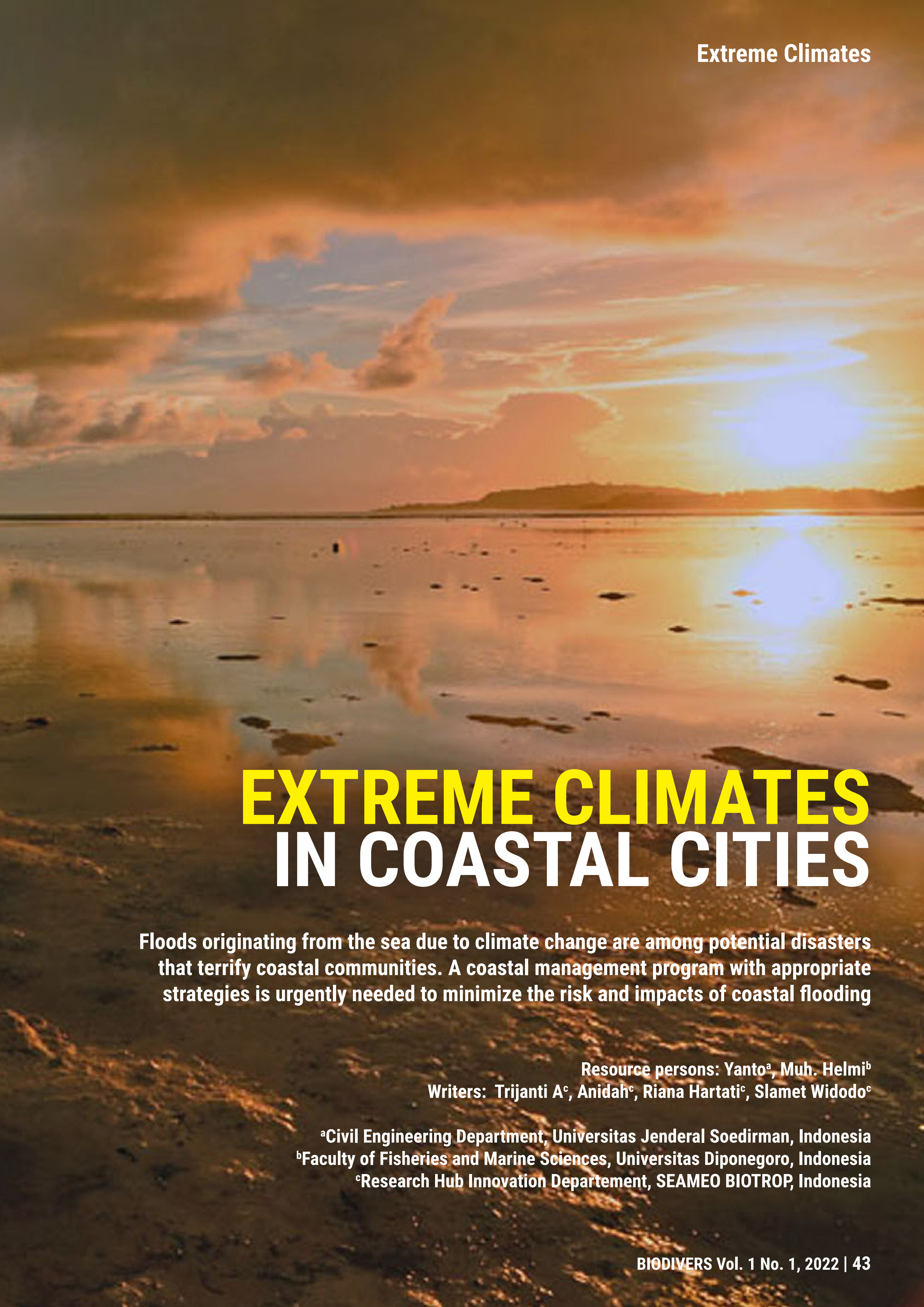

EXTREME CLIMATES IN COASTAL CITIES

Floods originating from the sea due to climate change are among potential disasters that terrify coastal communities. A coastal management program with appropriate strategies is urgently needed to minimize the risk and impacts of coastal flooding

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Flood in the Cities

Floods become the top third disasters that take the most lives globally after droughts and storms [1]. The economic losses caused by floods reach USD1,1 trillion globally, or 31% of the total reported economic losses due to disasters [1]. Floods have also been reported to hit big cities in nearly every country since the last century. Extreme weather, sea-level rise, and other climate change impact play important roles in the flooding mechanism.

