Understanding children's exposure to landslides in Nicaragua

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ABSTRACT

This article evaluates the integration of disaster risk reduction strategies within the educational framework of Nicaragua, with a particular emphasis on children's exposure to landslides and their vulnerability to climate-induced disasters. A comprehensive multi-stage methodology combines geospatial modelling, demographic analysis, and risk assessment to systematically assess landslide susceptibility and its implications for school infrastructure and student safety. The analysis is structured into three distinct phases. The first phase focuses on developing a Landslide Susceptibility Model, utilising historical landslide data along with geophysical parameters to create a robust predictive tool. The second phase entails a geospatial overlay that juxtaposes the identified susceptibility zones with the locations of educational institutions. In the third phase, the analysis centres on the demographic characteristics of children residing in high-risk areas, offering insights into their exposure. The findings identify regions that exhibit elevated risks of landslides, thus posing significant threats to school infrastructure and educational continuity. Moreover, the study highlights the dual role of schools in disaster-prone regions, where they are frequently repurposed as emergency shelters during crises, exacerbating disruptions to education. By integrating geospatial risk assessment with demographic analysis, this research provides a framework for evaluating children's exposure to landslides and calls for incorporating disaster risk reduction strategies into the planning processes of the educational sector.

KEYWORDS

children's exposure; landslides; disaster risk reduction; Integrated Disaster Management; Education-centred approach

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1. Introduction

Landslides represent a recurring and significant geohazard in Nicaragua, particularly exacerbated by the influence of tropical cyclones that induce slope instability through intense rainfall and increased soil saturation (Devoli et al. 2007a; 2007b). The country's mountainous topography, high deforestation rates, and climate variability further amplify the susceptibility to mass movements. This phenomenon disproportionately impacts vulnerable populations, notably children and adolescents.

The consequences of landslides extend beyond immediate casualties and infrastructure destruction; they also disrupt access to education, healthcare, and essential services, exacerbating existing socio-economic inequalities (Burrows et al. 2021; Few et al. 2021). In light of the increasing frequency and magnitude of extreme weather events attributed to climate change, there is an urgent imperative to assess and mitigate the associated risks to children and the educational infrastructure in Nicaragua.

This study seeks to provide an evidence-based understanding of children's landslide exposure by integrating geospatial analysis with demographic and infrastructural data. Specifically, the research develops a landslide susceptibility model for Nicaragua and investigates the spatial distribution of schools in high-risk zones. The study quantitatively assesses the number of schools and children at heightened risk by overlaying the susceptibility map with geospatial data on educational institutions. This analysis aims to inform targeted disaster risk reduction (DRR) strategies. Furthermore, the research contributes to an education-centred, integrated DRR framework by underscoring schools' vital role in fostering risk awareness and enhancing community resilience.

Education plays a critical role in disaster preparedness and the development of resilience, particularly within young populations (Peek 2008). Schools are essential platforms for disseminating DRR knowledge, equipping children with the necessary skills to respond effectively to disasters and fostering an awareness of risk within their communities (Clauss-Ehlers et al. 2004; Mitchell et al. 2009). An education-centred approach to DRR integrates disaster preparedness into school curricula, ensuring that children, educators, and communities are better prepared to mitigate the impacts of environmental hazards (Ruiz-Cortés and Alcántara-Ayala 2020). By analysing the spatial relationship between landslide susceptibility and school locations, this study provides vital insights for policymakers, educators, and disaster management authorities, enhancing the development of risk-informed educational strategies.

The research aligns with global DRR frameworks. It advocates for prospective risk assessment and resilience-building strategies that prioritise children's safety and educational continuity in disaster-prone areas (Sassa 2019, 2020, 2021; Alcántara-Ayala and Sassa 2021). The findings establish a solid foundation for integrating geospatial risk assessment into national disaster management policies. They emphasise the critical necessity of adopting an education-centred approach to enhancing disaster resilience, focusing on the unique challenges developing countries face.

2. Literature review: a general overview

2.1 Climate change-induced displacement and climatic variability: impacts on Children

The projected intensification of climate change, particularly scenarios anticipating a rise of 4 °C or more in global temperatures, poses significant risks of population displacement (Gemenne 2011).

Climate change has caused significant global displacement, affecting about 1.7 billion people through weather-related disasters in the past decade (IFRC 2020; UNICEF 2021). The IDMC projected 30.5 million internally displaced people due to 1,825 disaster situations, with significant displacement in Latin America caused by Hurricanes Eta and Iota, which displaced over 1.6 million individuals (Zuñiga 2022).

By 2050, an estimated 200 million climate-related migrants are expected globally, with over 17 million of these from Latin America, affecting particularly vulnerable children (Brown 2008; Henríquez and García 2023). In Central America, substantial climatic variability has led to increased frequency and intensity of hurricanes, resulting in notable economic and social impacts (ECLAC 2011; Conde and Saldaña 2007).

Climate change disproportionately impacts children's health through climate-induced migration. Children are at increased risk of malnutrition, disease, and psychological harm and often experience violations of their fundamental human rights. More robust global policies are needed to address these health impacts and protect children's rights during migration (Uddin et al. 2021).

Climate change can adversely affect children's mental capacity, particularly in their early developmental years, while access to education remains a significant challenge. During the COVID-19 pandemic, over 13 million children in Latin America and the Caribbean lacked access to remote education, and those in evacuation centres faced difficulties accessing formal education (Zuñiga 2022). Although some studies highlight the long-term impacts of childhood weather disturbances on well-being (Cornwell and Inder 2015), research into children's psychological responses to disasters is still emerging (Lee and Bhang 2018). The complexities of child protection continue to pose challenges at various methodological and conceptual levels (Boyden and Mann 2005).

Nicaragua is particularly vulnerable to climate change, with children comprising 39% of its population. These children are at heightened risk from extreme weather events, which can lead to landslides and other disasters, disrupting education and displacing families. The compounded effects of poverty, environmental degradation, and social challenges further exacerbate their vulnerability (Boyden and Mann 2005). As reported by IRCI, half of the global child population lives in high-risk countries, with 400 million children exposed to increasing tropical cyclones (UNICEF 2021).

2.2 The role of education in disaster risk reduction

Education is fundamental to disaster risk reduction, especially for children in disaster-prone areas (Apronti et al. 2015). Integrating DRR principles into school curricula helps students understand natural hazards and prepares them to respond effectively. Age-appropriate lessons and activities enhance children's awareness of risks and develop their critical thinking and problem-solving skills (Tomaszewski et al. 2020).

Education is essential for reducing the impact of disasters and enhancing community resilience. Educational programs help raise awareness and promote preparedness. Integrating disaster risk reduction into school curricula and involving local communities in educational initiatives are crucial for effective disaster risk management (Petal 2009).

Community resilience is enhanced by educating children in disaster preparedness and involving them in decision-making processes related to risk management (Clauss-Ehlers et al. 2004; Mitchell et al. 2009).

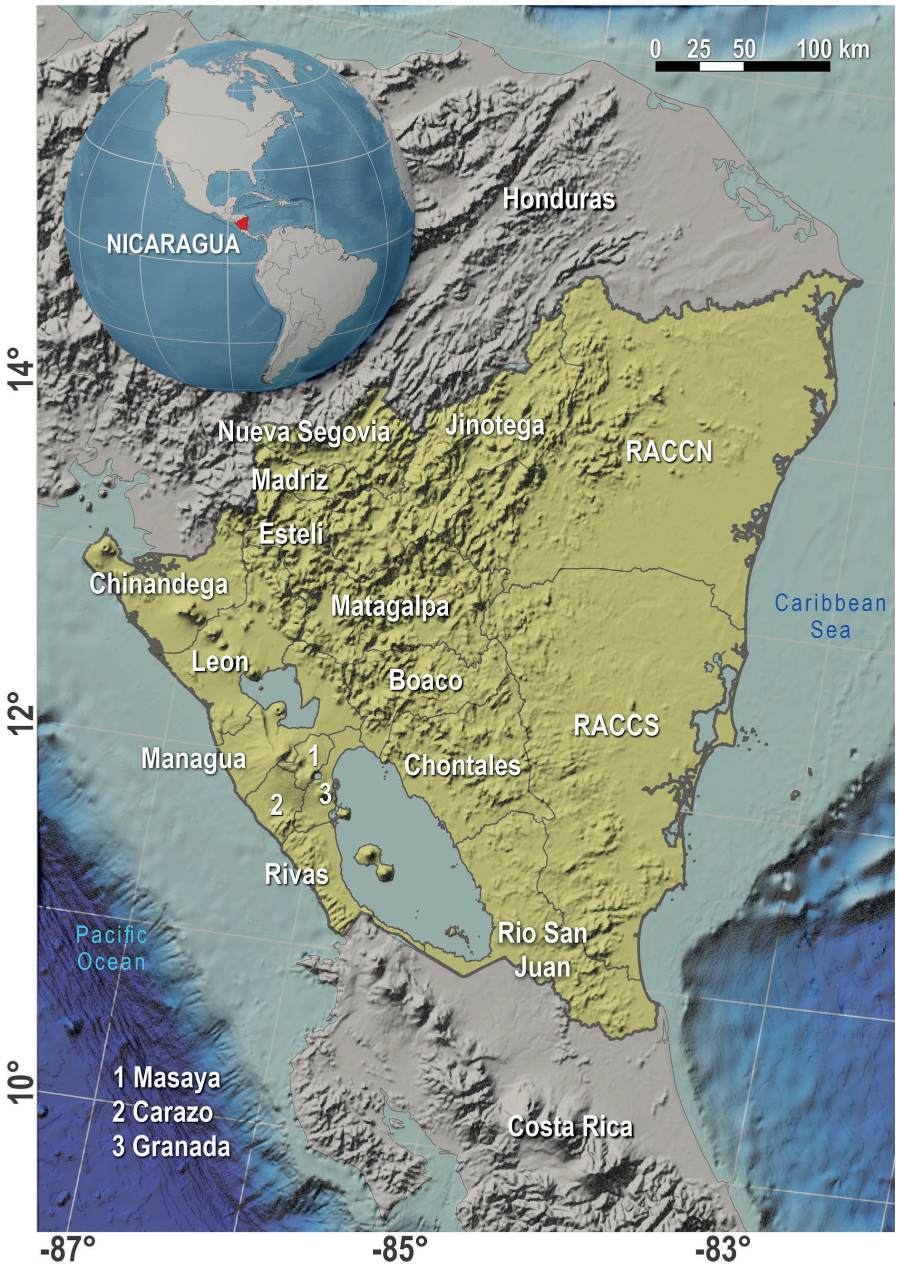

Fig. 1 Location of Nicaragua.

