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Research Article

Constructing a Composite Disaster Resilience Index towards Natural Disastersin Mauritius

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Abstract

Mauritius is a Small Island Developing State (SIDS) which faces regular environmental hazards due to its geographical location. Building disaster-resilient communities has become the goal of many disaster risk reduction (DRR) frameworks. This study aimed at quantifying the resilience of the population of Mauritius towards natural disasters using statistics drawn from secondary sources of data. A Composite Disaster Resilience Index (CDRI), which ranged from 0 to 100, was established. Four dimensions and sixteen variables which reflected domains of resilience in terms of community capacity, economic, built-up environment and social, were used to develop the CDRI. Geographic Information System (GIS) was used to map the CDRI across 144 administrative areas, which included 124 Village Council Areas (VCAs) and 20 Municipal Council Wards (MCWs), for a visual representation. Resilience indices were classified into least and most resilient. Results showed a spatial variation in resilience levels towards natural disasters across the administrative areas. Nearly fifty percent of the eleven most resilient communities were found in urban areas (MCWs). Twelve administrative areas were the least resilient and emerged from rural (VCAs) and marginalised areas only. Coastal villages of Grand Sable, Quatre-Soeurs, Bambous-Virieux, Le Morne and Case Noyale formed a cluster of least resilient communities along the East coast. A t-test analysis revealed a statistically significant difference in resilience levels between urban and rural regions at $p < 0.05$. Results suggested that infrastructure and the social capacity building were likely to be less developed in rural areas than in urban areas. Findings also demonstrated that most VCAs and MCWs performed less well in community resilience when compared to the rest of the dimensions of resilience. Results provided evidence with potential to help decision-makers in the allocation of resources to improve resilience in Mauritius.

Keywords: Natural Disasters, Administrative Regions, Coastal Communities, Composite Disaster Resilience Index, GIS, Mauritius.

Introduction

Pantin (1994) stated that Small Island Developing States (SIDS) comprise of islands which share similar characteristics in terms of geographic land area, socio-economic conditions and exposure to adverse environmental conditions. As one of the world's SIDS, Mauritius is generally more sensitive and vulnerable to climate change, with a lower adaptive capacity when compared to mainland countries (Kelman and Weichselgartner, 2014).

SIDS, such as Mauritius, are located in some of the World's most vulnerable regions. The island of Mauritius lies in the South West Indian Ocean which is an area prone to tropical cyclones from November to April. Mauritius has a warm tropical maritime climate. The relief of the island is uneven and prevailing winds blow from a South East direction almost all year round, except in times when tropical cyclones are close to Mauritius. The rainfall pattern of Mauritius is strongly influenced by its topography. The average annual precipitation over the island is 2120 mm, varying from 1500 mm on the East coast to 4000 mm on the Central Plateau and 900 mm on the West coast (Proag, 2006). As a result of its geographical location, Mauritius is, therefore, naturally prone to climate-induced hazards such as tropical cyclones, storm surges, flooding, droughts and their related consequences (MENDU Report, 2005).

Mauritius ranks 51st in terms of disaster risk and was the 10th most exposed country to natural hazards (Aleksandrova, 2021). Multi-hazards include tropical cyclones, torrential rainfall, floods, landslides, tsunamis, high waves, storm surges, tornadoes and droughts (Cutter et al., 2010). Mauritius is vulnerable to different types of hazards: geological (landslides and tsunamis), biological (epidemics, crop and animal pests, and diseases) and technological (industrial pollution, toxic waste, transport accidents in the national port, fires and chemical spills) (Cadri, 2020). However, Mauritius is particularly vulnerable to risks derived from floods and tropical cyclones (World Bank, 2016). The Global Facility for Disaster Reduction and Recovery (GFDRR) concluded that tropical cyclones caused 80% of the average losses associated with disasters yearly in Mauritius, while flooding was the second largest risk after tropical cyclones, leading to 20% of the direct economic losses, mostly affecting people's homes. In addition to direct economic losses, natural disasters also require significant amounts of emergency costs. The consequences of flooding have been exacerbated by rapid urbanisation on previously agricultural land. These have put much strain on the national drainage system and increased the occurrence of flash floods. The island is relatively safe from earthquakes as it lies within the African Plate, further away from plate boundaries.

In 2005, the Hyogo Framework for Action 2005-2015 (HFA) (United Nations, 2005) was developed, to outline strategies for DRR through an emphasis on understanding risk, reducing risk factors, building knowledge and strengthening preparedness. However, some authors argued that the HFA failed in its objective of reducing vulnerability towards natural disasters as human, economic, infrastructure and ecological losses were still apparent in the poorest nations (Scolobig et al., 2015; Tozier de la Poterie and Baudoin, 2015). Building disaster-resilient communities is a stated goal of the SENDAI Framework for Disaster Risk Reduction (SFDRR) for 2015-2030. In this context, a National Disaster Scheme was developed in 2015 to improve disaster risk reduction and management in Mauritius. The National Disaster Risk Reduction and Management Centre (NDRRMC) has applied enormous efforts in developing strategies and taking actions towards the effective implementation of DRR programmes and policies in terms of preparedness, response, and recovery in Mauritius.

The occurrence of natural hazards is hardly avoidable, but efforts can be sustained to limit human and economic losses. An evaluation of progress towards community resilience requires a thorough understanding of community resilience. An analysis and a benchmark of community, social, economic, and infrastructural resilience based on available characteristics and variables can be used to assess resilience of communities, thus ensuring timely recovery of inhabitants.

Relevant Studies in Disaster Management in Mauritius

There have been several attempts to study disaster management at local level in Mauritius (Chacowry, 2014; Chacowry et al., 2018; Gray and Lalljee, 2013; Gunputh, 2008; Panray et al., 2011; Ruchama and Ansaram, 2020). Chacowry (2014) investigated the ability of three selected communities to recover from the adverse effects of flood hazards in Mauritius. Results in her study demonstrated clear evidence of unequal distribution of wealth among the low-income groups such that a number of social and environmental factors were responsible for their low resilience levels to flood hazards. However, solidarity in times of adversity was visible among some of the community members. Her study concluded that social networking, experiential knowledge of how to cope with floods, and a combination of local and scientific knowledge were essential in strengthening community resilience.

