone disasters. These results underscore the significance of social capital in bolstering community resilience and facilitating effective disaster management strategies[17].

Results

Multicollinearity check for variables: Multicollinearity between the independent variables in this study was evaluated utilizing a variety of diagnostic techniques[17]. To assess multicollinearity, tolerance values and the variance inflation factor (VIF) were first calculated. The results indicate that the VIF values for bonding social capital (SCBN), bridging social capital (SCBB) and linking social capital (SCL) were 1.799, 2.586 and 2.415 respectively, all well below the threshold of 5 (Table 3), suggesting no significant multicollinearity issues [10].

Additionally, matching tolerance levels above 0.2 further indicated the absence of multicollinearity (Table 3). The condition index values, Eigen values and variance proportions were also examined to verify the independence of the variables. There were no collinearity issues since the condition index values fell considerably below the threshold of 15, but we obtained them from 1 to 11.663 (Table 4). The dataset's Eigen values did not approach zero (Table 4) and variance proportions were within acceptable ranges, indicating that multicollinearity is not a significant concern. This assessment aligns with established guidelines for detecting multicollinearity issues in regression analysis[10,17].

Table 1
Attributes of the respondent

Variable	Number	Percent
Sample size	210	
Gender		
Male	130	62
Female	80	38.1
Age		
18–25	42	20
26–35	40	19
36–45	39	18.6
46–55	44	20.9
Above 55	45	21.4
Occupation		
Job Holders	60	28.6
Agriculture/Farming/ local craftsman	45	21.4
Self-Employed	30	14.3
Non-Working/Students	30	14.3
Youth Leaders	20	9.5
Village Assoc. Members	20	9.5
Self Help Groups / NGO	20	9.5
Local Leaders	15	7.1
Woman Workers	10	4.8

Table 2
Measures of the variable structure

Variable	Item	Description	Mean	SD
Bonding Social Capital	BNSC1	My family cooperated before disaster. (pre disaster stage)	4.06	1.092
	BNSC2	We actively participated in early warning systems. (pre disaster stage)	4.06	.918
	BNSC3	Effective information passing was practiced within the community. (pre disaster stage)	4.11	.989
	BNSC4	Stockpiling of essential supplies was carried out collectively. (pre disaster stage)	3.98	.988
	BNSC5	Skill-building programs were conducted for disaster preparedness. (pre disaster stage)	3.82	1.142
	BNSC6	Active involvement in search, rescue and evacuation activities. (during disaster stage)	4.10	.971
	BNSC7	Continued support for search, rescue and evacuation after the disaster. (post disaster stage)	4.09	1.020
	BNSC8	Providing food, water and shelter for the affected individuals. (post disaster stage)	4.26	.919
Bridging Social Capital	BBSC1	Actively involved in information receiving and passing. (pre disaster stage)	4.08	.997
	BBSC2	Contributed to spreading awareness and preparedness activities. (pre disaster stage)	4.10	1.014
	BBSC3	Received support from NGOs and volunteers in risk and crisis management. (during disaster stage)	3.90	1.071
	BBSC4	Participated in information sharing on relief programs. (during disaster stage)	4.04	1.028
	BBSC5	Continued support from NGOs in providing relief materials. (post disaster stage)	4.03	1.051
Linking Social Capital	LSC1	NGOs provided community leaders with training. (pre disaster stage)	3.78	1.058
	LSC2	The mapping of hazards, vulnerabilities and capacity was done by Stakeholders (pre disaster stage)	3.93	1.052
	LSC3	Active participation of decision makers like Government and Local bodies. (during disaster stage)	4.11	.905
	LSC4	External rescue officers implemented effective evacuation measures. (during disaster stage)	4.03	.999
	LSC5	Government provided relief like food, non-food items and shelters for the most affected people. (post disaster stage)	4.15	1.045
Scaling Social Impact	SCBN	Bonding capital, characterized by relations of trust and cooperation among people with similar social identity, was achieved during all the stages of disaster.	4.10	.904
	SCBB	Bridging capital, involving connections and interactions between diverse groups, was achieved during all stages of the disaster.	4.11	.847
	SCL	Linking capital, which involves connections between the community and external entities like NGOs and government, was achieved during all stages of disaster.	3.98	1.004

