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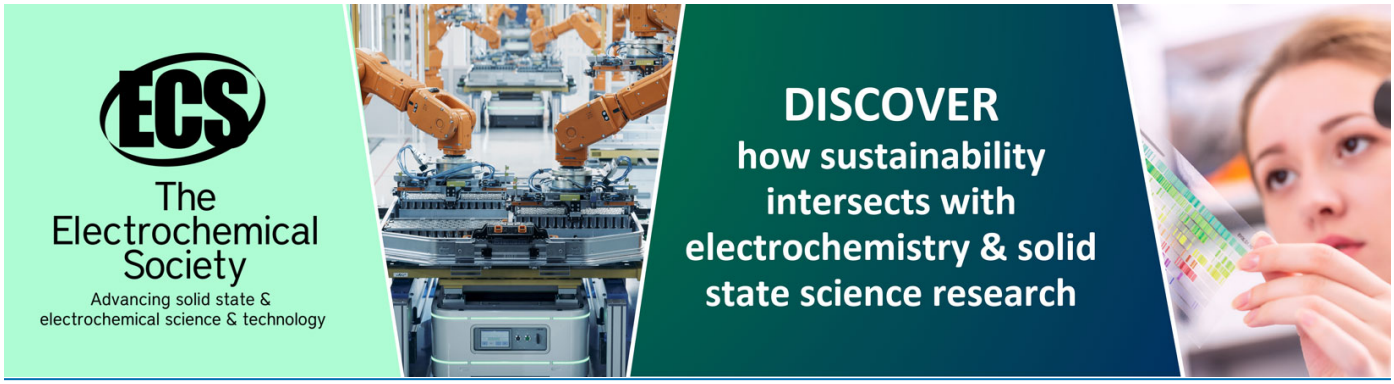

Methods for addressing tidal floods in coastal cities: an overview

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Abstract. Coastal cities are prone to tidal floods because coastal cities are centers of economic activities, trades and services; in addition, there are residential and housing centers. In general, this kind of natural disaster has flooded the lower area, which greatly negative impacts on the health, lifestyle and socioeconomic life of the affected population in coastal cities. In the following decades, tidal floods will damage more than a hundred major coastal cities worldwide. This paper aims to examine the causes, effects and impacts of tidal floods as well as methods that have been taken globally by reviewing papers published in global indexed journals concerning the handling of tidal floods around the world. This study reveals three methods; the first is the hard solution method involving infrastructures such as dikes, sea walls, water storage and pumps (polder system). Then the second is the soft solution method related to social, cultural, and habitual methods, such as adaptation, encouraging local wisdom and collective action. While the third is the policy and management system solution method that implements integrated policies and flood management.

1. Introduction

Tidal floods are floods caused by high tides. At the same time, the floods are generally described as temporary events when water is on land that is regularly dry or waterless, including water from the sea and the rivers [1–3]. Tidal floods are also related to rising water in coastal areas due to high tide conditions, which regularly disturbance during bright weather in the lower area, unaffected by rain and storm effects [4–6], so tidal floods can be defined as natural phenomena like overflowing sea water that floods low-lying coastal areas due to high tides.

In general, floods are kind of natural disaster that can cause considerable losses [7], likewise with tidal floods also have a fairly large destructive power which generally occurs in coastal areas. As part of the coastal area, coastal cities have characteristics identical to coastal areas [8], so in particular, the damage caused by tidal floods will increase when they hit coastal cities. This is because of the characteristics of coastal cities, which are centers of economic activities such as ports, trade centers and

warehousing. In addition, coastal cities are also centers of commercial activities such as shops, offices, marinas and residential areas. Henceforth, this paper will focus on tidal floods that hit coastal cities.

This research aims to review the methods that have been taken globally to address tidal floods phenomena, including regarding the causes, effects and impacts. This research was conducted with reviews of relevant papers published in globally indexed journals that discuss the handling of tidal floods globally. Then the elaboration of the findings will be presented in the following section. Section 2 describes the methods overview. Then section 3 explains the results and discussions, including the causes, effects and impacts of tidal floods, as well as the methods to addressing tidal floods respectively. Conclusions and recommendations will present in section 4.