Panray et al. (2011) performed a vulnerability assessment towards natural disasters in coastal communities in both the West and East regions of Mauritius. In their study, a set of physical, biological, social, economic and cultural conditions of selected villages, as well as participatory techniques such as an informal education session on climate science, were used to develop a Vulnerability Index. This Vulnerability Index was the aggregate of a village assessment score and an individual assessment score.

Means and methods to assist people affected by natural disasters in Mauritius have also been investigated. Gunputh (2008) acknowledged that no international law which deals directly with the plight of victims of natural disasters can be found, and that funding and international humanitarian aids were not only the solution. Therefore, it would be more beneficial to invest in early warning systems, preparedness, and awareness sessions. Her study proposed to set up some regulatory framework with respect to strategic inundation maps, new rainfall gauges, setting up of sea-level stations, and a regional tsunami watch. Gray and Lalljee (2013) also examined the need for institutional framework to effectively build Mauritius' resilience to climate change. Capacity building among local stakeholders would be required to facilitate implementation and coordination of climate change related projects.

The most effective innovations for DRR in Mauritius were education measures, community-based DRR services and social networking services (Ruchama and Ansaram, 2020). Their study explored the engagement of the local community in disaster risk management through an online survey and focus group discussions across different sectors in Mauritius. Their results revealed that community engagement in DRR was low. While respondents were mostly aware about the occurrence of an imminent disaster, they were often oblivious of the protection measures to adopt.
Taking into consideration the inherent vulnerabilities arising from extreme climatic events, Proag (2016) evaluated the present water supply system. His study explored the need for an adequate distribution of water all year round through a resilient water supply network. Sungkur and Kissoonah (2019) also attempted to find innovative ways of improving our infrastructural resilience to natural disasters. They examined the role of Information and Technology (ICT) in disaster management and emergency response with the main aim of developing unconventional methods to disseminate early warning systems. A more people-centred approach was adopted by Walshe et al. (2020) in their attempt to assess the vulnerability of the Mauritian towards extreme weather events using historical discourses. Their study revealed a number of repetitive patterns in terms of response and recovery actions taken by Mauritians over many of the largest cyclones studied. These patterns could be characterised as cycles and these suggest that Mauritian people might be conditioned by the new conceptualization of long-term memory disaster memory patterns (Walshe et al., 2020).

While previous studies have investigated the infrastructural resilience to natural disasters in Mauritius (Proag 2016; Sungkur and Kissoonah, 2019), institutional adaptive capacity (Gray and Lalljee, 2013; Gunputh, 2008), socio-economic vulnerability and resilience (Chacowry, 2014; Panray et al., 2011; Ruchama and Ansaram, 2020; Walshe et al., 2020), those studies which examined the overall resilience of communities towards natural disasters using an aggregated measurement of social, economic, community and infrastructural variables are scant. Hence, this study made an attempt at developing such a Resilience Index that would fill in this research gap.

The Theory of Disaster Resilience

The term "Resilience" was reportedly first cited in the work of Holling (1973) to denote ecological resilience. Subsequently, researchers in the field of disaster management extended and adapted the concept to human or community resilience in facing shocks and stresses from hazards (Folke, 2006). Scholars proposed many definitions of disaster resilience. Koliou et al. (2018) listed seventeen definitions of community resilience, among which three key components of community resilience could be found: reducing impacts or consequences, reducing recovery time and reducing future vulnerabilities. The United Nations International Strategy for Disaster Reduction (UNISDR) has defined community resilience as the "ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" (UNISDR, 2012).

Increasingly, the term "resilience" is gaining importance (Alexander, 2013), and gradually overshadowing its closely-related "vulnerability" and "adaptive capacity" terms. Despite the wide range of definitions provided in literature and its application to a variety of different settings, there is no universally accepted definition for "resilience" (Alexander, 2013; Lewis and Kelman, 2010). However, many definitions would, however, agree that resilience would encompass a range of ways in which a system responds to and bounces back from external stresses (Holling, 1973; Norris et al., 2008).

Scholars proposed many dimensions to measure resilience. While several studies would refer to physical, social, environmental and economic characteristics as dimensions of resilience, the number of dimensions used to measure resilience level would vary across studies. For instance, Bruneau et al. (2003) proposed four-inter-related dimensions of resilience, namely technical, organisational, social and economic. On the other hand, Cutter et al. (2008) used more dimensions in their measurement of resilience, for instance, ecological, social, economic, institutional, infrastructural and community capacity. Some would measure resilience as the adaptive and coping capacity of communities. Ogugua (2022) studied the adaptive capacity of communities through a selection of peer-reviewed articles and found that community resilience increases the chance of community adaptation during and after a disaster. His study aimed at encouraging private businesses and professional individuals to become part of a community by providing them with resources needed to survive in the face or after a disaster. Parsons et al. (2021) conducted research on disaster resilience in Australia, focusing on coping and adaptive capacity as the main dimensions of resilience. Becker and Van Niekerk (2015) studied the limitations to the development of a sustainable capacity for DRR in Southern African states. Their study revealed that much efforts have been put in place to develop policies and legal acts. However, translation of these policies and plans into action was often a slow and difficult process. Similarly, Manyena (2006) argued that building institutional capacity is a fundamental step in achieving disaster resilience.

Other studies developed methods to establish either a vulnerability or a resilience index as a measurement of resilience towards natural disasters. Kafle (2012) and Kusumastuti et al. (2014) developed an index to assess the resilience of communities living in disaster-prone areas in Indonesia. Kusumastuti et al. (2014) defined resilience as the ratio between preparedness and vulnerability using social, economic, community capacity, institutional and infrastructural characteristics as dimensions of measurement. Meher et al. (2011) also attempted to create a community resilience index for disaster prone areas in Orissa in India using a set of social, economic, human, physical, natural indicators and measures of self-governance. Aksha and Emrich (2020) attempted to quantify disaster resilience at local level in Nepal using social, economic, community, environmental and infrastructure as dimensions of resilience. Marzi et al. (2019) developed a disaster resilience index at municipal level in Italy using a sensitivity analysis. Their study highlighted a variation in patterns of social vulnerability and resilience across the northern and southern regions of Italy. The term Composite was used to indicate an aggregate of individual variables which consisted of social, economic, institutional, infrastructure and community. Cutter et al. (2010) developed a composite index to assess disaster resilience of counties in Southeastern of the United States while Mavhura et al. (2021) carried out a similar study in Zimbabwe.

