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ORIGINAL ARTICLE

Assessing the livelihood vulnerability of rural Guyanese communities due to accelerating environmental change

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Abstract

Environmental change is increasing vulnerability for many local communities worldwide. This can affect social, health, economic, environmental and cultural values, and challenges our ability to achieve Sustainable Development Goals. Previous research has quantified such community vulnerability using indices such as the Livelihood Vulnerability Index (LVI) and the Livelihood Vulnerability Index-Intergovernmental Panel on Climate Change (LVI-IPCC) to assess the impacts of climate change on the livelihoods of local communities. However, there remains a gap in our understanding regarding how the vulnerability of communities is impacted by industries that lead to environmental degradation such as mining and logging, and how these may interact with changes linked to climate change such as increased intensity and duration of floods and droughts. We address this, utilising the LVI, LVI-IPCC and a livelihood-based analysis, by quantifying the vulnerability of four rural (primarily Indigenous) communities in Guyana, northern Amazon. We assessed the degree to which these communities and households are exposed, sensitive and have adaptive capacity towards a changing environment and climate and identify key community and household-level components contributing to that vulnerability. We find that communities and households dependent on mining and logging displayed lower overall vulnerability yet exhibited heightened sensitivity to environmental change due to natural resource depletion and degradation. In contrast, subsistence-based communities faced higher overall vulnerability, partly attributed to their susceptibility to flooding and lack of livelihood diversification. Our research improves our understanding of the processes and factors that predict vulnerability in rural communities and can help to guide the development of appropriate interventions.

Keywords Subsistence · Mining · Resilience · Climate change · Amazon · Indigenous

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Introduction

Human-induced environmental change, encompassing land-use change, climate change and biodiversity loss, is leading to increased risks to local communities worldwide (Huntington et al. 2017). However, local communities in developing countries face a disproportionate burden of environmental stressors, as they heavily rely on natural resources for livelihoods and have limited resources and infrastructure for adaptation. This vulnerability is further compounded by socio-economic factors such as poverty and inequality (Adger and Brown 2009; Díaz et al. 2019; Ford 2012). These pressures can have far-reaching consequences across social, health, economic, environmental and cultural dimensions of their lives and wider communities (Szabo et al. 2016). For example, in the northern Amazon, environmental degradation negatively affects rural subsistence cultures that rely heavily on natural resources, such as intact forests and river systems (Kingsbury 2001). It is predicted that deforestation in the northern Amazon will intensify flooding, resulting in crop damage, restricting road travel, decreasing fish catch, reducing water quality and promoting water borne diseases (Bovolo et al. 2018).

In light of these challenges, recent research has highlighted that some Indigenous communities have developed resilience to environmental changes, actively adapting in a variety of ways (Ford et al. 2020; Mistry et al. 2016). For instance, in Bangladesh, villagers have created floating vegetable gardens to combat flooding (Irfanullah et al. 2011). In the Central, South American and Caribbean regions, Indigenous communities are adapting their agricultural practices and relocating settlements, to improve food and resource security, and reduce vulnerability to adverse climate conditions (Felipe Pérez and Tomaselli 2021; Ramos et al. 2016). However, the process of adaptation to certain challenges can be complex and constrained by external factors beyond the direct control of local communities.

Rural communities in areas of resource extraction, such as mining operations, often bear the social and environmental costs (Martínez et al. 2007). Although mining operations can create employment opportunities and support local economies, their establishment can also have direct and indirect impacts on local livelihoods, including pollution such as mercury poisoning (Cordy et al. 2011), increased risk of malaria (Castellanos et al. 2016) and HIV transmission (Palmer et al. 2002), cultural erosion and conflict between neighbouring communities (De Theije and Salman 2018; Hilson and Laing 2017). Mining also degrades the integrity of ecosystems through soil erosion (Jarsjö et al. 2017), contamination of freshwater systems (Garcia-Ordiales et al. 2017), habitat loss and disruption to ecosystem service provision (Mensah et al. 2015; Sonter et al. 2018). Consequently, it is important to understand the risks and vulnerabilities faced by local communities impacted by resource extraction, to inform measures to protect future livelihoods.

The vulnerability of local community livelihoods to environmental change cannot be understood solely through assessing impacts on the natural surroundings. Indeed, multiple factors, including social, demographic and economic factors, determine the vulnerability of local communities to environmental pressures (Di Noi and Ciroth 2018; Veland et al. 2013). Vulnerability has been generally defined as the magnitude to which a community is susceptible to, and unable to cope with, threats (McCarthy 2001). To measure this, vulnerability indicators aim to monitor susceptibility to change, to identify contributing factors, help prioritise assistance strategies and evaluate potential alleviation strategies (Eriksen and Kelly 2007; Shah et al. 2013).

The Livelihood Vulnerability Index (LVI) and the Livelihood Vulnerability Index within the Intergovernmental Panel on Climate Change's (IPCC) vulnerability framework (LVI-IPCC) have been commonly applied to assess livelihood vulnerability (Adu et al. 2018; Hahn et al. 2009; Shah et al. 2013; Simane et al. 2016; Tewari and Bhowmick 2014). These indices are implementations of the sustainable livelihoods approach, which examines household assets encompassing natural, social, financial, physical and human capital (Chambers & Conway 1992). The LVI, developed from this approach by Hahn et al. (2009), utilises a set of household questions to generate a metricised index, and includes several components, such as socio-demographic factors, health and water. The LVI-IPCC incorporates these components into the three main factors contributing to vulnerability: exposure, sensitivity and adaptive capacity (Hahn et al. 2009). Exposure is associated with the duration and magnitude of environmental pressures that can introduce hazards into a system, while sensitivity is the degree to which a system is affected by exposure stress. Adaptive capacity is defined as the ability to cope with and adjust to the consequences of the exposure (Hahn et al. 2009). By using a combination of both indices, we can obtain a comprehensive understanding of local community vulnerability.

Application of the LVI and LVI-IPCC approach has tended to focus on the impacts of climate change on the livelihoods of local communities (Adu et al. 2018; Hahn et al. 2009; Shah et al. 2013; Simane et al. 2016; Tewari and Bhowmick 2014). Yet, this leaves a critical gap in our understanding of the environmental vulnerability of communities affected by resource extraction industries, alongside concurrent changes associated with climate change. We address this gap, using both LVI and LVI-IPCC by quantifying the vulnerability of rural Indigenous households in Guyana, northern Amazon. Over the past 15 years, Guyana's artisanal and small-scale

gold mining, historically a major economic pillar, has experienced remarkable growth, expanding by nearly 250% from 2006 to 2016 (Laing et al. 2023; Singh et al. 2013). Furthermore, the recent discovery of substantial oil reserves offshore has further accelerated Guyana's economic growth (Panelli 2019), but concerns arise due to the "resource curse", which can impede developmental outcomes for resource-rich economies (McDonald and Üngör, 2021). Simultaneously, climate projections indicate rising temperatures and more extreme weather events in Guyana (Saleh 2020), with anticipated temperature increases of 1.2 °C by 2050 and 4.2 °C by 2100 (Hickey and Weis 2012; Mycoo 2014).

The expansion of the mining sector in Guyana, combined with potential rapid socio-economic changes resulting from the oil and gas industry, and shifting weather patterns driven by climate change may lead to substantial social and environmental changes, significantly impacting rural Indigenous communities (Mahdu 2019; Oyedotun and Burningham 2021; Panelli 2019). Here, we use this adaptive vulnerability assessment tool to assess the degree to which rural Indigenous communities are exposed, sensitive and have adaptive capacity towards a changing environment and climate and identify key community- and household-level components contributing to livelihood vulnerability.

Methods

Synopsis of the Livelihood Vulnerability Index process pipeline

The LVI is a flexible tool as it allows for its adaptation to local contexts (Hahn et al. 2009), making it possible to tailor the index to reflect the unique conditions and constraints faced by households in the study area. The LVI uses primary data from household surveys to construct the index. Here, we outline the pipeline of the LVI process, with further detail below in each sub-section, and displayed graphically in Fig. 1. Table 1. also includes the details of each community and Table 2 additionally includes the details of each major and sub-component used in the LVI.

