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Perspective

The need for data integration to address the challenges of climate change on the Guyana coast

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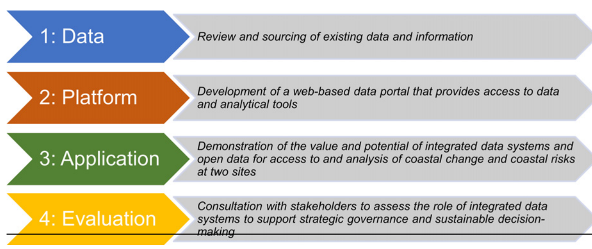
HIGHLIGHTS

- Accurate measurement of coastal processes is vital to monitoring coastal changes
- Data integration is key in preparation for climate mitigation and adaptation
- Creation of a central resource for data supports strategic decision making
- Real-time coastal information helps in understanding of the coastal behavior.

GRAPHICAL ABSTRACT



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ABSTRACT

Guyana's capacity to address the impacts of climate change on its coastal environment requires the ability to monitor, quantify and understand coastal change over short-, medium- and long- term. Understanding the drivers of change in coastal and marine environment can be achieved through the accurate measurement and critical analyses of morphologies, flows, processes and responses. This manuscript presents a strategy developed to create a central resource, database and web-based platform to integrate data and information on the drivers and the changes within Guyana coastal and marine environment. The strategy involves four complimentary work packages including data collection, development of a platform for data integration, application of the data for coastal change analyses and consultation with stakeholders. The last aims to assess the role of the integrated data systems to support strategic governance and sustainable decision-making. It is hoped that the output of this strategy would support the country's climate-focused agencies, organisations, decision-makers, and researchers in their tasks and endeavours.

1. Introduction

The accompanying environmental effects of climate crises are particularly significant on coastal territories and environments (Robert and Schleyer-Lindenmann, 2021). Coasts and coastal systems across the globe are directly exposed to the environmental pressures and societal challenges from both climate and anthropogenic changes. These include hazards associated with sea-level rise, rising temperatures, increasing storm frequencies, unpredictable wave current and climate events, ocean acidification, and myriads of connected coastal-environmental issues (Nicholls, 1995; Chaumillon et al., 2017; Losada et al., 2019; Robert and Schleyer-Lindenmann, 2021). With no country immune to the threats and risks of the influence of these climate-related crises that specifically impact low elevation coastal zones (Hickey and Weis, 2012), governmental authorities are increasingly facing the need to developing adaptation strategies, especially in the coastal territory facing the challenges of growing population, pressures on socio-economic amenities and coastal morphodynamics (Nicholls, 2011). Pressures from anthropogenic activities, as well as erratic climate parameters, are changing the coast and causing enormous variations which are amplifying risks and threats in this dynamic environment (Losada et al., 2019).

Sourcing and analysing coastal data requires, for example, exhaustive processes and multi-task endeavours that involve searching for and selecting earth observation data, reviewing and downloading data (many of which are freely available on USGS Earth Explorer and other data hubs), processing and calibrating the data for local environment. In

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addition, the demand for higher quality data, with high resolution (spatial, spectral, radiometric, etc.), requires additional computing storage capacity, and computing processing power and capacity. Other requirements are mostly beyond the reach of many researchers and coastal scientists, especially in low and middle income developing countries. The potential of web platforms to hold and host a growing number and range of publicly available datasets from different sources is proving essential in ameliorating some of the computational challenges faced by researchers and stakeholders in developing countries.

There are various global reports, statistics and databases on climate-induced disasters such as those from the World Meteorological Organisation (https://public.wmo.int/en), the United Nations Climate and Environment (https://news.un.org/en/story/2021/09/1098662), the United Nations Environment Programme (https://www.unep.org/), United Nations Framework Convention on Climate Change (https://unfccc.int/), United Nations Office for Disaster Risk Reduction (https://www.undrr.org/), the International Charter Space and Major disasters (https://disasterscharter.org/web/guest/home), and Oxfam International (https://www.oxfam.org/en/5-natural-disasters-beg-climate-action). There is also a plethora of research articles on the coastal environment (e.g., Archer et al., 2014; Bulkeley and Newell, 2015; Manning et al., 2015; Vila et al., 2015; Hetz, 2016; Murakami et al., 2017; Spencer et al., 2017; Luijendijk et al., 2018; Mentaschi et al., 2018; Nerem et al., 2018; Baills et al., 2020; Voudoukas et al., 2020; Busayo and Kalumba, 2021; Morelli et al., 2021). It is well known that global occurrence of disasters and their severity on coastal environments have escalated significantly in recent years.

Numerous tools have been developed for coastal studies. These include, for example, shoreline monitoring for studies in coastal vulnerabilities and management (McLaughlin and Cooper, 2010), shoreline prediction tools (Montaño et al., 2020), shoreline detection tools (Pardo-Pascual et al., 2018), Digital Shoreline Analysis System (Thieler et al., 2017), CoastSat software (Vos et al., 2019), Coastal Analyst System from Space Imagery Engine (CASSIE) (Almeida et al., 2021), and a plethora of GIS tools and applications (e.g., Elkafrawy et al., 2020; Marzouk et al., 2021; Nicolodi et al., 2021; de Lima et al., 2021). Despite the development of tools, data scarcity and data integration remain a challenge for the long- and short-term monitoring programmes in the coastal environment, especially in developing countries where a different perspective and approach need to be taken to deliver a central resource and web-platform database with a focus on climate change.

