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Farming household vulnerability in coal mining regions: Insights from the Godavari valley coalfields, Telangana

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Abstract

Aims: To assess and compare the livelihood vulnerability of farming households in mining and non-mining (Control) areas using the Livelihood Vulnerability Index-IPCC (LVI-IPCC) framework and to identify key drivers of vulnerability in the coal-mining region of Godavari Valley Coalfields.

Study design: Comparative cross-sectional study.

Place and Duration of Study: The study was conducted in Kakatiya Khani OC-II region of Godavari Valley Coalfields and selected control villages of Telangana State, India, during 2024 - 2025.

Methodology: A total of 240 farming households were selected using purposive sampling, comprising 120 households from mining-affected villages located within 5 km of the mining core zone and 120 households from control villages. Primary data were collected using a structured schedule covering socio-economic conditions, environmental quality, health, livelihood activities, and institutional support. The LVI-IPCC framework was applied to estimate exposure, sensitivity, adaptive capacity, and overall vulnerability.

Results: Mining households exhibited significantly higher exposure (0.74) than control households (0.40), driven by air, water and soil pollution, environmental degradation, noise from mining operations, and climate variability. Sensitivity was also greater in mining areas (0.64) compared to control areas (0.28) due to land and water degradation, pollution-related health problems, structural damage from blasting, and limited access to education and healthcare. Adaptive capacity in mining areas (0.44) was lower than in control areas (0.48), reflecting limited livelihood diversification and weaker social networks. Consequently, overall vulnerability was markedly higher in mining areas (0.20) than in control areas (-0.01).

Conclusion: The results show that coal mining has made farming households more vulnerable. Improving institutional support, encouraging diversified sources of income, and adopting effective environmental management practices are essential for strengthening resilience in mining-affected areas.

Keywords: Livelihood vulnerability, mining, Godavari valley coal fields, exposure, sensitivity and adaptive capacity

Introduction

The rapid increase in population has intensified the global demand for goods and services. To meet these needs, governments have prioritized the establishment of diverse industries, with mineral resources serving as a critical foundation for economic development, particularly in developing nations like India (Mishra, 2009) [23]. Coal, as the dominant fossil fuel worldwide, plays a pivotal role in driving industrialization and energy generation. Coal mining has historically contributed to both national and local economies by generating revenue, creating employment opportunities, attracting foreign investment, and improving infrastructure. It has further enhanced living standards, literacy levels, and economic growth (Yelpaala and Ali, 2005; Fatah, 2008; Ghose and Roy, 2007) [31, 12, 13].

However, these economic benefits are offset by the substantial social and environmental costs associated with mining. The damage to ecosystems, human health, and community well-being undermines the sustainability of such development (Zarsky and Stanley, 2013) [32]. Coal mining frequently imposes significant burdens on local communities, including unemployment, poverty, landlessness, and loss of biodiversity, alongside environmental degradation that affects air, water, soil, and vegetation (Singh *et al.,* 2018) [28]. The reliance on fossil fuels continues to shape the global energy mix, with projections indicating that coal will remain a major source of energy until at least 2050, primarily due to its affordability compared to alternatives such as natural gas (International Energy Outlook, 2019; Huertas *et al.,* 2012) [19, 17].

While developing countries rely heavily on coal for economic growth, they also face sensitive vulnerability to its adverse effects. Weak regulatory frameworks, rapid industrialization, overpopulation, and inadequate access to basic services exacerbate the health impacts of environmental pollution in these regions (Hota and Behera, 2015) [16]. Mining projects influence economic, social, and environmental systems at multiple levels, often disrupting traditional livelihoods and eroding socio-cultural values. This creates conditions where communities face compounded risks that are not only environmental but also social and economic in nature.

Understanding the impacts of coal mining therefore requires a multidimensional perspective, recognizing that livelihood vulnerability arises from the interplay between environmental changes and socio-economic conditions. Vulnerability is shaped by social, demographic, institutional, and political factors that either exacerbate risk or foster resilience. Identifying these factors is critical for assessing the livelihood vulnerability of local communities to mining (Zarsky and Stanley, 2013) [32]. Such an approach enables scientists, practitioners, and policymakers to design targeted mitigation and adaptation strategies. Importantly, it provides the basis for interventions that enhance household resilience, reduce vulnerability, and support more sustainable pathways of development in mining regions. The present study addresses this gap by assessing livelihood vulnerability in coal mining regions, quantifying how environmental, economic, and social stressors affect households, and providing a basis for targeted interventions to enhance community resilience.

Coal Mining in India and Telangana

Coal mining is a vital industry in India, supporting energy production and economic growth. India, the world's second-largest coal producer, has mined coal commercially since 1774, and coal still supplies over (70%) of the country's electricity (Anon., 2024). Production has risen from 382.62 MT in 2004-05 to 893.19 MT in 2023-24, with an expected 1,000 MT in 2024-25.

Coal mining has driven the development of states like Jharkhand, Chhattisgarh, Odisha, West Bengal, and Telangana. In Telangana, Singareni Collieries Company Limited (SCCL), operating for over 125 years, contributes 9.2 per cent of India's coal. SCCL primarily works in the Pranahitha-Godavari Valley, part of the 470 km Godavari Valley Coal Field across Adilabad, Karimnagar, Warangal, Jayashankar Bhupalapally, and Khammam districts, making Telangana a major coal-producing region.

Coal mining and farming households vulnerability

Vulnerability arises from physical, social, economic, and environmental factors that increases the community's risk to hazards. Mining in agricultural regions leads to soil contamination, reduced crop yields, and food shortages, threatening food security and farmer livelihoods (Mishra, 2009) [, 23]. Communities near mines face health risks from polluted air and water. In Brazil, Indigenous groups suffered heavy metal contamination from mining. Additionally, deforestation and habitat destruction further degrade ecosystems (Hota and Behera, 2015) [16].