We first conducted an in-depth review of current environmental pressures in the study setting, followed by stakeholder engagement to ensure comprehensive participation and inform the major components of the index and questionnaire design. Subsequently, participant communities were carefully selected, and necessary research permissions obtained. Vulnerability indicators (i.e. Major components) were then chosen, and the questionnaire design finalised. We then collected data, facilitating the computation of the LVI. This involved data preparation, standardisation and the calculation of sub-component and major component scores, ultimately resulting in the determination of the final LVI score. Additionally, the LVI-IPCC was calculated, using major component scores from the LVI to evaluate adaptive capacity, sensitivity and exposure scores, thereby offering a comprehensive understanding of vulnerability within the selected communities.

Study area

We surveyed households in two biogeographical regions of Guyana: the north-west and the south-west (Fig. 2). For both interior areas, the north-west is dominated by forest and river systems, while the south-west (hereafter known as the Rupununi) is an agro-ecological wetland savanna system, allowing for some spatial comparative analysis. Rural communities in the Rupununi are subjected to considerable climate variability, in terms of both increasing precipitation and temperature that has resulted in an increase of flooding events in the region (Table 1; Saleh 2020; Whitaker 2020). Forest communities in the north-west experience environmental degradation due to increasing mining and logging operations (Table 1; Laing and Moonsammy 2021; Rahm et al. 2015). However, mining-related environmental pressures are not confined solely to this region, with mining operations now increasing in the southern Rupununi, putting community lands and waterways at risk of degradation (Table 1.; Rahm et al. 2015; Alonso et al. 2016).

Communities were selected to capture a diverse range of environmental pressures (Fig. 2; Table 1), livelihood strategies, infrastructure conditions and Indigenous representation across Guyana's hinterland, as well as considerations of accessibility and existing collaborations between co-authors and local Indigenous communities and non-governmental organisations (NGOs) established through project partnerships. Prior to fieldwork, permission to conduct the survey was obtained from community leaders, the Ministry of Amerindian Affairs (MOAA) and the Environmental Protection Agency (EPA), ensuring compliance with ethical and legal protocols.

The four communities, Aranaputa (Makushi), Aishalton and Achawib (Wapichan), and Karrau (Lokono and Arawak), reflect contrasting eco-regions (savanna and rainforest), exposure to key environmental threats (drought, flooding and mining impacts), and varying levels of remoteness and service access. The possible causes of vulnerability in each of the communities were determined via the literature (e.g. governmental reports, published journal papers) and engagement with a diverse array of stakeholders (e.g. non-governmental organisations operating in the area, community groups). Aranaputa lies along the main road that links the Rupununi to coastal Guyana, making it one of the more accessible communities in the region. Households engage in both subsistence and small-scale

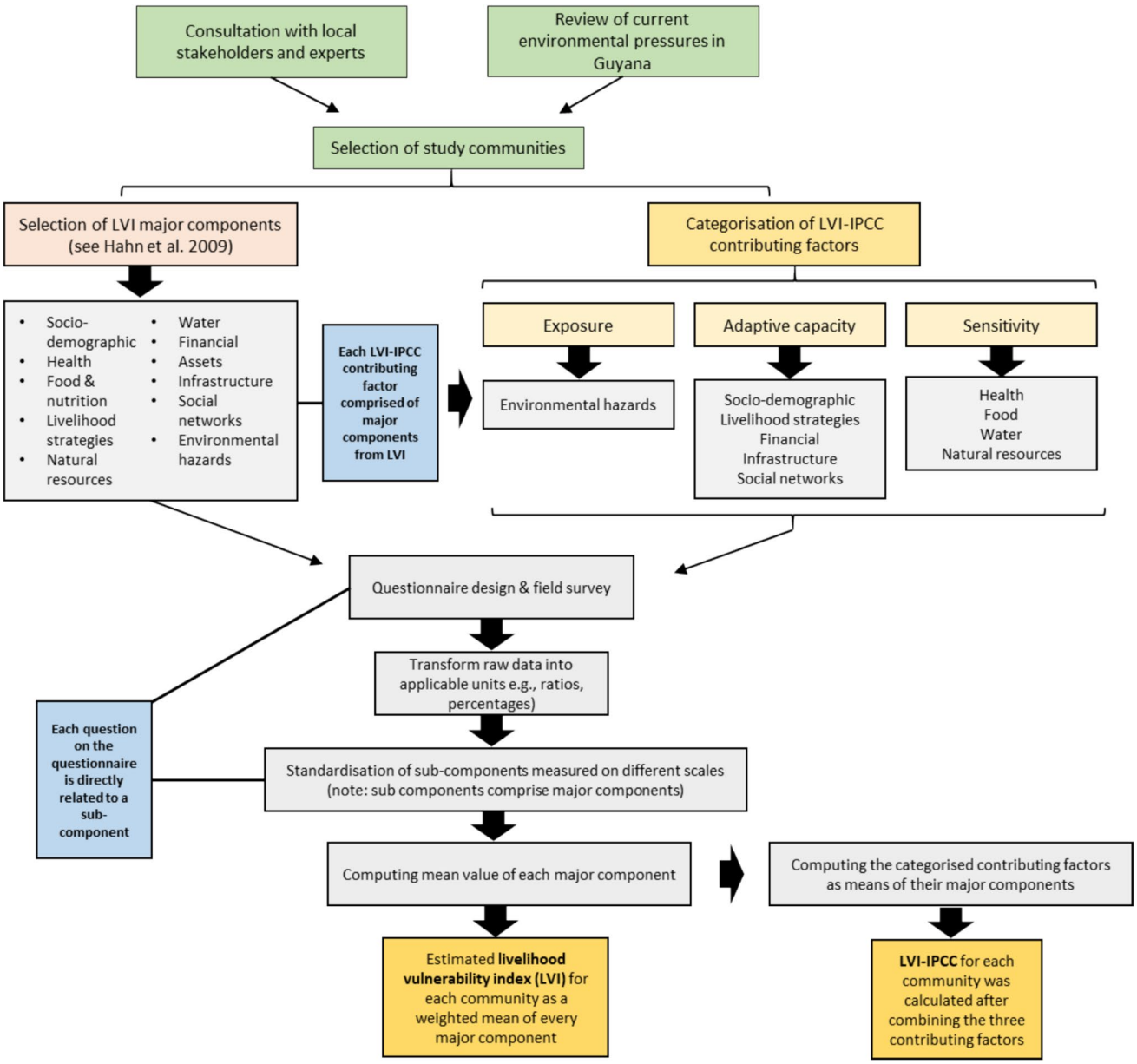

Fig. 1 Livelihood Vulnerability Index (LVI) process flowchart

commercial livelihoods. Aishalton in the South Rupununi serves as a sub-regional hub for administration, healthcare, education and trade and, consequently, has better infrastructure and services amidst ongoing environmental challenges such as unpredictable rainy seasons and flooding. In contrast, Achawib is a highly isolated, both geographically and in terms of transport infrastructure, subsistence-based community with emerging concerns over unpredictable rainy seasons and water quality linked to upstream mining. Karrau, a riverine forest community, faces significant mining-related pressures, including water pollution and deforestation.

Questionnaire design

A set of initial LVI pilot questions were constructed following Hahn et al. (2009), with additional content derived from other studies (Adu et al. 2018; Astuti and Handayani 2020; Azam et al. 2021; Can et al. 2013; Hahn et al. 2009; Mendoza et al. 2014; Tewari and Bhowmick 2014). First, we added an additional major component—*Natural Resources*—to the LVI to capture a more holistic picture of household's sensitivity to environmental change. Natural resources like forests and water bodies are vital for food and products like fuel, especially in rural areas. Their availability and quality

Table 1 Rural Indigenous communities included in the study in Guyana, South America, including the primary environmental pressures they face. Population figures are from the last national census in 2012 and may have changed due to demographic shifts

Community	Location	Population (2012 census)*	Number of households (2022)**	Number of households surveyed (%)	Primary livelihoods*	Primary environmental pressures
Karrau	North-west	141	90	44 (48.8%)	Mining, forestry, transportation	Mining, logging (Hook 2019; Rahm et al. 2015; ter Steege et al. 2002)
Aishalton	South Rupununi	1069	305	154 (50.4%)	Agriculture, forestry, fishing	Flooding, mining, unpredictable weather patterns (Rahm et al. 2015; Saleh 2020; Whitaker 2020)
Achawib	South Rupununi	586	129	64 (49.6%)	Agriculture, forestry, fishing, mining	Flooding, mining, unpredictable weather patterns (Rahm et al. 2015; 2020; Saleh 2020; Whitaker 2020)
Aranaputa	North Rupununi	353	106	55 (51.8%)	Agriculture, forestry, fishing	Flooding (Saleh 2020, Ruiz-Ramos et al. 2020; Whitaker 2020)

*Community population and primary livelihood information from Guyana Bureau of Statistics (2020)

**Number of households is based on conversation with members of each village council

greatly influence households' well-being, emphasising the need to incorporate them in this vulnerability assessment (Robinson 2016).