To improve the ability of decision-makers, environmental managers, conservationists, disaster risk managers, policymakers, governmental and non-governmental institutions in making informed decisions for current or projected coastal change scenarios for Guyana, and other developing countries, the integration and combination of morphological data with other change causal real-time measurements are critical. There is a gap for a data integration analysis system in Guyana and this paper aims to demonstrate the need of filling this gap, and the inadequacies of existing approaches utilised in developed nations. Our goal is to describe a web-based data integration and analysis system to capture observation and monitoring at the catchment-coastal-marine interface. This development will raise Guyana's capacity and capability to use a range of open access environmental datasets across different platforms and timeframes, thereby meeting the data integration need for the country. These datasets can be used to generate quantitative and qualitative information and support subsequent analyses for the benefit of stakeholders from Guyana's coastal environment.

2. Guyana's coast

Guyana is a tropical Atlantic country in South America with approximately 2% of its land area below 5 m (Fig. 1). With a geographic area of 214,970 km^2 (including 196,850 km^2 of land and 18,120 km^2 of water), a 430 km coastline on the northeast, and a continental extent of about 724 km, Guyana has a coast that is 0.5 m to 1 m below mean high tide (Government of Guyana, 2012). Guyana's vulnerabilities to climate variabilities are well articulated in several governmental and national policy documents. Examples of these documents include the Low Carbon Development Strategy (LCDS), Second National Communications (SNC), and the Green State Development Strategy (GSDS). Further examples of similar works which articulate the vulnerabilities of coastal environment to climate scenarios and the need for a database are described in Bulkeley et al. (2012) and Dawson et al. (2020). In Guyana, the key climate vulnerabilities are floods and droughts.

Guyana's low-lying coastal zone is home to more than 90% of the country's population (approximately 800,000 inhabitants) and hosts the main socio-economic activities, seats of governments, bulk of the population livelihoods, economic activities and infrastructures (Government of Guyana, 2012). The level of vulnerability is illustrated in the fluvial and coastal floods experienced in 2013, 2014, and 2015, and the droughts of 2015 and 2016 (Office of Climate Change, 2016a). Many areas along the coast, for instance, became inundated from heavy and continuous rainfall and overtopping of the sea defence infrastructure. The existing technologies used to protect the coastal zone include concrete sea defences (seawalls and groynes) and stationary and mobile pumps to control water levels and coordinate irrigation activities.

Through the Technology Needs Assessments (TNA) (Office of Climate Change, 2016b), the country has identified initiatives to support the existing technologies for the coastal zone, specifically: i) conducting studies on developing Early Warning Systems to monitor, predict and disseminate information on possible hazards in the coastal zone and plain, and ii) mapping and modelling of coastal processes. For these identified initiatives, access to integrated data is key, hence this research presents an innovative plan and application that meets the obvious and existing gap.

Climate projections for Guyana indicate a continuous rise in temperature and increasing intensity and frequency of extreme climate-based events (Office of Climate Change, 2015). These projections are based on assumptions of a doubling concentration of carbon dioxide over the next two decades, which will lead to a projected increase of 1.2°C above the 1995 temperature by 2050 and of 4.2°C by 2100 (Government of Guyana, 2012; Hickey and Weis, 2012; Mycoo, 2014). The southern region of the country is expected to be severely affected by these projected scenarios. Environmental consequences of these projections will include the exposure of the southern, coastal region to inundations, saline intrusion into groundwater, overtopping of sea walls and other coastal defences, increasing intensity of flood volumes and frequencies, bringing a wide range of impacts on coastal agriculture and other socio-economic assets (Office of Climate Change, 2016a). Guyana is already implementing several adaptation measures. Flood protection, for example, is being taken at national, regional and local levels, but there are concerns regarding their effectiveness (Ministry of Agriculture, 2016; Office of Climate Change, 2016a). Efforts are directed to promoting sound adaptation measures guided by precise, relevant and real-time data in keeping with Decision 17/CP8, Paragraph 29 of the UNFCCC (Office of Climate Change, 2016a).

3. Climate change research in Guyana between 2012 and 2021

The 2012–2021 decade has witnessed a growing interest and research on climate-related issues in Guyana, despite the challenges brought by inadequate funding from the national and regional government to academic research involving climate change. This includes the evaluation of citizen's response and adaptation to the continuous effects of climate change, and the building capacity for governance responses to their effects in urban environments (Hickey and Weis, 2012; Mycoo, 2014; Garschagen and Romero-Lankao, 2015; Johnson-Bhola, 2016; Filho et al., 2019), research on how citizens and indigenous communities' deal with vulnerability issues regarding climate change (Berardi et al., 2013; Fook, 2013; Kalamandeen, 2013;

