Assessment of flood mitigation strategy based on integrated approach of remote sensing and coastal vulnerability geospatial modeling at the coastal plain of Suriname

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Abstract. Suriname is the smallest South American nation with a low-lying coastal plain that is vulnerable to inundation from the Atlantic Ocean and inland rivers, as well as pluvial flooding primarily due to rainfall. Paramaribo, the capital of Suriname, has the highest population density, and its demographics extend into the surrounding districts of Wanica and Commewijne. Suriname has experienced flood disasters almost annually, which has exacerbated in recent years, posing a significant socioeconomic challenge. The country must balance the need for flood disaster adaptation and climate resilience with the potential impact on its resources and well-being of settlement areas. Policymakers and other stakeholders are working to address environmental impacts on the coast, but there is still a need for a comprehensive approach to monitor and manage flood impacts. This research objective is to use a geospatial-based multi-criteria decision approach to determine the Flood Vulnerability Index for the coastal plain at the district level, with the aim of assessing its resilience of coastal settlement areas and inform decision-making for flood risk management. Accordingly, the research methodology uses a multi-criteria decision making (MCDM) analysis regarding settlement areas and ranking each component by expert opinion and integrating MCDM in a Coastal Flood Vulnerability Index (CFVI) equation derived from Intergovernmental Panel on Climate Change (IPCC) assessment report at district level. The CFVI indices focusses primarily on secondary data acquisition from national and global datasets or referenced works with the addition of conducted interviews to better understand the stakeholder's perspectives that are at a strategic or governing level, in order to evaluate the existence of flood early-warning and other adaptation capabilities. Flood mitigation and resilience are assessed for the two districts with the highest CFVI scores, in order to determine the most effective measures for reducing their vulnerability to flooding.

Keywords: Suriname, Coastal flood, Vulnerability index, Settlement area, Mitigation Strategy, Flood frequency

1. Introduction

The smallest nation in South America, Suriname is situated in the Guiana Shield, on the northern Atlantic coast. The country's sustenance hinge primarily on the exploitation activities of its abundant natural resources that produce a majority of its gross domestic product (GDP) (Paiva & Bacha, 2019). Nearly half of the public sector revenue comes from mining and gold represents 80 percent of total exports (Keersemaker, 2020). As a developing country, nation-building propositions are challenged by the combination of a traumatic colonial history, a multi-ethnic population, and economic or political instability has made it difficult to implement successful nation-building policies (Hoefte & Veenendaal, 2019; Khadan, 2018). Rapid urban expansion in the northern coastal plain causes detrimental impacts on real estate value, and pressure inland towards forested areas (Koorndijk, 2019).

The Chenier plains of Suriname, as part of the coastal Guiana Shield region, experience sediment exchange through an intricate combination of oceanic waves and tides. This can result in either erosion or the accumulation of muddy debris originating from the Amazon River, forming a low-level plain in the Holocene (Anthony et al., 2019; Augustinus et al., 1989; de Vries et al., 2022). The physical properties of mud and the resistance within the structure prevents itself from washing away, where it accumulates along the coast and eventually provide rapid vegetation growth, significantly the mangrove habitat (De Jong et al., 2021; de Vries et al., 2022). This is the definition of mud banks present along the coast, protecting itself against erosion and forming a natural barrier against the sea (Anthony et al., 2019; Brunier et al., 2022).

Flood disasters in the Republic of Suriname have exacerbated in recent years by a rise in affected residential areas (ReliefWeb, 2022). The emergency is reoccurring in an annual trend and peaks during the rainy season (Pfeffer et al., 2015), that exceeds the soil capacity (pluvial flooding) with lesser occurrences of sea water intrusion in the coastline (Nijbroek, 2014; Rentschler et al., 2022). This poses an important socioeconomic issue for the developing and economically dispositioned nation. The country has a population of a little above half a million, with most development, commerce, and government infrastructure located in the low-lying coastal plain along the Atlantic Ocean (Kroonenberg & Noordam, 2018), concentrated in and around the capital city of Paramaribo (Algemeen Bureau voor de Statistiek Suriname, 2023; Holband et al., 2020).

Suriname has had to deal with these losses and damages, undertake adaptation interventions and build climate resilience mainly from its small national budget. Moreover, recognizing the vulnerability of the coast and ever-increasing impacts on a significant percentage of the population, Suriname's dilemma is whether to continue to invest heavily in adaptation or relocate and rebuild its entire economy away from the threat of the rising sea. This would mean shifting inland, a massive costly venture which would also put pressure on the country's forest resources and which could be jeopardizing Suriname's contribution of maintaining 15 million ha forest as both a huge carbon sinks and the "lungs of the Earth" for the global community (United Nations Development Programme, 2020; United Nations Development Programme in Suriname, 2016).

It is evident that the country must find ways to manage the implications and to take timely measures to prevent big losses. Resulting from this, policy makers, governmental bodies and national institutes especially, have drawn more attention to the preservation of the coastal areas, but also non-governmental organizations, national university and the Surinamese society itself in general are aware of the consequences. As a result, resources are sought, and activities undertaken by these parties to address environmental impacts on the coast. However, there is still no evidence of a generalized approach for basic assessment of these environmental impacts, and no strong enforcement of the environmental law (Milieu Raamwet, 2020) and designated model or system that deals with all aspects of monitoring the coast, by organizations involved in mitigation efforts individually act on their own best interests (Berrenstein & Gompers-Small, 2016; Government of the Republic of Suriname, 2023; United Nations Development Programme, 2020). Remote Sensing (RS) and Geographic Information System (GIS) for geoprocessing are the basis for assessing large terrain comprehensively (Chaminé et al., 2021; Hadipour et al., 2020). However, Suriname has a poor academic representation which covers only a handful of research, in an already low representation of flood mapping in development countries (Membele et al., 2022). In addition, Suriname is currently experiencing economic difficulties, and therefore a cost-effective approach would be most appropriate to ensure the continuity of the flood risk assessment model.