Two other components were also added—*Assets* and *Infrastructure*—to help us better understand household capital and consequently ability to adapt and recover from potential environmental shocks. Assets, including land, livestock, savings and other tangible resources, are vital for household well-being and resilience. In rural communities, farmland is particularly crucial for food and income generation, while assets like livestock provide safety nets and income stability (Robinson 2016). Infrastructure comprises essential facilities and services like electricity and Wi-Fi, improving the quality of life and enabling economic and social activities (Huerta et al. 2023; Olanrele et al. 2020). Second, a number of non-applicable questions were removed from Hahn et al. (2009). These were focused on the need for houses to save water. As water is highly abundant in our study region, these questions were removed from the questionnaire to reduce participant burden.

Both the original LVI and proposed modifications to it were explored via a series of in-country interviews in February 2020. These consultations involved local stakeholders, including Indigenous community members and NGO staff, who were selected based on their expertise and familiarity with the local Guyanese context. Our initial LVI questions were subsequently adapted, based on the feedback we received. The final questionnaire included eleven sections developed to gather the information required for the calculation of the LVI and LVI-IPCC indices (Table 2). We also collected household socio-demographic data with respect to sex, age, household size and primary livelihood activities of each household member. We piloted the questionnaire with 15 households from in the north-west of the country in February 2022. This helped to clarify and improve the wording of some of the questions. The study was approved by the University of Kent Faculty of Social Sciences Research Ethics Advisory Group.

Sampling and data collection

All survey team members were trained in questionnaire delivery encompassing cultural sensitivity, community engagement, ethical considerations and standardised questionnaire administration. Once the survey team arrived in each community, we visited the community leader to obtain permission to visit households. A "household" was defined as a group of people living together, making common arrangements for food and other essentials for a living.

This study aimed to assess and compare inherent vulnerability profiles across diverse Indigenous communities using the LVI. Our approach follows established LVI practice, where communities are selected to represent different socio-environmental contexts, and systematic sampling is used within each community to ensure representativeness. Systematic household sampling has been widely used in LVI studies for this purpose, including Shah et al. (2013) in Trinidad and Mekonen and Berlie (2021) in Ethiopia, who selected every *n*th household to obtain unbiased, evenly distributed samples. In these studies, observed differences in LVI scores captured real variations in environmental pressures and livelihood conditions across communities. Our use of systematic sampling aimed to achieve similar context-specific LVI profiles, allowing for

Table 2 The eleven major components and sub-components comprising the Livelihood Vulnerability Index (LVI) developed for four Indigenous communities in Guyana

Major components	Sub-components	Explanation of sub-components	Survey question	Status in LVI/source
1 Socio-demographic	Dependency ratio	Ratio of the population < 15 and > 70 years of age to the population between 18 and 70 years of age	Please list the ages and sex of every person living in this household?	Adapted from Hahn et al. (2009)
	Average age of household members	Average of age of all members of household	Please list the ages and sex of every person living in this household?	Adapted from Hahn et al. (2009)
	Percent of households where head of household has not completed secondary school	Percentage of households where head of household has not completed secondary school education	Please list the highest level of education completed for each member of the household	Adapted from Mendoza et al. (2014)
	Percent of households where no members have received any vocational training	Percentage of households where no members have received any form of vocational training	Has anyone in your household ever received vocational training?	Adapted from Mendoza et al. (2014)
2 Health	Average time to health facility (minutes)	Average time it takes the households to get to the nearest health facility	How long does it take you to get to a health facility?	Adapted from Hahn et al. (2009)
	Percent of households with family member with chronic illness	Percentage of households that report at least one family member with chronic illness. Chronic illness was defined as someone who gets sick most of the time	Is anybody in your family chronically ill (they are sick most of the time)?	Adapted from Hahn et al. (2009)
	Percent of households where a family member had to miss work or school in the last 2 weeks due to illness	Percentage of households that report at least one family member who had to miss school of work due to illness in the last 2 weeks	Has anyone in your household been so sick in the past two weeks that they have not been able to work or attend school?	Adapted from Hahn et al. (2009)
	Percent of households with a member injured or sick as a result of their work	Percentage of households who've had at least one member injured or sick as a result of their work in last year	Has anyone in your household become injured or sick as a result of their livelihood activity over the last year?	Developed for this study
	Percent of household with access to vaccinations	Percentage of households who report they have access to vaccinations when needed. Access defines as "If something you want or need is available, you can find it or obtain it"	Do you or members of your household have access to vaccinations or immunisations	Developed for this study
3. Food and Nutrition	Percent of households dependant on own farm for food	Percentage of households that get food from their own farm to feed the household	Where does your household get its food from?	Developed for this study
	Percentage of households dependant on fishing and hunting for food	Percentage of households that get food from their fishing or farming in the surrounding area	Where does your household get its food from?	Developed for this study
	Percent of households seeing a decrease in crop yield over last five years	Percentage of households seeing a decrease in their crop yield over last 5 years	If you grow crops, have you noticed any recent change in the amount of crops over the last five years?	Developed for this study
	Percent of household who have an area to produce own food	Percentage of households who report they have an area to produce their own food for consumption	Does your household have access to a farm or somewhere you can grow your own food?	Developed for this study

Table 2 (continued)

Major components	Sub-components	Explanation of sub-components	Survey question	Status in LVI/source
4. Livelihood strategies	Percent of households with only one source of livelihood	Percentage of households with only one source of livelihood	Please list the livelihood activities of every member of this household	Developed for this study
	Average number of livelihood activities in each household	Number of livelihood activities in the household	Please list the livelihood activities of every member of this household	Adapted from Hahn et al. (2009)
	Percent of households with lack of opportunity to engage in new or different livelihood activities	Percentage of households reporting a lack of job opportunities over the last 5 years	In the last five years, did anyone in your household switch or change livelihood activities or paid labour? If no, why not?	Developed for this study
	Percent of households without members working outside the community	Percentage of households that report at least one family member who works outside of the community for their primary livelihood activity	Do people from your household leave the community to work?	Adapted from Hahn et al. (2009)
	Percent of households without non-agricultural livelihood activities	Percentage of households reporting livelihoods other than agriculture/fishing/hunting as the primary or secondary source of livelihood	Please list the primary and secondary livelihood activities of this household	Adapted from Adu et al. (2018)
	Average time household member leaves the community for work (weeks)	Average time household members leave the community for in weeks	If a member of your households leaves the community for work, for how long do they go for?	Developed for this study
5. Natural Resources	Percent of household dependant on forest/savanna-based materials as fuels for cooking	Percentage of households reporting they depend on materials from the forest and/savannas as cooking fuel	Where do you get you fuel/materials for cooking?	Adapted from Tewari and Bhowmick (2014)
	Percent of households reporting a decline in natural resources from the area	Percentage of households reporting a decline in natural resources in the area over the last 5 years Natural resources defined as "materials or substances supplied from the forest, savanna or rivers"	In the last five years, have you noticed any recent change in the availability or quality of natural resources in your community?	Developed for this study
6. Water	Average time to drinking water source (minutes)	Average time it takes the households to travel to their primary drinking water source	How long does it take to get to your drinking water source?	Adapted from Hahn et al. (2009)
	Percent of households utilising natural water source for drinking water	Percentage of households that report a creek, river, lake, pool or hole as their primary drinking water source	Where do you collect your drinking water from?	Developed for this study
	Percent of households reporting water sources becoming polluted	Percentage of households reporting Local waterways becoming polluted over the last 5 years	Over the last five years have you noticed any changes in local rivers/creeks/ponds?	Developed for this study
	Percent of household seeing an increase in amount of water in rivers and streams	Percentage of household reporting an increase in amount of water in rivers and streams or increase in the size of rivers or streams over the last 5 years	Over the last five years have you noticed any changes in local rivers/creeks/ponds?	Developed for this study