A flood is defined as an event or condition where an area or land is submerged due to an increased volume of water [2]. Floods can occur by the overflow of inland waters (fluvial flood), excess of extremely heavy rainfall (pluvial flood), or inundation of land areas along the coast by seawater (coastal flooding). Fluvial flooding occurs when the water level in a river, lake, or stream rises and overflows onto the banks, beaches, and surrounding lands. Fluvial flooding can also occur when extreme rainfall events create floods that are not dependent on many flowing water bodies. Some floods also happen due to the inundation of seawater's land areas along the coast, known as coastal flooding. This type of flooding is triggered by extreme climate change. It can occur not only when there is a storm wave produced when the air pressure at sea falls, the wind is significantly strong but also when both the wave set-up and swash, producing the run-up altogether, are powerful (Fig. 1)

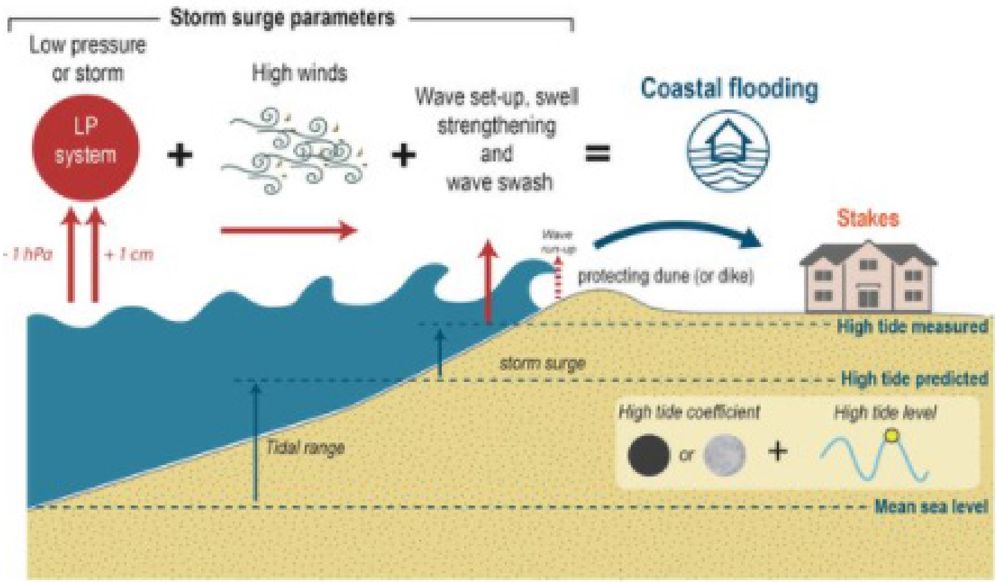

Figure 1. Coastal flooding mechanism (Source: Yanto 2021)

Common causes of coastal flooding are extreme windstorm events co-occurring as the high tide (storm surge) and tsunamis. Coastal flooding occurs at low speed with an average depth of 50 cm and occurs in hours. In addition, these events usually caused no fatalities, so people think that is common. This event can affect future temperature fluctuations and sea level waves that can cause land subsidence and greatly influence human lives in the long term.

Globally, coastal flooding as a threat due to sea-level rise and storm surges that expose port cities in many countries has emerged in the last decade [3]. Many coastal communities around the world live at risk from coastal flooding. According to the UCCRN technical report titled "The Future We Don't Want", the total urban population at risk from sea-level rise could number more than 800 million people, living in 570 cities, by 2050 if emissions don't go down as mandated in the Paris Agreement (Fig. 2) [4].