Involving children in DRR initiatives strengthens them and fosters a sense of agency and responsibility (Izadkhah and Hosseini 2005). When children are encouraged to participate in local decision-making processes related to risk management, they become invested stakeholders in their communities' safety and sustainability.

Education in DRR strategies helps mitigate immediate impacts on children and develops a resilient generation (Fernandez et al. 2023). This investment is essential for cultivating informed citizens capable of advocating for and implementing disaster risk reduction strategies (Mitchell et al. 2008).

3. The Nicaraguan context

Nicaragua, situated in Central America, is positioned between latitudes 10° and 15°45′ North and longitudes 79°30′ and 88° West. It shares its borders with the Republic of Honduras to the north, the Republic of Costa Rica to the south, the Caribbean Sea to the east, and the Pacific Ocean to the west (Fig. 1). The nation is politically composed of 15 departments and two autonomous regions: the North Caribbean Coast and the South Caribbean Coast. The total population of Nicaragua is approximately 6,664,364, comprising 3,288,408 men and 3,375,956 women. Of this population, 3,922,596 reside in urban areas, while 2,741,769 live in rural areas. Notably, children aged 0 to 19 comprise 39% of the total population, about 2,604,498 individuals (Fig. 2) (INIDE 2022).

In Nicaragua, most of the population is concentrated in the western region around the capital city of Managua. The coastal areas, especially along the Pacific Coast, have significant population clusters due to their economic roles in trade, tourism, and natural resource management. This uneven population distribution reflects geographic and socio-economic factors influencing urbanisation patterns in Nicaragua (World Bank n.d.).

Light manufacturing, the service sector, and agriculture primarily drive Nicaragua's economy. The country has recently benefited from increased foreign direct investment and remittances, representing 8.3% and 20.6% of its Gross Domestic Product in 2022, respectively. These external financial inflows have played a crucial role in sustaining the country's economic activity and underscore Nicaragua's growing global economic ties (World Bank n.d.).

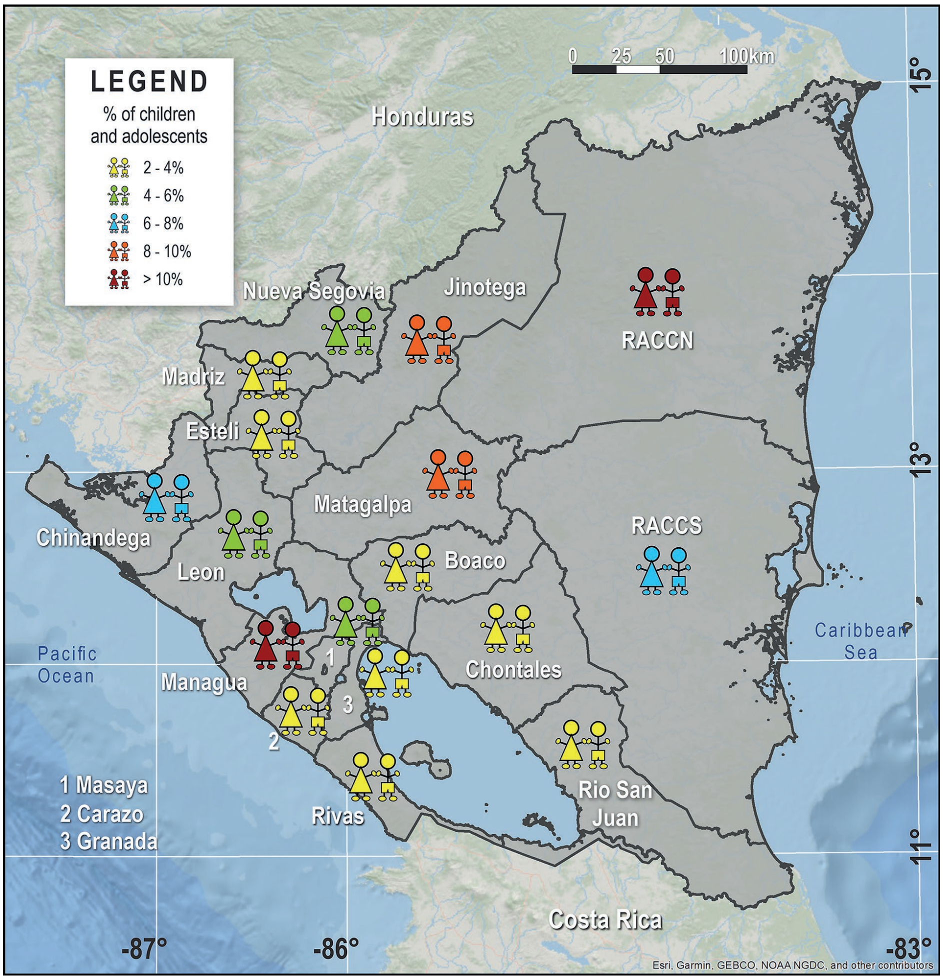

Fig. 2 Percentage of children and adolescents population in Nicaragua by department (Source elaborated with information from INIDE 2022).

Nicaragua faces significant economic challenges and remains one of the poorest nations in Central America. It is highly susceptible to external shocks and frequent disasters, which can disrupt its economic progress. Since 2005, Nicaragua has experienced growing poverty and food insecurity, exacerbated by recent crises. The economy heavily relies on remittances from Nicaraguans abroad, highlighting structural weaknesses in generating employment and income opportunities domestically. International sanctions have restricted Nicaragua's access to foreign capital and limited its ability to attract foreign direct investment, impeding economic recovery and contributing to rising social inequality and financial distress. Nicaragua's path to sustainable development remains precarious due to domestic governance issues and international economic constraints (World Bank n.d.).

Nicaragua's geology exhibits a sophisticated and multifaceted interplay of volcanic, sedimentary, and metamorphic rock formations. It reflects its strategic location within the Central American volcanic arc and the complex dynamics of tectonic plate interactions. Active and dormant volcanoes, including prominent examples such as Masaya, Mombacho, and San Cristóbal, integral to the Nicaraguan Highlands, define the landscape. These volcanic systems play a crucial role in shaping the region's geomorphology and significantly enhance soil fertility, thereby bolstering agricultural productivity across the country. Additionally, Nicaragua's geological diversity is evidenced by extensive sedimentary basins, particularly in its northern and eastern regions, characterised by limestone, sandstone, and shale formations. The Caribbean coastal region further exemplifies this geological complexity, showcasing a dynamic arrangement of limestone and sedimentary rocks that reflects a rich and varied marine environment throughout its geological history (Arengi and Hodgson 2000).

Nicaragua's geological framework can be systematically categorised into five distinct regions, each with unique characteristics. Palaeozoic metamorphic rocks primarily define the Northern Region, which testify to the ancient geological processes that have shaped the area. In contrast, the Central Region, called the Highlands, consists of Tertiary volcanic rocks indicative of more recent volcanic activity. Cretaceous-Tertiary sedimentary formations characterise the Pacific Coast Plain Region, while the Atlantic Coastal Plain Region primarily comprises Quaternary sedimentary rocks, reflecting a younger geological history. Lastly, the Nicaraguan Depression, oriented in a northwest-southeast direction, is notable for its significant deposits of Quaternary volcanic rocks, highlighting the ongoing geological evolution of the region. Collectively, these geological features illustrate the diverse and dynamic nature of Nicaragua's geological landscape, which has profound implications for its ecology, natural resources, and agricultural practices (McBirney and Williams 1965; Kuang 1971; Parsons Corporation 1972; Elming 1998).