Table 2 (continued)

Major components	Sub-components	Explanation of sub-components	Survey question	Status in LVI/source
7. Financial	Percent of households living under minimum wage	Percent of households living under Guyana's annual minimum wage	What is your household's average monthly cash income (GY$)?	Adapted from Azam et al. (2021)
	Percent of households with debts	Percentage of households reporting that they owe money to someone else. Debt defined as "Money that is owed to someone else"	Do you have any debts with a bank or village council or community revolving fund or other?	Adapted from Azam et al. (2021)
	Percent of households who have savings	Percentage of households reporting they have savings in the form of cash or something they would be able to sell in an emergency (e.g. cattle)	Do you have cash savings? Do you have any other form of savings?	Adapted from Astuti and Handayani (2020)
8. Assets	Percent of households who have access to a farm	Percentage of households reporting they own their own farm or access to farmlands	Does your household have own or have access to a farm?	Adapted from Can et al. (2013)
	Average size of household farms (acres)	Average size of household farm in acres	What is the size of your farm?	Adapted from Can et al. (2013)
	Percent of households who own a motorised vehicle	Percentage of households reporting they own at least one motorised vehicle	Does a member of your household own a means of transport? If yes, what type?	Developed for this study
	Percent of households who have access to own form of transport	Percentage of households reporting they have access to their own form of transport	Does a member of your household own a means of transport? If yes, what type?	Developed for this study
9. Infrastructure	Average time to reach nearest Wi-Fi connection (minutes)	Average time to reach nearest Wi-Fi connection in minutes	How long does it take you to reach the nearest internet access?	Developed for this study
	Percent of households with access to an electricity source	Percentage of households reporting access to an electricity source in the form of solar, generator or power company	Do you have electricity?	Developed for this study
10. Social networks	Average Receive:Give ratio	Ratio of (the number of times help received by a household in the past month+1) to (the number of times help given by a household to someone else in the past month+1). Help defined as "to do something that makes it easier for someone to do a job, to deal with a problem"	In the past month, did relatives or friends outside of your household help or support you and anyone from your household? If yes, how many times? In the past month, did you and your household help or support relatives or friends from outside of your household? If yes, how many times?	Adapted from Hahn et al. (2009)
	Percent of households that have not gone to their Local government for assistance in the past 12 months	Percentage of households that reported that they have not asked their Local government for any assistance in the past 12 months	In the past 12 months, have you or someone in your household gone to your village council or local government for help?	Adapted from Hahn et al. (2009)

Table 2 (continued)

Major components	Sub-components	Explanation of sub-components	Survey question	Status in LVI/source
11. Environmental hazards	Average number of flood events in last 6 years	Total number of years floods were reported by households in the past 6 years	How many times has this area been affected by flooding over the last six years?	Adapted from Hahn et al. (2009)
	Average number of drought events in last 6 years	Total number of years droughts were reported by households in the past 6 years	How many times has this area been affected by drought over the last six years?	Adapted from Hahn et al. (2009)
	Average number of bad weather events in last 6 years	Total number of years bad weather events were reported by households in the past 6 years	How many times has this area been affected by bad weather over the last six years?	Adapted from Hahn et al. (2009)
	Percent of households with Loss of physical assets over last 6 years due to flooding/drought/bad weather	Percentage of households that have suffered losses of physical assets that causes loss/damage of livelihood	Has anything you owned been lost or damaged due to flooding, bad weather or drought over the last six years?	Adapted from Hahn et al. (2009)
	Mean standard deviation of monthly avg. of avg. max daily temperature (2017–2021)	Standard deviation of the average daily maximum temperature by month between 2017 and 2021 was averaged for each area	-	Adapted from Hahn et al. (2009)
	Mean std. deviation of monthly avg. of avg. minimum daily temperature (2017–2021)	Standard deviation of the average daily minimum temperature by month between 2017 and 2021 was averaged for each area	-	Adapted from Hahn et al. (2009)
	Mean std. dev. of monthly avg. precipitation (2017–2021)	Standard deviation of the average monthly precipitation between 2017 and 2021 was averaged or each area	-	Adapted from Hahn et al. (2009)
	Distance to mines	Distance from village centre in kilometres to nearest mining permit	-	Developed for this study

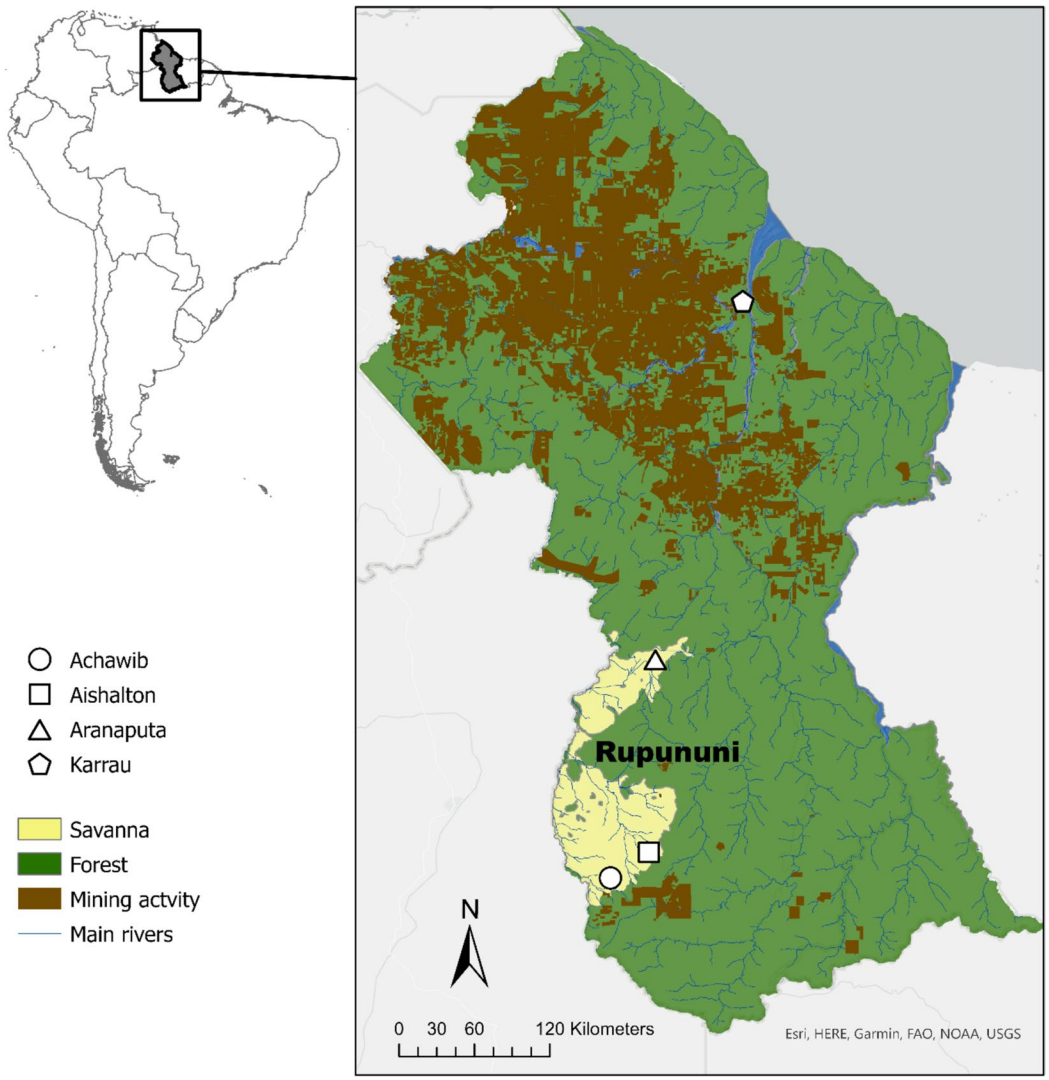

Fig. 2 Study area. Location of communities included in this study. Inset shows the location of Guyana in South America

cross-community comparisons within a standardised assessment framework while remaining sensitive to local differences.