Purpose of Study

The objective of the study is to develop a CDRI to assess the resilience level towards natural hazards in Mauritius. It makes a preliminary attempt in quantifying community resilience. Hence, this study aims at investigating the following research questions:

1. How do social, economic, built-up environment, community resilience scores and the CDRI scores vary across Mauritius?
2. Where do clusters of lower CDRI scores exist in Mauritius?
3. Is there any significant difference between urban and rural disaster resilience levels towards natural hazards in Mauritius?

Materials and Methods

Justification of Methodology

In this study, the CDRI is a single index which represents an estimate of the spatial distribution of resilience to natural disasters. It combined four sub-indices using a mathematical formula with applied weighting factors and was based on sixteen indicators (variables) hypothesised to influence the resilience of a region to natural disasters. Shim (2015) also applied sixteen indicators with three resilience dimensions to his study on resilience to natural hazards. Indices have been used in several studies to measure a given aspect in the field of disaster management (Aksha and Emrich, 2020; Cutter et al., 2010; Kafle, 2012; Kusumastuti et al., 2014; Marzi et al., 2019; Mavhura et al., 2021; Norris et al., 2008). Dimensions of resilience were carefully selected in this study based on plublished literature in this field and on availability of data. They were selected from indicators proposed by previous studies (Cutter et al., 2010; Kusumastuti et al., 2014). Dimensions, similar to those used in Cutter et al. (2010), were considered: social, economic, built-up environment and community capacity. Social resilience consists of demographic characteristics (Cutter et al., 2010). Community resilience is related to the empowerment of people living in an an area to enhance their wellness and awareness, quality of life and emotional health (Norris et al., 2008). Economic resilience is related to the financial well-being of the community and built-up environment consists of physical aspects of an area, such as access to electricity and clean water supply (Cutter et al., 2010). Similarly, this study combines the social, infrastructural, economic and community dimensions and their mapping revealed distinctive geographic variations across local administrative regions.

Data were collected from various secondary sources. These included electronic databases from a number of organisations and some datasets were obtained upon an official request made to the relevant authorities. As in previous studies, resilience indicators applicable at national or regional levels mostly employed existing statistical data (Burton, 2015; Cutter et al., 2008). In Mauritius, there are five Municipal Council Areas (MCAs) and four District Council Areas (DCAs). The MCAs and DCAs are further broken down into smaller areas, the MCWs and VCAs respectively such that the MCWs constitute the urban regions and the VCAs consist of the rural regions. All MCW and VCA boundaries have been mentioned as they were in 2011, and all census data are in relation to these boundaries. Comparison of the 2011 Census data with upcoming 2023 census data at MCW/VCA level should be made with caution since there have been revisions of boundaries between the two censuses. In this study, the CDRI ranged from 0 to 100, with 0 being the least resilient and 100 being the most resilient towards natural disasters. The geographical distribution of the CDRI scores was shown on a map. The ‘equal interval’ classification method was used for the index value scale categorisation, based on the assumption that, if every class had the same difference between the lower and the higher bound, the graphical output would be easy to interpret by a non-technical audience (Papathoma-Köhle, 2019).

Datasets:

Housing and Population Census Data This dataset was made available on request by the Office of Statistics in Mauritius. The housing and population census were conducted in 2011, making it the most recent census for the island of Mauritius. This dataset was made up of tabulation reports covering housing and living conditions, demographic and fertility characteristics, economic characteristics, educational characteristics, disability characteristics, economic characteristics, geographical characteristics and household characteristics. Relevant indicators were retrieved from this dataset to compute the social index, economic index and part of the built-up environment index.

Medical Capacity

This online dataset was available on the website of the Ministry of Health and Wellness in its directory known as health service points and population figures for the year 2015. The number of regional hospitals, specialised hospitals, district hospitals, community hospitals, medi-clinics, area health centres, community health centres and family health clinics were reported in this electronic database . The island was divided into 5 regions. The number of inhabitants and number of hospital beds and medical staff was given for each region.

Shelter Capacity

This electronic dataset was available online on the website of the Ministry of Social Integration, Social Security and National Solidarity under its natural disasters portal. A list of evacuee centres and staffing was also made available on this website for the cyclone season 2021-2022.

Community Volunteering

This dataset was obtained from the National Disaster Risk Reduction and Management Centre on request. The dataset was made up of the number of DRR programmes carried out in each MCA/DCA and which were reported to the NDRRMC by the local disaster Management Coordinator who acts as the liaison officer between the MCA/DCA and the NDRRMC. DRR programmes consisted of awareness and sensitisation campaigns, simulation exercises, formulation of contingency plans, and setting up of community disaster response teams.

Constructing the CDRI

Once the dimensions and sub-dimensions of resilience were identified, the variables representing the dimensions were collected from readily available secondary database sources. The selected variables, all of which had a positive impact on resilience scores, were grouped under one of the four resilience dimensions as shown in Table 1.

Computing the CDRI

A weighted sub-index was calculated for each of the four dimensions listed in Table 1 and was denoted by parameter R, as shown in Equation 1 below. In each of the four sub-indices, C represented the dimension used, that is, either the Social (S), Built-Up Environment (B), Economic (E) or Community (Co), *i* represented the sub-dimension within the respective dimension C, and *j* represented the total number of sub-dimensions within the respective dimension C. W_i represented the weighting factor used for each of the sixteen variables, *x*,

Table 1: Dimensions and Sub-Dimensions (Indicators/Variables) of Resilience

S/N	Resilience Sub-Dimensions	Description of Indicators (Variables)	Source of Data	Individual Weighting (%)
		Dimension 1: Social Resilience		
1	Demographic Characteristics	% non-dependent population (15-64 years old)	Population and Housing Census 2011	$W_1^s = 5$
		% population proficient in English, French, Bhojpuri or Creole		$W_2^s = 5$
		% population with non-special needs		$W_3^s = 5$
		% population aged 10 years and above and who are literate		$W_4^s = 5$
		% households with access to a radio and TV		$W_5^s = 10$
		% households with fixed telephone line and mobile phone		$W_6^s = 10$
		Dimension 2: Built-Up Environment Resilience		
2	Infrastructure	% households with concrete walls/roof	Population and Housing Census 2011	$W_1^B = 5$
		% households with access to piped water		$W_2^B = 5$
		% households with access to electricity		$W_3^B = 5$
		% households with access to internet infrastructure		$W_4^B = 10$
		% households with one or more room per person		$W_5^B = 5$
	Medical Capacity	Nº of hospital beds per 10 000 people	Ministry of Health and Wellness 2015	$w_6^B = 10$
		Dimension 3: Economic Resilience		
3	Assets owned by Residents	% labour force employed	Population and Housing Census 2011	$W_1^E = 5$
		% households which are owner-occupied		$W_2^E = 5$
		Dimension 4: Community Resilience		
4	Shelter Capacity	Nº of available seats per 1000 people	Ministry of Social Integration, Social Security and National Solidarity 2021-2022	$w_1^{Co} = 5$
	Community Volunteering	% community members that have been exposed to DRR activities for e.g., the community disaster response programmes and sensitisation campaigns	NDRRMC 2021	$W_2^{Co} = 5$