4. Methodology

The study employs a multi-stage methodology that integrates geospatial modelling, demographic

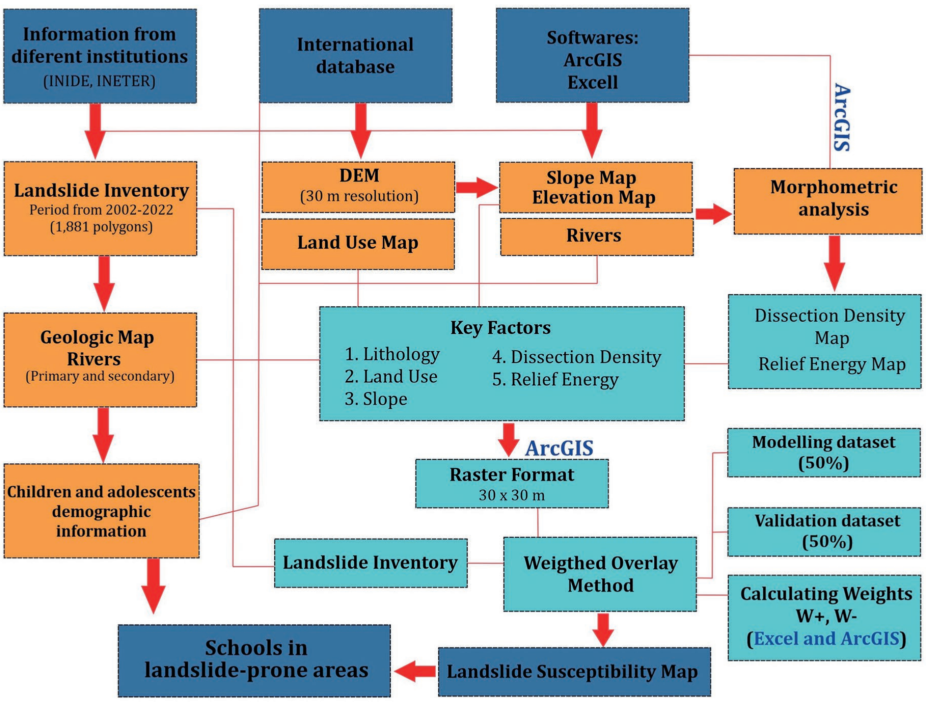

Fig. 3 The methodological framework of the study.

analysis, and risk assessment to evaluate landslide susceptibility and its implications for school exposure (Fig. 3). This approach is structured into three primary phases: (1) the development of a landslide susceptibility map utilising historical landslide data in conjunction with geophysical parameters; (2) the geospatial overlay of susceptibility zones with the locations of educational institutions; and (3) a demographic analysis of the children who are situated in high-risk areas.

4.1 Landslide inventory and data preparation

In the initial phase of the study, a comprehensive analysis of the national landslide inventory was conducted to extract geospatial data relevant to susceptibility modelling. This dataset, obtained from the Nicaraguan Institute of Territorial Studies (INETER), comprises 1,881 polygons representing documented landslide events recorded between 2002 and 2022 (Fig. 4). The inventory provides a spatially explicit representation of past landslide occurrences, serving as a fundamental input for developing and validating the susceptibility model.

The landslide susceptibility model was developed based on five key conditioning factors selected for their well-documented influence on slope instability: relief energy, slope gradient, dissection density, land use, and lithology. Relief energy was derived from a 30-metre resolution Digital Elevation Model (DEM) (Neal and Hawker 2023) and calculated using a hexagonal mesh with a 10 km^2 resolution. This parameter was categorised into six classes: less than 50 metres, 50–200 metres, 200–400 metres, 400–600 metres, 600–800 metres, and greater than 800 metres (Fig. 5A).

Another critical determinant of mass movement susceptibility, slope gradient, was extracted from the same DEM and classified into four intervals: 0–1°, 1–10°, 10–20°, and greater than 20° (Fig. 5B), following the classification scheme proposed by INETER (2003). Dissection density, which reflects terrain incision and fragmentation, was computed from the primary and secondary river networks and categorised into six distinct classes (Fig. 5C).

Land use data were sourced from the 2020 Global Land Cover and Land Use dataset (Potapov et al. 2022) and reclassified into ten categories: forest cover, cultivated land, and urban areas (Fig. 5D). Finally, lithological data were extracted from geological maps (Instituto Geográfico Nacional et al. 1974) and standardised into six major rock types (Fig. 6). These

Fig. 4 Landslide inventory (Source: adapted from data provided by INETER).

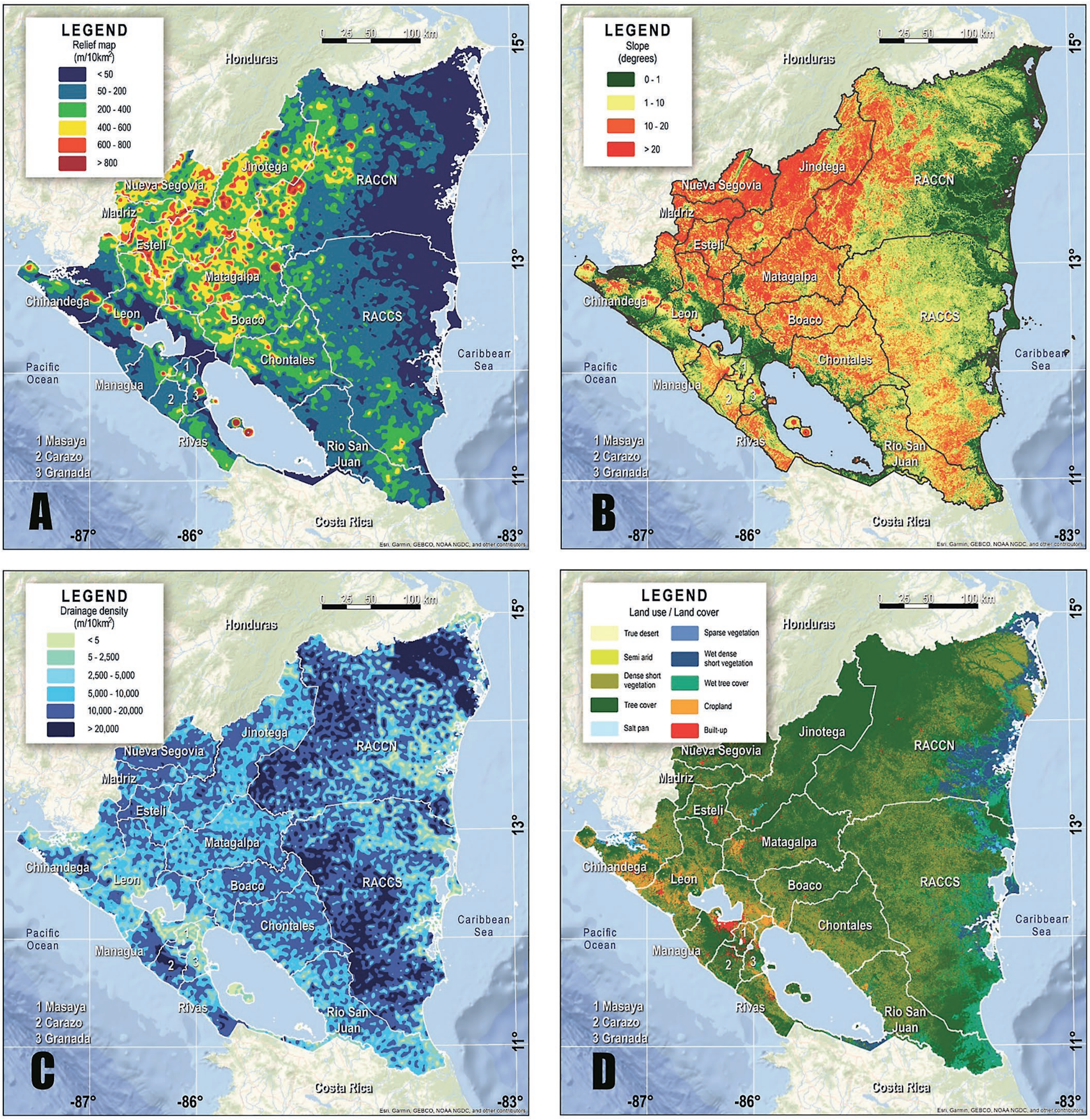

Fig. 5 A. Relief energy map, B. Slope map, C. Dissection density map, D. Land use map.

factors were subsequently rasterised and standardised to a standard spatial resolution, ensuring consistency in the geospatial analysis.

The susceptibility model was constructed using a bivariate statistical approach, specifically the Weight of Evidence (WOE) method, a probabilistic technique based on Bayesian probability theory (Bonham-Carter 1989; 1994). This methodology quantifies the statistical relationship between historical landslides and the selected conditioning factors by computing weight contrast values that indicate the degree of association between each factor and landslide occurrence. The fundamental premise of this approach is that future landslides will occur under conditions similar to those that triggered past events, assuming that the spatial distribution of conditioning factors remains stable over time (Regmi et al. 2010; Oh and Lee 2011; Sujatha et al. 2014).