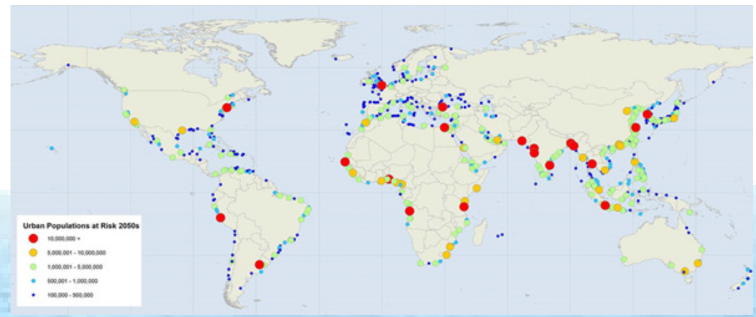

Figure 2. Cities a risk from sea level rise of 0.5 meters by 2050s (Source: UCCRN 2018)

Global initiatives and networks play an essential role in addressing the effect of climate change. C40 is a network of mayors of nearly 100 world-leading cities collaborating to deliver the urgent action needed to confront the climate crisis. City mayors are the key persons at the city level due to their decision to affect global achievement facing climate changes. New York City and Jakarta are both coastal areas and already dealing with the effects of climate change. They pursue local action through science-based decisions to develop a resilience strategy to strengthen coastal protection. New York City has completed the flood-proof project namely Rockaway Boardwalk, which integrates coastal protection and numerous recreational facilities within the park, parallel to the beach and boardwalk. Meanwhile, the Indonesian capital Jakarta has developed a city-wide climate adaptation strategy that includes a Sea Defense Wall Master Plan with assistance from the Dutch government [4].

Besides Jakarta, other cities in Java also facing the same threat. Some data show that permanent tidal inundation has occurred in Demak, Pekalongan and Semarang. Permanent tidal flood inundation at Sayung, Demak Regency in 2003 - 2014 caused the inundation area to reach 2,073 ha in 2014. Meanwhile, the inundation area in Semarang in 2011 reached 1,211.2 ha. Permanent tidal inundation in Demak and Pekalongan resulted in land subsidence between 8.65 to 14.25 cm/year in both regions based on Persistent Scatterer Interferometry (PSI) Monitoring 2016 - 2021. Besides Demak and Pekalongan, land subsidence observed by LAPAN in 2015 - 2020 also occurred in Jakarta (0.1 - 8 cm/year), Bandung (0.1 - 4.3 cm/year), Cirebon (0.28 - 4 cm/year), Tegal (2.1 - 11 cm/year), Semarang (0.9 - 6 cm/year), and Surabaya (0.3 - 4.3 cm/year).

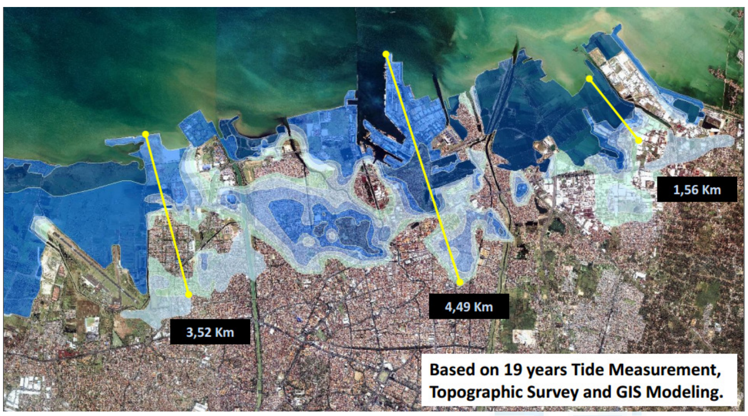

Figure 3. Sea level rise simulation model at Semarang, Central Java
Note: Sea level rise = 77.5 cm (100 years SLR simulation model)
(Source: Helmi 2021)

Some of the main factors causing land subsidence include 1) Natural consolidation/compaction of young alluvial land; 2) Uncontrolled groundwater abstraction; 3) Building and Infrastructures weight, and 4) Local tectonic movements. Based on the geospatial model of the existing and predicted inundation model in 2020 to 2035 conducted by Helmi (2021), the inundation distance from the shoreline will be further away landward, increasing between 2 - 3 times after 15 years. Data show that the total area inundated by seawater will increase every year (Fig. 3). The areas most affected by inundation are the residential areas, followed by rice fields/crops planted areas, industry, and barren land.