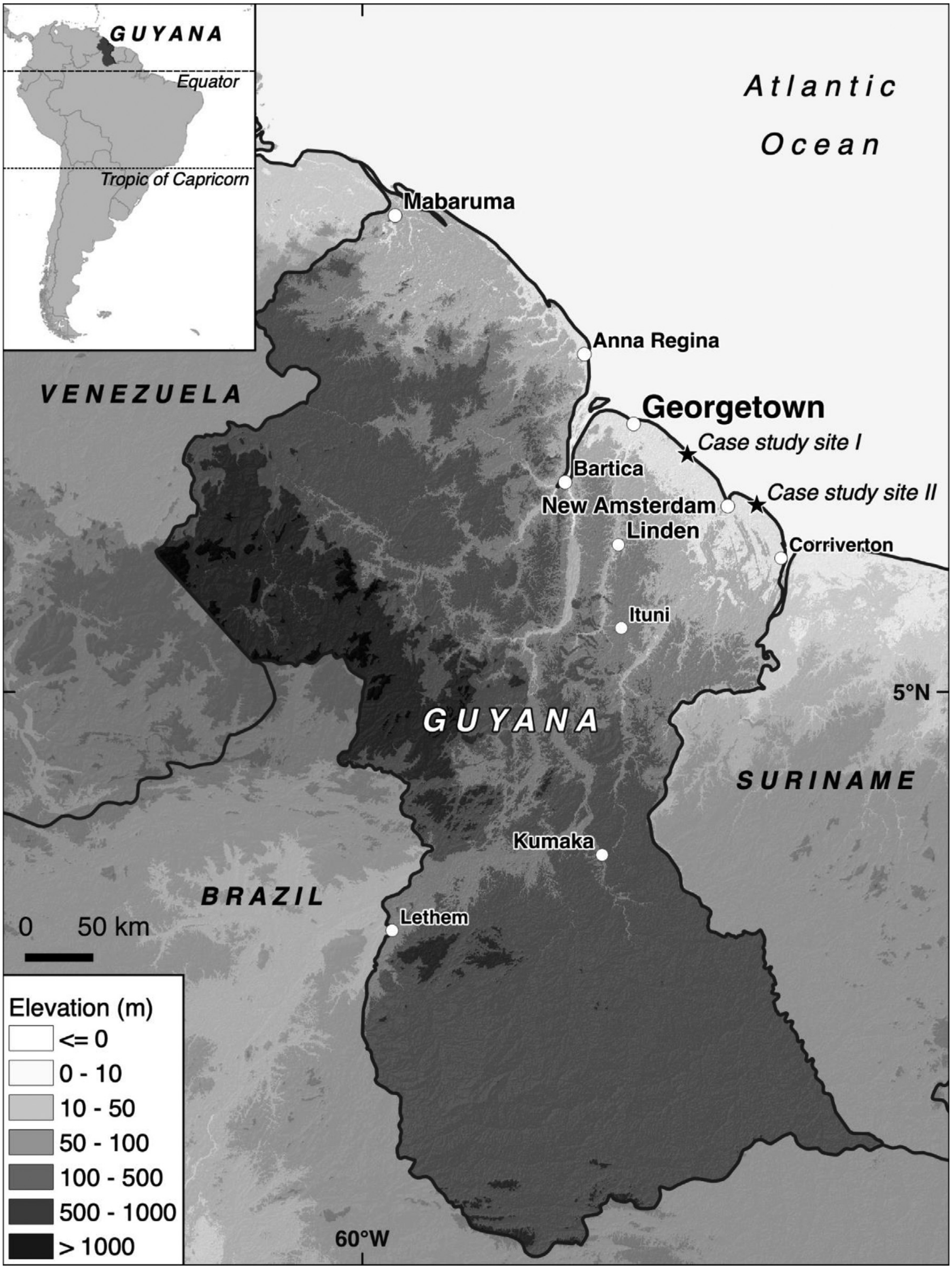

Fig. 1. Map of Guyana showing the country elevation. Inset: South America continent with the location of Cooperative Republic of Guyana indicated.

Vaughn, 2013; La Rose et al., 2014; Ozanne et al., 2014; Butt et al., 2015; Saleh, 2020; Whitaker, 2020; Becerra et al., 2021), planning and formulation of future developmental agendas incorporating climate vulnerability scenarios (Bishop and Payne, 2012; Reymondin et al., 2014), the effects of climate-related vulnerabilities on gender (Goh, 2012; Eastin, 2018) and the appraisal of climate change education (Bynoe and Simmons, 2014). The effects of climate change on rivers (Labat et al., 2012; Misir et al., 2013; Pereira et al., 2014), meteorological variables (de Mondonca, 2015), biodiversity (Brodie et al., 2012; Taylor et al., 2012), farming (Mahdu, 2019) and mining activities (Lowe, 2014) are well documented. The impact of changes in climate parameters on political economy (Bynoe, 2014) and population health (Saunders-Hastings et al., 2018) in Guyana are also documented in the literature. Additional published work examined the activities of international and non-governmental organisations on national adaptation and mitigation strategies. These include, for example, the report on a community-based monitoring system (CBMS) to “reduce emissions from deforestation and forest degradation (REDD+)” programme in Guyana (Bellfield et al., 2015; Sabogal, 2015), Guyana-Norway REDD+ agreement (Henders and Ostwald, 2013; Bholanath et al., 2013; Laing, 2015b), and the impacts of financing the intervention programmes (Laing, 2015a).