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listed in Table 1. Fourteen raw data variables, denoted by x, were converted into comparable scales using percentages (Table 1) and a scaling factor was applied to the remaining two variables to ensure standardisation in each sub-index.

$$R = \sum_{C=S,B,E,Co} \sum_{i=1}^{j} C_i \, x w_i^C \qquad \textit{Equation (1)}$$

Where C represented the dimension for the Social (S), Built-Up Environment (B), Economic (E) and Community (Co), i represented the sub-dimension within the respective dimension C and j represented the total number of sub-dimensions within the respective dimension C. W_i represented the weighting factor used for each of the indicators/variables,

The CDRI was calculated using the arithmetic sum of the four weighted sub-indices' scores; social index, economic index, built-up environment index, and community index for each of the 144 administrative areas in Mauritius. The expanded variation of the CDRI is given in Equation 2 below. The formula for the CDRI was computed by categorising the variables, x, in the dimensions to which they belong, that is, either in the Social (S), Built-Up Environment (B), Economic (E) or the Community (Co) dimension. Each of the six variables within the Social (S) dimension, (S_1x to S_6x), was multiplied to its respective weighting factor (Table 1). Similarly, each of the six variables within the Built-Up Environment (B) dimension, (B_1x to $(\frac{B_6}{1})x$), was multiplied to its respective weighting factor (Table 1). Likewise, each of the two variables within the Economic (E) dimension, (E_1x to E_2x), was multiplied to its respective weighting factor (Table 1) and each of the two variables within the Community (Co) dimesnion (($\frac{Co_1}{0.25}$) to Co_2x) was multiplied to its respective weighting factor (Table 1). Based on the study of Perfrement and Lloyd (2015), a scaling factor of 1 was used for B_6, (N° of hospital beds per 10 000 people), and a scaling factor of 0.25 was used for Co_1, (N° of available seats per 1000 people in emergency shelters) to ensure standardisation with the remaining fourteen variables. The weighting factor was given by, w_i^j, where *i* represented each variable, and *j* represented each dimension S, B, E or Co within which the variables fell.

$$CDRI = [S_1xW_1^s + S_2xW_2^s + S_3xW_3^s + S_4xW_4^s + S_5xW_5^s + S_6xW_6^s + B_1xW_1^B + B_2xW_2^B + B_3xW_3^B + B_4xW_4^B + B_5xW_5^B + (\frac{B_6}{1})xw_6^B + E_1xW_1^E + E_2xW_2^E + (\frac{Co_1}{0.25})xw_1^{Co} + Co_2xW_2^{Co}] \quad \text{Equation (2)}$$

(Composite Disaster Resilience Index adapted from Perfrement and Lloyd, 2015)

Index Scale Categorisation

Given that the 'equal interval' classification method was used for the index value categorisation, the difference between the minimum (Min) and the maximum (Max) values for each class in every sub-index parameter, R, and the CDRI, was the same. The lower bound of the interval class represented the minimum value while the higher bound represented the maximum value achieved within each of the dimensions S, B, E and Co. As shown in Table 2, the index categorisation was 28.0≤ R≤ 35.9 and a class interval of 1.9 was used for the Social (S) dimension (on a scale of 0 to 40). For the Built-Up Environment (B) dimension (on a scale of 0 to 40), the index categorisation was 16.9≤ R≤ 28.0 and a class interval of 2.7 was used. For the Economic (E) dimension (on a scale of 0 to 10), the index categorisation was 7.70≤ R≤ 9.69 and a class interval of 0.49 was used. Finally, for the Community (Co) dimension (on a scale of 0 to 10), the index categorisation was 0.37≤ R≤ 2.69 and a class interval of 0.59 was used. The maximum achievable score for the CDRI was 100 while the minimum possible score was 0. The CDRI scale categorisation was 60.0≤CDRI≤ 73.99 and a class of 3.49 was adopted (Table 2).

Table 2: Values representing the Index Scale Categorisation for each Parameter R (sub-index) and the CDRI

Index	Scale	Min Value	Max Value	Index Scale Categorisation	Class Interval
Social (S)	0 to 40	28.0	35.9	28.0≤ R≤ 35.9	1.9
Built-Up Environment (B)	0 to 40	16.9	28.0	16.9≤ R≤ 28.0	2.7
Economic (E)	0 to 10	7.70	9.69	7.70≤ R≤ 9.69	0.49
Community (Co)	0 to 10	0.37	2.69	0.37≤ R≤ 2.69	0.59
Composite Disaster Resilience Index (CDRI)	0 to 100	60.0	73.99	60.0≤CDRI≤ 73.99	3.49

Determining the Weighting Factors

The rank reciprocal method (Buede, 2008), shown in Equation 3, was used to determine the weighting factors for each of the indicators (variables) shown in Table 1. The indicators (variables) were rated within each dimension, S, B, E and Co, such that the indicator (variable) having the highest correlation to resilience was ranked first within its dimension and the indicator (variable) with the lowest correlation was ranked nth within its dimension, where n is the total number of indicators (variables) within the dimension. Once the ranks were assigned, the numerical weights corresponding to the ranks were derived using the rank reciprocal method and were then expressed as percentages. Hence, with *n* criteria, the weight for rank *r* was $\frac{1}{r}$, that is its reciprocal value. Each of the surveyed rankings for the indicators (variables) was then averaged to provide an overall averaged rank. (Equation 3).

$$\frac{\frac{1}{r_{c,avg}}}{\sum_c = S, B, E, Co\ (\frac{1}{r_{c,avg}})}$$

Equation (3)

Where wt_c represented the parameter for the weighting factor, r_c represented the average (*avg*) rank of dimension C, and C represented the indicator (variable) with the Social (S), Built-Up Environment (B), Economic (E) and Community (Co) dimensions.