Implementing the WOE model involved assigning positive (W^+) and negative (W^-) weights to each factor based on its relative influence on landslide occurrence. The weight contrast values were computed and integrated into a weighted overlay analysis using ArcGIS 10.8. Four susceptibility models were generated to assess model robustness, each incorporating different weight contrast values. These models were cross-compared to ensure that variations in factor weighting did not significantly alter the results. The

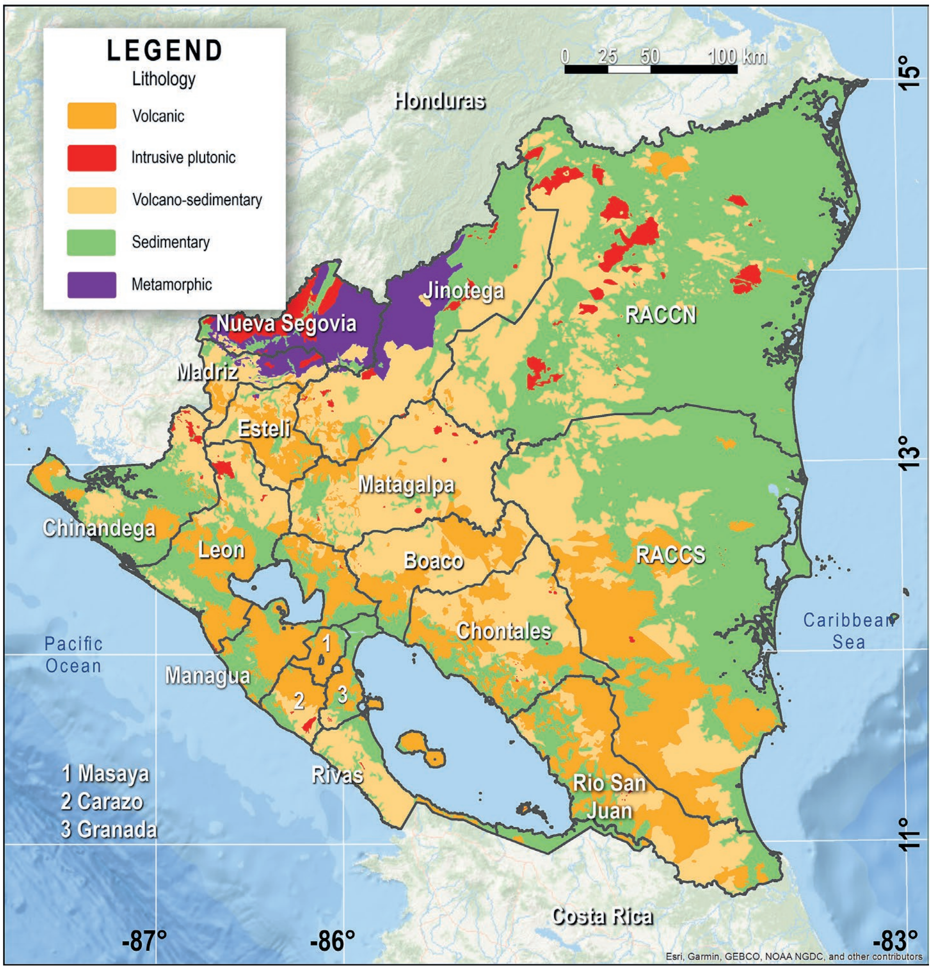

Fig. 6 Lithological map (Source: adapted from Instituto Geográfico Nacional et al. 1974).

final model was selected based on its predictive reliability and stability.

4.1.1 Training and validation of the model

To ensure an objective evaluation of the model's performance, the landslide inventory was randomly partitioned into two equal subsets:

a) The training dataset (940 landslides) was used to establish the statistical relationships between landslide occurrences and conditioning factors.
b) The Validation dataset (941 landslides) was used for independent model testing, ensuring an unbiased assessment of predictive performance.

The independent validation dataset was subsequently overlaid with the predicted susceptibility zones, and model accuracy was evaluated by assessing the proportion of observed landslides that fell within the highest susceptibility zones. The validation results indicated that:

a) 96% of known landslides were located within areas classified as very high susceptibility,
b) 3% were situated in high susceptibility zones,
c) 1% fell within moderate susceptibility zones.

These findings demonstrate the model's high predictive capability and confirm its effectiveness in delineating areas prone to landslides.

The final landslide susceptibility map was produced by integrating the weighted contrast values of all conditioning factors. This map delineates high-risk zones, providing a critical tool for DRR and land-use planning (Fig. 7). The methodological approach applied in this study has been extensively validated in previous research and has been employed in various landslide susceptibility assessments (Lee et al. 2002; Dahal et al. 2008; Lee and Choi 2004; Regmi et al. 2010; Pradhan et al. 2010; Armas 2012; Galindo and Alcántara-Ayala 2014; Sujatha et al. 2014; Getachew and Meten 2021; Bhandari et al. 2024).

Given the high quality of the input data, the robustness of the statistical methodology, and the GIS-based processing workflow, this study's results are considered satisfactory. The final susceptibility map serves as a valuable resource for policy-making and targeted intervention strategies, enabling authorities to prioritise risk mitigation measures in vulnerable regions.

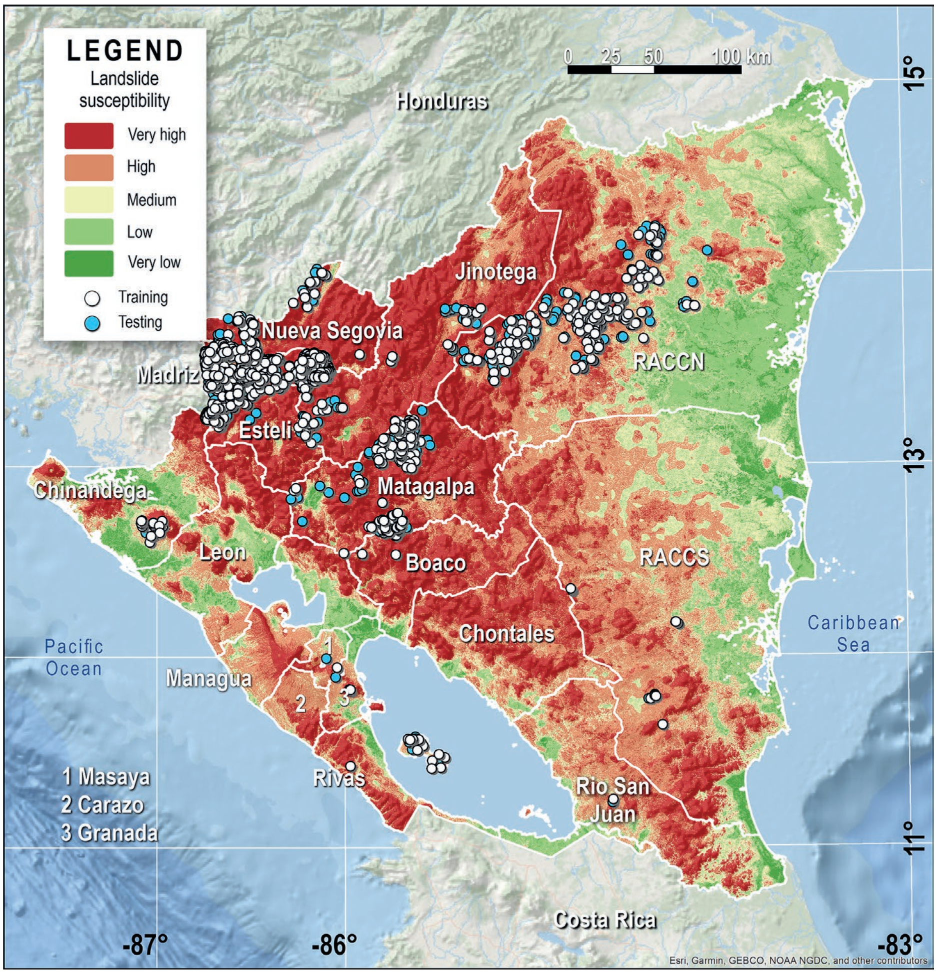

Fig. 7 Landslide susceptibility map.

4.2 Geospatial overlay of susceptibility zones with the locations of educational institutions

In the second phase, the geospatial distribution of schools was analysed to assess exposure within landslide-prone areas. The school database, obtained from INETER (2003), was classified by educational level: Initial Education, Primary Education, and Secondary Education. School locations were verified using Google Maps and Google Earth to ensure spatial accuracy. The susceptibility map was overlaid with school locations, enabling the identification of educational institutions situated within high-risk areas.

4.3 Demographic analysis of children in high-risk areas

The third phase involved demographic analysis to estimate the number of children exposed to landslides. Population data were sourced from national censuses (1971; 2005) and the 2021 statistical yearbook, supplemented by online databases, including Population Density Explorer (https://population-explorer.org) and The Humanitarian Data Exchange (HDX) (https://data.humdata.org). By integrating geospatial school data with demographic datasets, the study quantified the population aged 0–19 residing within landslide-prone areas, providing a comprehensive assessment of children's exposure. Additionally, a literature review of disaster impacts on children, including major hurricanes such as Joan (1988), Mitch (1998), Félix (2007), Eta and Iota (2020), informed the contextual analysis of vulnerabilities (Velásquez and Alcántara-Ayala 2024).

By synthesising geospatial risk assessment with demographic and infrastructural analysis, this methodology provides a robust framework for understanding children's exposure to landslides in Nicaragua. The findings contribute to an evidence-based approach for integrating DRR strategies within the education system, reinforcing the need for proactive risk mitigation measures to enhance community resilience.

5. Results

After creating a landslide susceptibility map, the research analysed demographic data related to children and educational institutions to identify the spatial distribution of schools within landslide-prone regions in Nicaragua. This analysis aimed to understand the interplay between natural hazards and social determinants, emphasising the need for targeted interventions to support the resilience of young populations.

5.1 Landslide susceptibility map

The factors considered in this research to create the landslide susceptibility map (Fig. 7) were classified into five classes within a GIS, to which weighted values (W^+ and W^-) were assigned. The difference between these two variables was then calculated to evaluate the individual contributions of each factor class to the spatial occurrence of landslides (Tab. 1).