2. Materials and methods

This research begins with searching for published papers, mainly using the database from Scopus and Science Direct, as well as several papers using the database from Google Scholar over 10-20 years back. These papers consist of either research papers or review papers, including papers from conference proceedings and other related papers. The search process for these papers uses several search keywords such as tidal floods, tidal floods in coastal areas, tidal floods in coastal cities, tidal floods in port areas, engineering solutions for tidal floods, non-engineering solutions for tidal floods, policies and flood management systems for tidal floods.

The next step is to search for papers using these search keywords, producing 220 papers. Then the 220 papers were briefly reviewed whose contents were relevant to the purpose of this study, such as causes, effects and impacts, as well as methods to address tidal floods, so 173 papers were obtained.

Conducting an in-depth review of the selected 173 papers is the next process which is then divides into several major discussion groups related to tidal floods, such as causes, effects and impacts. In addition, there are several methods to addressing tidal floods, such as hard and soft solutions, as well as policy and management system solutions. All the methods overview mentioned above can be illustrated in Figure 1.

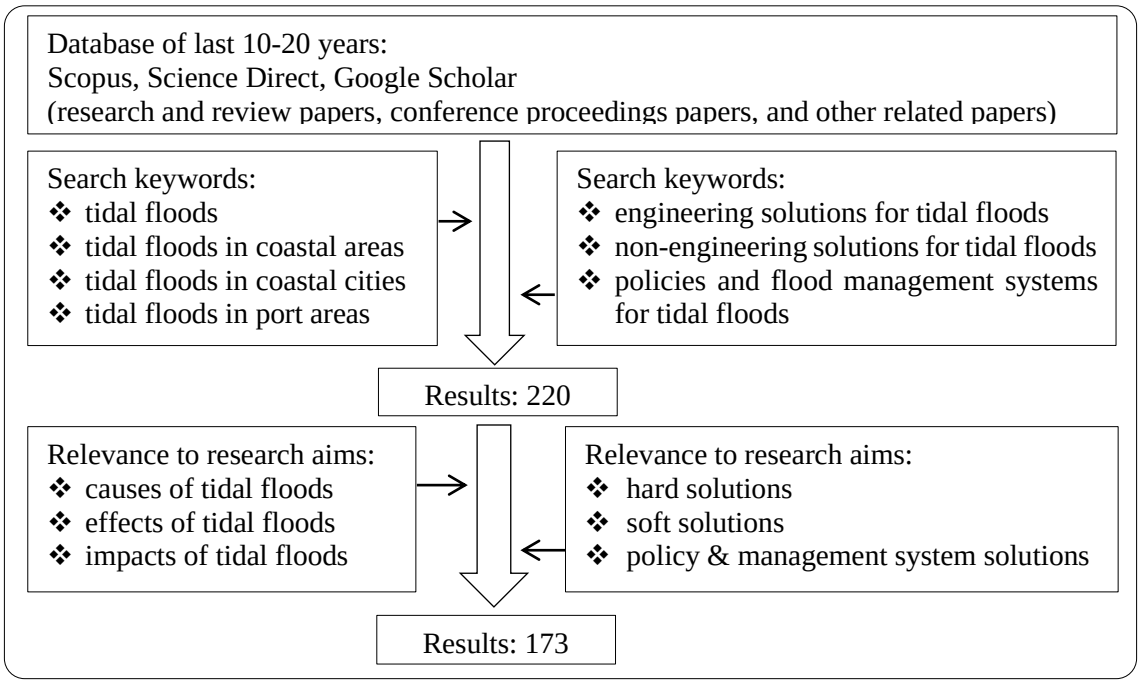

Figure 1. Methods overview.

3. Results and discussion

In-depth reviews were carried out after 173 papers were selected by dividing them into points of discussion that were adapted to the purpose of this research as follows:

3.1. Review of tidal floods causes

Based on the reviews that have been carried out, in general, 3 (three) points of view are considered to cause tidal floods, such as climate change phenomena, land subsidence phenomena and a combination of these two phenomena, which will be described in detail below.