The proposed guiding question for this research is: How can multi-temporal satellite image processing and geospatial multi-criteria analysis be utilized to assess flood susceptibility and guide mitigation methods in coastal areas? The following complex hypothesis (Barroga & Matanguihan, 2022) predicts the relationship between one dependent variable with multiple independent variables: The Coastal Flood Vulnerability Index (CFVI) can be determined through the integration of multi-temporal satellite image processing and geospatial multi-criteria analysis. By using a geospatial-based multi-criteria decision approach, the Flood Vulnerability Index for the coastal plain at the district level can be assessed, providing a comprehensive understanding of flood susceptibility and guiding mitigation methods in coastal areas. Accordingly, the objective of this research is to use a geospatial-based multi-criteria decision approach to determine the Flood Vulnerability Index for the coastal plain at the district level, with the aim of assessing its resilience of coastal settlement areas and inform decision-making for flood risk management.

2. Methodology

2.1. Research type

The case study and field research method is chosen by its adaptability to independent research by its cost effectiveness and less time needed in to acquiring data, and is applied by best practice for small target area or a small group, delivering a comprehensive open data flood disaster monitoring model (Creswell & Poth, 2016; Roudgarmi, 2011; Yin,

2014). Although the case study was categorized within qualitative design, it can be considered a dynamic method, as it allows for thorough and comprehensive examination (Roudgarmi, 2011).

2.2. Study area

It is important to suggest a predictive flood model for the entire country of Suriname, but the area of interest is kept within the districts that are part of the coastal plain (Kroonenberg & Noordam, 2018; Wong et al., 2017) (see Figure 1) to highlight the settlement majority of the nation's population, infrastructure and low-lying geological formation, in order to find an efficient way to test the hypothesis. The width of the coast is approximately 386km. Each district is bounded by main rivers that lead towards the Atlantic Ocean, and each its coastline with Para excluded.

Figure 1. Geological map of Surinamese districts that are part of the study area.

2.3. CFVI model

As the objectives suggests, the research involves the developing of a Coastal Vulnerability Index (CFVI) model, which is based on secondary data indices with relevant stakeholder feedback as primary data, by interviews conducted in June 2023. The following equation (1) is derived from the Intergovernmental Panel on Climate Change (IPCC), 4th Assessment Report (Parry et al., 2007):

$$CFVI = \frac{E \times S}{AC} \qquad (1)$$

where, E represents exposure, S the sensitivity, and AC for the adaptive capacity criteria.

The purpose of the interviews is to attribute to CFVI components, especially adaptive capacity, for the potential flood early warning, mitigation works or other monitoring facilities or attendance within the country or at district level. (see appendix I for interview questions). Kobotoolbox (kobotoolbox.org) is used to distribute the questionnaires via web platform, and then to collect and summarize the data from the interview participants. The open access QualCoder software (Curtain, 2023) is chosen as Qualitative Data Analysis (QDA) tool for the coding process as part of the six step thematic analysis to differentiate the various themes from the interviewee data (Braun et al., 2022; Clarke et al., 2015).

The Table 1 gives an overall view of the data type used for each CFVI criterion, where each subcriteria has mentioned details for functionality, the relevant date and sources that developed the datasets. The resolution is included for the satellite based earth observation data.

Table 1. Acquired type indices and its sources.

Criteria/ Subcriteria	Details	Update/ timeframe	Source(s)
Exposure			
Land Use and Land Cover (LULC)	Settlement markers, i.e. Infrastructural (built) areas. Resolution Sentinel-2 30meters.	2017 to 2022	(Karra et al., 2021)
Historic (most frequent) flood events.	Flood analysis are carried out using the United Nations- SPIDER source code for Google Earth Engine (GEE), utilizing Sentinel-1 SAR (10 meters), among other RS indices.	Multi-temporal settings from 2021 to 2023	(Ali et al., 2018; European Commission. Joint Research Centre., 2017; Notti et al., 2018)
Global surface waters	Distance to water bodies (shoreline, lakes and inland rivers). Landsat 5,7 and 8 at ~30 m	1984 to 2021	(Pekel et al., 2016)
Digital Elevation Model (DEM)	SRTM in ~30 meter (1-arc) resolution void filled and Global DEM	2014	(Earth Resources Observation And Science (EROS) Center, 2018)
Sensitivity			
Population density	Demographical statistics given per district	2012 Census	(Algemeen Bureau voor de Statistiek Suriname, 2014)
National multidimensional poverty index	Poverty markers	2012 Census	(Algemeen Bureau voor de Statistiek Suriname, 2023; Rosita Sobhie; Anjali Kisoensingh, 2023)
Vulnerable population	60+ elderly	2012 Census	(Algemeen Bureau voor de Statistiek Suriname, 2014)
Gender	Population female ratio	2012 Census	
Adaptive Capacity			
Public health facility	Number of Regional Health facilities per district.	2023	(Stichting Regionale Gezondheidsdienst (RGD), 2023)
Health care	Number of doctors per district.	2022	(Staatsziekenfonds (SZF), 2022)
Barriers	Natural barriers, especially mangrove habitat and dykes.	2020	(Bunting et al., 2018, 2022; Haage et al., 2018) ; Stakeholder interview.
Flood early warning	Literature indication, but Relying mainly on stakeholder confirmation for any early warning installation.	2023	(Government of the Republic of Suriname, 2023; United Nations Development Programme, 2020); Stakeholder interview.

