Future flood management strategies in Indonesia

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Abstract. Rapid developments in the catchments, such as deforestation and loss of swamp areas, and in the city, such us sealing off unpaved areas have resulted in higher runoff and deteriorated the river's conveyance capacity. Critical flooding conditions occur in the city, particularly during heavy rainfall and high tidal flow. Inundation can be characterized as river, tidal, flash and urban flood. A number of flood defense measures have been implemented, designed for return periods of 15 to 50 years, and nonstructural measures within communities who live in flood-prone areas. However, strategies consisting of both structural and nonstructural measures should be developed, upgrade current flood defense practices in Indonesia to a higher safety level, complying with a return period of 50 to 100 years. An integrated and holistic approach is necessary to find solutions for flood management problems in Indonesia. Besides, a regional Water Resources Management plan should be developed, taking into account both flooding and water scarcity issues. The study at hand describes various flood management strategies, each compiled on the basis of different starting points, such as structural measures, non-structural measures, environmental considerations, etc. The implementation of strategies, or separate measures, should focus on priorities for areas most frequently affected. On the short term, efficiency and low-cost measures should be implemented, such as flood forecasting and early warming and flood proofing. In addition, planning of mid and long-term measures should commence on short notice. In the mid-term, larger scale and sustainable measures should be implemented in order to reach a safe level with return periods of 50 to 100 years in the future. Finally, however involving stakeholders and the local communities in planning, development, and implementation of strategies and measures are of utmost importance.

1 Introduction

The increasing demand for land strongly influences the land-use in a catchments area. The land-use changes adversely affect areas that naturally absorb (flood) waters such as; swamps, forest, etc. Settlement and other anthropogenic activities in these areas strongly influence the flooding charge, and the vulnerability to flooding damage [1-3] Population settlements and economic activities increase rapidly in Indonesia, especially along the floodplains of the river.

The flooding problems and accompanying damages might be the result of area cultivation and land-use changes without any control. In addition, it seems that increasing rainfall intensities in the upstream catchments of the river and in a city are contributing to the problem of flooding as well [4]. At the same time, the rising tide is dammed up as a result of a backwater in the river [5, 6]. These events cause the river to overflow and inundate the settlement areas in the floodplains and lower high lands.

The study area is located on the middle of Sumatra island, where most areas are situated on the lowland, well known as Riau province. The capital of the province is Pekanbaru, which has a unique characteristic as influenced by two significant catchments; at the upstream and downstream. The boundary of upstream catchments is the hills, and the downstream boundary is Malacca Strait. Pekanbaru is a center of government administration and economic activities. Pekanbaru is located about 160 km upstream of the Siak River. The Siak River is one of the biggest rivers in Riau Province. The Siak River crosses through Pekanbaru and flows from west to the east. The right and the left side of the river basin are occupied by an increasing number of people with various economic activities. The main function of this river is navigation, which strongly supports the social-economic development of the region. The societies surrounding the river work as traders and traditional fisherman.

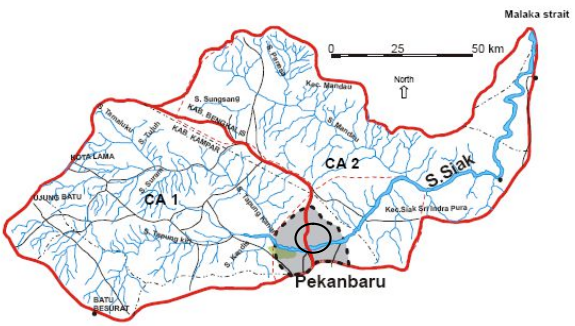

Fig. 1. Siak catchment area, Pekanbaru, Riau Province

The Siak river has a total catchments area of 1,102,600 ha, while the catchments area up to Pekanbaru (CA_1) is 542,900 ha, 559,700 ha from Pekanbaru to the

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estuary (CA_2), and the capital city of Pekanbaru is 63,220 ha. It figures out that the surface and subsurface water flows of the capital city has been influenced from two directions of upstream and downstream.