Tab. 1 Classes and weights of conditioning factors.

Conditioning Factors	Classes	$W^+ - W^-$
Lithology	1. Volcanic rocks	−0.4394
	2. Water bodies	−13.6268
	3. Intrusive/plutonic rocks	1.2073
	4. Volcanic-sedimentary rocks	1.2926
	5. Sedimentary rocks	−2.3756
	6. Metamorphic rocks	1.2355
Land Use	1. True desert	−10.8570
	2. Semi-arid	−13.2025
	3. Dense, short vegetation	−0.4733
	4. Tree cover	1.1056
	5. Salt pan	−10.6492
	6. Sparse vegetation	−1.0967
	7. Wet, dense short vegetation	−1.8851
	8. Wet tree cover	−18.2950
	9. Cropland	−16.7154
	10. Built-up	0.6673
Relief Energy	1. <50 m	−19.6126
	2. 50–200	−2.6745
	3. 200–400	0.2448
	4. 400–600	1.6883
	5. 600–800	2.4125
	6. >800 m	2.4533
Slope	1. 0–1°	−19.5116
	2. 1–10°	−1.4473
	3. 10–20°	1.0194
	4. >20°	2.0579
Drainage Density	1. <5 m	−1.6354
	2. 5–2500	−1.9599
	3. 2500–5000	−0.4626
	4. 5000–10000	0.3519
	5. 10000–20000	0.3264
	6. >20000	−0.5201

The slope and relief energy factors significantly contributed to landslide formation. Among the four slope classes, the slope class more significant than 20° exhibits the highest positive weighting, indicating a strong correlation with landslide occurrence. Similarly, in the relief energy factor, the highest positive weightings are observed in classes 5 and 6 (600–800 m and >800 m), where a notable relationship between relief energy and the slope is evident.

Regarding lithology, volcanic-sedimentary rocks (tuff, basalt, ignimbrites), plutonic volcanic rocks (granite), and metamorphic rocks (schists) demonstrate a higher correlation with landslide frequency. Higher weathering and erosion rates make These lithological units more susceptible to landslides. This is further supported by the drainage density data, where classes 4 and 5 show positive weightings for landslides, underscoring the connection between lithology and erosional processes.

Regarding land use, the forest cover class (tree cover) presents a positive weighting. Overall, slope and lithology are the most critical variables influencing landslide frequency in Nicaragua, highlighting their dominant role in landslide susceptibility across the region.

The landslide susceptibility map was generated using the weighted overlay method, which assigns weight values to various factors. The resulting range of weighted values was classified into five susceptibility zones: Very Low, Low, Medium, High, and Very High (Fig. 7). The map reveals that 19% of the territory exhibits Very Low susceptibility, 14% Low, 4% Medium, 30% High, and 33% Very High susceptibility.

The map indicates that landslides are primarily influenced by two key conditioning factors: slope (>20°) and lithology (volcanic and metamorphic rocks). The areas with Very High to High susceptibility are predominantly located in the North-Central region of the country, particularly in the departments of Madriz (notably in the municipalities of Somoto, San Lucas, San Juan del Río Coco, San José de Cusmapa, Telpaneca, and Totogalpa), the North Caribbean Coast Autonomous Region (RACCN) (with a focus on the municipality of Siuna), Matagalpa (in the municipality of El Tuma-La Dalia), and Nueva Segovia (in the municipality of Jalapa).

The susceptibility map is deemed satisfactory based on the quality of the data collected, the method applied, and the GIS processes employed. This outcome is valuable for planning purposes and broad-scale assessments related to integrated risk management.

The model was validated by comparing 50% of the landslide inventory data used for testing. The results demonstrate that the method effectively predicts known and previously unreported landslides. The model's prediction accuracy indicates that 96%

of known landslides occur in high-susceptibility zones, 3% in Medium-susceptibility zones, and 1% in low-susceptibility zones.

Given the limited availability of data on factors such as precipitation, seismic activity, and soil plasticity index in Nicaragua, this analysis's findings are considered satisfactory for a regional-scale study encompassing 130,373 km^2.

5.2 Children and disaster risk: a demographic perspective from Nicaragua

Countries with poor communities are at the most risk of suffering the effects of climate change. These communities are more vulnerable and struggle to adapt to extreme weather events. Children under 14 are 44% more likely to die due to environmental factors in lower-income countries (Bartlett 2009; Ahsanuzzaman and Muhammad 2020).

Like the rest of the countries in the region, Nicaragua has multiethnic, pluricultural, and multilingual particularities. According to INIDE (2022), a population of 6.7 million people is estimated, of which 50.6% are women and 49.4% are men. The urban population is divided into 59%, and the rural population is divided into 41%. The population pyramid base comprises infants and adolescents aged 5–14 (Fig. 8) (INIDE 2022).

According to the Children's Climate Risk Index (IRCI), Nicaragua occupies position No. 94 (low-medium severity), where climate and environmental disturbances are 4.6, child vulnerability is 4.5, and climate and environmental risk of childhood at 4.6 (UNICEF 2021). Also, it is classified among the 5 Latin American countries as highly vulnerable to climate change's effects and lacking the capacity to adapt (Henríquez and García 2023). The Autonomous Region of the North Atlantic has the lowest social indicators in Nicaragua, which is reflected in the quality of the educational infrastructure and the possibilities of access to this service for the school population and its quality (CEPAL, UNDP 2008).

As specified by Bartlett (2009), the most vulnerable population is children under four years of age, which represent 10% of the country's population, because children are in a phase of rapid development and are less prepared to cope with stress because their nervous system is more immature, which has long-term repercussions compared to adults. In Nicaragua, the population under 19 years of age represents around 39.6% of the inhabitants (divided into 20.9% of the urban population and 18.7% of the rural population), exposed and vulnerable to climate change.

The departments with the highest population index in infants and adolescents are Managua with 5,247.76 (7.9%), followed by the Autonomous Region of the Northern Caribbean Coast (RACCN), with 268,261 (4%), then the department of Matagalpa 255,164 (3.8%), the department of Jinotega with 233,963 (3.5%) and finally the department of Chinandega

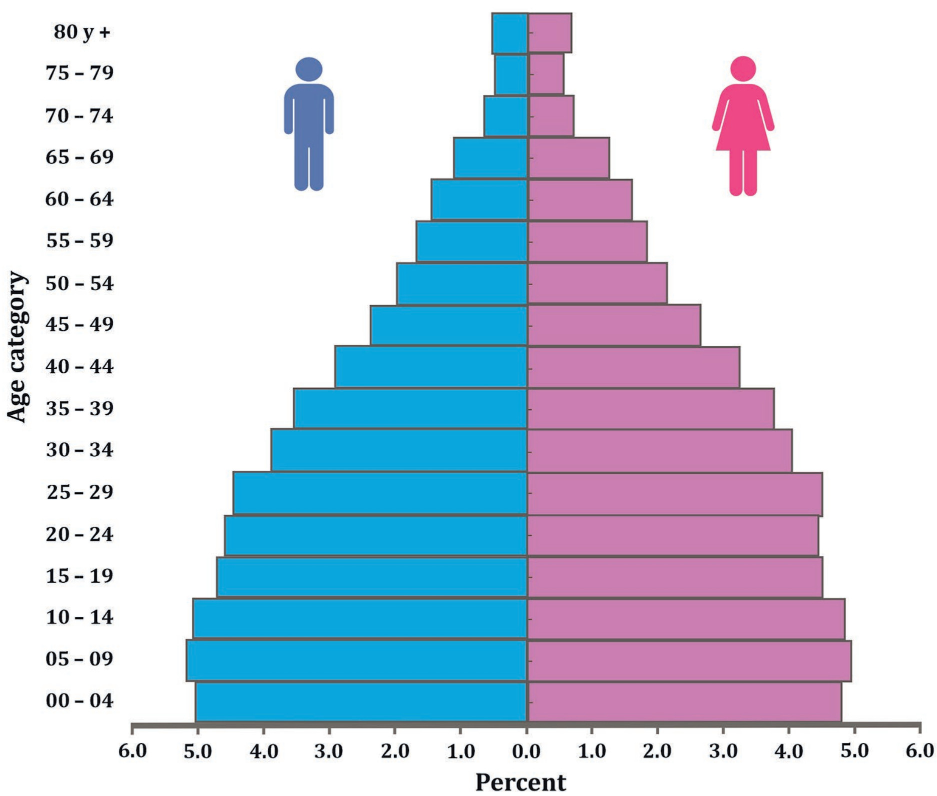

Fig. 8 Estimation and projection of the population of Nicaragua (Source: National Institute of Development Information, INIDE 2022).

with a population of 166,597 (6.4%) of the country's total population (INIDE 2022). These departments were affected by the trajectories of tropical cyclones throughout history, among which the following stand out: Hurricane Joan in 1988, Hurricane Mitch in 1998, which did not impact the Nicaraguan territory directly but caused significant damages, Hurricane Félix in 2007 and finally and in recent years Hurricane Eta and Iota 2020.