The research outputs cover a wide range of topics but can be grouped generally on: i) socio-economic effects of climate vulnerabilities on local communities; ii) transfer of climate change knowledge to indigenous communities; iii) evaluation of climate change education; iv) observation and documentation of previous and ongoing environmental, ecological and social responses/dynamics to climate change scenarios; v) adaptation to climate change; vi) impact assessments; vii) mitigation and adaptation strategies and mainstreaming; and, viii) policies on climate change (Government of Guyana, 2021).

Despite all the published works over the last decades, only a few have focused on coastal areas, addressing for example the growing climate vulnerability coupled with sea-level rise (Bassett and Scruggs, 2013) and the cascading effects on coastal tourism (Scott et al., 2012). Other works include the documentation of environmental effects of the destruction of coastal engineering and large-scale mangrove (Anthony and Gratiot, 2012), management of environmental changes influenced by climate change impacts on coastal communities (Lane et al., 2013), identification of shoreline changes in Guyana coast (Oyedotun and Johnson-Bhola, 2019) and the issue of sustainable management and restoration of the coast (Johnson-Bhola and Oyedotun, 2018; Anthony et al., 2021). Thus, to the authors’ knowledge, the lack of access to integrated coastal climate data on the nation’s coastal environment might have contributed to the paucity of investigation in this type of environment. Hence, there is a need to understand if climate change adaptation challenges along the Guyana’s coast or those countries in similar contexts are being appropriately addressed.

4. Data integration need

Environmental management, decision-making and governance targeting coastal resilience to climate-driven phenomena requires the ability to monitor, quantify and understand coastal change over timeframes of years, decades and centuries. Understanding the drivers of coastal, catchment and marine environmental changes can be achieved through accurate measurements and critical analysis of morphologies, flows, processes, and responses. However, many organisations within Guyana, tasked with governance and decision-making, are not exploiting the potential of recently developed technologies and techniques, many of them readily available. This is largely due to a lack of central resources, databases or facilities that can integrate data and information on the drivers and changes within the coastal and marine environment (Office of Climate Change, 2016b). Accurate and real-time information on a range of processes and morphologies, such as tides and sea-level, wind and wave conditions, shoreline position, and catchment and coastal flooding, inform perspectives and support understanding of the dynamics and behaviour across the catchment-coast-marine system (Rogers and Woodroffe, 2016). Crucially, the establishment of monitoring programmes and the development of environmental information centres can increase support in enhancing the country’s preparedness to mitigate the existing and expected influence of climate-driven changes, and thereby encourage the establishment of resilient coastal communities (e.g., Vos et al., 2019; Almeida et al., 2021).

In addition to several data sources already available but not being utilised in the country, different methods, technologies and techniques for coastal and marine morphological change detection (CMMCD) are also existent (e.g., McLaughlin and Cooper, 2010; Vos et al., 2019; Elkafrawy et al., 2020; Montaño et al., 2020; Almeida et al., 2021; de Lima et al., 2021; Marzouk et al., 2021; Nicolodi et al., 2021). The selection of appropriate data and methods, many of which have global and regional context, requires the consideration of local environment in terms of context, type of desired outputs, level of changing details (volumetric and/or linear) for meaningful consideration and evaluation by local organisations (e.g., Baills et al., 2020). In Guyana, as in other developing countries, there are currently no comprehensive or dedicated coastal and marine monitoring programmes or systems, and the web-based platform development proposed in this manuscript is hoped to address this significant knowledge gap.

Most coastal change analyses for Guyana are carried out by those outside academia, using rudimentary methods (e.g., rod and level technique, manual surveying) (Ministry of Agriculture, 2016; Office of Climate Change, 2016a). This is because of inadequate understanding of the available open-access earth observations and online analytical capabilities and techniques. There is a need to address these challenges through sourcing, reviewing and utilisation of cloud-based earth observation data and analytical methods, followed by practical application and exploration at case study sites in Guyana. We know that a web-based platform prototype providing coastal practitioners the access to data and analytical tools to support their daily and/or operational planning to enhance coastal/marine disaster risk preparation and management, coastal conservation, and/or develop appropriate response (adaptation or mitigation) to climate change, will be of tremendous benefit to addressing the countries’ adaptation and/or mitigation needs.

This kind of strategy will demonstrate how valuable the combination between the analysis of near-real-time and remotely sensed data is in raising the level of awareness and understanding of coastal change. The outputs (e.g., data integration and analysis system, comprehensive feeding of data collation to a central database system, analyses of sampled data, publications regarding previous findings) will support coastal researchers, policy and decision-makers, among other stakeholders in selecting appropriate catchment, coastal and marine morphological change detection (CMMCD) methods.

5. Path to strategy development

To understand coastal dynamics and shoreline behaviour, the knowledge of processes driving the catchment-coastal-marine system and dynamics is vital (Oyedotun, 2016, 2017; Almeida et al., 2021). Monitoring these environments and processes separately would require different data, technologies, techniques, and unique operation workflows. Coastal dynamics along the shoreline, nearshore, inshore and seabed are integrally linked to the process of accretion and depletion, as well as flooding events that occur along the shoreline and across the coastal plain (Rogers and Woodroffe, 2016). Many coastal processes and drivers are monitored in the near-shore environment, and datasets are hosted by different data acquisition entities or organisations (Bulkeley et al., 2012). These data have the potential to show the spatio-temporal morphological dynamic (morphodynamic evolution) of coastal areas but are available on different platforms. Integration of these diverse data is essential to understanding and evaluating contemporary and future dynamics. Therefore, to maximise the desired impact of any data integration strategy development without compromising its sustainability, the strategic activities recommended to be followed could be identified in four distinct but complementary work packages (Fig. 2).