Methodology

Study area: The Singareni Collieries Company Limited (SCCL) has been mining coal for over 125 years. The Pranahitha-Godavari Valley Coalfields (PGVCF) stretch 470 km, with 350 km in Telangana. To meet growing coal demand, SCCL has expanded exploration into deeper and new coal rich areas. Initially surveyed by the Geological Survey of India, SCCL conducted detailed studies between 1980-1983. The KTK OC-II Project, which includes KTK-II and IIA Inclines, is near the exhausted KTK OC-I Project in Bhupalpally Block-I. It was launched in 2014-15 to continue coal production. The Mulug Coal Belt, across 82 square km, holds 1,292 million tonnes of shallow coal reserves, making it ideal for opencast mining. The project is located in Jayashankar Bhupalpally district, about 260 km from Telangana's capital. The project was situated in the Jayashanker Bhupalpally district, formerly known as Kakatiya Khani open cast II. It is positioned between the coordinates N 18°26'41.6704" to N 18°28'7.0715" latitude and E 79°50'16.1445" to E 79°52'36.3261" longitude. Bhupalapally district in northern Telangana relies heavily on coal mining. OC-I, the first major opencast mine, operated for decades before depleting its reserves. In 2015, OC-II began operations with advanced machinery, marking a new phase of coal excavation and significantly increasing coal extraction in the region.

Sampling strategy and data collection

A purposive random sampling method was used to select the study area and respondents. The present district was chosen due to its 25 year history of coal mining, allowing an assessment of its impact on agriculture and livelihoods. Bhupalpally and Koyyuru mandals, located within 12 km of the Singareni mining area, were selected to study the effects of mining on farming. Four villages from the mining region and three from non-mining areas were chosen for comparison. A total of 240 farmers participated 120 from mining-affected villages and 120 from control villages.

Table 1: Particulars of selected mandals, villages, farmers in the Singareni mining region of Bhupalpally

Sl. No	District	Mandal	Mining Villages	No. of samples
1	J. Bhupalpally	Bhupalpally	Gaddiganapally	30
			Jangedu	30
			Khasimpally	30
			Velishalapally	30
Total				120
Sl. No	**District**	**Mandal**	**Control villages**	**No. of samples**
2	J. Bhupalpally	Bhupalpally	Gollapally	40
		Koyyuru	Tadwai	40
			Thumdla	40
Total				120
Total Sample respondents				240

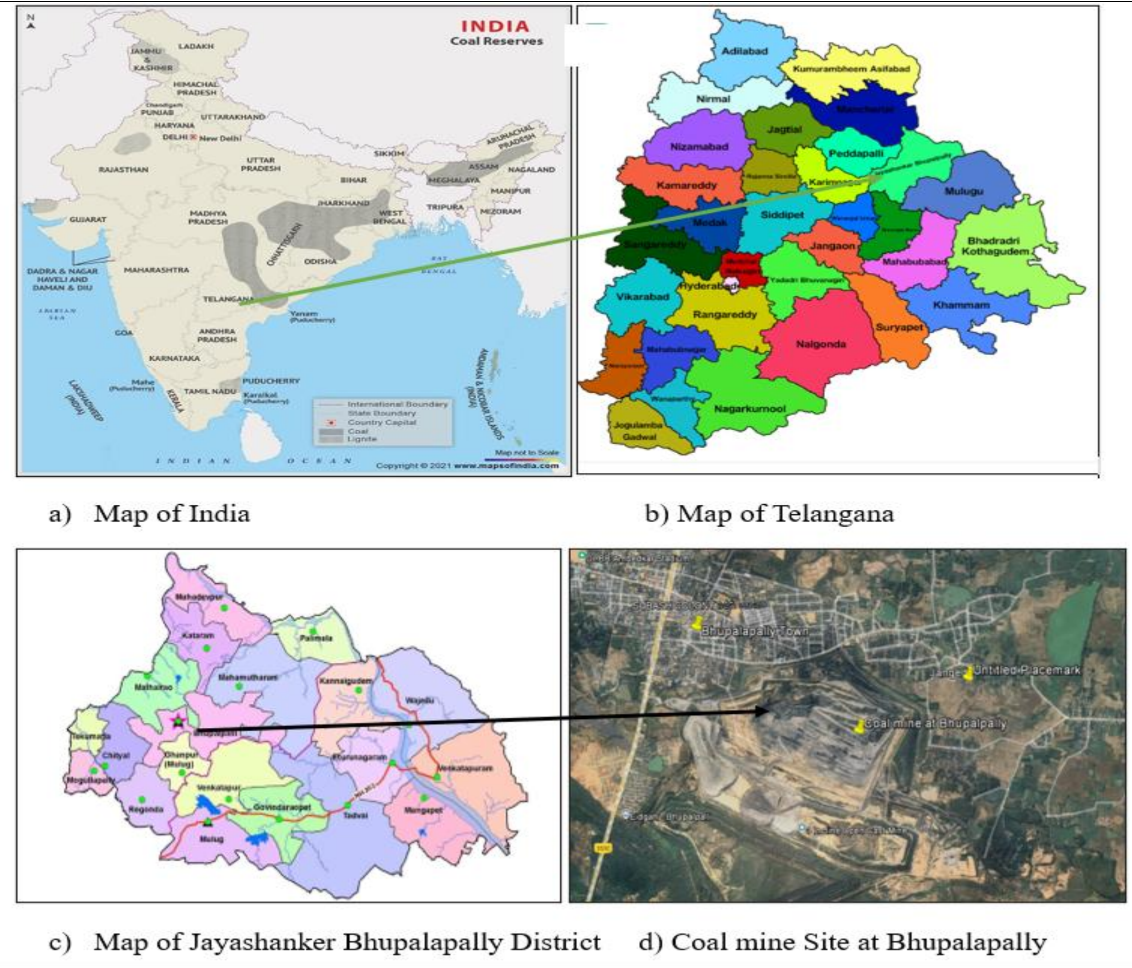

Fig 1: Location of the study area

Livelihood Vulnerability Index (LVI)

Vulnerability happens when people and communities face risks due to social, economic, environmental, and institutional factors. It is important to measure vulnerability to plan better solutions, especially for climate change adaptation. The Livelihood Vulnerability Index (LVI) helps assess how communities are affected by environmental and economic challenges. It has three key parts: Exposure, Sensitivity, and Adaptive Capacity.

Exposure: Exposure is the nature and degree to which a system is exposed to significant climate variation. This refers to how much a household or community is exposed to risks like pollution, climate change, and land degradation. In mining areas, families near coal mines face dust pollution, water contamination, and soil damage.