Student t-Test

The two-tailed Student t-test was used at a 95% confidence interval assuming the data to follow a normal distribution. Based on 124 VCAs and 20 MCWs, the Student t-test aimed at providing evidence that there was a significant difference between urban and rural resilience levels to natural disasters. The t-value was calculated using equation 4:

$$t = \frac{\mu_1 - \mu_2}{S_{12}}, \text{ where } S_{12} = \sqrt{\frac{\sigma_1^2}{n_1}} + \sqrt{\frac{\sigma_2^2}{n_2}}$$

Equation (4)

Where μ represented mean urban/rural CDRI score, σ represented the standard deviation and *n* represented the number of MCWs/VCAs.)

Visualising the CDRI Scores via GIS Mapping

The CDRI scores of each of the 144 administrative regions were mapped using ArcGIS and the digital administrative map was provided by the Statistics Office Mauritius to visualise the most and the least resilient VCAs and MCWs in Mauritius. A graduated colour scheme from red (least resilient) to green (most resilient) was used. Intermediate colours yellow and orange would indicate medium to most resilience and medium to least resilient respectively.

Results

Results for each sub-index (Social, Economic, Built-Up Environment, Community) and the CDRI were cartographically displayed on maps, shown in Figure 1 to Figure 5, to demonstrate the spatial distribution of disaster resilience across Mauritius.