In addition to GEE, data preprocessing for the exposure component was performed in the GIS environment QGIS version 3.20.3 (QGIS Association, 2023).

2.4. Weighting and scoring

Multi Criteria Decision Making (MCDM) approach is applied using the common Weighted Sum Model (WSM) in addition to the judgements of experts (Triantaphyllou, 2000). They score each sub criterion from 1 to 5 as lowest and highest scores, respectively. The expert opinions of Dr. Muhammad Helmi, S.Si., M.Si., as academic within the field,

and that of Dr. Armand Amatali, as expert in Suriname were taken into consideration (see appendix II for their score chart)

The WSM is applied for each sub criterion of the CFVI. The requirements of WSM is to have single dimensional units of measurement, therefore having normalization (criterion average) applied for each criterion value (Triantaphyllou, 2000), which can be applied to multi-criteria GIS indices (Malczewski & Rinner, 2015). The WSM is depicted in the next equation (2 (Fishburn, 1967).

$$A_{score}^* = max_i \sum_{j=1}^{n} a_{ij} w_j \text{ , for } i = 1,2,3, \dots, m \tag{2}$$

where applied, A_{score}^* is the score of the highest alternatives, namely districts, n is the number of CFVI subcriteria, a_{ij} is the actual value of the i-th district in terms of the j-th subcriterion, and w_j is the weight of importance of the j-th CFVI subcriterion and dependent on expert judgement, presented by the subsequent equation (3.

$$w_j = \frac{\sum_{k=1}^{p} S_{jk}}{p \sum_{k=1}^{n} E_k} \tag{3}$$

where, w_j is the normalized expert scoring, S_{jk} score given by judge k for criterion j, p amount of experts, normalized by the rest of denominator where E_q is the score for each expert every n times the subcriteria. Thus, the weighted CFVI is subjugated per district as equation (4 presents.

$$CFVI = \frac{S_{A_{score}^*} \times E_{A_{score}^*}}{AC_{A_{score}^*}} \tag{4}$$

2.5. Relevant studies

The Table 2 presents some of the most recent similar application in academia.

Table 2. List of recent relevant researches

#	Citation	Title	Method	Context relevance	Difference
1	(Guzman et al., 2017)	Paramaribo Strategic Flood Risk Assessment Final Report.	Mix method.	Thorough assessment of flooding in Paramaribo that includes infrastructural mismanagement and already suggested off-the-shelf systems such as Deltares.	General approach and limited to Greater Paramaribo, and flood relief for public infrastructure.
2	(Allafta & Opp, 2021)	GIS-based multi-criteria analysis for flood prone areas mapping in the trans-boundary Shatt Al-Arab basin, Iraq-Iran	GIS multi-criteria analysis.	Flood analysis accentuating remote sensed data and AHP through expert opinion.	Trans-boundary case of Iraq-Iran, flood assessment model by remote sensing/ GIS and addition of traditional data.
3	(Padhan & Madheswaran, 2023)	An integrated assessment of vulnerability to floods in coastal Odisha: a district-level analysis.	Indicators relying on secondary data and normalized indices using the Iyengar & Sudarshan (1982) method.	Flood Vulnerability Index (FVI) derived from IPCC 2007 reporting. FVI Indicators of socioeconomic , physical and environmental components are used to rank the up to district level; ranked high globally as a vulnerable coastal region	It's a case study of Odisha, India where there are other calamitous natural disasters and FVI indicators have a larger extent, especially in the demographics.

| 4 | (Tempa, 2022) | District flood vulnerability assessment using analytic hierarchy process (AHP) with historical flood events in Bhutan | Analytic hierarchy process (AHP) type MCDM. | Flood vulnerability assessment at district level, the use of AHP method for scoring and weighing each variable | Case study in Bhutan, Extensive historic flood event analysis and different flood vulnerability model structure, use of MCDM. |

3. Result and Discussion

3.1. CFVI Exposure maps.

The following images are the generalized results of the CFVI Exposure component variables to express the role of RS and GIS in the total vulnerability score (see appendix for complete CFVI). The LULC map in Figure 2 brings the overall land use of settlement areas in view.
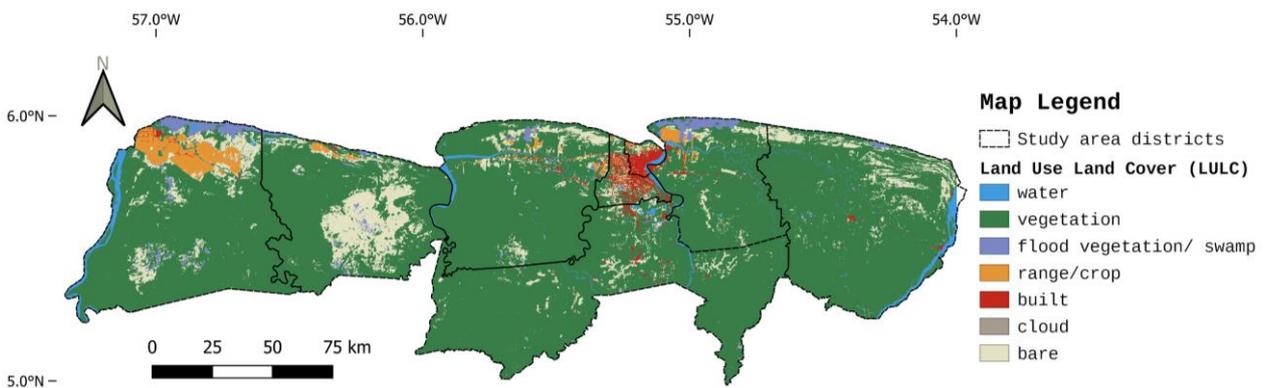