Sensitivity: These measures how badly a community is affected by these risks. Farmers are highly sensitive because they rely on agriculture and livestock. Health problems from pollution make them more vulnerable.

Adaptive Capacity: This is the ability to cope with challenges. Education, income and government support help communities adapt and reduce their vulnerability.

Table 2: The explanation of major and sub components taken for livelihood vulnerability Index (LVI)

Major Components	Sub components
Water	HH with access to the potable water
	HH reporting water pollution
Environment	HH reports that there is a change in rainfall pattern
	HH believes that increase in hot humid Months
	HH reports poor air quality
	HH reports poor soil quality
	HH reports poor water quality
	HH reports excess noise from mine
	HH are dissatisfied with environmental quality
	HH reports blasting as a major issue
Knowledge and Skills	HH with no formal education
	HH with primary schooling

Health	HH reporting presence of health issues in their villages
	HH benefitting from health campaign programmes organised by the mining company
Land	HH reporting land lost due to mining
Production	HH reporting pollution affects farm output
	HH reporting the loss of vegetation
House	HH reporting blasting from the mine effected house
	HH reporting loss of assets due to mining
Skill Enhancement	HH are benefitting from the improved technology
	HH heads not access to extension advisory
Net work and relationships	HH receives assistance from NGOs, Government and other organisations
	Average no. of people would help in the time of crisis
Livelihood strategies	HH are having subsidiary source of Income
Socio demographics	HH where primary adults are females (Female Headed Households)
	HH with semi pucca or kutcha houses
	HH with high dependent (More than >5)

Table 3: Directional relationship for the livelihood vulnerability Indicators

Components	Contributing factors of LVI	Direction	Relevant References
Exposure			
Water	HH with access to the potable water	Negative (-)	Danquah *et al.,* 2017 [8]
	HH reporting water pollution	Positive (+)	Hota and Behera 2015; Kicinska and Wikar 2021 [16, 20]
Environment	HH reports that there is a change in rainfall pattern	Positive (+)	Dumenu and Takam Tiamgne, 2020 [11]
	HH believes that increase in hot humid Months	Positive (+)	Sahoo and Senapathi, 2021 [26]
	HH reports poor air quality	Positive (+)	
	HH reports poor soil quality	Positive (+)	
	HH reports poor water quality	Positive (+)	
	HH reports excess noise from mine	Positive (+)	
	HH are dissatisfied with environmental quality	Positive (+)	
	HH reports blasting as a major issue	Positive (+)	
Sensitivity			
Knowledge and Skills	HH with no formal education	Positive (+)	Dumenu and Obeng 2016; Danquah *et al*., 2017; Phu and Tran 2019; [10, 8, 25]
	HH with primary schooling	Negative (-)	Dumenu and Takam Tiamgne, 2020 [11]
Health	HH reporting presence of health issues in their villages	Positive (+)	Adjei 2007; Hahn *et al*., 2009 [1, 14]
	HH benefitting from health campaign programmes organised by the mining company	Negative (-)	Akanwa *et al.,* 2017 [3]
Land	HH reporting land lost due to mining	Positive (+)	Danquah *et al.,* 2017; Phu and Tran 2019 [8, 25]
PRODUCTION	HH reporting pollution affects farm output	Positive (+)	Akanwa *et al.,* 2017, Hota and Behera 2015 [3, 16]
	HH reporting the loss of vegetation	Positive (+)	Akanwa *et al.,* 2017, Hota and Behera 2015 [3, 16]
House	HH reporting blasting from the mine effected house	Positive (+)	Adjei 2007; Hahn *et al*., 2009 [1, 14]
	HH reporting loss of assets due to mining	Positive (+)	Danquah *et al.,* 2017 [8]
Skill Enhancement	HH are benefitting from the improved technology (YES1/NO0)	Negative (-)	Phu and Tran 2019; Minh *et al.,* 2019 [25, 22]
	HH heads not access to extension advisory	Positive (+)	Phu and Tran 2019 [25]
Adaptive Capacity			
Net work and relationships	HH receives assistance from NGOs, Government and other organisations	Positive (+)	Ahsan and Warner 2014; Danquah *et al.,* 2017 [2, 8]
	Average no. of people would help in the time of crisis	Positive (+)	Sahoo and Senapathi, 2021 [26]
Livelihood strategies	HH are having subsidiary source of Income	Positive (+)	Phu and Tran 2019 [25]
Socio demographics	HH where primary adults are females (Female Headed Households)	Positive (+)	Hahn *et al*., 2009; Phu and Tran 2019; Minh *et al.,* 2019 [14, 25, 22]
	HH with semi pucca or kutcha houses	Positive (+)	Mishra PP (2009) [23]
	HH with high dependent (More than >5)	Positive (+)	Cong, *et al.* 2016; Danquah *et al*. 2017 [7, 8]

Importance of Livelihood vulnerability in the present study

In coal mining regions, the Livelihood Vulnerability Index (LVI) is crucial for assessing the socio-economic impact on farming households. Coal mining affects livelihoods by depleting natural resources, polluting water, reducing soil fertility, and increasing health risks. Calculating the LVI allows comparison of vulnerability between mining and control communities, identifies the most affected groups, and highlights key contributing factors. The findings can guide targeted policies, such as livelihood diversification, improved healthcare, and sustainable farming practices, to enhance resilience. Incorporating LVI provides a systematic approach to evaluating the impact of coal mining on rural livelihoods and supports effective policy formulation.