5.3 Rainfall-induced landslide disasters: the exposure of children

The education system in Nicaragua comprises 10,185 educational centres distributed throughout the 15 departments and two autonomous regions of the Caribbean Coast (Tab. 2). This system is organised into several levels, including initial education, inclusive special education, primary education, secondary education, and education for youth and adults. Initial education serves as the first level of both basic and secondary education, catering to children aged 3 to 5 years through three modalities: formal, community, and multilevel education. Primary education is designed for children aged 6 to 11, forming part of the basic and secondary education subsystem. Regular secondary education addresses the educational needs of adolescents and young adults between the ages of 12 and 16, taking into consideration their physical, psychosocial, and cognitive development (MINED n.d. [a]).

Tab. 2 Number of educational centres in Nicaragua categorised by department (MINED n.d. [b]: https://serviciosenlinea.mined.gob.ni/mapa-de-la-educacion/Index.aspx).

Department	Number of Educational Centres	%
Chinandega	515	5.1
León	556	5.5
Managua	975	9.6
Carazo	222	2.2
Masaya	235	2.3
Granada	170	1.7
Rivas	236	2.3
Estelí	359	3.5
Madriz	316	3.1
Nueva Segovia	501	4.9
Jinotega	903	8.9
Matagalpa	1098	10.8
Boaco	441	4.3
Chontales	405	4.0
Rio San Juan	467	4.6
RACCN	1251	12.3
RACCS	1535	15.1
Total	10185	100.0

The departments classified as having a very high to high susceptibility to landslides include Madriz, Matagalpa, Nueva Segovia, and the Autonomous Region of the North Caribbean Coast (RACCN). The coverage of educational centres in these regions is notably

limited, with Madriz at 3.1%, Matagalpa at 10.8%, Nueva Segovia at 4.9%, and the RACCN at 12.3%. These educational establishments often experience partial or total disruption due to climatic, socio-natural, and natural hazards. Furthermore, they frequently serve as emergency shelters during disasters, which interrupts educational activities and adversely affects the comprehensive training of students across various educational levels.

Landslides induced by hurricanes and intense rainfall present a significant risk to communities in Nicaragua, particularly with respect to educational infrastructure and the safety of children. The susceptibility of the country's mountainous regions to mass movements is exacerbated by heavy precipitation associated with tropical storms, which often leads to slope instability. The resulting landslides can inflict considerable damage on schools, disrupt educational activities, and pose substantial risks to the well-being of children. During these events, educational institutions frequently serve as emergency shelters, thereby further compromising the continuity of education. Moreover, children in rural and vulnerable urban areas are especially exposed to these hazards, increasing their vulnerability to the immediate and long-term effects of such disasters. Given the high concentration of children living in landslide-prone areas, there is an urgent need for targeted interventions aimed at safeguarding educational infrastructure, ensuring the protection of students, and incorporating disaster resilience strategies into school planning and policy frameworks.

Hurricane Joan, a category 4 Saffir Simpson scale, impacted Nicaraguan territory in October 1988 (Velásquez and Alcántara-Ayala 2023). The hurricane affected the educational infrastructure, damaging 705 classrooms in urban (43%) and rural areas (57%), and the authorities decided to shorten the duration of the school year. Academic activities were interrupted entirely in the Autonomous Region of the Atlantic because some education centres were used as temporary shelters for the evacuated and affected population (ECLAC 1988). The departments directly affected by the path of Hurricane Joan (due to winds with speeds that varied between 232 km/h – 83 km/h) were the Autonomous Region of the Southern Caribbean Coast (RACCS) (Divided in 1971 as Rio San Juan and Zelaya), Chontales, Boaco, Managua, León, Masaya and Granada (Velásquez and Alcántara-Ayala 2024).

According to the 1971 Census, the territory's population was 1,877,952 inhabitants (921,543 men and 956,409 women). Hurricane Joan directly affected 60% of the population, and the total number of children and adolescents (0–19 years) affected by the direct path of Hurricane Joan was 656,800 (equivalent to 59%) (Tab. 3).

Hurricane Mitch in October 1998 affected the Central American region, and the most significant damage was reported in Honduras and Nicaragua (EIRD and OPS 2000). Although Hurricane Mitch did not directly impact Nicaraguan territory, it caused substantial damage in the country (Velásquez and Alcántara-Ayala 2023). The most affected areas of the country were the departments of Managua, León, Chinandega, Jinotega, Estelí, Nueva Segovia, Madriz and the Autonomous Region of the North Atlantic, Masaya and Granada (ERN Latin America Consortium n.d.; ECLAC 1999).

Tab. 3 Total population between 0 and 19 years that was affected by Hurricane Joan (Source: Executive Office of Surveys and Censuses 1975).

Age range	Total	Urban	Rural
Boaco Department			
00–04	12,260	2,508	9,752
05–09	12,285	2,637	9,648
10–14	10,167	2,451	7,716
15–19	7,169	1,725	5,444
Chontales Department			
00–04	12,895	3,376	9,519
05–09	12,246	3,425	8,821
10–14	10,159	3,082	7,077
15–19	7,221	2,222	4,999
Granada Department			
00–04	11,619	7,064	4,555
05–09	11,810	7,422	4,388
10–14	10,396	6,862	3,533
15–19	7,765	5,328	2,437
Masaya Department			
00–04	15,531	8,114	7,417
05–09	15,370	8,171	7,199
10–14	13,339	7,598	5,741
15–19	9,860	5,806	4,054
Managua Department			
00–04	76,350	61,884	14,466
05–09	76,019	61,396	14,623
10–14	67,069	54,760	12,309
15–19	57,084	47,421	9,663
León Department			
00–04	28,175	12,625	15,550
05–09	28,384	12,779	15,605
10–14	24,477	11,792	12,685
15–19	18,379	9,497	8,882
Rio San Juan Department (RACCS)			
00–04	3,888	795	3,093
05–09	3,695	806	2,889
10–14	2,830	657	2,173
15–19	2,088	610	1,478
Zelaya Department (RACCS)			
00–04	27,235	5,245	21,990
05–09	25,819	5,595	20,224
10–14	20,328	4,946	15,382
15–19	14,888	3,811	11,077

The consequences of Hurricane Mitch stand as one of the most devastating disasters in the region's history. The hurricane's relentless winds and torrential rains precipitated catastrophic flooding and widespread landslides, resulting in an estimated 11,000 fatalities and the displacement of hundreds of thousands of individuals (Cupples 2007). Nicaragua's infrastructure suffered approximately 90% damage, impacting the agricultural sector and leading to economic instability. Around 165,000 people fell below the poverty line, with vulnerable populations experiencing an 18% reduction in assets. Agricultural output declined by 19%, and 20% of healthcare and educational facilities were affected (World Bank 2008). The scale of the disaster revealed deep vulnerabilities in Nicaraguan society's social and economic fabric.

In a widespread disaster, around 2,500 people died due to a mudflow triggered by heavy precipitation from a hurricane. The mudflow occurred on the slopes of Casita Volcano in northwestern Nicaragua, devastating the towns of El Porvenir and Rolando Rodriguez, along with smaller settlements in the low-lying regions. The destructive flow, consisting of water, volcanic debris, and sediment, covered an area of about 12 km^2, leaving it devoid of human life and vegetation (Fig. 9) (Ferraro et al. 1999; Kerle and De Vries 2001).

It was estimated that 52% of the affected population were children with physical damage, orphans, and severe psychological traumas. The interruption

Fig. 9 Casita volcano disaster in western Nicaragua after a mudslide triggered by Hurricane Mitch in October 1998 (Source: United States Geological Survey-Public domain).

Fig. 10 Disaster relief efforts in areas affected by Hurricane Felix in Puerto Cabezas, Nicaragua (Source: U.S. Navy photo by Mass Communication Specialist 2nd Class Todd Frantom-Public domain).

of school activities in several departments had consequences for students' education. It was estimated that 216 schools were destroyed and 296 were partially damaged, with a total of 14.65 million in damages to infrastructure (ECLAC 1999). The estimated losses and damages to educational infrastructure amount to US$21.30 million, while the projected costs for reconstruction are estimated at US$43.3 million (ERN Latin America Consortium n.d.).

Another hurricane that affected the Nicaraguan territory and its population was Hurricane Felix, a category four on the Saffir-Simpson scale. This hurricane impacted the Autonomous Region of the Northern Caribbean Coast (RACCN) with a 259 km/h wind speed in September 2007 (Velásquez and Alcántara-Ayala 2024). The passage of Hurricane Félix completely damaged 58 school buildings and left 57 partially damaged in most of the municipalities of the RACCN (Fig. 10). In addition, most of the damaged infrastructure was primary schools, and classes had to be suspended for two or three weeks. The affected student population was 26,614 people. The damage caused by the disaster in the educational sector reached an amount of 62.3 million cordoba (CEPAL and UNDP 2008). The total population of the country was approximately 5,142,098 inhabitants, where the population directly affected by the path of the hurricane was 314,130 inhabitants of the Autonomous Region of the North Caribbean Coast, of which 185,396 are children and adolescents (0–19 years old) (INEC 2006) (Tab. 4). Hurricane Félix resulted in extensive landslides across the region due to significant rainfall. The departments that experienced the most severe impact included Jinotega, Estelí, Madriz, Nueva Segovia, and the Autonomous Region of the North Caribbean Coast (Consorcio ERN América Latina n.d.).

Tab. 4 RACCN population between 0 and 19 years old affected by Hurricane Felix (Source: National Institute of Statistics and Census, INEC 2006).