Figure 2. LULC dataset classification and cropped within the study area for quantifying the built areas.

The color classified raster image dataset is built with six bands (red, green, blue, nir (near-infrared), swir1 (short-wave infrared 1), and swir2 (short-wave infrared 2)) of Sentinel 2 L2A surface reflectance corrected imagery at 85% sampling accuracy (Karra et al., 2021). The extracted LULC map of the Surinamese coastal plain supports the idea of centralized development in the capital city, with expansion occurring outward into nearby districts. The rural district Nickerie has a large portion of land use identified as agriculture.

The coastal plain distinctively grouped in elevation in the next Figure 3, where digital elevation model (DEM) and SRTM (Shuttle Radar Topographic Mission) were used for the topographic assessment (Earth Resources Observation And Science (EROS) Center, 2018; Zhou et al., 2022). Since the definition of low-lying coast varies for each coastal region (Bao et al., 2020; Parvin et al., 2022), the CFVI takes into account areas with a Digital Elevation Model (DEM) below 7 meters when classifying them into 5 distinct classes.
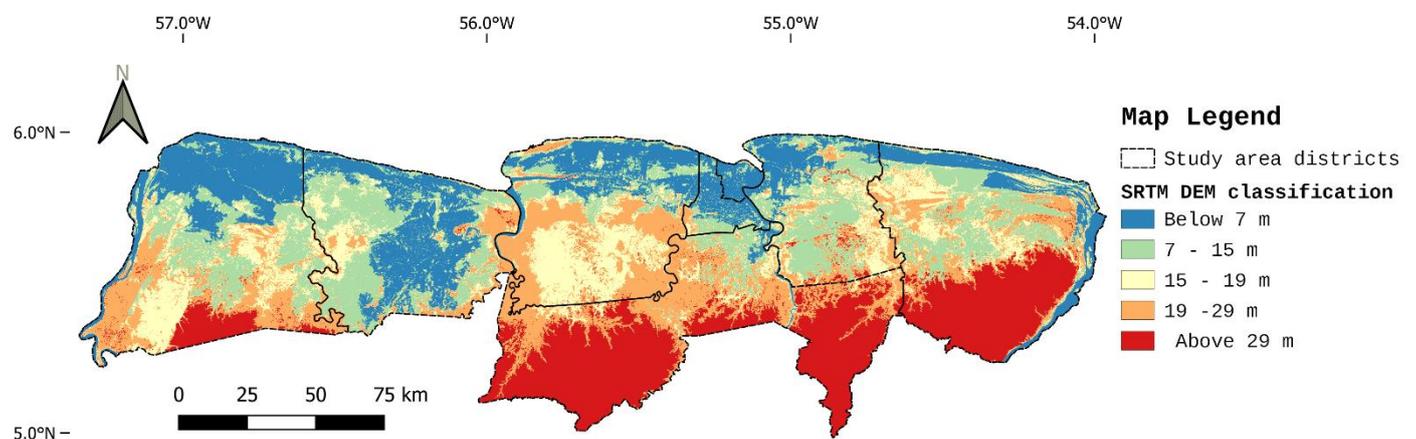

Figure 3. DEM map represented by vertical variation in meters.

The global water occurrences dataset combines Atlantic Ocean, inland rivers and major swamps, for a unified distance to permanent water bodies classification (Crăciun et al., 2022; Pekel et al., 2016). The distance classification is presented in Figure 4, where the first 2km distance class to permanent water bodies is considered for CFVI.
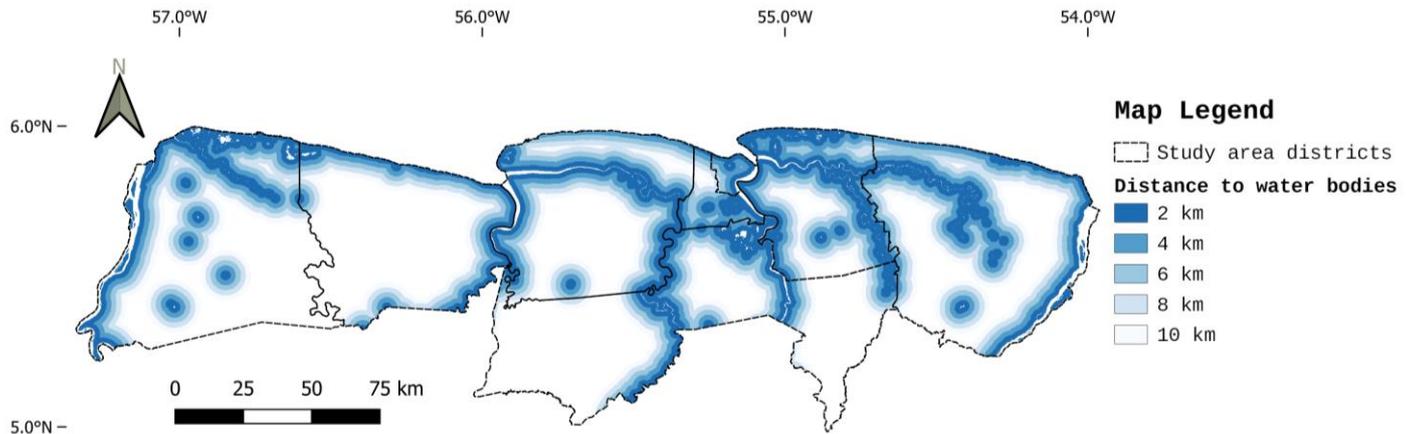