Based on the first cause point of view, several thoughts generally state that the cause of tidal floods is the occurrence of sea level rise events which are phenomena of climate change. Tidal floods hit coastal cities when high tide occurs, one of which is caused by high sea level rise. Meanwhile, climate change and global warming influence sea level rise [9–11]. In general, sea level rise has increased over the last 12 decades by an average of almost 20 cm [12]. Global warming can cause rising sea level, exacerbating flooding when the tide is high [13]. In general, global warming is considered to affect sea level rise with various modern human activities, which then causes an increase in melting ice in Green land and Antarctica. It is further projected, as reported in the IPCC Sixth Assessment Report, that in 2100 the world's average sea level will rise to 0.6 - 1.0 meters if greenhouse gas emissions are not reduced [14]. In addition, high tides that are beyond normal can also cause flooding. This higher-than-normal tide is associated with the appearance of a full moon or new moon [15].

Then from the point of view of the second cause, it is stated that several views generally state that one of the causes of tidal floods is the land subsidence phenomena. Land subsidence in coastal cities is thought to be one of the causes of tidal floods, while one of the causes of land subsidence is estimated to be due to massive groundwater extraction [11,16]. Based on several studies that in the coastal areas of Semarang City, the rate of land subsidence per year on average up to 6-7 cm, even in certain locations, it can reach 14-19 cm/year. However, further research is still needed on the causes of land subsidence, whether related to excessive groundwater extraction or related to natural consolidation of soil in coastal areas caused by building loads [17].

The third point of view is a fairly moderate and realistic regarding the causes of tidal floods, a combination of climate change and land subsidence phenomena. Actually, there is no single cause of tidal floods. There are two main causes, such as sea level rise as a result of climate change and land subsidence caused by extreme groundwater extraction and regional building loads, as happened in several coastal cities in Indonesia, such as Semarang City, Pekalongan City, Tegal City, all of which are located on the north side of the coast of the island of Java [8,18–20]. In several segments of the coastal areas there are variations in sea level rise that occur due to several factors such as sedimentation, erosion and even land subsidence [3]. In some places, the causes of tidal floods are a combination of high tides and land subsidence, when storm surges occur. This combination can exacerbates tidal floods such as those on the East Coast of US, the US Gulf region and Hawaii [21]. Both heavy rainfall and high tides can also make flooding in coastal cities more severe [22]. In addition, the rapid economic development of coastal cities also increases the risk of damage to coastal cities that are prone to tidal floods [7]. Tidal floods hazard is estimated to increase in coastal cities as a result of mixed causes; both sea level rise and land subsidence are the main causes. In addition, increased storm surges and river water discharge lead to coastal cities [23,24].

From several explanations regarding the causes of tidal floods, it can be summarized that there are 3 groups of points of view. The first is the occurrence of sea level rise events which are phenomena of climate change while the second is land subsidence phenomena. The third point of view is a combination of climate change and land subsidence phenomena. It is not easy to give an assessment which is the most appropriate, but the third point of view is a more acceptable view, that there is no single cause of tidal floods but rather a combination of sea level rise and land subsidence phenomena.

3.2. Review of tidal floods effects

Coastal cities are important because around 600 million people, or more than 10% of the earth's citizens, live in low-lying areas with a height of 1-10 meters above sea level, most of which are in Asia [25–29]. In general, high sea level rise will expose flood- and erosion-retaining infrastructure while negatively impacting people living in coastal cities [15,30,31].

One of the coastal cities in Asia, namely Semarang City, is a city that often experiences tidal floods yearly [32]. The areas of Semarang City prone to tidal floods are the northern coastal areas with almost flat contours [33], with a height of tidal floods on the house floor up to 80 cm [34].