Age range	Total	Urban	Rural
Autonomous Region of the North Caribbean Coast (RACCN)			
00–04	51,525	11,473	40,052
05–09	51,214	11,985	39,229
10–14	46,922	12,670	34,252
15–19	35,735	11,311	24,424

Furthermore, Hurricane Félix affected the three main activities that supported the livelihoods of the RACCN population: subsistence agriculture, fishing, and activities related to the use and exploitation of forests (ECLAC 2008).

Other meteorological phenomena that impacted the Nicaraguan territory in November 2020 were hurricanes Eta and Iota, both category four on the Saffir-Simpson scale. In both events, the Ministry of Education (MINED) reported in the municipality of Bilwi and Prinzapolka that 76 schools (63 public schools, 10 subsidised and three private schools) were partially affected; the damage occurred to perimeter walls and the destruction of classrooms. The number of children affected was 7,151 (CODIRECCIÓN – SINAPRED 2020).

The departments directly affected by the path of Hurricane Eta and Iota were the Autonomous Region of the Northern Caribbean Coast (RACCN), Jinotega, Nueva Segovia and Madriz, with winds between 222 km/h – 60 km/h in the case of Hurricane Eta and

Tab. 5 RACCN population between 0 and 19 years old affected by Hurricanes Eta and Iota (Source: INIDE 2022).

Age range	Total	Urban	Rural
Autonomous Region of the Northern Caribbean Coast (RACCN)			
00–04	78,054	20,223	57,831
05–09	70,748	21,257	49,491
10–14	61,744	21,163	40,581
15–19	60,496	21,866	38,630
Madriz Department			
00–04	17,912	5,124	12,788
05–09	18,212	5,522	12,690
10–14	17,848	5,689	12,159
15–19	17,721	5,846	11,875
Jinotega Department			
00–04	64,044	11,349	52,695
05–09	60,372	12,473	47,899
10–14	56,074	13,294	42,780
15–19	54,844	13,687	41,157
Nueva Segovia Department			
00–04	29,448	11,958	17,490
05–09	29,657	12,868	16,789
10–14	29,303	13,474	15,829
15–19	29,229	13,828	15,401

winds between 232 km/h – 74km/h for Hurricane Iota (Velásquez and Alcántara-Ayala 2024).

According to the directly affected departments, the population was 1,476,804 (22% of the country's total). In addition, the total affected population among children and adolescents (age range between 0 and 19 years) was 695,706, equivalent to 26.7% (INIDE 2022) (Tab. 5).

Climatic conditions have been evolving and will continue to do so through changes in temperature and precipitation patterns. Therefore, it is vitally important to understand the impact of these changes on the most vulnerable populations, such as children and poor households. These problems will become more acute as these populations and communities experience continuous changes in climate patterns (Cornwell and Inder 2015).

According to Boyden and Mann (2005), children's vulnerability and psychological resilience depend on factors such as internal strength, health, home dynamics, levels of social support, and how they perceive and interpret experiences. However, the effects of climate change on health will increase inequalities in child health (Helldén et al. 2021).

Added to this, the agricultural populations that are more vulnerable (rural population) in the face of meteorological hazards and households are exposed to having less access to health, food, employment, and education, among others. The absence of effective mechanisms to face decisions in response to disasters puts families in a position to make provisions on what expenses should be reduced, where such decisions can significantly affect children after reallocating resources when assets and income fall drastically (Baez and Santos 2007).

Disasters go beyond normality and the human experience because they cause disturbances and disorders at the personal and family levels and in the community (Boyden and Mann 2005). To improve the aspects of adaptation-preparation-protection-repair and reconstruction at different levels (community, local and regional government), some primary considerations must be considered for an effective response to children and adolescents based on knowledge of the lives and experiences of children, family and community. These measures and actions must be integrated into the planning and decision-making processes at various levels of governance.

In general, countries with impoverished communities around the world face the most significant risk of experiencing the potential impacts of climate change. This does not necessarily imply that climate change will be more extreme in these countries or communities; however, it does suggest that people and the areas they inhabit are more vulnerable, with limited capacity to adapt and prepare for extreme weather events. Among the most vulnerable populations are children, particularly the youngest ones. Children under 14 years of age are 44% more likely to die due to environmental factors compared to the general population. In lower-income countries, the loss of life during phenomena such as floods, hurricane winds, and landslides is disproportionately high among children, women, and older people (Bartlett 2009; Ahsanuzzaman and Muhammad 2020).

5.4 Early findings on landslide risk and the spatial distribution of schools in Nicaragua

The departments categorised within the high susceptibility range for landslides, namely Madriz, Matagalpa, Nueva Segovia, and the Autonomous Region of the North Caribbean Coast (RACCN), are characterised by significant vulnerability to these hazards. The primary economic activities in these regions are predominantly agricultural and tourism-based, reflecting the local populations' reliance on natural resources for their livelihoods. In the case of the RACCN, subsistence fishing and hunting also play crucial roles in the local economy, underscoring the region's dependence on environmental conditions. Notably, the RACCN has the highest population density of children and adolescents, followed closely by Matagalpa.

These demographic trends raise essential concerns, as the socio-economic characteristics of these departments adversely impact household income and restrict access to quality education, particularly in rural areas. Consequently, vulnerable populations, especially children and adolescents, face significant risks to their health, educational attainment, and overall well-being. This scenario presents formidable challenges in addressing the intertwined issues of poverty, education, and vulnerability to environmental hazards, necessitating urgent interventions to improve the living conditions and prospects for future generations.

The educational infrastructure within these departments includes initial, primary, and secondary education, which is critical for fostering human capital development. Of the total schools included in this study, 14.5% are located in these high-risk departments, with specific distributions as follows: preschool institutions account for 1%, primary schools comprise 6.4%, secondary schools represent 2.5%, and comprehensive educational institutions make up 4.6%. However, these educational facilities frequently experience partial or complete disruption due to climate-related events and socio-natural hazards, such as landslides and flooding. Such disruptions hinder students' academic progress and pose significant barriers to holistic development.

Moreover, many schools are repurposed as emergency shelters during disasters, interrupting regular educational activities and adversely affecting students' psychological and social well-being. This dual function of educational institutions as shelters highlights the urgent need for resilience-building measures that protect educational continuity and community safety in the face of climate change and hazards.

6. Discussion

The analysis of landslide susceptibility and the spatial distribution of schools in Nicaragua reveals critical insights with profound policy implications (Ahsanuzzaman and Muhammad 2020). This study underscores the urgent need for an integrated disaster risk management approach incorporating child-centric strategies, strengthening institutional frameworks, and enhancing educational initiatives. The results highlight that disaster impacts are disproportionately borne by children, particularly in high-risk areas where educational infrastructure is vulnerable to climate-related hazards (Baez and Santos 2007). Consequently, policy interventions must prioritise school safety, community resilience, and proactive engagement with DRR principles.

A comprehensive disaster risk management strategy necessitates coordinating efforts among governmental agencies, local authorities, international organisations, and community stakeholders (Alcántara-Ayala et al. 2020). Given the crucial role of children as agents of change, embedding DRR principles within the education system is fundamental to fostering long-term resilience. Moreover, regulatory frameworks must incorporate child-specific vulnerabilities in risk assessments and disaster response planning. The following policy recommendations address these challenges and ensure a structured, evidence-based approach to disaster resilience.

6.1 Policy implications and recommendations

6.1.1 Advocating for integrated disaster management

To strengthen disaster risk management in Nicaragua, a systematic, integrated approach must be established, prioritising child safety in all disaster planning and response aspects. The following measures are recommended:

- **Develop a National Disaster Risk Management Policy:** Establish a comprehensive regulatory framework delineating roles, responsibilities, and coordination mechanisms among governmental and non-governmental actors (UNISDR 2015).
- **Strengthen Institutional Capacity:** Enhance government personnel's expertise in disaster risk assessment, emergency response, and recovery through structured training programmes.
- **Implement Early Warning Systems:** Develop and maintain reliable early warning systems tailored to local risk profiles, ensuring effective risk communication with communities (UNISDR 2015).
- **Enhance Community Engagement:** Foster participatory disaster planning by integrating local communities into risk reduction strategies, ensuring that Indigenous knowledge and local needs are reflected in policy interventions.
- **Promote Integrated Land Use Planning:** Enforce disaster risk-sensitive land use policies to mitigate vulnerabilities in high-risk areas, particularly regarding school infrastructure and community centres.
- **Allocate Resources for Disaster Preparedness:** Secure sustainable funding mechanisms for preparedness initiatives, including school safety audits, capacity-building programmes, and infrastructure resilience projects.
- **Strengthen Interagency Coordination:** Establish formal collaboration mechanisms between government agencies, NGOs, and the private sector to facilitate cohesive disaster management policies (UNISDR 2015).
- **Implement Regular Drills and Simulations:** Conduct periodic emergency preparedness exercises to enhance response capacities among schools and communities.
- **Integrate Climate Change Adaptation:** Align disaster management strategies with climate adaptation policies, ensuring that resilience-building measures reflect long-term environmental challenges (UNFCCC 2015).
- **Evaluate and Update Policies:** Establish a continuous monitoring framework to assess the effectiveness of disaster risk management policies, incorporating lessons learned and emerging risks.