Figure 4. Distance to water bodies (Atlantic Ocean, inland rivers and swamps) classified by 5 distance categories of 2 km increments.

To monitor frequent flood events during the annual rainy season, a difference layer is generated using Sentinel-1 Ground Range Detection (GRD) through Synthetic Aperture Radar (SAR) multi-looking. This layer is created by comparing before and after flood mosaics. The difference layer is optimized at a threshold of 1.10 through trial and error in Google Earth Engine (GEE). Global Surface Water and Digital Elevation Model maps are used to exclude permanent water bodies and slopes higher than 5%, respectively (Ali et al., 2018; European Commission. Joint Research Centre., 2017; Notti et al., 2018). A time period between 2021 and 2023 is selected to classify flooding in all districts. A combination of VH (Vertical Transmit, Horizontal Receive) and VV (Vertical Transmit, Vertical Receive) polarizations in both descending and ascending orbits is used. The more frequent flood event threshold map is shown in Figure 5.

Figure 5. Most frequent flood events classified in GEE with Sentinel-1 images of 2021 to 2023.

According to the aforementioned LULC map, crop areas in Nickerie and Commewijne are prone to annual flooding. Additionally, areas near Wanica, central Para, and Paramaribo are of particular concern due to their proximity to built-up areas.

3.2. Final CFVI map

The final score for the CFVI mapping in Figure 6 presents the highest scores in urbanized Paramaribo and Wanica.
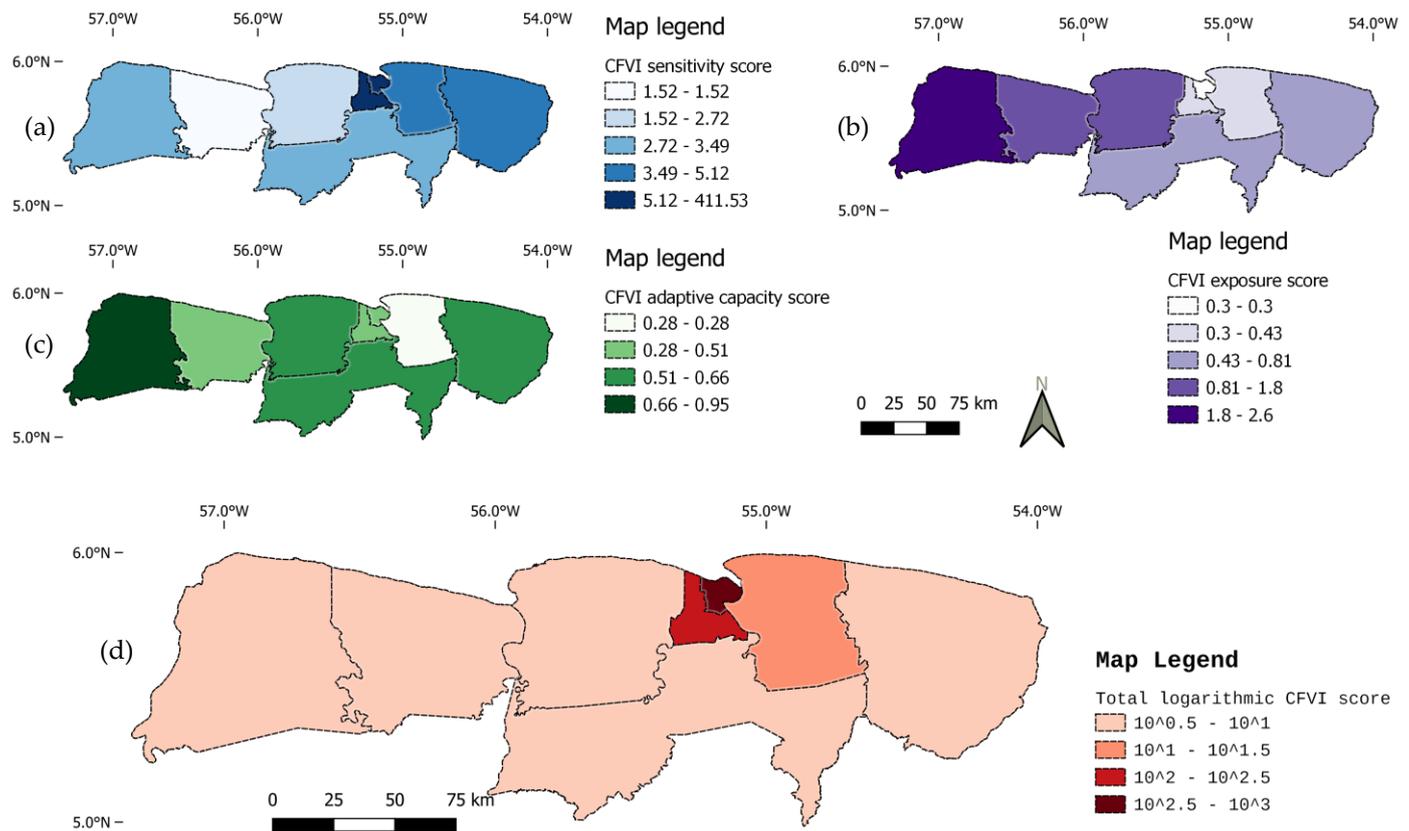
Figure 6. The CFVI criterion are visualized in Jenks natural breaks classification method where: (a) Sensitivity scores high for Paramaribo and Wanica; (b) Exposure via remote sensing scores high in the Western districts and highest in Nickerie; (c) Adaptive Capacity score is highest in Nickerie. (d) The total CFVI is presented in logarithmic range to distinguish the highest vulnerability for Paramaribo, followed by Wanica and Commewijne.