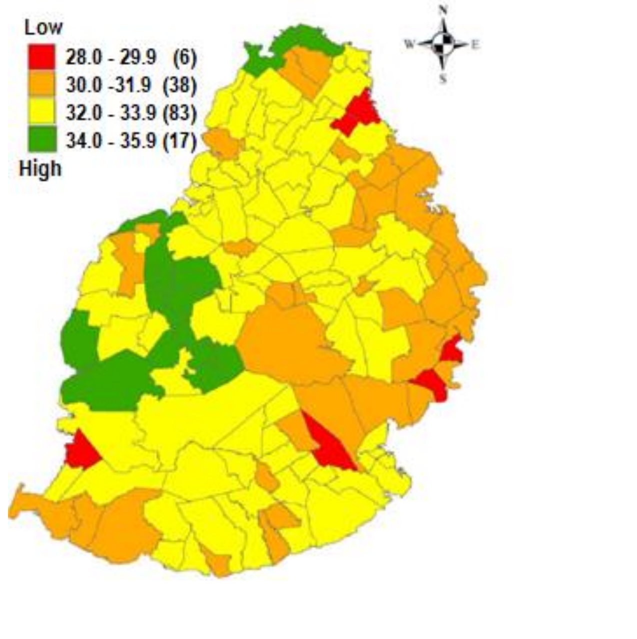

Fig1: Social Resilience Indexby VCA/MCW

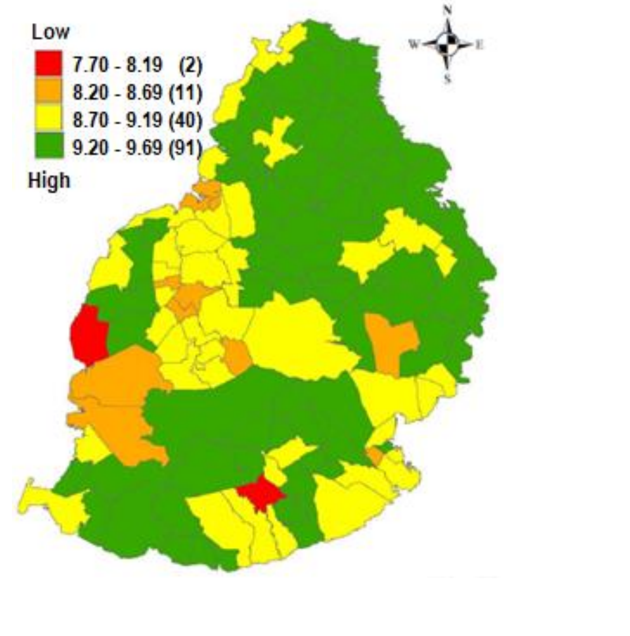

Fig. 2: Economic Resilience Index by VCA/MCW

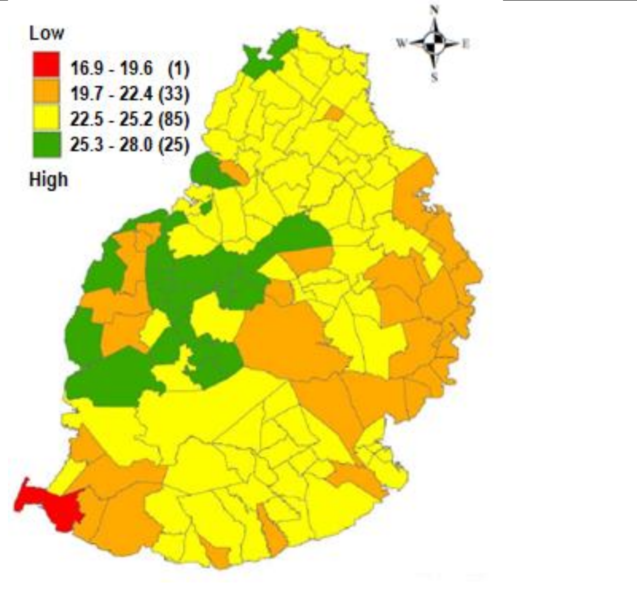

Fig. 3: Built-Up Environment Resilience Index by VCA/MCW

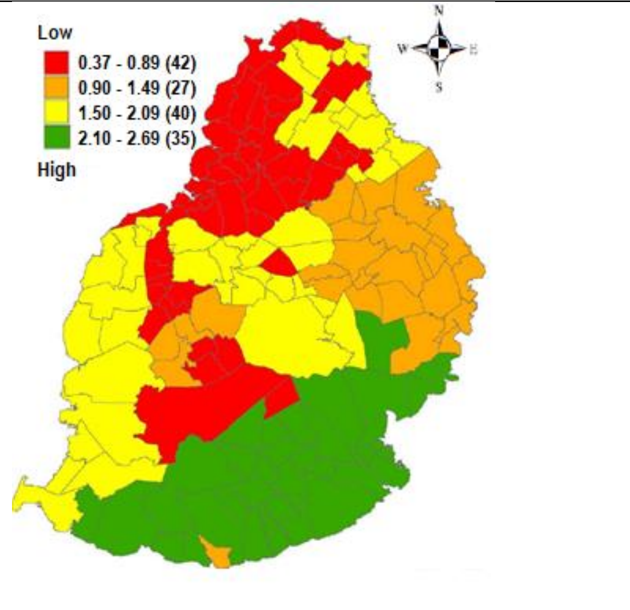

Fig. 4: Community Resilience Indexby VCA/MCW

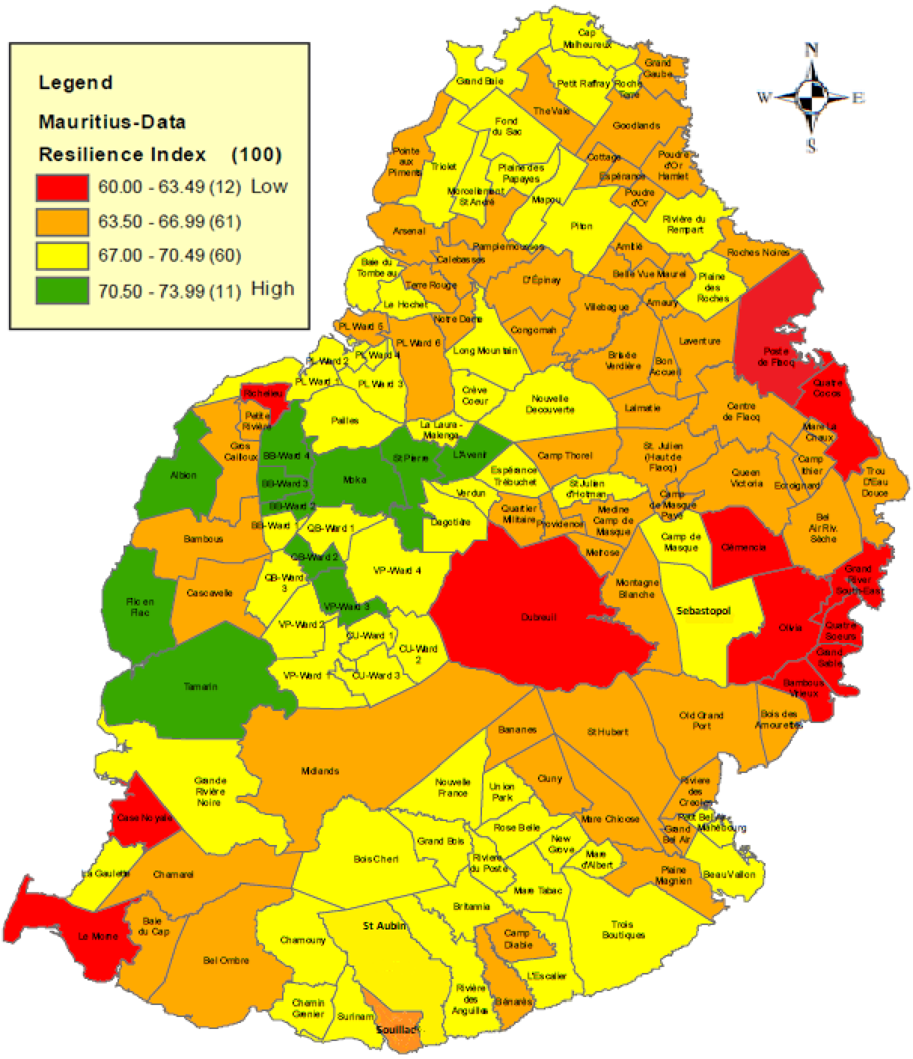

Fig. 5: Composite Disaster Resilience Index (CDRI) by VCA/MCW in Mauritius

CDRI scores indicated that twelve administrative regions were the least resilient to natural disasters (Figure 5) (Table 3), all of which were in rural areas. Eleven communities were found to be the most resilient to natural disasters, nearly half of which were in urban regions (Figure 5) (Table 4). The geographic distribution of CDRI scores indicated that most of the administrative regions in Mauritius were within the intermediate colour category, that is, moderately resilient to natural disasters (Figure 5). Individual result components showed moderate to very high scores in economic aspects except for Flic-en-Flac VCA and Britannia VCA (Figure 2). The twenty MCWs were classified as moderately resilient to natural disasters and could not fit in the highly-resilient group in the economic category. Most administrative regions were also moderately resilient in the social and built-up environment dimensions (Figure 1 and Figure 3), except for most of the urban regions and a few VCAs which showed high resilience scores in these two categories (Figure 1 and Figure 3). Le Morne VCA was the only community to be the least resilient in the built-up environment category (Figure 3, Table 3). The five least resilient communities in the social category were all found in rural and coastal regions, except for Mare-Chicose (Figure 1) which is an inland region. Results also demonstrated that most VCAs and MCWs performed less well in community resilience when compared to the rest of the dimensions of resilience. In spite of the very low overall scores in this category, a clear difference was observed among DCAs as each DCA is responsible to carry out its own DRR activities. VCAs found within the districts of Pamplemousses (North West), Savanne (South) and Grand-Port (South East) were exposed to the greatest number of DRR activities and were more likely to have an easier access to shelters due the greater availability of seating capacity and hence showed the highest community resilience (Figure 4). Urban regions of Quatre-Bornes, Beau-Bassin/Rose-Hill and Curepipe, as well as VCAs in the district of Rivière du Rempart, were the least resilient in the community category (Figure 4). This indicated that they were involved in few DRR campaigns only and access to shelters would be quite difficult for them due to the limited number of seating capacity per 1000 inhabitants in these regions.