Normalization of data

Data on variables used to estimate the vulnerability index were normalized to make them unit and scale free for comparison. When the variables have positive relationship in relation to indicators, normalization was done using the formula given below:

$$\text{Index}_S = \frac{S_{\text{obs}} - S_{\text{min}}}{S_{\text{max}} - S_{\text{min}}} \quad \text{………}(i)$$

When the variables have negative relationship in relation to indicators, normalization was done as given below:

$$\text{Index}_S = \frac{S_{\text{max}} - S_{\text{obs}}}{S_{\text{max}} - S_{\text{min}}} \quad \text{…………}(ia)$$

Where S is the Subcomponent,
Sobs = Observed value/ actual value of the sub-component
S min = Minimum observed value in the dataset
Smax = Maximum observed value in the dataset
After each sub-component was standardised, they were averaged using the following formula to calculate the value of each major component

$$M_{\text{com}} = \frac{\sum_{i=1}^{n} \text{Index}_{S_{ci}}}{n} \quad \text{……………}(ii)$$

The Major Component Index was calculated as the average of the normalized sub-component indices within each major component. It is expressed as
Where:

- M_{com} = Major component index
- Index S_{ci} = Normalized value of the i^{th} sub-component within the major component
- n = Total number of sub-components within the major component

$$LVI = \frac{\sum_{i=1}^{n} W_{M_i} \times M_{\text{com}_i}}{\sum_{i=1}^{n} W_{M_i}} \quad \text{…………}(iii)$$

Where:

- LVI = Livelihood Vulnerability Index
- M $_{comi}$ = Value of the i^{th} major component index
- W M_i = Weight assigned to the i^{th} major component
- i representing the total number of major components considered, The Major components are water (W), environment (ENV), knowledge (K), health (H), land (L), production (P), house (H), skill enhancement (SE), network and relationships (NR), livelihood strategies (LS) and socio demographics (SD), This equation can also be written as

$$LVI = \frac{W_{SD}\,SD + W_{LS}\,LS + W_{NR}\,NR + W_{HH} + W_P P + W_W W + W_{ENV}\,ENV + W_K K + W_{SE} SE + W_L L}{W_{SD} + W_{LS} + W_{NR} + W_H + W_P + W_W + W_{ENV} + W_K + W_{SE} + W_L} \quad \text{……… }(iii)\ a$$

LVI-IPPCC (d) frame work

The LVI-IPCC is based on the IPCC definition of vulnerability, which comprises three components: Exposure, Sensitivity, and Adaptive Capacity. For estimation, the 11 major LVI components are grouped accordingly: Exposure (water, environment), Sensitivity (knowledge, production, health, land, housing, skills), and Adaptive Capacity (networks, livelihoods, socio-demographics). Unlike the standard LVI, the LVI-IPCC first combines the major components before aggregating them into a single index.

$$\text{CF} = \frac{\sum_{i=1}^{n} \text{W}_{\text{Mi}}\, \text{M}_{\text{i}}}{\sum_{i=1}^{n} \text{W}_{\text{Mi}}} \quad \text{………….}(iv)$$

In the LVI-IPCC, CF represents contributing factors (Exposure, Sensitivity, Adaptive Capacity), Mi are the indexed major components, Wmi is the weight of each component, and n is the number of components per factor. Exposure and Sensitivity increase vulnerability (higher values = higher vulnerability), while Adaptive Capacity reduces it. To account for this, the Adaptive Capacity index is calculated using the inverse of its subcomponents, ensuring that communities with better education, skills, networks, and diversified livelihoods are correctly identified as less vulnerable.
Once the three contributing factors (Exposure, Sensitivity, and Adaptive Capacity) are calculated, they are integrated using the following formula to derive the LVI-IPCC value

$$LVI - IPCC = (E - AC) \times S \quad \text{……………}(v)$$

The LVI-IPCC (d) ranges from -1 to -0.4 (Not Vulnerable), -0.4 to 0.3 (Moderate Vulnerable),0.31 to 1 (Highly Vulnerable) according to (Sullivan, 2002) classification.

Livelihood Effect Index (LEI)

The Livelihood Effect Index (LEI), based on the Sustainable Livelihoods Framework, measures the impact of external factors like coal mining on household livelihoods. It assesses five key capitals Natural, Human, Physical, Social, and Financial to understand how stressors affect community resilience and economic well-being. The figure 01: illustrates this conceptual framework.

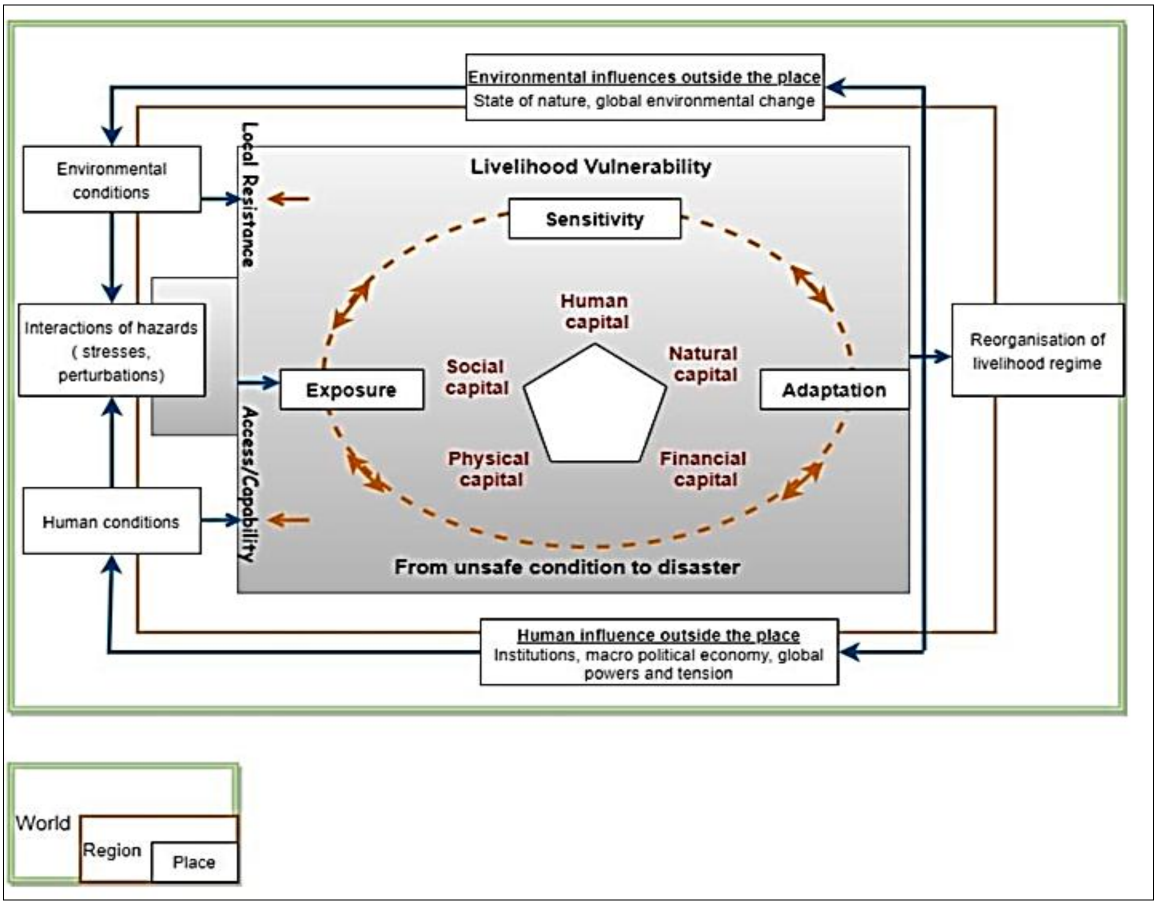

Fig 1: Conceptual frame work for livelihood vulnerability was obtained from (Adopted from Lin and Polsky, 2016)