To implement this, we selected every second household with the goal of surveying approximately 50% of households in each community. Surveys were administered between 8:00 and 18:00, as recommended by community leaders. Only responses from the household heads or their spouses were recorded. Surveys were administered to spouses only if the household head was not present. If a household was unoccupied or declined to participate, the survey team approached the nearest neighbouring household that had not yet been assessed. In the southern communities, weekends were avoided as household heads were likely to be at their farms. Each interview took between 15 and 55 min to complete. No monetary incentives were offered to secure participation. As per the agreement with village leaders, findings of this study will be shared with them upon completion, and individual reports will be given to all communities. Individuals that declined to participate were recorded as non-respondents.

Data analysis

To obtain an in-depth understanding of local vulnerability, three analyses were conducted per community: (1) calculation of LVI; (2) calculation of LVI-IPCC; (3) livelihood-based analysis.

Calculating community's Livelihood Vulnerability Index

Evaluation of the LVI relies on weighting equally each major component (Table 2) (Hahn et al. 2009). There are

four steps to the LVI calculation. The first step involved cleaning and transforming the raw household data into the applicable measurement units (e.g. ratios, percentages). For instance, in the question regarding the number of floods occurring over the last 6 years, each household provided a numerical response ranging from 0 to 6. Subsequently, the average for each community was calculated by aggregating the responses from all households within that community. For example, the average for the community of Aishalton was approximately 4.72 years out of the total 6 years. In the second step, each sub-component is standardised, because it is measured using different scales, to allow every measure to be combined into a single LVI index score later in the analytical process. The equation used for this conversion was adapted from that used in the Human Development Index to calculate the life expectancy index, which is the ratio of the difference of the actual life expectancy and a pre-selected minimum, and the range of pre-determined maximum and minimum life expectancy (Hahn et al. 2009).

$$index_{S_c} = \frac{S_c - S_{min}}{S_{max} - S_{min}}$$

where S_c is the original sub-component for community c, and S_{min} and S_{max} are the minimum and maximum values, respectively, for each sub-component determined using data from all communities. For example, the "average number of floods over the last six years" sub-component ranked from 0 to 6 years. These minimum and maximum values were used to transform this indicator into a standardised index so it could be integrated into the *Environmental hazards* major component of the LVI. Some sub-components, such as "Average number of livelihood activities in each household", were designed in a way that associates an increase in the crude indicator with a reduction in vulnerability. In other words, we assumed that a household who was farming and mining was less vulnerable than a household solely farming (Tiamgne et al. 2022). To reflect this, and assign a higher value to households with fewer livelihood activities, the crude indicator was transformed by taking its inverse. In the third step, the average standardised scores for each main component were calculated, producing a final value for each major component. (e.g. for the major component *Water*, this would be the average of the values for the sub-components "average time to reach drinking water source", "% of households utilising natural water source for drinking water", "% of households reporting water sources becoming polluted" and "% of household seeing an increase in amount of water in rivers and streams"). Finally, the averages of every major component were combined to give the final LVI score. The weights of the major components are determined by the number of sub-components of which it is comprised. This makes certain that all major components used contribute evenly to the overall LVI. The overall LVI is scaled from 0 (least vulnerable) to 0.5 (most vulnerable).

Calculating Livelihood Vulnerability Index-Intergovernmental Panel on Climate Change

The following approach is used to produce the values of exposure, sensitivity and adaptive capacity from the major components (Hahn et al. 2009):

$$CF_d = \frac{\sum_{i=1}^{n} W_{Mi} M_{di}}{\sum_{i=1}^{n} W_{Mi}}$$

where CF_d is a contributing factor defined by IPCC (exposure, sensitivity or adaptive capacity) for community d, M_{di} being the major components for d indexed by i, W_{Mi} being the weight of each major component and n being the number of major components comprising each contributing factor. A high value for exposure or sensitivity indices indicates a high vulnerability, but a high adaptive capacity index is inversely related to vulnerability. The final LVI-IPCC using the abovementioned contributing factors value was calculated using the following:

$$\text{LVI} - \text{IPCC} = (E - AC) * S$$

where E is exposure (equivalent to the *Environmental hazards* major component), AC is adaptive capacity (weighted average of *Socio-demographic*, *Livelihood Strategies*, *Finance*, *Assets*, *Infrastructure* and *Social Network* major components) and S is sensitivity (weighted average of *Health*, *Food*, *Water* and *Natural Resources* major components). The LVI-IPCC was scaled from −1 (least vulnerable) to +1 (most vulnerable).

Livelihood-based analysis

Households from all communities were consolidated into a single dataset and then categorised based on their primary livelihood. We classified livelihoods into four main types: S*ubsistence*, *Government jobs*, *Mining* and *Other*. *Subsistence* comprised farming, fishing and hunting. *Government jobs* consisted of village council staff, education and health workers. All other households besides *Mining* households were grouped as *Other*. The LVI and LVI-IPCC analyses were rerun using the livelihood categories to detect the vulnerability of households engaged in different types of primary livelihood activities. It is necessary to rerun the LVI as the LVI-IPCC is derived from the LVI results.

Results

In total, 317 household questionnaires were completed across four communities. All but three households agreed to participate in the questionnaire. Households took part in a wide variety of livelihood activities (Table 3), with subsistence identified as the most common primary livelihood activity in Aranaputa, Aishalton and Achawib. In Karrau, mining, logging, transport and catering (associated with the logging and mining industries) were the most common primary livelihood activities.

Livelihood Vulnerability Index

Overall, Achawib, a community heavily reliant on agriculture, had the highest LVI (0.416), suggesting it is the most vulnerable to the impacts of environmental change (Fig. 3). Karrau was the least vulnerable (0.274), reflecting the fact that the community reliant on mining and logging is likely to be less affected by environmental change.

Communities varied in terms of their vulnerability across different major components. Achawib had particularly high vulnerability scores relating to *Natural Resources*, *Environmental hazards* and *Financial* (Tables S1 and S2; Fig. 3). This is partly due to the highest proportion of participants dependent on forest- and/or savanna-based materials for cooking. In addition, this community had the highest proportion of households reporting a decline in natural resources over the last 5 years. On the other hand, Aishalton households reported the highest average number of flooding and bad weather events over the last 6 years, followed by Achawib, contributing to their high vulnerability score on the *Environmental hazards* major component. The scores on the *Financial* major component showed that all communities had medium to high levels of vulnerability, with Achawib having the greatest. This was due to the highest percentage of households living under minimum wage in the community and the highest proportion of participants having no savings. Karrau had the top vulnerability score on the *Assets* index, mainly attributed to the lowest access to their own mode of transport, lowest ownership of farmland and the smallest average farm size. However, this community had the lowest vulnerability related to *Financial*, *Infrastructure*, *Social networks* and *Environmental hazards*.

Table 3 Summary of the primary livelihoods of systematically sampled households ($N=317$) across four communities in Guyana, South America: Karrau ($n=44$), Aishalton ($n=154$), Aranaputa ($n=55$) and Achawib ($n=64$)

Livelihood activity	Karrau		Aishalton		Aranaputa		Achawib	
	n	%	*n*	%	*n*	%	*n*	%
Subsistence (total)	2	4.5	93	61.0	30	55.6	56	87.5
Farming	2	4.5	93	60.4	27	50.0	48	75.0
Hunting	-	-	-	-	-	-	3	4.7
Fishing	-	-	1	0.6	3	5.6	5	7.8
Government jobs (total)	0	0.0	22	14.3	8	14.8	1	1.6
Village council	-	-	4	2.6	-	-	-	-
Education	-	-	4	2.6	5	9.3	1	1.6
Receptionist	-	-	1	0.6	1	1.9	-	-
Health workers	-	-	5	3.2	2	3.7	-	-
Unspecified	-	-	8	5.2	-	-	-	-
Mining (total)	11	25.0	11	7.1	-	-	3	4.7
Other (total)	31	70.5	27	17.5	16	29.6	4	6.3
Transport	11	25.0*	1	0.6	1	1.9	-	-
Catering	11	25.0*	2	1.3	3	5.6	2	3.1
Masonry	-	-	2	1.3	-	-	-	-
Carpentry	1	2.3	2	1.3	3	5.6	1	1.6
Mechanic	-	-	2	1.3	1	1.9	-	-
Logging	5	11.4	1	0.6	2	3.7	-	-
Small business	-	-	6	3.9	4	7.4	-	-
Security	-	-	1	0.6	-	-	-	-
Unspecified	3	6.8	10	6.5	2	3.7	1	1.6
Total number of households sampled per community	44		154		55		64	