5.1. Work package one: Reviewing data opportunities/access

This work package would source, host, and explore extensive quantities of available open-source coastal datasets. This is the first step of the strategy and should focus on a case study sample site (as identified in Fig. 1) to demonstrate the potential of the approach. Both internal and external, open and/or private owned, and emerging data sources should be considered. There should be a plan to access the data, and establish the processes required to enable the data to be integrated and/or drawn for analyses. Principally, the strategy will highlight the subsets of all available emerging data (mostly the remote sensed data) that could be

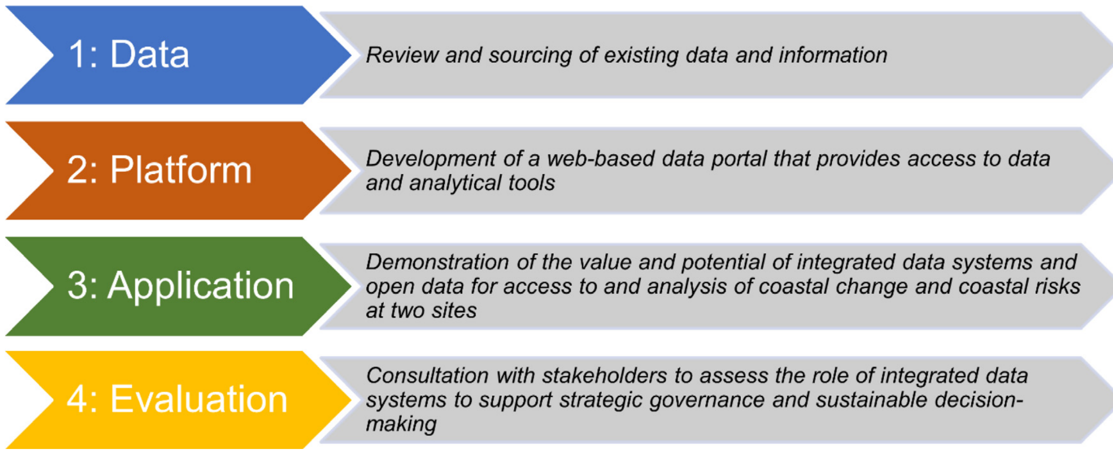

Fig. 2. Four distinct but complementary work packages to facilitate the development and delivery of integrated data systems to researchers and practitioners.

found for the selected study site(s) (Table 1 lists examples of the dataset that could be sourced in this strategy).

The main challenge that may arise is the restriction to access some (but not all) data. This could be met by making official requests for datasets or providing a link to where they can be sourced if no direct access is given. Similarly, there should be a collaboration between distinct local agencies to explore ways in which data, or derivatives of the data, can be shared, for example through web map services release. For the initial phase of this strategy, the focus can be on open-source/access data and software, and demonstrate the potential through outputs to encourage local, regional and possibly international organisations and agencies in using it.

A plan should detail a proposal for deployment of a new suite of monitoring systems to generate data that can be directly assimilated and integrated into the new system. This plan within the strategy may include, for example, the installation of water level sensors to monitor the tide at selected case study sites. The members of the community could be engaged in the installation and configuration on the monitoring systems, thereby promoting citizen science (Bulkeley et al., 2012; Chaffin and Scown, 2018), while the data to be generated will be delivered autonomously to the monitoring systems and feed the online platform. The strategy could seek engaging with organisations and agencies to support the procurement of a wider network of instruments if the plan and associated arrangements are well received and demonstrated.

This work package focusing on the strategy can include local knowledge and stakeholder input as well as exploration of crowd-sourced data. In Guyana, the plan should engage stakeholders like the Department for Environment and Climate Change (DECC), Hydrometeorological Services (Hydromet), Environmental Protection Agency (EPA), Guyana Land and Survey Commission (GLSC), and Civil Defence Commission (CDC), to solicit and include local data collected through their projects and provide local context and validation of the remotely-sensed data. Additionaly, the involvement of these stakeholders may be useful to solicit information on the benefits that could be expected from the outputs and the overall success of the strategy. Crowd-sourced data like those from OpenStreetMap could also be explored to characterise the human and natural infrastructure at risk driven by the climate influence on coastal processes anomalies. Google Earth Engine platform may be used extensively for remote sensing image processing, analysis and demonstration (Vos et al., 2019; Almeida et al., 2021).