LEI helps identify vulnerable groups and regions, guiding targeted policies to reduce livelihood risks.

Table 4: Categorisation of effect dimensions by indicators for LEI

Capital	Major components
Human Capital	Knowledge and Skills
	Health
	Skill enhancement
Natural Capital	Water
	Environment
Social Capital	Socio demographics
	Net work and relationships
Physical Capital	Land
	House
	Production
Financial Capital	Livelihood strategies

The Livelihood Vulnerability Index includes five key capitals: Human Capital (Knowledge, Skills, Health, Skill Enhancement), Natural Capital (Water, Environment), Social Capital (Socio-demographics, Networks, Relationships), Physical Capital (Land, House, Production), and Financial Capital (Livelihood Strategies). These components help assess the resilience and challenges faced by different communities.

Calculation of LEI (Livelihood Effect Index)

To calculate the LEI, we used the major components and their values from the LVI index to calculate the scores for each type of capital asset by combining them.

$$Cv = \frac{\sum_{i=1}^{n} L_i}{n} \quad \text{......(i)}$$

Where Cv is the value for each capital of LEI, L is the score for effect dimension for capital i, and n is the number of sub-dimensions forming the capital

LEI is then computed as the weighted average of all capitals using this formula,

$$LEI = \frac{\sum_{i=1}^{5} W_i C_{Vi}}{\sum W_i} \quad \text{....... (ii)}$$

LEI ranges from 0 to 1, with capital weights determined by dimensions, influencing livelihood resilience.

Results and Discussion

The Livelihood Vulnerability Index (LVI) reveals higher risks in mining regions (0.68) than control regions (0.37). The most vulnerable components in mining areas include poor air quality (0.93 vs. 0.40), soil degradation (0.91 vs. 0.38), and water quality issues (0.92 vs. 0.60). Health problems are significantly higher in mining regions (0.79) than (0.13). Noise pollution in mining (0.76) and controlled (0.35) and water pollution (0.46) was more in mining villages than controlled (0.09) are also concerns. Education disparities are minimal, with mining areas showing higher primary schooling (0.59) than control (0.43), while control regions have more households with no formal education (0.44) than (0.38). Access to potable water is better in mining regions (0.47 vs. 0.20), and participation in health campaigns is slightly higher in mining (0.37) than controlled (0.32), reflecting some corporate social responsibility efforts. Land loss is significantly higher in mining areas (0.70) than control (0.13). Pollution has reduced farm output (0.81) than control (0.35) and caused vegetation loss (0.84) vs. (0.39). Poor air quality (0.93), water quality (0.92), and soil degradation (0.91) are major concerns. Blasting effects have damaged houses, affecting 55 per cent of mining households compared to 7 per cent in control regions. Control regions receive more help from NGOs, government, and other groups (0.92) then (0.53), showing weaker support in mining areas. People in control regions also have stronger social networks, with more reliable contacts during crises (0.48 vs. 0.33). This suggests mining communities face more challenges with support and connections. Mining regions have more households with extra income sources (0.47 vs. 0.15), likely from mining jobs. Female-headed households are higher in mining areas (0.53 vs. 0.26), possibly due to male migration. Control areas have more dependents (0.33 vs. 0.13), suggesting stronger family support and stability.

The severe environmental degradation in mining regions, evident from poor air quality (0.93), soil degradation (0.91), and water contamination (0.92), is a major contributor to increased vulnerability. The intensive mining activities release dust, particulate matter, and pollutants into the atmosphere, worsening air quality and causing respiratory problems (Hota and Behera, 2015; Tiamgne *et al.,* 2022) [16, 30]. In the mining regions, even though the government provides water through the Mission Bhagiratha programme in Telangana, many households have complained about its poor quality. People have reported finding coal particles and dust in the water, making it unsafe to drink. Some families who can afford it buy clean water every day, while others have no choice but to filter and drink the contaminated water, leading to health issues like stomach infections, gastric issues, respiratory diseases and skin diseases. Additionally, some households have raised concerns that workers permanently employed by the mining company live in a separate area where the company provides water from external sources. However, other residents do not receive this supply, leaving them to struggle with polluted water.

Similarly, soil degradation results from land excavation, chemical exposure, and heavy metal contamination, reducing soil fertility and agricultural productivity. Water contamination arises due to mining waste disposal, affecting drinking water sources and irrigation. These factors collectively carries a serious threat to food security and public health in mining regions. Health issues are more common in the mining region due to dust, poor air quality, and contaminated water. Although the mining company organizes health campaigns, they mostly address minor illnesses like fever and cold. However, for serious health conditions like asthma and gastric problems, people need to visit a physician, which is difficult because there are no well-equipped hospitals in Bhupalpally district and they used to visit Waranagal- Hanmakonda for checkups which takes 2 hr to reach and if not in Warangal, they should go for Hyderabad nearly it takes 5 hrs if they have any serious health issues. As a result, those suffering from long-term health issues have to spend their own money on medical treatment, creating a financial burden on their families. Education differences between mining and control regions are minimal, with mining areas having slightly higher primary school enrolment. However, for upper primary, PUC, and higher education, students must leave their villages to continue their studies. One noticeable trend is that families in mining regions invest more in their children's education compared to those in control areas. This is because they want to secure a better future for their children and do not prefer them to take up mining jobs. Many parents hope that with higher education, their children will be able to raise their voices and challenge the mining companies for the injustices their communities face.