6.1.2 Strengthening educational initiatives

Given the critical intersection between education and disaster resilience, integrating DRR principles within school curricula is fundamental (Ruiz-Cortés and Alcántara-Ayala 2020). The following policies are recommended to ensure children are equipped with the necessary knowledge and skills to mitigate disaster risks:

- **Integrate Disaster Risk Reduction into School Curricula:** Mandating DRR education in primary and secondary curricula, covering hazards, preparedness measures, and community resilience strategies (Petal 2009).
- **Implement Training for Educators:** Provide targeted training for teachers to equip them with pedagogical tools for effectively delivering DRR education and fostering student engagement (Peek 2008).
- **Develop Age-Appropriate Educational Materials:** Create educational resources tailored to different age groups, ensuring accessibility and comprehension of DRR concepts.
- **Establish School Emergency Response Plans:** Require all schools to develop, test, and regularly update emergency preparedness plans, including evacuation protocols and safety drills (Mitchell et al. 2008).
- **Promote Extracurricular Activities Focused on DRR:** Encourage establishing school-based DRR clubs, competitions, and awareness campaigns to reinforce disaster preparedness knowledge (Izadkhah and Hosseini 2005).
- **Foster Community Involvement in Education:** Strengthen parental and community participation in school-based DRR initiatives to create a culture of resilience at both household and community levels (Fernandez et al. 2023).
- **Implement School Infrastructure Improvements:** Invest in retrofitting and constructing disaster-resilient educational facilities, ensuring schools serve as safe havens during emergencies (Fernandez et al. 2023).
- **Encourage Participation in National DRR Campaigns:** Actively involve students in national and regional DRR initiatives, fostering civic responsibility and proactive engagement in disaster preparedness efforts.
- **Create Partnerships with NGOs and International Organisations:** Leverage expertise and resources from international bodies to strengthen DRR education and school safety initiatives (UNISDR 2015).
- **Evaluate and Adapt Educational Policies:** Regularly assess the effectiveness of DRR education programmes and make necessary revisions based on feedback, technological advancements, and evolving risk landscapes.

6.2 Study limitations

Although this research offers valuable insights, it is important to acknowledge several limitations. These limitations primarily arise from data availability and fieldwork challenges, particularly in developing countries like Nicaragua. The landslide inventory, which serves as a critical foundation for the study, required adjustments for quality assurance. The original dataset, comprising 1,956 records, was refined by unifying lithological categories and removing duplicate polygons, resulting in a final inventory of 1,881 landslides. However, temporal gaps in the dataset, especially before 2002, restricted the study's ability to analyse trends over a more extended historical period. This gap was exacerbated by inconsistent and incomplete records, particularly following Hurricane Mitch. Consequently, the research could not account for potential shifts in landslide patterns over time, which may affect the accuracy of the susceptibility model.

The challenge of field validation further complicated these issues. Nicaragua's rugged terrain, especially in rural and remote areas, rendered on-the-ground surveys highly resource-intensive. Given the limited resources available for comprehensive field validation, corroborating the landslide inventory with real-time data was not feasible. This lack of ground truthing may compromise the reliability of the susceptibility model, as real-time data is essential for verifying the spatial accuracy of historical landslide records.

The use of generalised datasets for land use and geological factors, coupled with outdated demographic data (primarily sourced from the 2021 statistical yearbook), further constrained the resolution of the susceptibility model. While these datasets are often the best available in resource-constrained environments, their coarser spatial detail limits the model's precision. It adds uncertainty to the demographic analysis of children's exposure to landslides. Improved access to high-resolution data, particularly at local scales, would significantly enhance the accuracy of future susceptibility models and enable more detailed risk assessments.

Additionally, limitations in the availability of educational infrastructure data hindered the scope of the research. Information regarding schools, including educational levels (pre-school, primary, secondary), was often outdated or incomplete. This necessitated significant verification using secondary sources such as Google Maps and Google Earth, which may introduce inaccuracies in the spatial data. As a result, the study concentrated on selected departments with more reliable data, thereby limiting the geographic scope of the analysis and reducing the generalisability of the findings. Future research could benefit from efforts to collect more comprehensive, real-time data on educational infrastructure, facilitating a more robust, nationwide assessment of children's exposure to landslide hazards.

Despite these limitations, this research provides valuable insights into children's exposure to landslide risks in Nicaragua and represents an initial step towards a broader understanding of geohazards in vulnerable regions. As data availability improves and more field validation is conducted, future studies can build upon these findings to offer a more comprehensive analysis of landslide risks and their impacts on children in Nicaragua and similar contexts.

7. Conclusion

Globally, numerous populations face heightened vulnerability to the impacts of climate change, including the elderly, pregnant women, impoverished families, and marginalised groups. Among these demographics, children represent a particularly significant sector, as the repercussions of climate change on their development and well-being can be both profound and enduring. Therefore, it is imperative to implement comprehensive prevention measures, adaptive strategies, and responsive actions that specifically address the effects of climate change on children across various age groups. Prioritising the preparation and education of children for disasters induced by meteorological events, such as tropical cyclones, is essential for their protection and resilience. By fostering effective educational initiatives, stakeholders can strengthen children's agency to comprehend and navigate the risks associated with such phenomena, thereby enhancing their ability to respond to climate-related challenges and ensuring their safety and well-being in the face of an increasingly unpredictable climate.

Historically, Nicaragua has experienced significant impacts from Category 4 and 5 hurricanes on the Saffir-Simpson scale, notably Hurricane Joan (1988), Hurricane Félix (2007), and Hurricanes Eta and Iota (2020). The devastation wrought by these storms has resulted in floods, landslides (Fig. 11), widespread destruction and substantial economic losses, destabilising various departments and municipalities and affecting countless families throughout the country (Velásquez and Alcántara-Ayala 2024). In the aftermath of these catastrophic events, humanitarian organisations have mobilised to provide critical support to the most vulnerable communities impacted by the hurricanes. Such circumstances pose considerable risks to Nicaraguan children and adolescents' health, safety, and well-being, highlighting the urgent need for targeted disaster risk reduction measures and comprehensive support systems to protect this vulnerable population in future emergencies.

Reducing the vulnerability and exposure of children and adolescents to climate-related phenomena is an urgent endeavour, given that these individuals represent potential future leaders at municipal, regional, and international levels (Ruiz-Cortés and Alcántara-Ayala 2020). Equipping them with the necessary knowledge and skills can enhance the resilience of their families, communities, and regions across the country. Furthermore, fostering a heightened perception of risk among children is critical for improving their ability to respond effectively to disasters. Such awareness strengthens them to understand the significance of preparedness in the face of hydrometeorological hazards, including hurricanes, landslides, and floods. Consequently, it is essential to integrate the perspectives and voices of children and adolescents into strategies addressing climate change. Doing so ensures that their insights inform the development of effective disaster risk reduction measures, ultimately strengthening community resilience and promoting sustainable adaptation practices.

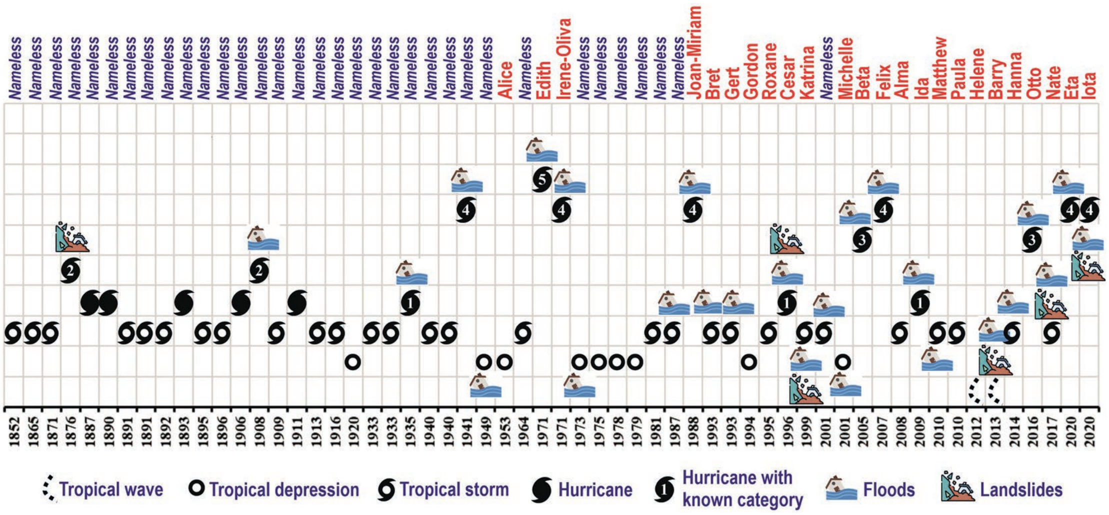

Fig. 11 Tropical cyclones that impacted Nicaragua from 1852 to 2020 and related hazards, including significant landslide disasters (Velásquez-Espinoza and Alcántara-Ayala 2024).

This study underscores the urgent need for evidence-based disaster risk management and education policy interventions. Given the significant exposure of Nicaragua's school infrastructure to climate-related hazards, a multifaceted approach is required – one that integrates institutional reforms, strengthens school curricula and fosters cross-sector collaboration. The proposed policy recommendations provide a roadmap for enhancing resilience through integrated disaster risk management and educational strategies. By embedding DRR principles into national frameworks, Nicaragua can ensure that future generations are prepared for disasters and empowered to contribute to long-term community resilience.

A comprehensive policy response that aligns disaster risk management with educational resilience will safeguard vulnerable populations and foster a culture of preparedness, ensuring that Nicaragua is better positioned to mitigate the adverse impacts of hazards in future years.

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