Table 3: Twelve Least Resilient Local Administrative Regions on the CDRI Scores

Rank	Name	Social Index (40)	Built-Up Environment Index (40)	Community Index (10)	Economic Index (10)	CDRI (100)
1.	Le Morne VCA	31.62	17.21	1.99	9.19	60.00
2.	Bambous-Virieux VCA	28.23	21.09	2.21	9.13	60.06
3.	Quatre Soeurs VCA	29.45	21.20	1.11	9.44	61.31
4.	Case Noyale VCA	29.65	20.72	1.99	9.13	61.49
5.	Olivia VCA	31.22	20.36	1.11	9.30	61.99
6.	Poste de Flacq VCA	30.36	21.30	1.11	9.31	62.08
7.	Quatre Cocos VCA	30.66	21.42	1.11	9.21	62.40
8.	Grand-Sable VCA	30.03	20.35	2.21	9.35	62.64
9.	Clemencia VCA	31.29	21.05	1.11	9.28	62.73
10.	Richelieu VCA	31.12	20.67	1.99	9.33	63.10
11.	Dubreuil VCA	30.59	21.97	1.62	9.15	63.33
12.	Grand River South East VCA	31.78	20.89	1.11	9.20	62.99

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Table 4: Eleven Most Resilient Local Administrative Regions on the CDRI Scores

Rank	Name	Social Index (40)	Built-Up Environment Index (40)	Community Index (10)	Economic Index (10)	CDRI (100)
1.	Moka VCA	34.28	27.88	1.62	9.06	72.84
2.	Flic-en-Flac VCA	34.98	26.85	1.99	8.16	71.98
3.	Beau-Bassin/Rose-Hill MCW 4	35.05	27.41	0.66	8.74	71.86
4.	Beau-Bassin/Rose-Hill MCW 3	34.70	27.27	0.66	8.91	71.54
5.	Tamarin VCA	34.29	26.67	1.99	8.42	71.37
6.	Quatre-Bornes MCW 2	34.61	27.58	0.37	8.67	71.24
7.	Albion VCA	33.88	26.13	1.99	8.86	70.85
8.	Beau-Bassin/Rose-Hill MCW 2	34.79	26.78	0.66	8.61	70.84
9.	St-Pierre VCA	33.84	26.03	1.62	9.16	70.64
10.	L'Avenir VCA	33.00	26.54	1.62	9.46	70.61
11.	Vacoas/Phoenix MCW 3	34.59	26.14	0.96	8.84	70.53

MCWs within the five municipal council areas of Curepipe, Vacoas-Phoenix, Port-Louis, Beau-Bassin/Rose-Hill and Quatre-Bornes showed higher CDRI scores when compared to VCAs (Figure 5). Moka VCA was the most resilient of all administrative regions (72.84) (Figure 5) (Table 4) with high resilience scores in social (Figure 1) and built-up environment (Figure 3) and moderate resilience scores in economic (Figure 2) and community aspects (Figure 4). Le Morne VCA had the least CDRI (60.00) (Figure 5) (Table 3) with low resilience scores in social (Figure 1) and built-up environment (Figure 3) and moderate resilience scores in community (Figure 4) and economic aspects (Figure 2) (Table 3). There exists one cluster of low resilience scores along the East coast (Figure 5). Eight out of the twelve local administrative regions with the least scores are located along the East coast. This region is a mountainous region and faces the sea. These topographical characteristics are likely to weaken these areas' resilience.

Table 5: Comparative Analysis and Significance Testing of Mean Resilience Scores of Rural (VCAs) and Urban (MCWs) Communities

Dimension	Urban (N=20 MCWs)		Rural (N=124 VCAs)		Student's t-test	Relevance
	Average	Standard Deviation	Average	Standard Deviation		
Social (40)	34.10	0.72	32.10	1.10	7.71	$p < 0.05$
Built-Up Environment (40)	25.62	1.09	23.51	1.58	5.46	$p < 0.05$
Community (10)	0.70	0.17	1.64	0.60	-10.15	$p < 0.05$
Economic (10)	8.80	0.23	9.26	0.27	-6.08	$p < 0.05$
CDRI (100)	69.21	1.65	66.52	2.35	4.65	$p < 0.05$

The descriptive statistics shown in Table 5 confirmed the lower mean CDRI scores for rural regions (N=124; VCAs=66.52) when compared to urban regions (N=20; MCWs=69.21) as shown on Figure 5. Lower mean resilience scores for rural regions when compared to urban regions were noted in all dimensions except in the economic and community dimensions. An independent t-test was conducted to investigate a significant statistical difference between the mean urban and rural resilience scores. Since the p-value was lower than the significance level, that is, 0.05, in the social dimension ($t=7.71$; $p<0.05$), the built-up environment dimension ($t=5.46$; $p<0.05$), the economic dimension ($t=-6.08$; $p<0.05$, -ve), the community dimension ($t=-10.15$; $p<0.05$, -ve) and the overall CDRI scores ($t=4.65$; $p<0.05$), the null hypothesis was rejected. Hence, the study concluded that there was a significant difference between the mean urban and rural resilience scores in all dimensions towards natural disasters.

Discussions

Results demonstrated a clear variation in CDRI scores and individual sub-indices, that is, in the socio-economic, infrastructural and community capacity themes. Results in this study were consistent with the findings of Aksha and Emrich (2020), Kusumastuti et al. (2014) and Siebeneck et al. (2015). Their study showed spatial variation in resilience levels towards natural disasters in Nepal, Indonesia and Thailand respectively. Overall disaster resilience was generally higher in more urbanised areas than in rural areas (Bazrafshan and Toulabi Nejad, 2018; Mongush et al., 2020; Siebeneck et al., 2015). However, differences were more visible when investigating factors impacting on individual resilience dimensions.

Several factors have been reported to influence disaster resilience scores, one of which is the socio-economic factor. Socio-economic status has often been cited to infuence the ability of communities to recover from the impact of disasters (Fothergill and Peek, 2004; Mongush et al., 2020). Flic-en Flac and Britannia were the only least resilient VCAs in the economic dimension (Figure 2). The two variables in the economic dimension were the percentage of people employed, and hence earning an income and the percentage of households which are house-owners. While Flic-en-Flac is a highly tourist destination, Britannia is an agricultural village with few resources. Mavhura et al. (2021) stated that earning below the minimum wage level would lower resilience capacity towards natural disasters as people are less able to prepare for them. Many communities would spend their income to fulfill their daily basic needs such as foods, clothing, and housing. As a result, when a disaster occurred, they heavily relied on the help of debt or selling some of their assets, as well as, using cash in hand as emergency funds (Viverita et al., 2014). Highly-resilient communities in the economic category excluded all the twenty MCWs. Urban areas showed a mean average score of 8.80 in the conomic dimension while rural areas achieved an average acore of 9.26 in that same dimension (Table 5). Consequently, results in this study were incongruous with those of Siebeneck et al. (2015) and Cutter et al. (2008). Their study revealed that poverty rates were generally higher in the rural areas and those regions were more likely to be associated low economic resilience scores. This could be explained by the fact that, in Mauritius, approximately 93% of households were house-owners in rural areas compared to about 83% only in urban regions and many informal settlements were concentrated on the edge of cities (Mauritius National Urban Profile, 2012b).