5.2. Work package two: Building an online system

The second work package of the strategy involves the creation of an integrated observation programme (online system) that will provide live data (especially the remotely sensed satellite feeds and other similar and relevant data), including storing and access to monitored data such as those resulting from community monitoring via localised observation through geotagged images (citizen science) (e.g., Wilcock et al., 2013; Ashmore, 2015; Nowak et al., 2021). With the increasing availability of different computation and cloud-based processing platforms (e.g., Software-as-a-Service, SaaS, Google Earth Engine, GEE) (Huikkola et al., 2021; Mao et al., 2021; Wu et al., 2021), the strategy can use spatial analyses that would involve the fusion of diverse data from different sources and machine learning algorithms in the development of an integrated data analysis and monitoring systems for Guyana. Such platforms provide access to a large variety of spatial-time scaled datasets that could be utilised in the analyses and dissemination of results to interested stakeholders. This should be of high consideration because of the high-performance parallel computing infrastructure that is available in platforms such as GEE.

5.3. Work package three: Application to case study sites

After collection and integration of the data, the strategy can undertake a focused analysis at case study sites to demonstrate the analytical value and improved understanding of coastal dynamics using the created platform. First, the evaluation of the short-term morphodynamics of the mud-dominated section of the Guyana coast can be evaluated for demonstration of how the collated data could be utilised in research and decision making. Specifically, the platform could use the integrated data and some sampled methodologies/software to evaluate the implications of mud movement, also observed from the remotely sensed images, on temporal shoreline mobility and river-mouth deflection. The coastal plain of Guyana is part of the mud-dominated coast of the Southern American continent (Anthony et al., 2021). The aim of the case study application of the strategy is to demonstrate how the expected data collation could document the short-term morphological dynamics at the mouth of the river system in response to regional and local environmental dynamics, using remotely sensed data (Oyedotun, 2016; Roger and Woodroffe, 2016). The mouth of Mahaica River, case study site 1 in Fig. 1, could be used as the sample application study site. This sample application could focus on understanding the mud-shoal movement and its effect on shoreline dynamics and river mouth deflection, in an area that has not been researched or studied in Guyana.

The second application of collected data could be in exploring the platform and data for flood detection and flood mapping (e.g., Anusha and Bharathi, 2019). The most threatening natural hazard to coastal communities is flooding. Over the past decades, global damages due to extreme floods have significantly increased. In Guyana, the 2005 flood was a major catastrophic event widely reported, which exposed the vulnerability of the country to climate-driven disasters. Apart

Table 1
The breadth, availability and source of catchment, coastal and marine related data for Guyana.

Data source	Data set	Data type	Available dataset
ASF earth data			
	Sentinel 1	Remote sensing data	2014 to present
	ALOS PALSAR	Remote sensing data	2006 to 2011
	ALOS AVNIR-2	Remote sensing data	2006–2011
	SIR-C (beta)	Remote sensing data	1994
	S1 InSAR (beta)	Remote sensing data	2014 to present
	SMAP	Remote sensing data	2015 to present
	UAVSAR	Remote sensing data	2008 to present
	RADARSAT-1	Remote sensing data	1996 to 2008
	ERS	Remote sensing data	1991 to 2011
	JERS-1	Remote sensing data	1992 to 1998
	AIRSAR	Remote sensing data	1990 to 2004
	SEASAT	Remote sensing data	1978
DIVA- GIS			
	Near global 90-meter resolution elevation data	Remote Sensing Data	
	High resolution satellite images (Landsat)	Remote sensing data	
Global PALSAR-2/PALSAR yearly mosaic	JAXA EORC		2007 to 2018
EarthData search	Sentinel-1		2014-04-03 ongoing
	VIIRS (S-NPP) I Band 375m Active Fire Product		2016-01-01 ongoing
	MODIS/Aqua Terra Thermal Anomalies		2002-05-04 ongoing
NOAA class	NOAA AVHRR Clear-Sky Products over Oceans		2011 to present
	Sea Surface Temperature,		
	Clear Sky Radiances		
	Aerosol Optical Depth for the Global Ocean		
Global weather data for SWAT	Temperature (°C)		1979–2014
	Precipitation (mm)		1979–2014
	Wind (m/s)		1979–2014
	Relative Humidity (fraction)		1979–2014
	Solar (MJ/m^2)		1979–2014
Permanent service for mean sea level (PSMSL)	Tide Guage		Varied
	Contributing data to the PSMSL		
	Other long records not in the PSMSL Data Set		
	ODINAfrica/GLOSS dipping calibration sheets		
NHD plus	National hydrography dataset		From 2006
	30-meter national elevation dataset		
	Elevation-based catchment for each flowline in the stream network		From 2004
	Catchment characteristics		
	Headwater node areas		
	Cumulative drainage area characteristics		
	Flow direction and flow accumulation grids		
	Flowline min/max elevations and slopes		
	Flow volume & velocity estimates for each flowline in the stream network		
Climate SERV	Climate hazards group IR Precipitation with Stations (CHIRPS)		1982 to present
	North American multi-model ensemble (NMME) dataset		
	MODIS-derived normalized difference vegetation index (eMODIS NDVI)		
GuyNode spatial data portal	Hydrology		Varied
	Geology		
	Soil		
	Sea defence		
	Land		
	Agriculture		
	Disaster		
	Hydrology		
	Ecology		
	Land Cover		
	Land Use		
	Climate		
	Biodiversity		
Local Agencies			
Bureau of statistics	Population by village	Census	2002
	Guyana regional population	Census	2012
	Average household size	Census	2012

(*continued on next page*)

Table 1 (*continued*)