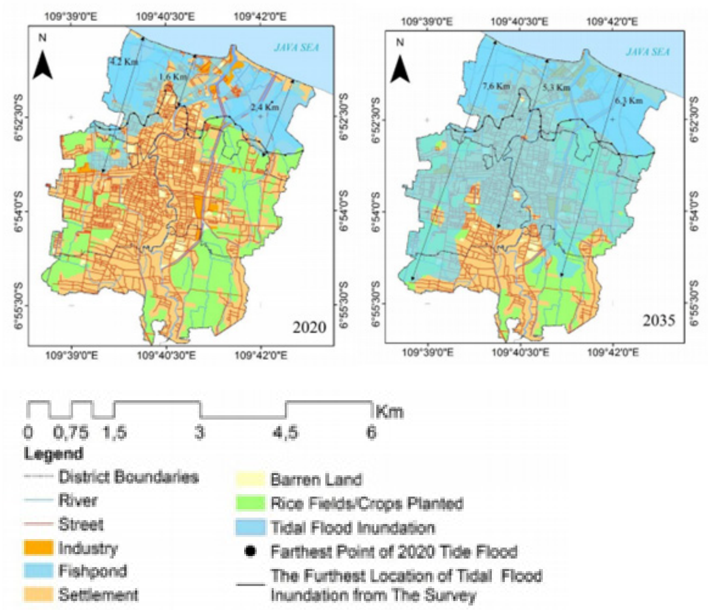

Figure 4. Geospatial model of existing and prediction inundation model in 2020 to 2035
(Source: Helmi 2021)

Human and Nature-Based Solution

Spatial observation

A coastal management program with appropriate strategies is urgently needed to minimize the risk of coastal flooding and to reduce its impact when it occurs. Several adaptation options that potentially mitigate the effects of tidal flooding conduct spatial observation such as Earth Observation (EO). The adaptation options also include the implementation of Coastal Protection "sea belt," a combination of seawall and breakwater, including hard and soft engineering approaches. Earth observation has a critical role in attaining success in terms of sustainability at scale, being a source of rich spatial and temporal datasets that complement other types of data, such as census information, civil registration, vital statistics, and in situ measurements [5].

Earth observation, including monitoring, understanding, and predicting marine coastal hazards, can be carried out using a variety of sensors to monitor coastal zone characteristics, various metocean variables relevant for different coastal hazards, and some coastal hazards

Photographer: Septiani Dewi Ariska - Philippines themselves. Metocean is the abbreviation of meteorology and oceanography. It includes atmospheric and physical oceanographic variables such as characterized wind, waves, sea level, bathymetry, sea currents, sea-ice (thickness, extent), seawater properties (salinity, temperature, stratification), water quality parameters.

Extensive research into coastal sustainability issues has highlighted EO data and technologies opportunities to support coastal management efforts, particularly environmental monitoring. Marine Spatial Planning [6] and coastal sustainable urban development [7, 8] efforts by actively combining multiple data sources, including EO data, can yield potential solutions to increasingly complex problems [6, 7, 8].

The exploitation of Big EO Data enables global mapping of natural resources along the coast, ranging from fisheries, water quality and bathymetry, and natural hazards, including storm surges, coastal inundation, and sea-level rise (SLR). Some examples of innovative advanced EO applications include 1) Optical water types for coastal water quality monitoring; 2) Species niche habitat distribution mapping; 3) Complementary multi-platform coastal bathymetry; and 4) Coastal inundation mapping and prediction and storm surge risk assessment.

Sea belt as a barrier

In addition to mitigation through EO, coastal protection by installing sea belts as barriers is also needed as the first step in preventing flooding on the coast. The primary reason to construct protection structures is to protect the harbor and other infrastructures from sea wave effects such as erosion and coastal flooding. The typical approach to any threat of coastal erosion or flooding has been hard engineering sea defenses or coastal protection structures. Various structures are considered or used as coastal protection structures, such as groins, seawalls, bulkheads, breakwaters, and jetties.