2 The existing flooding condition

The flood occurred along the river banks; however, Pekanbaru was also influenced by high intensities of rainfall, which also affected the catchments areas [7]. In addition, high tides inhibited the flow of floodwater downstream. Although the various efforts for an anticipation of the flood had been undertaken, i.e., constructing flood mitigation facilities, including water pumps the actual problems still could not be prevented. There were not enough facilities and infrastructure available, compared to the existing requirements.

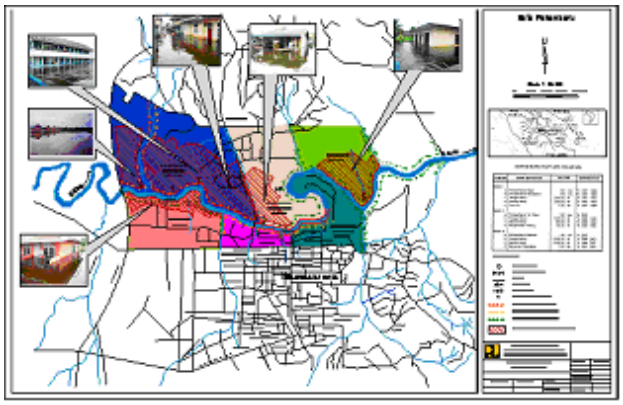


Fig. 2. Map of actual flooding areas at Pekanbaru

The flood elevation reached up to 1.25 m, and the duration was longer than one week [8] [9] [16]. In figure 3, the flood elevations in one of the newer settlement areas are indicated.

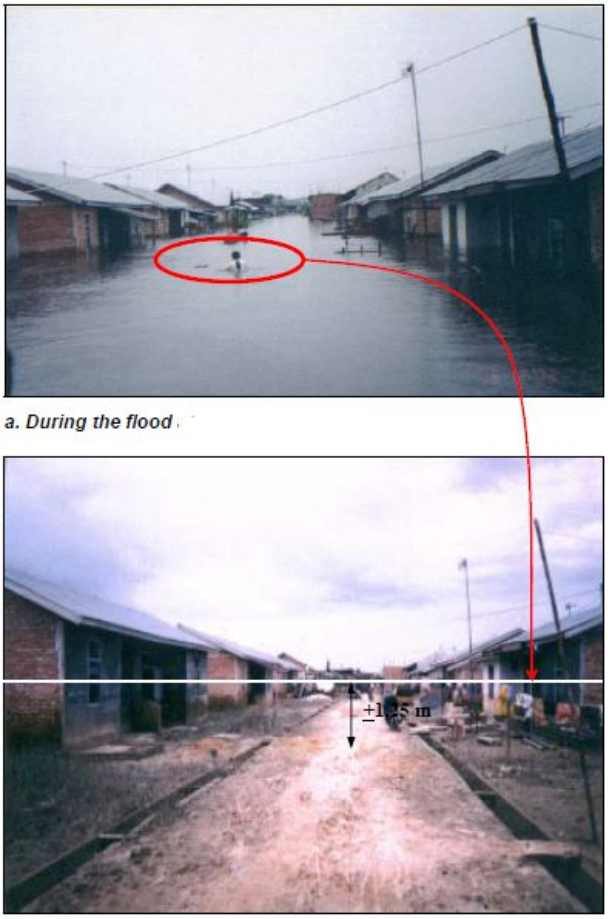
It was reported floods in Pekanbaru have begun to subside but still resulting over 10,000 people displaced persons since the occurrence on the 1st of December 2017 [10-11]. The evacuees are residing in various spots allocated for evacuation and assisted by the office of the Provincial Government. None of the victims have expressed their willingness to return home, as some houses are still flooded with water up to 1 meter.

In 2018, various areas were flooded in Pekanbaru during the wet season with inundation depths of 10 to 150 cm [12-13].

Nowadays, annual floods are still taking place, mostly involving 3 sub regencies in 2 Regencies of Pekanbaru.

The affected flooding area until December 2017 consisted of:

- Flooding discharge : 2,642 m3/s
- Duration of inundation : 10 days
- Elevation of inundation : 0.5 - 1 m
- Length of affected roads : 16 km
- Affected schools : 3 units
- Affected religious places : 8 units
- Affected rural/regencies : 3 regencies
- Affected residences : nearly 30,000 persons
- Erosion along river banks : 400 m
- Victims :1 dead



a. During the flood

b. After the flood had subsided

Fig. 3. Flood Elevations in Settlement Areas of Pekanbaru

2.1 Inundated areas

During floods, some areas in Pekanbaru are inundated temporarily, others more permanently. This depends on the magnitude and genesis of the flood and the topography of the inundated area.