	Population trends Guyana		1980–2012
	The coastal and hinterland population and growth rate	Census	1980–2012
	Population distribution by coastal regions	Census	2012
	Population trends in coastal areas	Census	1980–2012
	Population density, Guyana	Census	1980–2012
	Average hours of sunshine per day	Weather and climate	1994–2019
	The maximum and minimum shade temperature	Weather and climate	1982–2019
	Monthly humidity	Weather and climate	1982–2019
	Monthly rainfall coastal region	Weather and climate	1981–2019
Guyana lands and surveys commission (GLSC)	Digital gazetteer of Guyana		Varied
	British Guyana map 1910		
	Seacoast maps		
	Population by regional occupation		
	Population by religion, by region		
	Population by age group and by region		
	Population by sex per region		
	Population by ethnic group, per region		
	Population by marital status and region		
Hydro-meteorological service (Ministry of Agriculture)	Drought monitoring		2019–2021
	Guyana seasonal climate outlook		2017–2021
	Monthly bulleting		2017–2019
Maritime administration department	Nautical charts		Varied

from this disaster, there have been consistent and frequent coastal flood events causing havocs. In such flood events, the first response within a disaster risk management plan, as well as the vulnerable communities, need near-real-time and non-obstructed inundation information and maps to aid in responding to and acting during flood occurrence. The required information and maps can be generated using satellite-based data, to provide or give direction regarding secured areas. For this second application, the use of high-resolution multi-temporal remotely sensed data like Synthetic Aperture Radar, could be used, for example, in the strategy to detect the inundated areas driven by the incessant rise of sea level along with selected coastal communities of Guyana for the year 2019 and 2020, respectively. The obtained results could then be validated against the meteorological observations and records that could be acquired from Guyana Hydrometeorological Service. Mahaica Mahaicony Abary (MMA) area of Guyana could be considered as another study site for this application (Fig. 1). The strategy could utilise the near-real-time datasets to observe the evidence of overtopping of sea defences, inundation of villages and agricultural fields as examples of the effect of climate on flood scenarios that are very common in this site. The findings could provide evidence on the effectiveness of integrated data in providing the near-real-time flood inundation detection and mapping, which can help in flood disaster preparedness, augmenting flood response effectiveness, minimizing flood hazard and thereby strengthening coastal communities' resilience. The collection and integration of both passive and active remote sensing systems would be very important in enriching the temporally spare flood data for the coastal area of Guyana, and therefore be utilised by the stakeholders to estimate the status of flood-prone coastal areas in strengthening their resilience, preparedness, and response.

5.4. Work package four: Evaluation for stakeholders/decision-making

The proposed strategy will help Guyana to meet three of the United Nations Sustainable Development Goals (SDGs). These SDGs are SDG 11, intending to make Georgetown and other coastal cities of Guyana and their settlements safe, resilient and sustainable; SDG 13, providing the country with necessary data and resources for combating climate change by uncovering the best methods and data to support practitioners in taking actions; and, SDG 14, helping Guyana with the protection, care and sustainable use of its coastal environment resources, including oceans and marine resources for sustainable development.

Various stakeholders in Guyana (e.g., EPA, CDC) will find the strategy useful, and during the implementation of the idea, the plan should engage the key stakeholders to understand data needs that would aid in decision-making. An online stakeholder workshop could be organised in the latter stages of the implementation to promote the strategy and the online system developed, and to encourage discussion of the barriers and opportunities of open and transparent access to and analysis of coastal dynamics. One of the aims of this strategic plan is to enable a reflection about the real needs and priorities of the country in its climate adaptation and mitigation plans. To be able to evaluate the usability of the web platform, Nielsen Attributes of Usability (NAU) is recommended (Nielsen, 1993). NAU has many components and is traditionally and mostly associated with four main attributes of learning, efficiency, error handling, and satisfaction. Fig. 3 presents five steps of the Nielsen usability model modified that could be used to evaluate the prototype of the strategy by the stakeholders.

To evaluate the usability of the platform by the stakeholders, questionnaires based on NAU's five usability categories as well as a series of open-ended questions can be considered to describe: (i) their ability to understand the platform and easiness to search for specific information on the platform, fulfilling the Nielsen model's learnability criteria; (ii) the easiness to quickly download datasets and navigate in the platform, thereby evaluating the efficiency of the platform; (iii) the easiness to remember the configuration of the platform and to re-establish with the methods or the database within the platform, allowing to evaluate how memorable the platform is to stakeholders; (iv) the ability of stakeholders in detecting errors and the easiness of fixing the detected errors (usability); (v) evaluation of the stakeholder's satisfaction in using the platform, assessing how pleasant and comfortable it is for use, and how it could be used in their perception of climate change issues and how to address those issues. The purpose of the evaluation should focus on the usability of the platform and to identify stakeholders' proposed improvements where necessary or needed.