An individual assessment of each CFVI criterion shows that higher degrees of settlement sensitivity, which are based on demographic data, are present in the capital city due to its high population density per unit area. This is reflected in national statistics such as population density and welfare markers. The exposure map, created using GIS assessment, shows that the Nickerie district has the highest exposure to flooding. In terms of adaptive capacity against flooding, the Nickerie district is the most capable of managing frequent flood events. The final CFVI map, which is the result of applying the CFVI equation to each district, shows that Paramaribo followed by Wanica and Commewijne remained the most vulnerable due to their high population density compared to the rest of the country (See supplementary data for CFVI in details).

3.3. Interviews

In order to obtain information on possible current monitoring systems and the status of the nation's flood mitigation efforts, qualitative feedback is given to the CFVI by semi-structured interviews (Creswell & Poth, 2016; Yin, 2014) which are undertaken within management levels of relevant stakeholders. The most relevant organizations/ individuals are listed to be interviewed within governmental bodies, non-governmental organizations (NGOs), or influential private sector relevant to flood disaster monitoring. Figure 7 presents the general responses for flood - details, mitigation or early warning system.
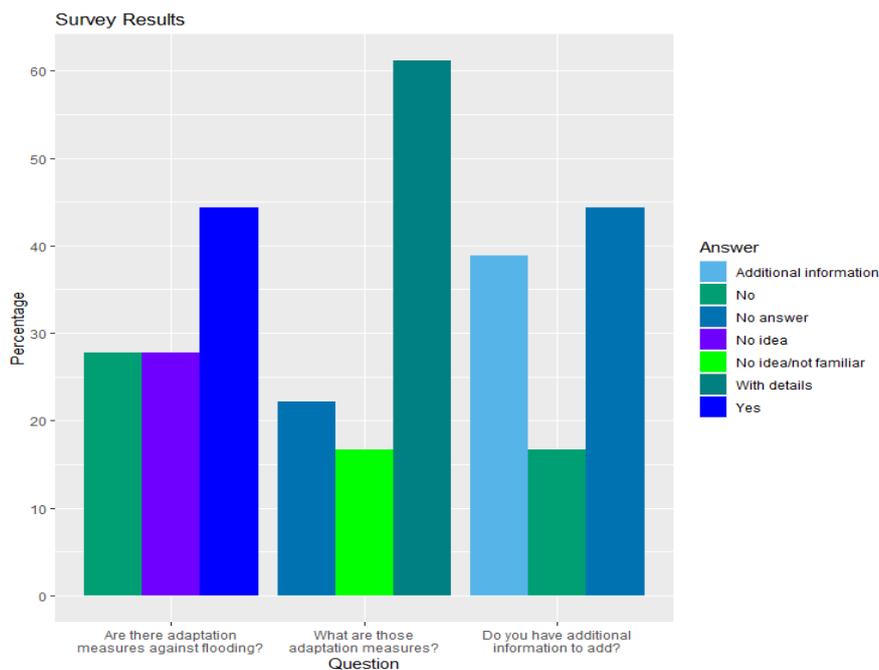
Figure 7. Generalized stakeholder perception towards adaptive capacity markers.

After the coding process in QualCoder, the subsequent thematic representation derived from the interviews is presented in the Table 3 below.

Table 3. Thematic assessment of stakeholder interview data.

Theme	Summary of response
Drainage system	Rehabilitate and adapt the drainage system, including timely maintenance of channels with public and private locks, creating overflow areas, and increasing pumping station capacity.
Building/ housing adjustments	Preventive housing construction includes moving to higher areas, obtaining proper building permits, and building homes on stilts or as flexibly floatable. Authorities should investigate and assist before approving construction.
Planning	The Master Plan update proposes solutions to reduce flooding, which the government will implement using loans or budgetary resources. Ongoing studies and research for Paramaribo and Wanica are financed by international monetary institutions. The World Bank-financed project to improve the Saramacca canal system and update the Master Plan for Greater Paramaribo's dewatering covers part of the Wanica District.
Suggestive Response	Set up a call support line or website for reporting flooding and requesting canal cleaning. Improve litter management. Execute spatial planning, retreat from vulnerable areas, and include climate change variables in planning and civil engineering actions with multi-annual impact.
Capacity development	Repeat disaster management training at district levels. A few years ago, some people were trained by NCCR (nation's disaster response unit) for disaster management. Today, most of them are no longer on the supervisory board of the districts
Climate change adaptation and mitigation	Mangrove habitat regrowth and conservation for coastal protection. Make data available on climate change effects and prepare people for it. Environmental effects have worsened, and UNDP, ministries, and NGOs are promoting activities such as disaster management training and mangrove planting. For more information, see the Third National Communication to the United Nations Framework Convention on Climate Change (Government of the Republic of Suriname, 2023).