Based on the estimated escalation in sea level rise supported by analysis of tidal records, globally, in the future, the tidal floods will experience an increasing trend in coastal cities [35], assuming that both sea level rise and land subsidence continue to increase [36]. Tidal floods can be affected by around 30% of sea level rise in almost 70% of coastal cities worldwide if no adaptation efforts are made [30]. It is estimated that by 2100 the tidal flood will hit millions of people globally and could potentially lead to climate-related migration if there is no adaptation effort [37,38].

It can be summed up that in general tidal floods will have a negative effect on coastal areas, in particular the most severe effects will be experienced by areas of coastal cities around the world

3.3. Review of tidal floods impacts

As kind of natural disaster, the tidal floods have quite large negative impacts [39] on residents living in coastal areas, especially in coastal cities, because coastal cities are centers of various economic activities and services, also centers of residential and housing areas [26,40]. The estimated damage to 136 large coastal cities in 2050 can reach US$1.600 billion [41]. This disaster, generally occurs daily or weekly depending on the tidal cycle in a coastal city area [42]. The negative impacts of tidal floods can hit wastewater treatment areas, interfering with freshwater sources and saltwater flooding in residential and business areas, negatively impacting health, life and socio-economic life [43]. These negative impacts of tidal floods on human life can occur during and after floods in the form of injury, illness and even death [44]. High and frequent tidal floods will reduce the quality of the environment, such as submerging houses, buildings and roads, which will negatively impacts community sanitation, population health and socio-economic activities [17]. Tidal floods can also negatively impacts economic and infrastructure development [15,45] and increase in line with the estimated sea level rise, due to climate change in the future [27,46,47].

Several cities in Asia experiencing heavy urbanization will suffer the negative impacts of the tidal floods [48,49]. As a coastal city in Southeast Asia that experienced severe tidal floods, Semarang City was also greatly affected by this silent disaster. In the city of Semarang, the capital of the province of Central Java, there is an international port of Tanjung Emas which plays a significant role in the region's economic growth [19]. However, the tidal floods covered the port areas and thus hampered the port loading and unloading operations [50]. In addition, tidal floods also have negative impacts on socio-economic activities and the health of city residents who live in other low-lying areas in the north of Semarang City [4]. The economic activities that were disrupted were the pond farmers, who were inundated by tidal floods water, which also caused the closure of access roads for public transportation [43]. Losses in the economic field occur due to land subsidence and the impact of submersion from tidal floods, mainly related to the disruption of land use as housing and residential land [34]. In addition, at the macro level, it costs a lot of money to build infrastructure for tidal floods control system, such as dikes, polders and pumps [42,51,52]. While at the micro level, the affected residents need additional funds for house renovations, furniture purchases, clothing and other health and psychological impacts [53].

Aside from hitting coastal areas in Indonesia, flood phenomena due to high tides have also hit in other parts of the world, such as Florida, US [15]. Tidal floods also often occur in other part of the United States, particularly in the East Coast region, recorded during 2015, such as Florida, Georgia, North and South Carolina. In addition, it also happened in Virginia and Delaware, as well as in New Jersey [6]. Likewise, in Europe, which has a very long coastline, about 185,000 km, its large coastal

cities also have several specific characteristics that must be managed. So that the vulnerability of coastal cities is increasing as a result of increasing population and rising sea levels, so the strategic process of coastal zone management is more challenging, especially with economic constraints [54].

Based on the elaboration above, it can be inventoried that the negative impacts of tidal floods on areas of coastal cities in the world are in the form of economic and infrastructure development, as well as health and socio-economic life.