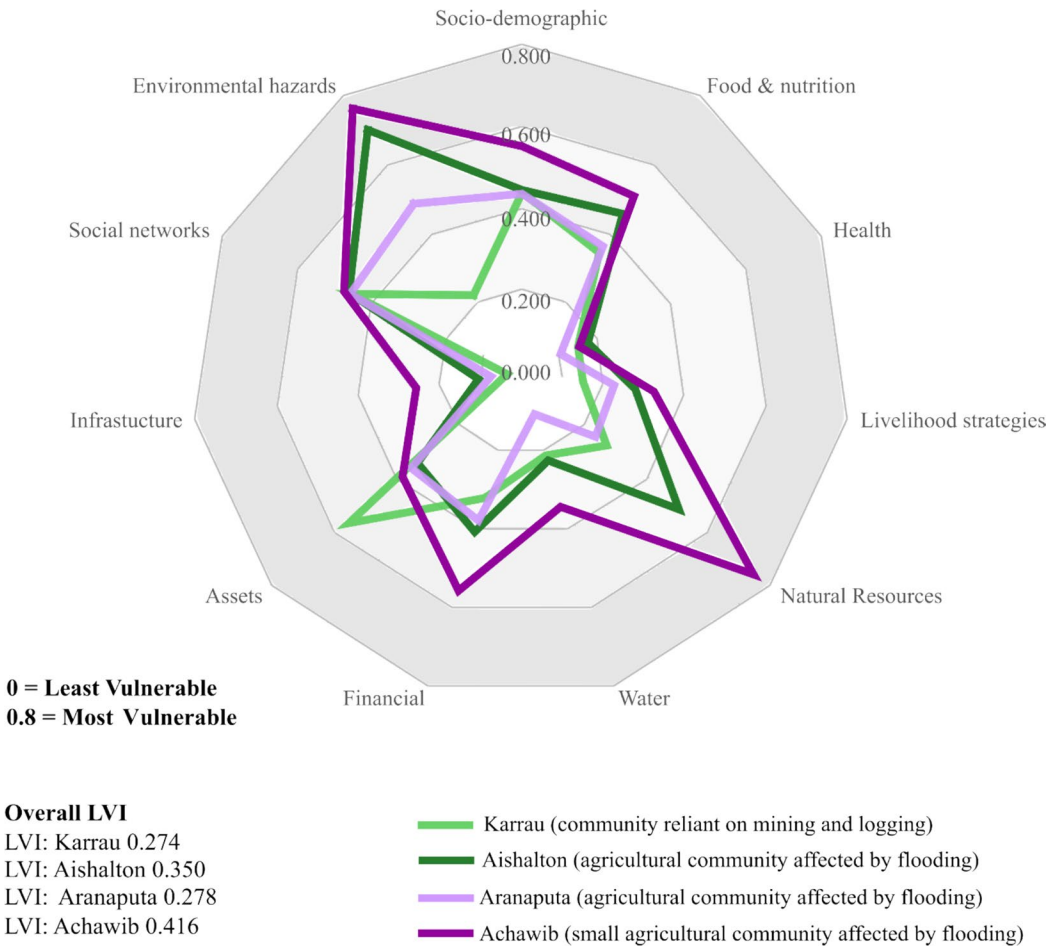

Fig. 3 Vulnerability spider diagram of the major components of the Livelihood Vulnerability Index (LVI) for Karrau, Aranaputa, Aishalton and Achawib communities in Guyana

Livelihood Vulnerability Index-Intergovernmental Panel on Climate Change

Overall, households in Achawib were most vulnerable to environmental change (overall LVI-IPCC = 0.165), while households in Karrau were least vulnerable (overall LVI-IPCC = −0.041) (Fig. 4; Table S3). The LVI-IPCCs for exposure and sensitivity to environmental change were highest for households in the communities of Achawib and Aishalton. Aranaputa households had the lowest LVI-IPCC for sensitivity, while Karrau had the lowest LVI for exposure.

Livelihood-based analysis

The livelihood-based analysis revealed that households dependent on *Subsistence* (farming, hunting, fishing) had the highest vulnerability (overall LVI-IPCC = 0.116) to environmental change according to LVI-IPCC (Fig. 5). *Subsistence* households scored highest on the exposure factor, which is associated with the duration and magnitude of environmental pressures that can introduce hazards into a system (e.g. number of bad weather events), indicating their high susceptibility to environmental change. *Mining* households had the highest sensitivity, which is the degree to which a system is affected by exposure stress, due to their vulnerability on LVI major components such as water, health and natural resources. Yet, they had the lowest overall vulnerability (overall LVI-IPCC = −0.003) to environmental change, along with *Other* households (overall LVI-IPCC = 0.002). Adaptive capacity, the ability to cope and recover from the exposure, was similar across all four livelihood categories.

Discussion

In light of escalating environmental challenges in Guyana (Mahdu 2019; Saleh 2020; Rahm et al. 2015), we utilised the LVI and LVI-IPCC to assess the vulnerability of local community livelihoods for the first time. Our study provides

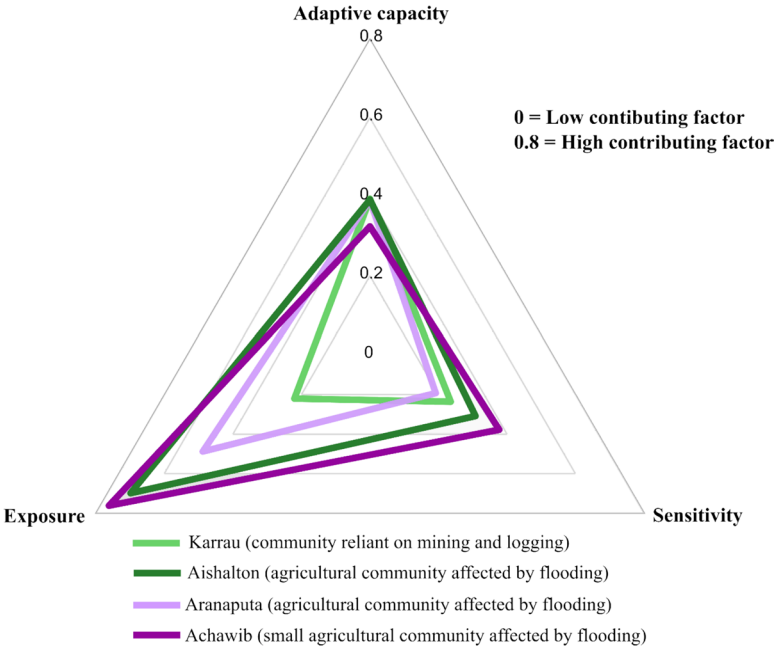

Fig. 4 Vulnerability triangle diagram of the contributing factors of the Livelihood Vulnerability Index-IPCC (LVI-IPCC) for Karrau, Aishalton, Aranaputa and Achawib, in Guyana

valuable insights into the broader dynamics of vulnerability and reveals that communities heavily reliant on agriculture are particularly susceptible to environmental change, as corroborated by other studies (Dumenu and Obeng 2016; Huq et al. 2015; Mertz et al. 2009). Moreover, households and communities with alternative livelihoods like government jobs, mining and logging may demonstrate reduced vulnerability, potentially owing to prospective economic benefits and infrastructural progress linked to these industries, consistent with findings from previous research (Arthur et al. 2016; Malhi et al. 2021). However, it is notable that communities situated in proximity to mining operations had an