Seawalls are large protection structures built using different construction materials, such as rubble mounds, granite masonry, or reinforced concrete. Seawalls are commonly built and run along the shoreline to prevent coastal structures and areas from detrimental ocean wave actions and flooding driven by storms. Various arrangements or configurations might be employed, including curved face seawall, stepped face seawall, rubble mound seawall. Bulkheads can be constructed with concrete, steel, or timber. There are two major types which are gravity structures and anchored sheet pile walls. In addition, groins are structures constructed by wooden or concrete structures perpendicular to the shoreline. They work by blocking part of the coastal drift, whereby they trap or maintain sand on their upstream side. Other structures are jetties constructed at river estuary or harbour entrance and extended into deeper water to oppose sandbars and limit currents. The last one is breakwaters which are offshore concrete walls that break waves out at sea so that their erosive power is reduced when they reach the coast [9].

In general, this hard engineering approach has some weaknesses, such as unsustainable and short-term with high impact on the landscape or environment and tend to be expensive. Some areas need other less costly alternatives, long term, attractive and sustainable. One of the choices is the soft engineering approach that works with the natural processes of the area by using the natural materials, features, and functions to absorb or reduce wave impact like mangroves [10]. Mangroves provide several critical ecosystem services, namely coastal protection and fisheries production.

Mangroves in coastal areas can reduce the height and energy of wind and swell waves passing through them, reducing their ability to erode sediments and cause damage to structures such as dikes and seawalls. Mangroves also reduce winds across the water's surface and thus, prevent the propagation or re-formation of waves. Mangroves with a complex structure of dense aerial roots and low branches, with various species of different ages and sizes, are most likely to be effective at reducing wave heights.

Option for flood risk management

Flood risk management strategies aim to reduce the probability and/or consequences of flooding events. Actions that address flood risk in areas under continual development include 1) strengthening the existing or constructing new protective structures; 2) increasing natural retention and storage capacities, such as the "Room for the River" projects in the Netherlands [11]; 3) expanding insurance for flood damage and improving flood resilience [12]; and 4) upgrading forecasting, early warning, and preparedness systems [13]. In this context, the data generated during the EO is the key to investing in the development of a patented approach to flood hazard calculation.

Based on information extracted from EO data, researchers and decision-makers can conceive and apply effective policies for environment protection and sustainable management of natural resources. To take advantage of all potential, users need to handle hundreds (or thousands) of EO data files, of different spectral, temporal, and spatial resolutions, by using or developing software scripts to extract information of interest [14]. So, in the current era of big spatial and EO data, there is a need for the next generation of spatial data infrastructures (SDIs) to properly deal with this vast amount of data.

In addition, the engagement of stakeholders in socio-economic-environmental modeling processes is key to developing a holistic qualitative model. For example, a system dynamics modeling approach capable of considering all socio-economic components and ensuring that all issues and relevant policy opinions have been addressed. Many models have a degree of flexibility concerning the spatial and temporal scales they can be implemented. Still, identification of relevant scales is essential in selecting the most appropriate modeling approach. The purpose of the modeling is likely to be a critical factor in this decision. Nature-based solutions (NBS) have been coined to encompass the answers available that provide opportunities for alleviating water-related challenges. In the context of modeling NBS to manage water-related challenges, a high level of spatial detail may be required.

More NBS implementation provides evidence for the benefits and risk-reduction capabilities of floodplain-based NBS, such as reconnecting and protecting floodplains. Floodplains can have the capacity to manage infiltration, overland flow, improve hydrological connectivity, regulate water supply, serve as biodiversity hotspots, and provide countless other benefits [15]. However, the degree to which floodplains can fulfill those functions depend on the presence and interaction of various biophysical factors.

To answer all these challenges requires the cooperation of various stakeholders, especially researchers and policymakers. Collaborative research with multiple fields of expertise such as remote sensing, mapping, hydrologists, and environmentalists is needed to produce integrated and applicable research. This is important to answer all challenges related to the impact of climate change on coastal cities.

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