3.4. Review of the methods in addressing tidal floods

As a natural disaster, several efforts have been made to overcome the effects and impacts of tidal floods. Based on the studies carried out by reviewing papers related to tidal floods handling, these efforts can be grouped into several methods, such as hard and soft solutions, as well as policy and management system solutions. Each of these methods will be elaborated as follows:

3.4.1. Hard solution. The hard solution method is the effort made to reduce and deal with the effects and impacts of tidal floods by using infrastructure in the form of dikes, sea walls, water storage and pumps. It is generally known as polder systems when all these infrastructure elements are integrated and involved. The main purpose of using a polder system is to protect an area from seawater. The elements of the polder system are dikes, retention ponds, pump systems and drainage systems [22,55]. The infrastructure implementation for coastal protection, such as dikes and sea walls, is said to provide a predictable level of certainty in protecting a coastal area [56]. The preference for using the hard solution method is an effort to protect with a higher level of certainty in areas that are center of economic activity and contain many valuable properties [57]. However, the hard solution method can only protect against tidal floods at certain heights. Construction of this hard solution structure is expensive, so a decent and detailed cost-benefit assessment is required to determine the choice of shape and size of the dike [57].

Using a polder system involving a pump system, retention pond, and drainage system is a proper method to managing flooding due to high tides with a case study of Tanjung Emas port in Semarang, Indonesia [33,58,59]. The success of the polder system in dealing with tidal floods in the Tanjung Emas port area, Semarang, is combined with raising the pier elevation, yard elevation, and access roads. In addition, coordination with port authorities, port operators and local governments is also carried out. So tidal floods have a significant impact on port operations [50]. In the long term, the retention ponds and the city's drainage system need to be sustainable. Then a strong institution is still needed to handle the operational and maintenance processes [16].

It can be concluded that the use of this hard solution method has several advantages such as being able to overcome problems in the long term with a wider scale of service. On the other hand, the use of this method has drawbacks such as requiring in-depth study and planning, requires a long time in the construction process, requires very high costs to build and maintain. In addition, this method is also vulnerable to environmental issues. And if there is a structural failure, there will be a high risk to the surrounding population and the environment.

Several papers related to their respective proposed efforts can be seen in table 1. These several efforts can be categorized as a hard solution and can be implemented according to each coastal city’s physical characteristics.

Table 1. Proposed efforts that are classified as a hard solution.

Type of Methods	Authors	Proposed Efforts
Hard Solution	Zeeberg, 2009 [57] Budinetro et al., 2012 [60]	dike improvement the main structure of the polder system: retention pond, embankment, pumping station, dam

	Smith, 2012 [22]	structures and barriers, storm water system upgrades, increasing of structures and roads
	Wahyudi et al., 2014 [55]	dike and retention pond
	Prayoga & A, n.d.; [59]	the retention pond and pump station
	Wahyudi et al., 2019 [16]	polder system drainage
	Kusumaning & Puriningsih, 2019 [50]	increasing access roads to ports, raising piers, building embankments, building polders
	Wahyudi et al., 2020 [58]	polder system

3.4.2. Soft solution. The soft solution method is the effort to reduce and deal with the effects and impacts of tidal floods by involving social, cultural, and habitual methods, such as adaptation, encouraging local wisdom and collective action. An integrated method and understanding of the socio-ecological system are needed in dealing with tidal floods so that it will increase the capacity of human response to risks arising from the environment [61]. In addition, several phenomena attract global attention in the form of nature-based solutions, which are solutions based on ecosystems and blue-green infrastructure [62].

Adaptation is the response and reaction needed to reduce vulnerability due to tidal floods and deal with their current and future impacts [63]. Several studies have shown that adaptation is an effective and cost-effective way to reduce coastal hazards [64]. Meanwhile, the adaptation strategy carried out at the national level will reduce the total cost of adaptation from each local area [65]. A conceptual framework was developed by PICC in 2014 on human responses to coastal hazards, including tidal floods, namely retreating from the shoreline and protection using hard and soft structures, as well as to accommodate changing activities [37]. Meanwhile, retreat and protection are interesting issues in science and media circles, including discussion of opinions regarding migration caused by climate change [66,67]. However, there are still some challenges in improving adaptation guidelines in coastal areas and assessing risks related to climate change, such as using multi-hazard methods to derive complexity and using appropriate methods to calculate uncertainty accurately [68].

To reduce the impact of tidal floods, residents living in coastal cities need to adapt to the effects and impacts of tidal floods. Adaptations made by residents of coastal cities an adaptation to houses, social and public facilities and social adaptation [13]. Some other adaptations are elevating the floor of the house, elevating electric switches, and elevating furniture that is adjusted to the income of each resident [34].