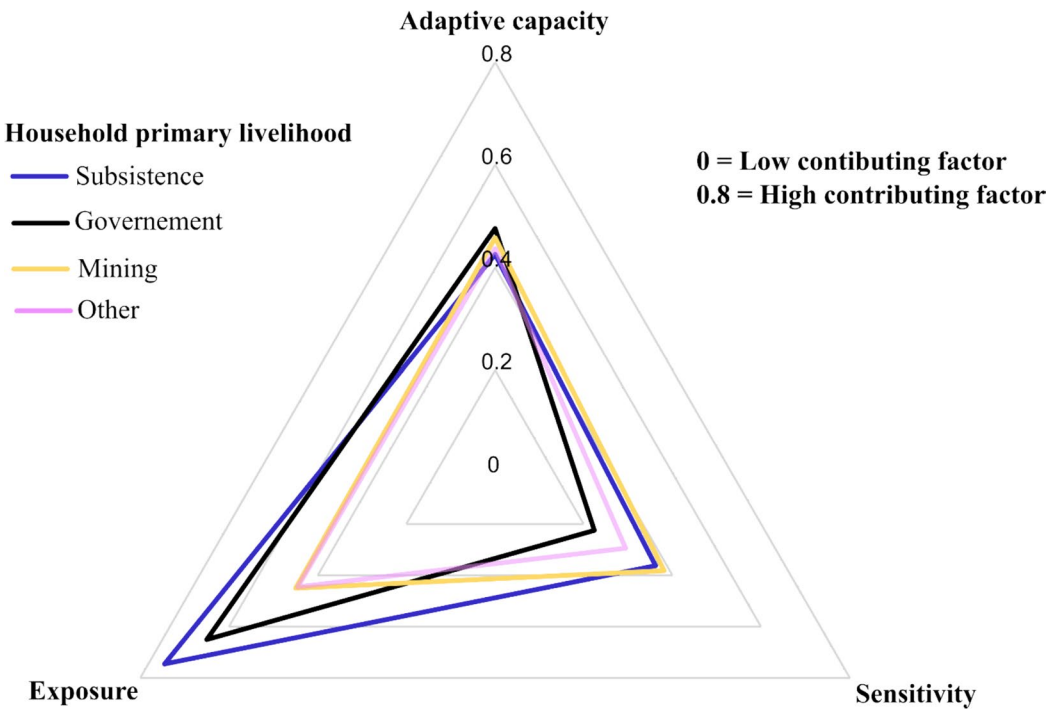

Fig. 5 Vulnerability triangle diagram of the contributing factors of the Livelihood Vulnerability Index-IPCC (LVI-IPCC) for the primary livelihood activities of 317 rural households in Guyana

elevated sensitivity to environmental shifts, primarily resulting from the depletion or degradation of natural resources.

The combination of LVI, LVI-IPCC and our novel livelihood-based analysis, as an extension of the LVI, offers comprehensive insights into the nuanced interplay of natural and socio-economic factors influencing vulnerability to environmental change at the community level. Specifically, within the scope of the LVI-IPCC results, our study not only dissects contributors to exposure, sensitivity and adaptive capacity but also provides novel insights for policy formulation. These findings hold relevance for fostering sustainable livelihoods and bolstering climate adaptation strategies not only in Guyana but across the broader northern Amazon region.

Exposure

Exposure to environmental pressures introduces stress into a system and the high overall exposure of Achawib and Aishalton communities to environmental change, both Located in the South Rupununi, could be attributed to multiple factors relating to climatic unpredictability. Households in both farming communities reported the highest incidence of bad weather and floods over the last 6 years, contributing to their high vulnerability score on the *Environmental hazards* major component of the LVI. Similar findings from the Rupununi have been reported by Saleh (2020), which point towards the unpredictability of recent rainfall patterns in the region. This environmental pressure is caused by decreasing average rainfall in the Rupununi and the unpredictability of heavy rains over recent decades, with these unpredictable weather patterns projected to continue for the next 30 years (Saleh 2020). Furthermore, climate projections for Guyana indicate a continuous rise in temperatures and increased intensity of extreme climate events (Office of Climate Change Guyana, 2015). The increased vulnerability of communities and households, which heavily rely on predictable weather patterns and growing seasons for their livelihoods (Malhi et al. 2021), is a direct consequence.

The impacts of these climatic events pose significant risks to livelihoods, particularly for households engaged in subsistence-based activities such as farming and fishing, as revealed by our livelihood-based analysis which highlights subsistence-dependant households as the most exposed to environmental changes. These impacts can be far-reaching, with long-term consequences for livelihoods and overall well-being (Seo and Mendelsohn 2007). Ongoing climatic changes are expected to further impact agricultural production in the future, with changes in climate variability and extreme weather events likely to significantly affect the prevalence of weeds, pests and crops (Thornton et al. 2014). These findings underscore the urgent need for adaptive measures and resilience-building strategies to mitigate the risks and protect the livelihoods of subsistence-based communities.

Sensitivity

The importance of healthy ecosystems and the naturally derived resources for well-being and even survival of numerous rural populations in tropical developing nations is evident (Perez et al. 1996). However, this dependency can heighten susceptibility to environmental fluctuations. For example, in the case of the Rupununi communities, their vulnerability to environmental changes is influenced by their reliance on *Natural resources*, as evidenced by the LVI and LVI-IPCC analysis. Particularly, households heavily dependent on resources from their surrounding ecosystems, such as in Achawib where 94% of households use savanna- or forest-based materials for cooking, show greater vulnerability to climate and land-use changes (Ofoegbu et al. 2017; Schueler et al. 2011). These results indicate that sensitivity, the extent to which a system is impacted by stress exposure, is influenced not only by household attributes but also by household dependencies on surrounding ecosystems. This emphasises the importance of incorporating effective natural resource management measures into community development plans.

The decline or degradation of natural resources, encompassing materials sourced from forests, savannas or rivers, is a prevailing concern. Approximately 56% of households in Achawib reported a decline in these resources, while in Karrau, 52% noted a similar decline, coupled with 77% reporting heightened water pollution over the past 5 years. This degradation is notably linked to extractive activities, particularly mining operations, which are recognised catalysts for environmental change (Martinez et al. 2018; Osumanu 2020). Gold mining, in particular, carries diverse environmental effects with negative repercussions (Sonter et al. 2018). Notably, Karrau stands out with the highest proportion of households whose primary livelihood is gold mining, and our livelihood-based analysis shows that these mining-dependent households exhibit heightened sensitivity to environmental changes. Although Achawib community is not as close in proximity to mining operations as Karrau, 61% of its households rely on natural water sources for drinking. Gold mining entails significant mercury releases into the environment, impacting water bodies far downstream, leading to health concerns, especially mercury-related damage to the central nervous system (Gibb and O'Leary 2014). In developing countries, livelihood vulnerability is intricately linked to natural resources (Armah et al. 2010; Barratt and Allison 2014). Without immediate tangible benefits to their livelihoods from conservation efforts or pollution mitigation, communities might experience heightened sensitivity to environmental pressures as these resources deteriorate.

Our data reveals sensitivity to environmental change was influenced by health infrastructure. A higher *Health* index vulnerability score on the LVI in Aishalton and Achawib indicates travel to a health facility as an important determinant of vulnerability, potentially leading to substantial health challenges (Kruk et al. 2010). It took nearly twice as long to travel to a health facility in Aishalton and Achawib, than it did in either Karrau or Aranaputa, reflecting the low number of accessible health facilities and serviceable roadways in parts of these communities. As also highlighted in Mistry et al. (2023), the lack of trained health personnel, insufficient healthcare infrastructure and the unavailability of medication in parts of the Rupununi result in only a basic level of healthcare being accessible to Indigenous peoples at the community level. Moreover, the high number of households in Karrau reporting a household member injured from work over the last year could be related to the mining operations, in which exposure to a polluted environment can lead to health concerns such as respiratory disorders, joint discomfort, malaria, skin infections and high blood pressure. Mining is a key component of sustainable development (Monteiro et al. 2019). However, it is essential to understand the issues and needs of communities in mining regions, such as Karrau, and provide measures to improve their well-being and health. Good health is essential for the stability of communities, and health issues can have severe social and economic impacts (Sivakumar et al. 2020); therefore, a community's ability to recover from health shocks depends on access to appropriate and accessible health facilities.

Adaptive capacity

In rural Guyana, households of various types reside in diverse geographic settings and possess varying income levels, educational backgrounds and degrees of livelihood diversification, including non-agricultural activities. These differences result in distinct livelihood opportunities and levels of access to climate information, which in turn influence their capacity to adapt to environmental changes (Agrawal and Perrin 2009). Our study suggests that, comparatively, households in Achawib, a primarily agriculture-based community, are less adaptive than all other communities to environmental change.