Land loss is a major issue in mining regions, as many households have lost their agricultural land to mining operations, limiting their ability to grow crops and sustain their livelihoods. Pollution has further reduced farm output and caused severe vegetation loss (Kenfact and Teguia, 2019) [21]. With cultivable land disappearing, many families are forced to seek alternative income sources, often relying on mining-related jobs. Although the mining company did not acquire forest land only barren and farmland farmers who lost their land were not given fair compensation, leading to widespread injustice. Land is one of the most valuable assets in rural areas, essential for both farming and housing. However, many affected farmers had to relocate, making mining regions more vulnerable than control villages. Under the Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement Act, 2013 (LARR Act, 2013), compensation was provided, but only in monetary form. No alternative land was given, leaving many farmers without a way to continue agriculture. Due to low literacy and limited skills, most could not secure technical jobs in mining and were forced to work as agricultural labourers in nearby villages, struggling to adapt to new livelihoods.

Mining regions have a higher proportion of households with additional income sources, likely due to employment in mining. However, many families rely on small, non-technical jobs that do not compensate for the health risks they face. While mining jobs may provide a stable income for some, the overall vulnerability of these households remains high due to forced consumption expenditure. This aligns with the Permanent Income Hypothesis (PIH) by Milton Friedman, which suggests that households adjust their consumption patterns based on expected long-term income rather than current earnings. In mining regions, despite higher incomes, families are compelled to spend more on healthcare, better housing, and improved living conditions, making them financially strained. Additionally, female-headed households are more prevalent in mining areas, likely due to male migration for work or occupational health risks affecting male workers. This shift in household structure increases the burden on women, who must balance both economic and domestic responsibilities. The absence of male members often reduces financial stability, making these households more susceptible to economic and social hardships.

Table 5: The Indexed Subcomponents for mining and control villages

Major Components	Subcomponents	Mining	Control
Water	HH with access to the potable water	0.47	0.20
	HH reporting water pollution	0.46	0.09
Environment	HH reports that there is a change in rainfall pattern	0.79	0.66
	HH believes that increase in hot humid Months	0.78	0.74
	HH reports poor air quality	0.93	0.40
	HH reports poor soil quality	0.91	0.38
	HH reports poor water quality	0.92	0.60
	HH reports excess Noise from mine	0.76	0.35
	HH are dissatisfied with environmental quality	0.71	0.46
	HH reports blasting as a major issue	0.64	0.14
Knowledge and Skills	HH with no formal education (No formal Education Yes 1/No 0)	0.38	0.44
	HH with primary schooling (Yes 1/No 0)	0.59	0.43
Health	HH reporting presence of health issues in their villages	0.79	0.13
	HH benefitting from health campaign programmes organised by the mining company	0.37	0.32
Land	HH reporting land lost due to mining	0.70	0.13
Production	HH reporting pollution affects farm output	0.81	0.35
	HH reporting the loss of vegetation	0.84	0.39
House	HH reporting blasting from the mine effected house	0.55	0.07
	HH reporting loss of assets due to mining	0.73	0.05
Skill Enhancement	HH are benefitting from the improved technology	0.63	0.48
	HH heads not access to extension advisory	0.68	0.18
Net work and relationships	HH receives assistance from NGOs, Government and other organisations	0.53	0.92
	Average no. of people would help in the time of crisis	0.33	0.48
Livelihood strategies	HH are having subsidiary source of Income	0.47	0.15
Socio demographics	HH where primary adults are females (Female Headed Households)	0.53	0.26
	HH with semi pucca or kutcha houses	0.63	0.71
	HH with high dependent (More than >5)	0.13	0.33
LVI		0.68	0.37

Major Components of mining and control villages

Livelihood vulnerability is higher in mining regions (0.68) than in control areas (0.37) due to environmental damage, land loss, and production challenges. Water (0.46 vs 0.15), environmental quality (0.81 vs 0.47), health risks (0.58 vs 0.35), land loss (0.70 vs 0.13), and production (0.83 vs 0.57) are all worse in mining areas. Housing is also more vulnerable (0.64 vs 0.08), while skill enhancement is slightly better (0.65 vs 0.47). However, social networks are weaker in mining regions (0.43 vs 0.70), and more households rely on additional income sources (0.47 vs 0.15) due to reduced farming opportunities. Previous studies highlight factors affecting livelihood vulnerability that align with mining regions. Shahzad *et al.* (2021) [27] noted that poor socio-economic conditions and weak social networks increase vulnerability, similar to mining areas with economic constraints and environmental degradation. Zhang (2019) emphasized that exposure and adaptability influence climate vulnerability, reflecting differences in resilience between mining and control regions. Suryanto & Rahman (2019) [29] observed varying vulnerability in agricultural villages, paralleling mining areas affected by land loss and dependence on mining jobs. Delu Wang *et al.* (2018) [9] reported financial insecurity due to compensation disparities and employment instability, similar to displaced farmers in mining regions. Diana *et al.* (2019) stressed the role of social networks and livelihood strategies, echoing the limited adaptive capacity in mining communities.

Table 6: Major Components of mining and control villages

Major Components	All Mining	All Controlled
Water	0.46	0.15
Environment	0.81	0.47
Knowledge and Skills	0.48	0.54
Health	0.58	0.35
Land	0.70	0.13
Production	0.83	0.57
House	0.64	0.08
Skill Enhancement	0.65	0.47
Net work and relationships	0.43	0.70
Livelihood strategies	0.47	0.15
Socio demographics	0.43	0.43