In addition, collective action is interesting by involving stakeholders from local, regional and central levels in risk sharing across regions [69]. Understanding flood risk, especially in urban areas, must include all influencing factors, such as rainfall, drainage, coast and rivers, so it is expected to make a more accurate estimate in dealing with the risk of tidal floods [70]. In addition, cultural involvement in risk is also important, namely by increasing awareness that, we have lived side by side with risk by not forgetting the floods that occurred in the past. In addition, prepare to face the risk of flooding in the future by adopting safety behavior [71].

There is another method, namely the non-polder method, that will benefit the ecosystem by restoring biodiversity so that it can be used for eco-recreation. The community has not accepted The application of this method because community associations regarding the use of sea walls are still very strong as the only appropriate way to deal with tidal floods. In addition, government policies on coastal risk management, including tidal floods, are also considered to have not shown significant progress, which has further encouraged community resistance to solutions other than sea walls [72].

It can be concluded that the use of the soft solution method has several advantages such as the implementation of this method can be adjusted to the financing capabilities of the surrounding

community. In addition, this method does not require detailed studies and planning, can be done relatively quickly and is not expensive. The use of this method is also more friendly to environmental issues. On the other hand, the use of this method has drawbacks, such as tidal flooding that cannot completely disappear, so periodic evaluation and improvement must be carried out in the use of this method.

Several papers related to their respective proposed efforts can be seen in table 2. These several efforts can be categorized as a soft solution and can be implemented according to the social and cultural characteristics of each coastal city.

Table 2. Proposed efforts that are classified as a soft solution.

Type of Methods	Authors	Proposed Efforts
Soft Solution	Adger et al., 2005 [61]	socio-ecological resilience
	Nicholls et al., 2007 [37]	adaptation to climate change and sea level rise
	Harwitasari, 2009 [20]	adaptation responses to climate change and tidal floods
	Erdlenbruch et al., 2009[69]	risk-sharing policies
	Trombetta, 2014 [66]	linking climate-induced migration and security
	Jiang & Tatano, 2015 [70]	spatial flood risk assessment
	Goeldner-Gianella et al., 2015 [72]	against the use of polders
	Baldwin & Fornalé, 2017 [67]	adaptive migration
	Lincke & Hinkel, 2018 [64]	financing coastal adaptation, consideration of high benefit-cost ratios of coastal protection
	Wiratuningsih et al., 2018 [13]	adaptation to public facilities and social facilities
	Oppenheimer, M; Glavovic, 2019 [62]	nature-based solutions, solutions based on ecosystems
	Paulik et al., 2020 [65]	central and local actions to plan adaptively to minimize future socioeconomic impacts
	Toimil et al., 2020 [68]	adaptive solutions such as nature-based
	Fajrin et al., 2021 [34]	ways in which society adapts to the construction of houses and their environment

3.4.3. Policy and management system solution. The policy and management system solution method is the effort to handle the effects and impacts of tidal floods, which involves integrated policies and flood management. The use of hard solutions such as sea walls, retention ponds and pump systems is not sufficient in dealing with tidal floods. A management system is needed, which contains governance and guidelines for operating and maintaining the elements of the hard solution, in order to ensure all systems run properly. However, the maintenance phase is often not carried out optimally, which reduces the protection capacity of the hard solution system [32,73]. Related to the maintenance phase, an institution that specifically handles the management of the polder system is needed, including operations and maintenance. This institution combines elements of both central and local government, business and

private sectors, as well as public participation to ensure the pumps and polder systems are functioning properly [32].

Early Warning Systems (EWS) can be directed to forecast tidal floods in coastal cities, although technically, many challenges are still related to the complexity of coastal morphology [74]. Increased capacity of Early Warning Systems is needed to improve preparedness in the future in mitigation efforts in reducing damage [54]. Integrated Flood Risk Management is a management system solution that applies a combination of hard and soft solutions in reducing and adapting to the effects and impacts of flood damage. It is projected to deliver integration in managing tidal floods [75].