Table 3
Multicollinearity diagnostics, Coefficient test

Coefficients								
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant) is dependable variable-SC– SOCIAL CAPITAL)	4.528	.332		13.645	.000		
	SCBN – bonding capital	.055	.093	.055	.590	.556	.556	1.799
	SCBB – bridging capital	.033	.119	.031	.280	.780	.387	2.586
	SCL – Linking capital	.027	.097	.030	.274	.784	.414	2.415

Table 4
Multicollinearity diagnostics, Collinearity Diagnostics

Collinearity Diagnostics							
Model		Eigenvalue	Condition Inde	Variance Proportions			
				(Constant)	SCBN	SCBB	SCL
1	(Constant) is dependable variable-SC–SOCIAL CAPITAL)	3.938	1.000	.00	.00	.00	.00
	SCBN – bonding capital	.127	7.213	.69	.00	.01	.29
	SCBB – bridging capital	.125	9.112	.18	.94	.02	.19
	SCL – Linking capital	.271	11.663	.12	.05	.97	.52

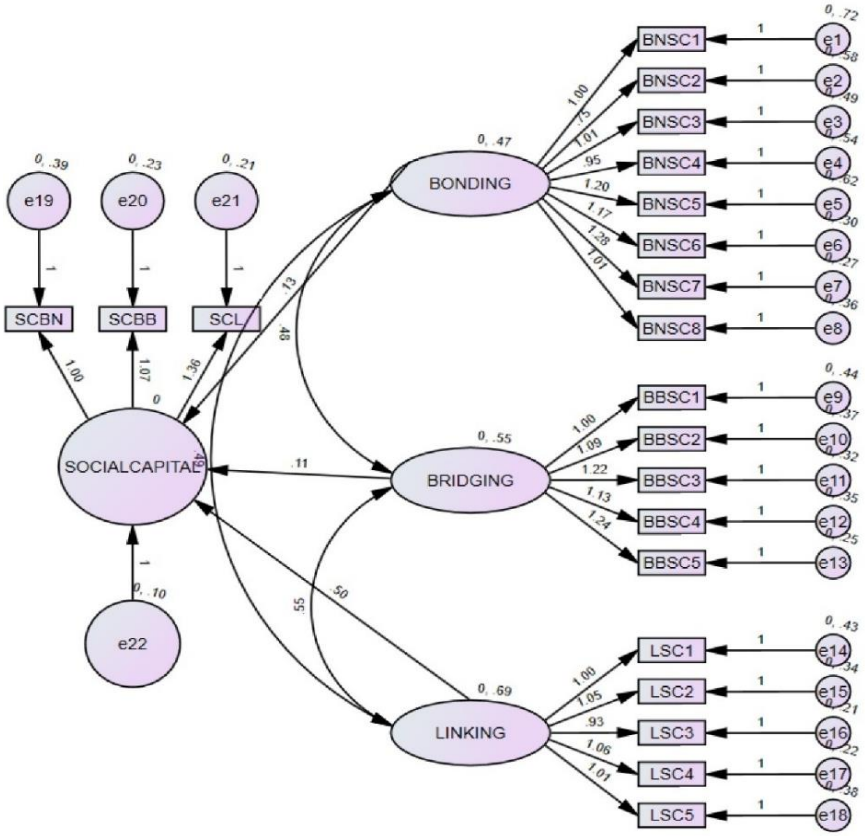

Fig. 2: Model Fit, Structural path model.
Source: author, AMOS 23 software.

Table 5
Confirmatory Factor Analysis (CFA) in AMOS 23 software

Abbreviation	Explanation	Model Fit Threshold	Attained
Likelihood Ratio	P-close[12]	≤ 0.05	0.000
C.M.I.N / D. F	Chi-square divided by Degree of Freedom[8]	≤ 3 = acceptable fit 1 = perfect fit ≥ 0.95 =	2.72
G.F. I	Goodness of Fit Index[13]	excellent fit ≥ 0.9 = acceptable fit	0.951
C.F. I	Comparative Fit Index[18]	excellent fit ≥ .90 = acceptable fit	0.965
R.M.S.E. A	Root Mean Square Error of Approximation[25]	≤ 0.05 = reasonable fit	0.051
S.R.M. R	Standardized Root Mean Squared Residual[25]	≤ 0.05 = acceptable fit	0.045

Table 6
Results of hypotheses.