In Achawib, 37% of households reported they have poor access to job opportunities. This finding aligns with previous research (Antwi-Agyei et al. 2013) which suggests a community comprised of households depending solely on farming activities, with limited options at non-agricultural livelihood diversification, can be considered more vulnerable to environmental changes, compared to those that engage in non-agricultural livelihood activities. The availability of an alternative non-farm income can be crucial for the survival of agriculture-dependant households, and by diversifying their livelihood portfolio vulnerable households in rural communities can spread the risks associated with environmental change (Antwi-Agyei et al. 2013), as they can turn to non-agricultural livelihoods in times of environmental and climatic disasters. However, it is important to note that the Livelihood Vulnerability Index (LVI) approach used in this study did not consider the flexibility of different farming techniques, which itself can reduce vulnerability to environmental changes in Guyana. For instance, Berardi et al. (2015) demonstrated how communities ensured flexibility in food security by adopting various farming techniques. These included utilising low-lying grounds to support crops during droughts, cultivating crops on higher grounds for better productivity during floods, planting resilient and productive varieties of cassava, and cultivating a diverse range of crops to avoid dependence on a single staple. Moreover, farming and other subsistence-based livelihood activities served as a safety net for communities in Guyana during the COVID-19 pandemic. Many households relocated to their isolated farms, minimising contact with others and enabling them to endure the pandemic (Mistry et al. 2023). Such specifics should be integrated into future research on livelihood vulnerability in Guyana, as they provide a more comprehensive understanding of indicators of household resilience and dynamics in response to environmental changes.

Previous research suggests wealth plays a major role in strengthening the resilience of rural households and highlights that financial capital can play a key role in reducing the negative impacts of environmental change (Adger and Vincent 2005; Moser and Satterthwaite 2010). Indicators such as households with savings and households living under national minimum wage contributed to higher vulnerability scores on the LVI *Financial* major component for the Achawib community. Lack of financial capital constrains a household's ability to either change crops or engage in other forms of adaptation in the face of environmental change (Nelson et al. 2009; Wang et al. 2010). Additionally, socio-demographic factors such as access to education may increase a household's ability to adapt to new agricultural technologies, particularly in farming communities, which can in turn help them to better cope with negative climate pressures and have a positive impact on overall farm productivity (Muttarak and Lutz 2014). Higher literacy rates, educational opportunities and financial support can help increase adaptive capacities and communities, such as Achawib, would benefit from improved access to these resources to better prepare for and adapt to a changing climate (Muttarak & Lutz 2014).

Village Sustainability Plans

The findings of this study hold particular significance for informing the Village Sustainability Plans under the

Guyanese Government's Low Carbon Development Strategy (LCDS). With a major emphasis on empowering Indigenous communities, the government is allocating 15% of revenues to bottom-up investments aligned with community plans in these Village Sustainability Plans. For instance, understanding the nuanced vulnerabilities and capacities of different communities, as highlighted in our study, can guide targeted investments in infrastructure development, education, healthcare initiatives, entrepreneurship support and cultural preservation.

By tailoring interventions based on the specific needs and challenges identified in the research, the Village Sustainability Plans can be more effectively designed and implemented to enhance social, economic and environmental well-being in these communities**.**

For example, improvements in healthcare and internet accessibility could be incorporated into the plans for Achawib, addressing the specific issues highlighted from that community in this research. Moreover, a study conducted in the North Rupununi (Berardi et al. 2013) demonstrated that certain communities have begun adopting non-indigenous tools such as motor vehicles, computers and internet access to facilitate connectivity with the global community and improve their daily lives. This integration is particularly beneficial considering the challenges faced by some communities in accessing government communications and information during the COVID-19 pandemic (Mistry et al. 2023).

Furthermore, based on the experience gained in this study, on a practical level it appears that the Livelihood Vulnerability Index (LVI) required only minimal training for the data collection personnel involved. The skills acquired could potentially be utilised for future data collection efforts in other communities. Additionally, the LVI is adaptable and easily replicable, making it suitable for use in various local contexts. This adaptability enables the LVI to offer valuable insights into potential strengths, weaknesses, issues and areas requiring attention in the development of Village Sustainability Plans.

Study limitations

While using the LVI and LVI-IPCC to assess vulnerability is useful, it is important to recognise limitations to our approach. The selection of sub-components for the LVI involves a subjective process that necessitates careful consideration. While efforts are made to include relevant indicators, there is a risk of overlooking crucial information or introducing bias (Hahn et al. 2009; Vincent 2004). This subjectivity arises from the need to strike a balance between comprehensiveness and practicality, as well as the incorporation of new questions that may influence the overall assessment. This is important to note, as underscored by Rufat et al. (2015), who assert that the prioritisation of practical considerations such as cost, data availability and measurability over validity within the utilisation of social vulnerability indicators could potentially misdirect decision-making.

Furthermore, comparisons between our LVI and LVI-IPCC results and studies conducted in other geographic regions may be challenging due to variations in sub-components and contextual factors. For example, Hahn et al. (2009) have highlighted the significant impact of sub-component selection on the assessment result of household livelihood vulnerability to climate change and natural hazards, while Panthi et al. (2016) argue that the local environment influences the framing and design of these sub-components. Designing suitable sub-components for vulnerability indices presents a challenge. However, unlike prevailing top-down methods using external indicators, subjective approaches to gauging livelihood vulnerability focus on individual perceptions, experiences and coping abilities, and can give important insight into community-level dynamics (Quandt and Paderes 2023).

While the LVI's standardised indicators allow for robust, descriptive comparisons among communities, we recognise that alternative analytical approaches, such as propensity score or other statistical matching, can further strengthen causal inference when the research objective is to estimate the effects of a specific intervention. In this study, the aim was to assess and compare baseline vulnerability profiles across diverse Indigenous communities using the LVI, which is intended as a descriptive and comparative diagnostic tool. Systematic household sampling (48.8–51.8% coverage per community) therefore offered an appropriate balance of rigour and feasibility, in line with earlier LVI applications in Trinidad and Ghana (Shah et al. 2013). Nevertheless, recent studies employing matching techniques (Agarwal et al. 2022; Lo et al. 2024) illustrate how such methods could add valuable nuance to future, impact-focused vulnerability studies.

In Guyana, Indigenous governance bodies such as village councils, the South Rupununi District Council (SRDC) and the North Rupununi District Development Board (NRDDB) support adaptive capacity through land-use oversight, mediation of external pressures (e.g. mining) and promotion of customary norms. Non-governmental organisations (NGOs) such as the Amerindian Peoples Association (APA) and the South Rupununi Conservation Society (SRCS) further strengthen resilience through training, legal advocacy and environmental monitoring. Therefore, although our indicators capture multiple dimensions of household vulnerability, the role of local institutions, such as Indigenous governance systems, NGOs (non-governmental organisations) and communal resource management practices, was not explicitly integrated, despite their influence on how communities

respond to environmental change and manage risks (Agarwal et al. 2017; Agarwal & Lambin 2024). Future research in Guyana should incorporate institutional analysis to better capture these underexplored governance dimensions of vulnerability. Lastly, while composite indices support clarity and comparability, they may mask intra-community variation, underscoring the value of mixed methods to more fully capture place-based nuance in future research.

Conclusions

Rural Indigenous communities in Guyana, and the wider northern Amazon, face an increasing challenge in adapting to the impacts of climate and environmental change, a reality underscored by existing research (Bellfield et al. 2015; Mahdu 2019; Roopnarine 2002; Saleh 2020; Whitaker 2020) and predictive models (Adde et al. 2016; Bovolo et al. 2018; Lima et al. 2015). Such pressures can lead to widespread social, health, economic, environmental and cultural ramifications, limiting our ability to achieve and sustain the Sustainable Development Goals (Szabo et al 2016). However, policymakers often lack empirical evidence-based knowledge into the specific locations of concentrated vulnerability and the nuanced dimensions through which these populations are susceptible to change. Our data reveals that while agricultural-dependent households face heightened vulnerability due to flood risk and lack of alternative job opportunities, mining, while currently bolstering local livelihoods through employment and infrastructure (Laing & Moonsammy 2021), may hold limited sustainability due to finite resource depletion. Simultaneously, pollution from mining disrupts local food and water availability (Watson et al. 2020). These findings improve our understanding of the processes and factors that create vulnerability in rural Indigenous households, offering valuable guidance for the development of effective policies in collaboration with these communities.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10113-025-02460-3.

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Data Availability The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to ethical approval and community permissions.

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