Additionally, the following Figure 8 gives a geospatial representation of frequent flood locations mentioned by the interviewees, where they have pinpointed by naming neighbourhoods, streets or certain district resorts that deals with frequently flooding events.
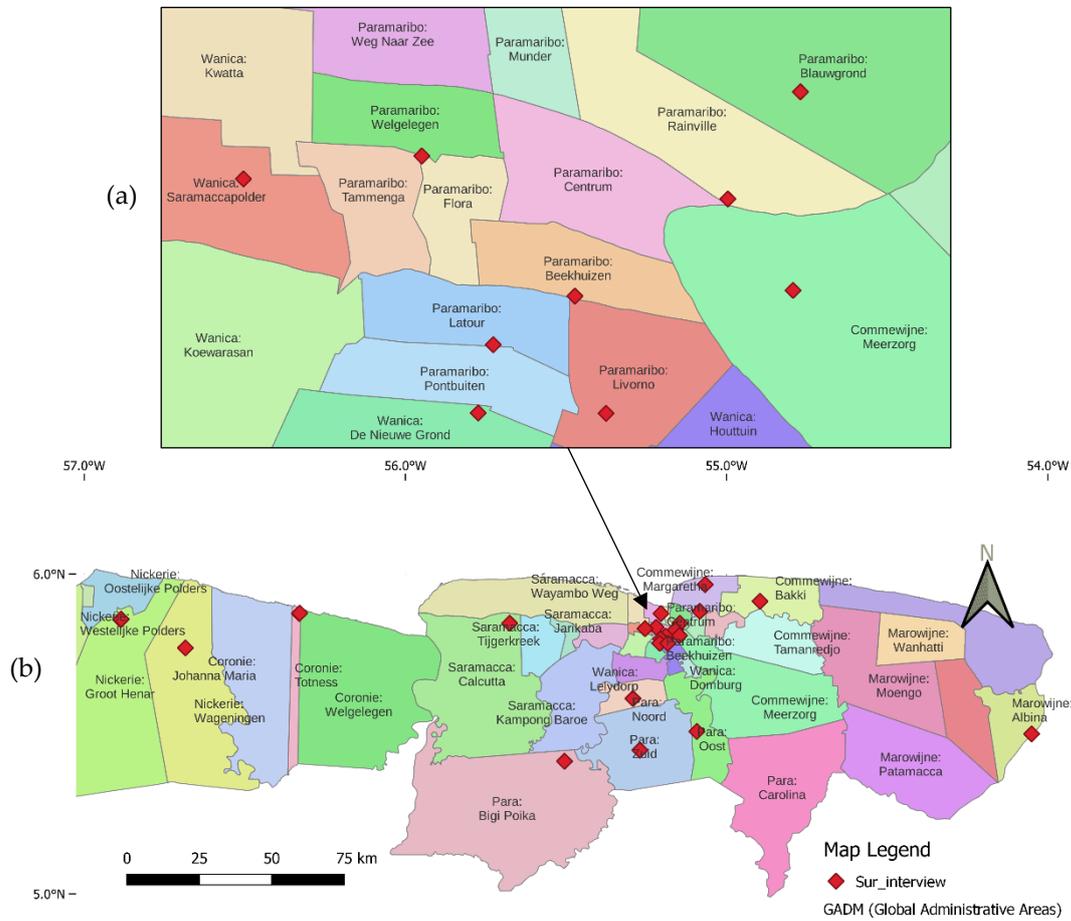

Figure 8. (a) Paramaribo presents a higher amount of (b) total pinpointed frequent flood events (red diamond symbology *Sur_interview* legend) by interview, and placement in district's resorts.

As depicted in Figure 8, in Paramaribo, the district usually suffers from flooding during heavy rainfall. About 30% of the Uitvlucht en Hermitage area is affected, with Tammenga and Flora experiencing high levels of flooding. Lachmon Street in Resort Flora also experiences high levels of flooding. Weg naar Zee experiences average levels of flooding, with Benni's Park and Beni's Park 1 in Resort Weg naar Zee experiencing moderate levels. Welgelegen experiences low levels of flooding, with the Academic Hospital area and Margrethalaan area in Resort Welgelegen experiencing high levels. Paramaribo North experiences moderate to high levels of flooding, with Tourtonnelaan and Maretraite 4 experiencing high levels. Paramaribo Center in Resort Centrum experiences high levels of flooding. In Paramaribo South-West, Latour experiences moderate to high levels of flooding, Pontbuiten experiences high levels, Winti Wai and Ephraimzegen experience moderate to high levels, and Livorno in Resort Livorno experiences low levels.