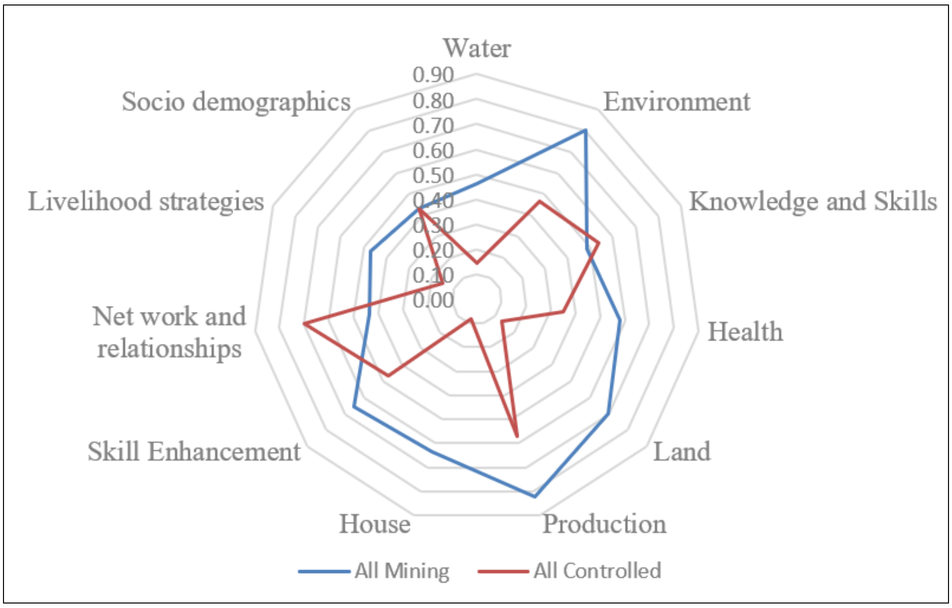

Fig 2: Radar chart for the major components in mining and control regions

Components of livelihood vulnerability Index in Mining and Controlled Regions

Mining areas have a high exposure index of 0.74 due to poor air, water, and soil quality, noise pollution, and climate changes. Sensitivity is also high at 0.64, as households depend on affected resources, face health issues, and suffer asset losses. Adaptive capacity is moderate at 0.44 but insufficient to balance risks. In contrast, controlled areas have lower exposure (0.40) and sensitivity (0.28) but slightly better adaptive capacity (0.48), making them more resilient.

Similar patterns have been observed in previous studies. Suryanto and Rahman (2019) [29] examined livelihood vulnerability among farmers in Sonorejo and Jiwo Wetan villages using LVI and LVI-IPCC indices. Their findings showed that Sonorejo Village had a medium vulnerability level (LVI: 0.363, LVI-IPCC: 0.044), while Jiwo Wetan Village had slightly lower vulnerability (LVI: 0.344, LVI-IPCC: 0.038). Their study effectively integrated spatial and statistical analyses, providing a strong assessment of climate-induced risks. However, further exploration of socio-economic factors and adaptive strategies could strengthen the findings. Similarly, Al Mamun (2023) assessed the livelihood vulnerability of char land communities in Bangladesh, focusing on Char Jotindro-Narayan and Kulaghat Char. The Climate Vulnerability Index (CVI) was 0.633 for Char Jotindro-Narayan and 0.639 for Kulaghat Char, indicating comparable overall vulnerability. The LVI-IPCC scores (0.148 and 0.139, respectively) suggest a moderate vulnerability level when considering adaptive capacity and sensitivity alongside exposure. These studies reinforce the importance of targeted adaptation strategies to enhance resilience in vulnerable communities and with Hahn *et al.* (2009) [14] assessed livelihood vulnerability in Mozambique using the IPCC's framework of exposure, sensitivity, and adaptive capacity. The study compared Moma and Mabote, revealing significant differences in their vulnerability levels. Moma had a lower exposure score (0.312) compared to Mabote (0.522), indicating that Mabote households faced greater climate-related risks. Similarly, sensitivity was higher in Mabote (0.409) than in Moma (0.353), suggesting that Mabote's socio-economic and environmental conditions made it more susceptible to external shocks.

Table 7: Components of livelihood vulnerability Index in Mining and Controlled Regions

Components	All Mining	All Controlled
Exposure	0.74	0.40
Sensitivity	0.64	0.28
Adaptive Capacity	0.44	0.48
LVI-IPCC(d)	0.20	-0.01

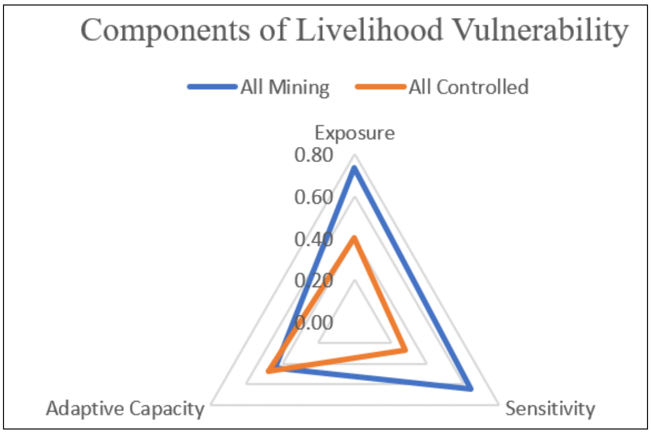

Fig 3: Vulnerability triangle diagram of the contributing factors of Livelihood Vulnerability Index- (LVI-IPCC) in mining and control villages

Categorisation of five capitals in the mining and control villages

Mining villages have higher human capital (0.57), natural capital (0.63), physical capital (0.66), and financial capital (0.47). In contrast, control villages have stronger social capital (0.57). The overall Livelihood Empowerment Index (LEI) is higher in mining villages (0.57) compared to control villages (0.47).

Similar trends have been observed in previous studies.

Danquah (2017) [8] found that mining negatively affects rural livelihoods in Ghana, particularly impacting social, physical, and human capital. The study emphasizes the need for regulating mining activities to ensure sustainable livelihoods. Similarly, Tiamgne (2022) [30] highlighted the economic benefits of mining, including employment, income generation, and infrastructure development. However, at the local level, the negative impacts of mining can outweigh these benefits if not properly managed. A livelihood vulnerability assessment in Zambia's Solwezi copper mining district showed that communities closer to mining activities faced higher vulnerability in human, natural, social, physical, and financial capitals. Environmental degradation, including loss of agricultural land, deforestation, and water pollution, further threatened local livelihoods.