Covariances						
		Estimate	**S.E.**	**C.R.**	**P**	**Label**
Hypothesis 1	H1	0.48	0.071	6.722	***	Accepted
Hypothesis 2	H2	0.545	0.074	7.373	***	Accepted
Hypothesis 3	H3	0.492	0.074	6.666	***	Accepted

***p value significant at .001 level.

Model fit: The confirmatory factor analysis (CFA) conducted in this study yielded a model with favorable fit indices indicating a robust representation of the underlying constructs[17]. The Likelihood ratio test produced a P of 0.000, underscoring an excellent fit to the data [11,17]. The Chi-square divided by Degree of Freedom (CMIN/DF) ratio was 2.72; the acceptable threshold is 3; and it is within an acceptable range, according to Gabrielle et al[8]. The Goodness of Fit Index (GFI) attained a value of 0.951, surpassing the recommended threshold of 0.9 for acceptable fit[13]. Similarly, the Comparative Fit Index (CFI) achieved a value of 0.965, indicating excellent fit, according to Meserve et al[18].

The root mean square error of approximation (RMSEA) and standardized root mean squared residual (SRMR) exhibited values of 0.051 and 0.045, respectively, both falling within acceptable ranges of less than or 0.05[25]. These findings collectively suggest that the CFA model adequately captures the relationships among the observed variables, aligning well with established criteria for model fit as recommended by various scholars. The findings in table 5 collectively suggest that the CFA model aligning well with established criteria for model fit was recommended by various scholars.

Hypothesis Testing: In our analysis, we investigated the relationships between bonding, bridging and linking with enhancing social impact, aiming to test several hypotheses[17]. The results, as shown in table 6, provide strong evidence supporting all the hypotheses, with statistically significant findings observed. The critical ratios for hypothesis 1 (H1), hypothesis 2 (H2) and hypothesis 3 (H3) are all above the usual threshold of 1.96, indicating statistical significance. The p-value is less than.001 and the critical ratios are all less than 001, confirming the findings.

Discussion

The study explores the role of social capital in enhancing disaster resilience, focusing on how network-integrated resources can utilize different forms of social capital in vulnerable communities. In vulnerable environments, social relationships within communities, or bonding social capital, had the biggest influence on disaster resilience. We used structural equation modelling (SEM)[17]. Disaster resilience can also be improved by bridging which entails external relationships outside of community bounds.

Moreover, our theoretical proposition regarding the role of linking external and vertical forms of social capital in bolstering disaster resilience received empirical support. These findings, which provide theoretical insights as well as practical ramifications, add to and expand upon the body of research currently available on disaster resilience. Our work contributes to the literature on effective techniques for increasing resilience in the face of catastrophes by clarifying the relationship between social capital characteristics and disaster resilience. This information is particularly useful for communities that are vulnerable to disasters in emerging economies.

Practical Contribution: The study emphasizes the importance of fostering strong intra-community social connections in disaster-prone regions, particularly within vulnerable communities, for effective disaster management and community resilience.

According to this realization, efforts like mutual support groups and community-building exercises that foster community cohesiveness and solidarity, can significantly increase disaster resilience. Furthermore, our findings highlight the need to bridging social capital to create external relationships outside of community bounds.

Organizations and authorities can strengthen external networks by utilizing platforms like local associations and Government funding agencies. This interconnectedness not only helps in sharing knowledge and expertise but also ensures a more coordinated and efficient response to disasters. Ultimately, building strong external networks can play a crucial role in enhancing overall disaster resilience at both the community and organizational levels.

Limitations

The study explores the bond between social capital and disaster resilience in vulnerable communities but acknowledges limitations and suggests future research on socio-economic factors and resource access. Furthermore, the sample size and geographic scope of our study were limited to regions in the Puri district of the State of Odisha. Increasing the sample size and geographic scope may improve the generalizability of our results and offer a more thorough grasp of the dynamics of disaster resilience in different situations.

Conclusion

The study enhances the comprehension of disaster resilience by elucidating the intricate relationship between social capital dimensions and community resilience in disaster-prone areas. Our findings highlight how crucial it is to

develop solid social ties within the community while simultaneously utilizing outside networks to improve capabilities for disaster preparedness and response.

Future investigations should carry out more studies to further our understanding of the dynamics of disaster resilience while accounting for the variety of factors that affect community resilience in the face of disasters. By doing this, we may create communities that are more resilient to disasters and create strategies and interventions that are more successful.

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