6. Conclusion

Environmental management, decision-making and governance for Guyana's low-land and coastal area's resilience to climate-related events and associated vulnerabilities require the ability to monitor, quantify and understand coastal change over short-, medium- and long- time frames (i.e., years, decades and centuries). The understanding of drivers

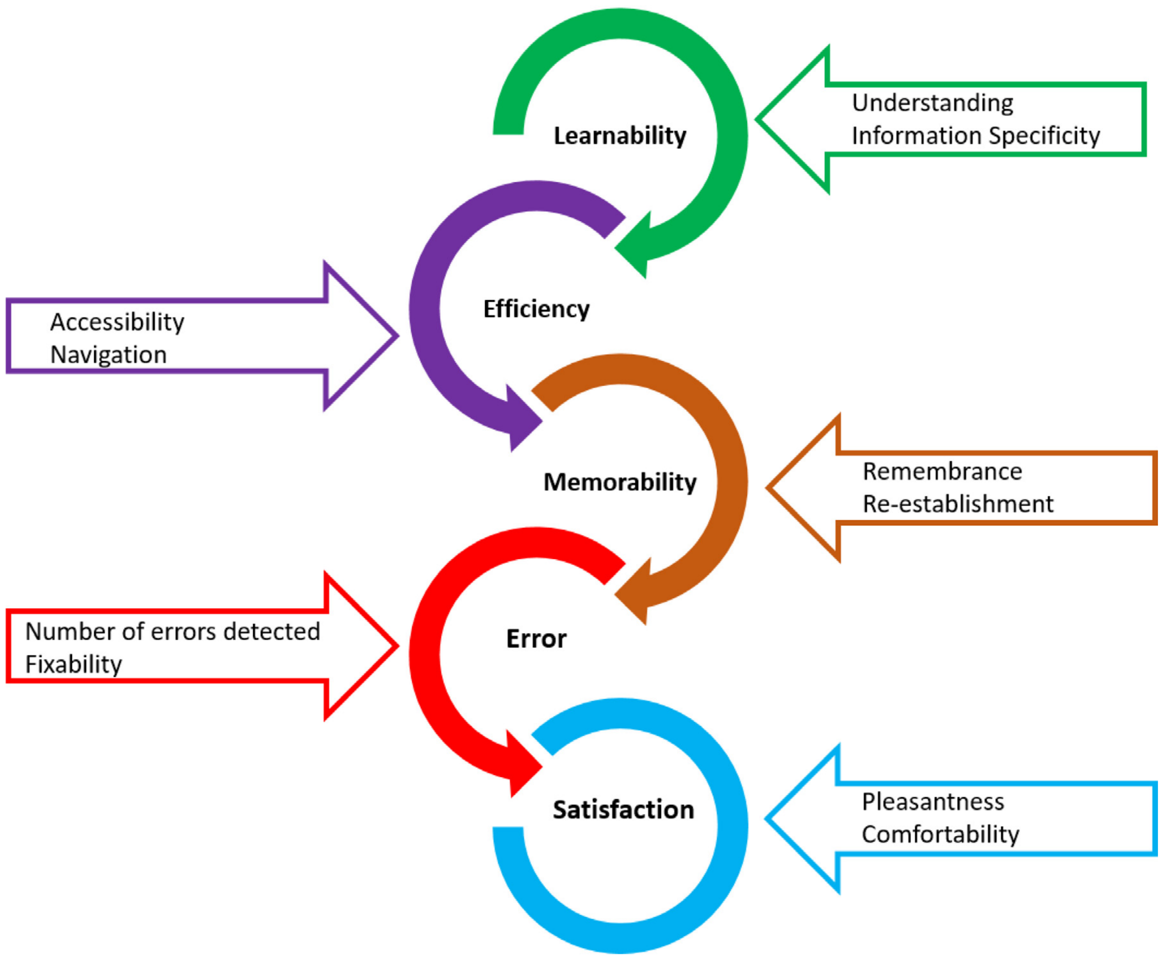

Fig. 3. Stakeholders' strategy usability and evaluation criteria, modified from Nielsen (1993).

of coastal, catchment and marine environmental change can be achieved through accurate measurement and critical analysis of morphologies, flows, processes, and responses. However, many organisations responsible for governance and decision-making within Guyana are not exploiting the available advanced technologies and relevant datasets and techniques. This is largely due to a lack of central resources, databases or facilities that can integrate data and information on the drivers and changes within the coastal and marine environment. Accurate and real-time information on a range of processes and morphologies, such as tides and sea-level, wind and wave conditions, shoreline position, and catchment and coastal flooding, provide information and understanding of the dynamics and behaviour across catchment-coast-marine systems. Crucially, the establishment of monitoring programmes and development of environmental information platforms enhances knowledge-based relevant to enhance the country's preparedness to mitigate the impacts of climate-induced changes and encourage resilient coastal communities. This paper describes a strategy to create a central resource, database and web-based platform able to integrate data and information on the drivers of coastal change with the changes within Guyana coastal and marine environment. The strategy proposed would involve four complimentary work packages including data collection, development of data integration platform, application of the data for coastal change analyses, and consultation with stakeholders to assess the role of the integrated data systems to support strategic governance and sustainable decision-making. It is hoped that the output of the strategy would support many local agencies, organisations, researchers and decision-makers in their tasks and endeavours. It is hoped that both knowledge and database from this strategy would enhance the opportunity for effective planning and management of the Guyana coastal environment, given the advantages of integrating analytical tools and databases in the near future for capacity and resilience.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Temitope D. Timothy Oyedotun: Conceptualization, Investigation, Writing – review & editing. **Helene Burningham:** Conceptualization, Investigation, Writing – review & editing.

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