Table 8: Categorisation of five capitals in the mining and control villages

Capital	All Mining	All Controlled
Human Capital	0.57	0.34
Natural	0.63	0.31
Social	0.43	0.57
Physical	0.66	0.19
Financial	0.47	0.15
LEI	0.57	0.47

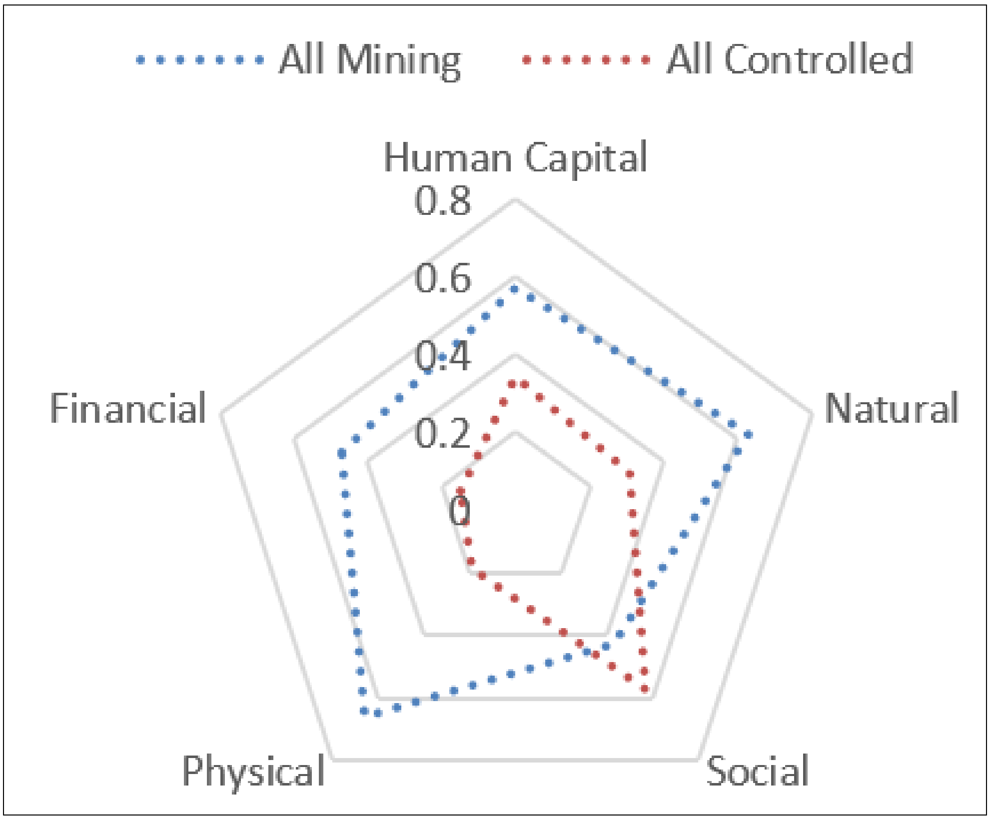

Fig 4: Radar chart for the five capitals in mining and control villages

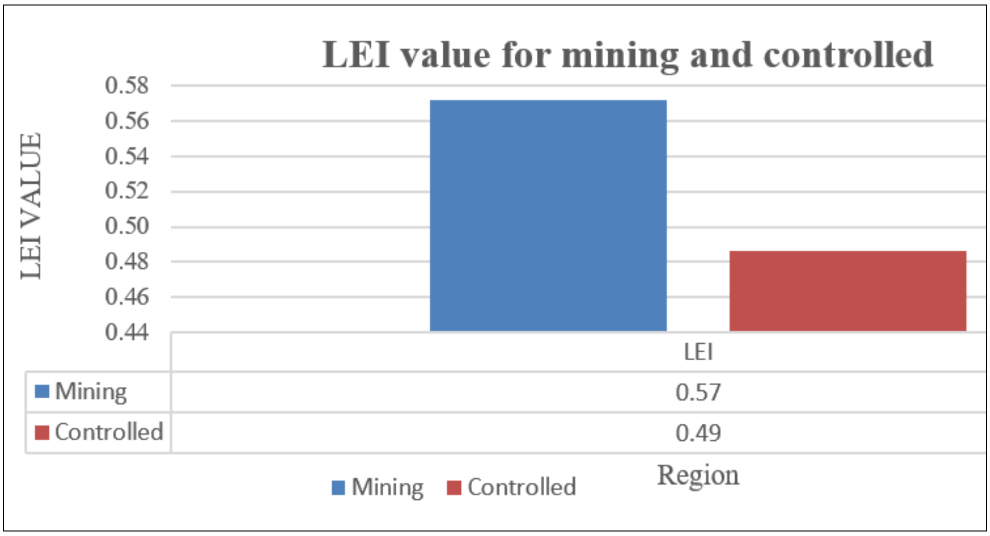

Fig 5: Comparison of LEI for mining and controlled regions

Conclusion

This study used a livelihood vulnerability framework to assess how farming households in Bhupalpally district are affected by coal mining. While mining activities have created some job opportunities, they have also displaced local communities and reduced farmland availability, limiting their ability to benefit from increased food demand. Many farmers lost their land to the Kakatiya Open Cast Mine-II, but the new jobs in mining were largely inaccessible to them due to a lack of necessary skills. Moreover, there was no government support to help them adapt to these changes or build new livelihoods. The Livelihood Vulnerability Index (LVI) shows that villages within 5 km of mining areas face higher vulnerability than those 12 km away. These findings highlight the urgent need for better planning and policies to support affected communities. The LVI can serve as an important tool for development planners and policymakers to assess and address livelihood risks in mining regions.

Recommendations

Improving access to clean water and healthcare must be prioritized to safeguard communities from the severe health risks associated with mining-related pollution. This requires not only reliable provision of safe drinking water but also the establishment of well-equipped medical facilities capable of addressing chronic respiratory, gastric, and skin diseases that are prevalent in mining regions. At the same time, stricter environmental regulations are needed to enforce compliance with air, water, and soil quality standards, holding mining companies accountable for the ecological damage they cause. Beyond environmental control, livelihood diversification should be actively promoted through skill development initiatives and the creation of non-mining employment opportunities, enabling affected households to build stable and sustainable income sources. Equally important is the need for fair and transparent land compensation policies that go beyond one-time monetary payments, ensuring displaced families receive adequate resettlement support and opportunities to continue farming or engage in alternative livelihoods. Together, these measures can reduce vulnerability, enhance resilience, and promote more equitable development outcomes in coal mining regions.

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