The state has an important role in making strategies to map coastal areas prone to tidal floods by making policies on tidal floods management plans [76]. Then local governments can cooperate and involve communities affected by tidal floods to develop plans to reduce the danger of tidal floods [77]. The government's role is also needed in mitigation options by making policies related to zoning regulations, including detailed building regulations. Then the policy on purchasing property and making infrastructure is supported by efforts to educate the public through public information networks [22].

The government can also take a role by making policies that regulate Integrated Coastal Zone Planning and Management to protect coastal areas following other government policies in the field of urban spatial planning. Then, together with community participation, increase the capacity of residents to adapt, including developing friendly financing schemes for low-income communities [63]. Furthermore, in addition to strong institutions between the government and the role of the community in managing the polder system, government policies and regulations related to urban spatial planning and capacity building of residents living in affected areas are also needed through training in adaptation [77].

It can be concluded that the use of the policy and management system solution method has several advantages such as this method includes control and maintenance of the hard and soft solution method, this method has a wider service area scale. The use of this method is also more friendly to environmental issues and involves public participation. On the other hand, the use of this method has drawbacks such as challenges in integration between sectors and related stakeholders. In addition, there will be many conflicts of interest because it involves various sectors and stakeholders.

Several papers related to their respective proposed efforts can be seen in table 3. These several efforts can be categorized as a policy and management system solution and can be implemented according to the governance characteristics of each coastal city.

Table 3. Proposed efforts that are classified as a policy and management system solution.

Type of Methods	Authors	Proposed Efforts
Policy and Management System Solution	Marfai et al., 2008 [77]	collaboration between affected communities and local government
	Harwitasari, 2009 [20]	policies that regulate Integrated Coastal Zone Planning and Management to protect the coastal area
	Haerens et al., 2012 [54]	increased capacity of Early Warning Systems
	Adi & Wahyudi, 2015 [32]	aspects of legal and financing, as well as public participation
	Nur & Shrestha, 2017 [75]	implementation of Integrated Flood Risk Management

	van Dongeren et al., 2018 [76]	a set of open-source and open-access to decrease danger and improve resilience to tidal floods (the RISC-KIT project), which contains methods, tools and management
	Bolle et al., 2018 [74]	implementation of Early Warning System
	Risnadinata et al., 2020 [73]	the standard operating procedure is expected to support the operation and maintenance

4. Conclusions and recommendation

Tidal floods, as natural disaster phenomena in coastal areas, can cause a lot of destruction and losses that will increase when they hit coastal cities. Rising sea levels cause these floods due to climate change. Land subsidence phenomena will exacerbate tidal floods.

In general, the effect of tidal floods is water covering the lower area, which then has large negative impacts on coastal cities as center of economic and residential activities. These negative impacts are environmental degradation by submerging houses, access roads, social and public facilities as well as sanitation installations and clean water wells. All reductions in the quality of the environment can lead to disturbances in the health, lifestyle and socio-economic life of the affected population in coastal cities.

There are 3 (three) methods to addressing tidal floods: hard, soft, and policy and management system solutions. The hard solution method involves infrastructure such as dikes, sea walls, water storage and pumps (polder system). The soft solution methods related to social, cultural, and habitual methods, such as adaptation, encouraging local wisdom and collective action. Meanwhile, the policy and management system method implements integrated policies and flood management.

Based on the description above, each of these methods has advantages and disadvantages, so that in-depth and comprehensive studies and planning are needed in dealing with tidal floods in the area of coastal cities. There is no single method that is most appropriate for dealing with tidal flooding. Each method is adapted to the physical, economic, socio-cultural and governance characteristics of each coastal city, as well as the geomorphological and climatic conditions of each coast.

The challenge for future research is to combine these methods to create a new equilibrium point at a cost that is not too high but can achieve satisfactory impacts, as well as being friendly to environmental issues. The integration role of the government and the private sector, as well as public participation, will certainly boost the achievement of this new equilibrium point.

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