The average height of the water level in the flooded area of Pekanbaru in October 1985 was noted at the elevation of +4.60 m, in March 1988 +4.40 , in November 1994 +3.80 m and finally in December 2004 +3.80 m above sea level. The water level of the floods in Pekanbaru rises gradually; at the same time, flow velocities are decreasing [9].

The average duration of inundation in Pekanbaru is 14 days. Nowadays, the sensitive and vulnerable regions are due to the unobstructed flood mitigation facilities such as dikes, pumps and water gates. The sensitive and vulnerable regions are due to the uncompleted flood mitigation facilities such as pumps and water gates.

The relationship between flood elevation, inundated areas and return periods along the Siak River in

Pekanbaru are illustrated in Figure 4. This relation shows that every year on average an area of approximately 3,000 ha is inundated in Pekanbaru.

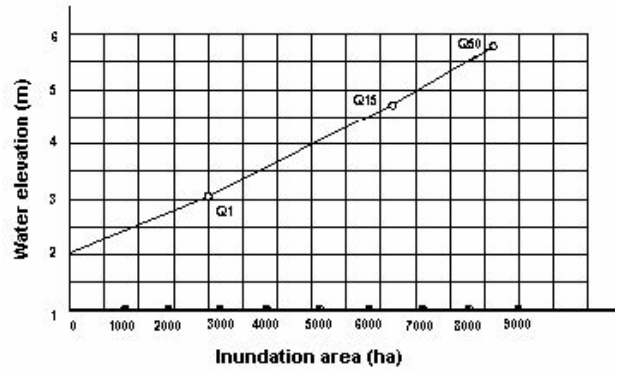


Fig. 4. The relation between water elevation, inundated area and return period

Figure 5 shows that the areas of actual flooding are located in the center of Pekanbaru, in particular on the occupied settlements and public service areas. Usually, these floodings occur during heavy local rainfall and coinciding high tides. In the last decade the number of events in which intense local rainfall caused flooding of Pekanbaru has increased due to the increasing development of infrastructure, without considerating the impact on the hydrological system and the environment.

Fig. 5. Location of inundated areas in Pekanbaru

2.2 Damages

The damages caused by flooding are generally substantial and are characterized as follows:

1. The inundations that occurred in the densely populated areas have resulted in destructions of houses and public infrastructures such as roads, public health services, schools, and wells.
2. These damages and destructions have disturbed socio-economic activities of the community in Pekanbaru. A significant number of students have been vacated, and the majority of the community in Pekanbaru have a refuge in the safer places.
3. The inundation cause odor around the area and several diseases have occurred.

Figure 6-9 illustrate several locations in Pekanbaru during and after the flood.

Fig. 6. Houses during and after the Flood

Fig. 7. Houses on stilts during and after the flood

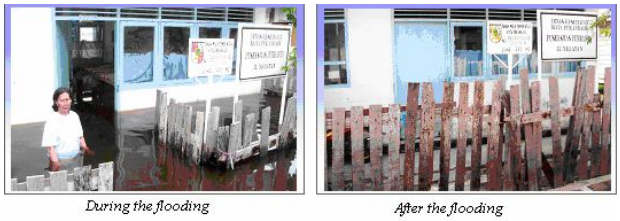


Fig. 8. Public Health Service, Pekanbaru, during and after the flood

Fig. 9. The Primary School SD 034 before and after the flood

2.3 Organization of flood management in indonesia

The formal institutions that are responsible for flood disaster mitigation and management in Indonesia and Pekanbaru, consist of national, provincial, city and site-specific level. The National Coordination Committee for hazard mitigation represents the coordinating institution, which is responsible for the management of flood hazards and victim relief [14]. The members of this committee are from several ministries (Home Affairs, Social, Health, Public works, Settlement, and Regional Infrastructure, Finance and Transportation), Indonesian National Armed Forces, the Indonesian Police, and Provincial government.