In Saramacca, Calcutta averages especially during extreme high tides and heavy rainfall. In Para, Para East (Paranam; Accaribo), North (Onverwacht; Bernarddorp), South (Berlijn, Cabendadorp, Hollandse Kamp, Matta, Onverdacht, Pikin Saron, Sabakoe, Witsanti and Zanderij) and the road to Tibiti are affected. In Marowijne, the Anjoemara project experiences low levels of flooding while Ingi Pikingweg and its surroundings experience high levels. In Nickerie, Resort Wageningen experiences low swamp area due to overdue maintenance of both dry and wet infrastructure. Henar / Eastern polders experience issues with broken locks and culverts. In Coronie, Resort Welgelegen (Jenny and Mary's Hope) and Resort Totness (Totness) experience low levels of flooding. In Commewijne, New Amsterdam resort; Military project experiences low levels of flooding as do Voorburg, Zoelen, Lust and Rust (Rosan project), and Jaglust (various allotments). Ressort Johanna Margaretha also experiences low levels of flooding while Resort Bakkie experiences low levels and Meerzorg and Laarwijk experience average levels. In Wanica, various locations at Leidingen are affected.

3.4. Discussion

The CFVI score indicate high vulnerability in Paramaribo and second highest in Wanica, which can be confirmed by the feedback with the stakeholders. The capital Paramaribo has the most concentrated frequent flood event indicated by interviewees. Many urban and peri-urban neighborhoods are expected to experience floods during heavy rainfall which can disrupt crucial infrastructures such as the hospital area.

It is important to note that Nickerie is the country's primary agricultural district, known for its rice cultivation (Ritzema & Naipal, 2013). As a result, most of the flooding in this district would be intentional and managed for agricultural purposes. To keep a consistent unit of measurement, only the built areas where considered for the CFVI. Based on the CFVI map, it appears that there are significant differences between the districts in terms of Total Sensitivity, Total Exposure, and Total Adaptive Capacity. Paramaribo has the highest total sensitivity due to the high population density.

The GEE algorithm by UN-SPIDER has some limitations, such as difficulties in detecting floods in urban or densely vegetated areas and uncertainties in damage assessment due to the spatial resolution of Sentinel 1 data and type of flood classification method used. Despite these limitations, high flooding in road areas for especially Paramaribo Noord region have been observed. The surveying of affected population of the settlement area to pinpoint the locations of frequent flood events can contribute to these limitations, and would be suitable as a follow up and indepth research.

A flood resilience assessment can be extracted from the interviews, whereby transparency of flood updates information sharing between the settlement areas, such as to set up a telephone hotline or website where people can report flooding and request cleaning of gutters and canals. Better management of plastic and other litter could also provide quick benefits. Spatial planning, including retreat from vulnerable areas prone to flooding and the inclusion of climate change variables in planning, could also be effective. Capacity development, such as repeating disaster management training at the district level, could also be beneficial.

In terms of climate change adaptation and mitigation, making data available on the effects of climate change on different living environments and preparing people for these changes is crucial. Environmental effects have become more severe due to climate change, and efforts are being made to address this through initiatives such as promoting activities with UNDP, training by NCCR on disaster management, and planting more mangroves along the coast. There was a referral to the mitigation proposals mentioned in the Third National Communication to the United Nations Framework Convention on Climate Change (Government of the Republic of Suriname, 2023) suggesting, among many: development of infrastructure for flood protection and drainage, but the zoning plans are important following a lack of spatial data being a limiting factor for proper flood adaptive infrastructural planning, education in regards to the changing climate, improving healthcare as diseases related to flood and climate change, as stated in page 19 (Government of the Republic of Suriname, 2023):

> Health risks are likely to increase as a result of climate change, including new pathogens, respiratory illnesses, diarrhea and cholera outbreaks which are most likely to impact low-lying communities (coastal and hinterland along rivers).

The purpose of the CFVI is to serve as a basic model that can be expanded to the resort level and include more relevant stakeholder contributions and sub-criteria. For example, in district Para, where the coastal plain transitions into higher elevations, a slope map can be included to the CFVI. Additionally, contemporary rainfall and storm patterns can be incorporated for a more extensive predictive model that is in line with climate trends. The CFVI can be refined to focus on the capital city and its administrative resorts, providing a foundation for flood mitigation modeling that includes community-level assessments of frequent flooding. This can help efficiently pinpoint vulnerable areas and suggest resilience measures and forecasting such as crucial flood insurance, flood-resistant domestic infrastructure, and early warning systems (Qi et al., 2021).

4. Conclusion

The near-annual occurrences of flood events were analyzed using remote sensing Sentinel-1 SAR products from 2021 to 2023 to determine their merit. While this method can be useful for detecting large flood events, it has limitations in detecting more common flood events in roadways and neighborhoods, particularly in urban areas such as Paramaribo and Wanica, where accurately detecting and managing flood events is crucial.

This research aimed to generate a Coastal Flood Vulnerability Index (CFVI) for flood using a geospatial multi-criteria analysis approach based on exposure, sensitivity, and adaptive capacity components. The CFVI model equation incorporates various relevant flood disaster variables in a well-structured manner and can be further expanded for a more comprehensive and in-depth approach to assess flood vulnerability per district.

Furthermore, a flood vulnerability assessment for the districts with the highest and second highest CFVI values is concluded through an integrated approach that combines a literature review and stakeholder feedback. Stakeholders have provided their insights and pinpointed areas that frequently experience flooding, thereby contributing to initiating a flood early warning, which can assist in further follow-up analysis within the communities. The CFVI can be easily adjusted and shaped to fit available criteria. It can provide continuity by relying mainly on off-the-shelf open accessible datasets.

Acknowledgements

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