Social resilience is a function of demographic characteristics and access to resources (Mavhura et al., 2021). Variations in social resilience scores could, therefore, be explained by the demographic characteristics of the communities. The five VCAs which scored the lowest social resilience scores are those villages where ageing population was high due to high levels of out-migration of the young population. Results were consistent with those of Alshehri et al. (2013). Their study pointed out that communities with a higher proportion of elderly were likely to be less resilient to natural disasters. This could be attributed to the lower ability of the elderly population to learn and access information pertaining to disasters than the younger population (Manyena, 2006).

The two variables in the built-up environment dimension were the infrastructural and medical capacity. Le Morne VCA was the least resilient in this dimension (Figure 3). Remote and marginalised regions have the most difficult access to electricity, piped water, proper sanitation and access to healthcare (Mavhura et al., 2021). While a few studies identified infrastructural utilities to impact positively on resilience levels (Dodman et al., 2017; Mavhura et al., 2021), Sung and Liaw (2020) found no influence of infrastructure on resilience levels in Taiwan. The SFDRR recommended that access to health care be an indicator of resilience assessment (Maini et al., 2017). Boyd et al. (2017) also stated that access to health is essential in times of crisis. The ability to recover is also related to the number of hospital beds available for injured citizens (Siebeneck et al., 2015). VCAs with a low built-up environment score may have health care centres with few hospital beds and people may have to travel longer distances to reach out for medical help.

Community resilience is related to the attributes of the area that promote population wellness, quality of life, and emotional health (Cutter et al., 2008). Furthermore, community resilience is related to the efforts of local government to raise the awareness and resilience of the residents towards disaster. In this study, variables used to assess community resilience were the percentage of people exposed to DRR activities and shelter capacity. Disaster education is an essential part of community preparedness (Alshehri et al., 2013; Rosenfeld et al., 2005). It aims at increasing public awareness of what can happen and at enhancing readiness to act according to the proposed emergency operation plan (Jang and Wang, 2009). Such activities are meant to increase the disaster literacy of people. Triyanto et al. (2021) defined disaster literacy as the ability of people living in disaster-prone areas to have access to information, understand warning information, interpret it and take necessary actions. Increasing disaster literacy can help to improve public understanding of risks. While human beings have no power in changing natural disasters, they are capable of coping with their effects (Jang and Wang, 2009).

The second variable used for assessing community resilience was seating capacity of shelters. Disaster shelter demand is highly uncertain after a disaster (Zhao et al., 2017). Their study emphasised on the need to determine the size and location of shelters in the preparedness phase as evacuees should be able to reach the shelter within a short period of time after the disaster, and, as far as possible on foot given that major routes might be obstructed after a disaster. The number of people in a shelter should also not exceed the shelter's maximum capacity. The low community resilience scores in urban areas (Figure 4) may be explained by the densely populated urban regions and the limited number of shelters available in these regions. Hence, the higher mean community resilience scores in rural areas when compared to urban regions (Table 5).

Findings also revealed a cluster of least resilient communities along the East coast of Mauritius (Figure 5). These regions are found on sloping lands. Sung and Liaw (2021) stated that mountainous areas are known to be extremely vulnerable and lack resilience. In contrast, the urban regions in plain areas were likely to show low vulnerability and high resilience towards natural disasters. High elevations could potentially hinder socio-economic development and result in areas of high vulnerability and low resilience. The other regions, including the urban settlements in the flat lowland areas, have favourable topography for socio-economic development, thus increasing their resilience levels.

Differences between urban and rural resilience scores in all dimensions were explored using a comparative statistical analysis (Table 5). Results indicated that community capacity building was an important driver of disaster resilience in rural areas and these were consistent with Cutter et al. (2016). However, economic capital was not a primary driver of resilience in urban areas of Mauritius as reported in several other studies (Cutter et al., 2008; Cutter et al., 2016; Siebeneck et al., 2015). Instead, infrastructure and social characteristics were found to be most prominent in urban areas of Mauritius and these results were congruous with the findings of Su et al. (2022). On the other hand, results showed that rural areas possessed prominent abilities in terms of community and economic capacities. A gradual change in urban household size from large to small with urbanisation, along with an improvement in education level of urban dwellers has also been highlighted by Su et al. (2022). Ultimately, Suárez et al. (2016) pointed out that social cohesion would enhance urban resilience as it would increase the communities' capacity to respond collectively to an imminent threat.

Conclusions

The main purpose of this study was to develop a Composite Disaster Resilience Index which could be used as an evidence-based tool to assess disaster resilience of communities towards natural hazards in Mauritius.

The following conclusions were drawn from this study:

- There was a spatial variation in disaster resilience levels towards natural hazards across the 144 administrative areas.
- CDRI scores showed that there were eleven administrative areas with the highest disaster resilience, nearly half of which were found in urban areas.
- CDRI scores revealed twelve least resilient communities towards natural hazards, all of which emerged from rural areas.
- There was a cluster of least resilient communities on the East and South-West coast of Mauritius which included coastal villages of Grand Sable, Quatre-Soeurs, Bambous-Virieux, Le Morne and Case Noyale.
- Results showed a statistically significant difference between urban and rural resilience levels. Overall, urban regions were likely to be more resilient than their rural counterparts except in the economic and community dimensions. Findings suggested that service provision and infrastructure were likely to be less developed in rural areas than in urban areas, while the communities' capacity building and financial means were likely to be more developed in VCAs than in MCWs.
- Most VCAs and MCWs performed less well in community resilience when compared to the rest of the dimensions of disaster resilience.

While this study may present an evidence for the allocation of resources during times of crisis, there are a few limitations which need to be considered. The use of the housing and population census dated 2011 was unavoidable since this exercise is carried out once every ten years in Mauritius (Housing and population census report, 2011). Due to the Covid-19 pandemic, there has been a delay in this exercise and the next census data would be available at some point in 2023. Variables drawn from the census data may have changed during the last ten years. Moreover, some disaster resilience indicators pointed out in literature could not be captured in this study due to the unavailability of such data at VCA/MVW level. Ultimately, comparison of changes across all administrative areas would have been made easier if the Population and Housing Census data and other datasets used in this study were published within relatively the same period of time.

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