The representative coordinating organization for flood hazards and victim relief on the provincial level is formed by the Executor Coordination Unit. The unit is headed by the Governor. The Executor Coordination Unit consists of members from Regional Development

Committees, Public Works Services, Public Health Services, Indonesian National Armed Forces and Indonesian Police.

The Executor Unit represents the coordinating institution on the city level, responsible for flood hazard management and victim relief. The Executor Unit consists of members of Regional Development Committees, Public Works Services, Public Health Services, NGO's, Indonesian National Armed Forces and Indonesian Polices, and is headed by the mayor.

The Flood Hazard Mitigation Unit is responsible for the guidance and management of flood hazard mitigation activities on the site.

The members of the Flood Hazard Mitigation Unit are from the Society, Duty of regency and sub regency, Public health and others on official duty, and are headed by the head of the Regency.

The organization structure is illustrated in Figure 10.

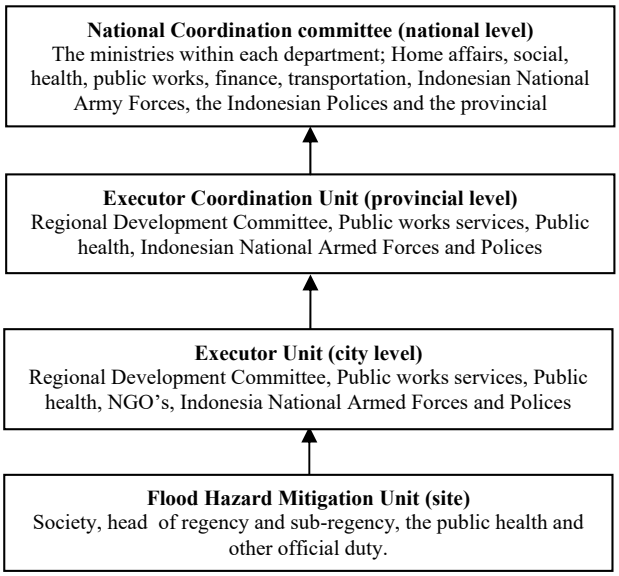


Fig. 10. Organization of flood hazard management in Indonesia

The most important responsibilities of the National Coordination Committee are:

- Formulating and specifying management policies for flood hazard mitigation, which should be quick, efficient, and effective.
- Coordinating the execution of integrated activities for management of flood hazards mitigation.
- Giving guidance to efforts for the management of flood hazards mitigation, which consists of prevention, rehabilitation, and reconstruction.

The responsibilities of the Executor Coordination Unit are:

- Coordinating efforts to manage flood hazards mitigation in its region, according to the policies specified by the National Coordination Committee (prevention, rehabilitation, and reconstruction).

The responsibilities of the Executor Unit are:

- Executing activities for the management of flood hazards that could occur in its area with reference to the instructions and policies given by the National Coordination Committee.

3 Future flood management strategies

Basically, developing a flood management system is a complex problem, including many technical science disciplines, like Hydrology, Hydraulics, erosion of the catchments area, river engineering, river morphology and sedimentation, drainage system, waterworks, and else. Besides, the success of a flood management system also depends on other aspects that are related to social, economic, environment, institutions, organizations, law, etc.

For any type of these flood causes and problems, there is no unique solution which is perfect, because problems may occur in different time and space, and the solution cannot be applicable for all conditions. Solutions might be structural and/or no-structural, depending on the type, conditions, time and space of the problem. In this research we just focus on strategies to mitigate floods, which should also be beneficial to water scarcity in Pekanbaru for example, storing floodwater and reusing it.

The locations that are most affected by floods in the past are situated in Pekanbaru city centered (Figure 6-9).

3.1 Development of flood management strategies

In order to develop a sustainable flood management system in Pekanbaru, several strategies with a combination of measures will be elaborated. In total four strategies will be developed, based on a specific starting point:

1) The strategy based on structural measures;
2) The strategy based on nonstructural measures;
3) The strategy with a combination of structural and non-structural measures;
4) The strategy based on environmental considerations.

The justifications of these strategies are based on their specific focal point (structural, non-structural, both combination or environment consideration) and priority locations that are directly impacted by floods and sustainability[15]. In this study, the concept of sustainability is related to the continuity of economic, social, institutional and environmental aspects of human society. Structural measures are aimed at 'keeping floodwaters away from the people', involving flood mitigation works. Typical structural measures include flood mitigation dikes and flood detention basins. Non-structural approaches for flood management comprise the activities, which are planned to eliminate or mitigate the adverse effects of flooding without involving the construction of flow-modifying structures. Measures with an environmental consideration are measures in terms of positive effects on the environment, including people and communities.

3.2 Development of flood management strategies

The flood management strategies described in this section provide the responsible authorities in Pekanbaru with information and a framework to plan future flood-

related studies and projects within the Siak catchments region. The implementation of a particular measure (or strategy) will ultimately depend on the priority given, and the resources made available. The contents (measures) of the various flood management strategies are further illustrated in Table 1.

3.3 Additional actions for flood hazards management in Indonesia

The concept of flood hazard mitigation management should be conducted for the situation before, during and after flooding. Figure 11 illustrates the sequence of activities related to the management of flood hazard.

1.1.1 Before Flooding

The actions that need to be done before flooding occurs are:

1. The prevention; action is taken to prevent impacts of flooding, which are directly related to the community and essential facilities. The followings are some examples of general prevention measures; land use management, e.g., people are not allowed to live on the flood-prone areas. Construct dikes along the river in order to protect areas from overflowing or river flooding.
2. Mitigation; Actions were taken to eliminate or reduce the degree of long-term flood risk to human life and property. Mitigation assumes that society is exposed to flood risks whether or not it occurs. Examples of general measures of mitigation are monitoring inspection and land acquisition.
3. Preparedness; Action was taken in advance of a flood event to develop operational capabilities and facilitate an effective response in the event flooding occurs; general measures of preparedness are, e.g., warning systems and evacuation procedures.

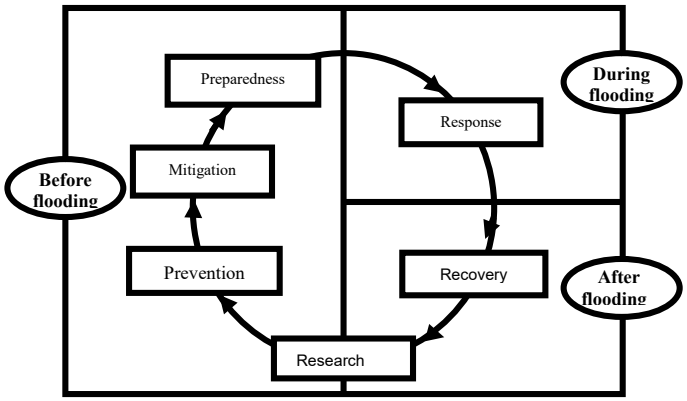


Fig. 11. The sequence of flood hazard management activities

Table 1. Flood management strategies in Indonesia

Strategy I **Structural Measures**	**Strategy II** **Non-Structural Measures**	**Strategy III** **Combination**	**Strategy IV** **Environmental Consideration**
A. Protect areas Rumbai, Tampan,Senapelan, Limapuluh and Sail by **dikes** on the left and right sides of Siak river	**H**. **Law enforcement**	**J.** Adjustment **drainage system** and create a **SUDS** in Pekanbaru	**J.** Adjustment **drainage system** and create a **SUDS** in Pekanbaru
	I. Development of **flood forecasting and early warning system** in Riau province and Pekanbaru in particular	**N**. Develop operation and maintenance programmes for existing **pumps** and **gates**	**B**. Create **retention ponds** on
B. Create **retention ponds**	**J**. Adjustment **drainage system** and create a **SUDS** in Pekanbaru	**B**. Create **retention ponds** on	**M**. **Rainwater harvesting** in-house/store/office
	K. **Flood proofing** of buildings in flood prone areas	**H**. **Law enforcement**	**O**. **Catchment area management**; land use control in the upstream and downstream parts of the Siak catchment area, Pekanbaru, and its surroundings. Reforestation, land conservation, keep swampy areas as natural storage, Relocation of industrial and commercial areas and prevent new industrial activities in flood-prone areas
C. Create **retarding basin** in the upstream part of Siak catchment as flood storage, to support agriculture practices and other functions	**L**. **Public participation**	**O**. **Catchment area management**; land use control in the upstream and downstream parts of the Siak catchment area, Pekanbaru, and its surroundings. Reforestation, land conservation, keep swampy areas as natural storage, Relocation of industrial and commercial areas and prevent new industrial activities in flood-prone areas	
	M. **Rainwater harvesting** in house/store/office		
D. Construct **Floodway** (canal) on Umbansari and Nelayan river	**N**. Implement a number of **pumps** and **gates** on some locations and develop operation and maintenance programmes for existing pumps and gates		
E. Improvement of river channels (deepening and widening of tributaries)	**O**. **Catchment area management**; land use control in the upstream and downstream parts of the Siak catchment area, Pekanbaru, and its surroundings. Reforestation, land conservation, keep swampy areas as natural storage, Relocation of industrial and commercial areas and prevent new industrial activities in flood-prone areas		**F**. **Riverbank protection** along the Siak river in Pekanbaru and some critical (sliding and erosion) areas along the Siak river
F. **Riverbank protection** along the Siak river in Pekanbaru and some critical (sliding and erosion) areas along the Siak river		**C**. Create **retarding basin** in upstream part of Siak catchment as flood storage, to support agriculture practices and other functions	**C**. Create **retarding basin** in the upstream part of Siak catchment as flood storage, to support agriculture practices and other functions
G. **Dredging** in Siak River		**M**. **Rainwater harvesting** in-house/store/office	
		L. **Public participation**	**L**. **Public participation** **H**. **Law enforcement**

1.1.2 During flooding

Response actions are taken immediately before, during or directly after a flood occurs, to save lives, minimize damage to property and enhance the effectiveness of recovery. An example of a general response measure is emergency medical assistance.

1.1.2 After flooding

There are two activities that need to be done after a flood has occurred:

1. Recovery; is activities to return vital life support systems to minimum operating standards and long-term activities designed to return life to normal or improved levels. Several phases of recovery are restoration, rehabilitation, and reconstruction. An example of a general recovery measure is the supply of temporary housing.
2. Research; the results of research activities after flooding need to be taken into consideration for the adaptation of future flood management action plans. The research activities are related to:
    - Site investigation;
    - Data collection (hydrological and hydraulic data, damages, inundated areas, etc.);
    - Study and analysis causes of flooding;
    - The recommendation to the action plan.

The results of research should also contain an evaluation and monitoring activities after flooding which will be used as a reference to determine disaster management activities locally, regency, city, province and also on a national level, divided into temporal, short-term, midterm and/or long-term activities. An example of research activities is the production of maps of potential flooding areas and law enforcement.

In planning solutions for flood mitigation in Pekanbaru, there are five aspects that need to be taken into consideration:

a. Economic aspects; provide new land for relocation of settlements and industries and improve (financial) compensation measures.

b. Social aspect; the peoples who live in flood-prone areas, which are directly impacted by flooding, should be involved in the public participation process. In addition, poverty alleviation and social rehabilitation projects should be integrated with flood mitigation strategies.

c. Law aspects; policies of the government should be rightful regarding land status and compensation regulations. Law enforcement regarding illegal activities (deforestation) in the catchments is also necessary.

d. Technical aspects; implementation of structural flood defense measures and management, as well as operation and maintenance is needed to achieve flood protection levels of once in 50 years.

e. Environmental aspects, including water quality, catchments preservation, and groundwater recharge.

4 Conclusions and recommendations

4.1 Conclusions

1. Flooding in Pekanbaru occurs most frequently in the city center which consists mainly of settlement areas. Annually on average 3,000 Ha areas are inundated. The areas which are often impacted by flooding are with an average duration of inundation of 7 days/year.
2. The leading causes of flooding in Pekanbaru are due to river flow. The flood affected area is usually quite extensive because the bed of the Siak river is rather flat. Tidal influences also reduce the conveyance capacity of the Siak river. When the discharge of the Siak river is increasing, together with high tide and a lodged drainage system, the probability of flooding in Pekanbaru will increase. Besides, The loss of swamp areas as natural storage, also induces flooding, since swampy areas are used for new settlements and agriculture.
3. In order to reduce damages, individually to peoples who live in flood-prone areas conduct preparedness measures face the floods. A number of houses in flood-prone areas are building on stilts and have multi-storeys. People choose to stay at home during the flood because they are worried that their house will be looted. As a result, people who choose to stay at home cannot do their daily activities. Most people are impacted by sickness after flooding. Although their health is impacted, they do not like to move to other places which are free from flooding, because these locations are not near their place of work.
4. Four flood mitigation strategies have been suggested to solve the flooding problems in Pekanbaru and the Siak catchments. The justifications of strategies are based on specific focal points (structural measures, nonstructural measures, a combination of structural and nonstructural measures and environmental considerations), priority locations and sustainable development. The selection of strategies depends on available resources, local demands, and specific situation.
5. Flood water can be stored in retention and retarding basins to be used for clean water resources. Rainwater harvesting techniques can mitigate the adverse impacts of flooding and can be used as clean water resources as well.
6. The implementation of strategies (or measures) in Pekanbaru cannot be conducted in a short-term period, due to limited resources. It should be spread out over time, divided in 5 years for a short term, 10 years for midterm and 20 years for a long-term period. The locations that are directly impacted by flooding should be a priority for the implementation of a strategy.

4.2. Recommendations

1. Upgrade the existing, and implement this "new" flood forecasting and early warning system as quickly as possible;
2. Focus initially on the short term implementation strategy ('emergency measures');
3. Gradually change the (provincial and local) 'water management organization' into a flexible organization, capable of managing the flood problems in Pekanbaru;
4. Discussions needed with local authorities and the public (participatory process) in order to develop and implement 'tailor-made' flood mitigation strategies;
5. Development of a regional Water Resources Management Plan (including floods and water scarcity);

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References

1. Wheater, H. and E. Evans, *Land use, water management, and future flood risk.* Land use policy, 2009. **26**: p. S251-S264.
2. Lammert, M. and J.D. Allan, *Assessing biotic integrity of streams: effects of scale in measuring the influence of land use/cover and habitat structure on fish and macroinvertebrates.* Environmental Management, 1999. **23**(2): p. 257-270.
3. Allan, D., D. Erickson, and J. Fay, *The influence of catchment land use on stream integrity across multiple spatial scales.* Freshwater Biology, 1997. **37**(1): p. 149-161.
4. Cummings, D., et al., *The tide-dominated Han River Delta, Korea: Geomorphology, sedimentology, and stratigraphic architecture*2015: Elsevier.
5. Le, T.V.H., et al., *The combined impact on the flooding in Vietnam's Mekong River delta of local man-made structures, sea level rise, and dams upstream in the river catchment.* Estuarine, Coastal and Shelf Science, 2007. **71**(1-2): p. 110-116.
6. Siegel, H., et al., *Siak River System — East-Sumatra Characterisation of sources, estuarine processes, and discharge into the Malacca Strait.* Journal of Marine Systems, 2009.
7. Teriyoko, W., Mudjiatko., & Sutikno, S. (2015). *Identification of Flood Prone Areas Using Inundation Geographic Information Systems Pekanbaru Case Study*. Jom F ENGINEERING. 2 (1)
8. Nurhamidah, N., B. Rusman, et al. (2017). "Social, economic and environmental perspectives of flood assessment on delta lowland." International Journal of Civil Engineering and Technology: 966-978.
9. *Feasibility study of flood control of the Siak River in the Pekanbaru city of Riau province*, K. end, Editor, CV. Sigma Moment ENG.
10. Misgiono, S., *Siak River Overflowed, 10 Thousands of Pekanbaru Residents Flooded*, in Tribunnews2017
11. Tanjung, C., Flooded, P*ekanbaru Residents Evacuate in Tents,* in Detiknews2018.
12. INDRIANI, C., *Floods Inundate Roads in Pekanbaru, Police Help Dorong Motor Warga*, in Kompas2018.
13. Bayu and A. Romadhoni, *A number of points in the city of Pekanbaru were flooded*, in Antaranews2017.
14. HARYATI, S., *Effectiveness of National Search and Rescue Agency in Disaster Management and Disasters in Pekanbaru.* 2011.
15. Sastrodihardjo, S., *Efforts to overcome the flood problem as a whole2010*: Foundation for Public Works Publishers, Mediatama Saptakarya.
16. Tanjung, B.H., Flood 1 Meter Soak Housing in Pekanbaru, in Okezone 2014: Jakarta.