Can Tho University Journal of Science
website: ctujs.ctu.edu.vn

DOI: 10.22144/ctu.jen.2022.037

Application of socio-hydrological approach to study water-related hazards in Can Tho City

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Article info.

Received 22 Sep 2021
Revised 24 May 2022
Accepted 25 May 2022

Keywords

Can Tho, drivers, natural hazards, sociology, water

ABSTRACT

The concept of socio-hydrology was applied in this study to explore the interaction between urban development and water-related hazards in Can Tho using both primary and secondary data. The results showed that water-related hazards tend to increase. Many drivers are identified including both social and hydrological. The trend of water level at Can Tho station (mid-stream) in the last 20 years has a positive relationship with down-stream (Dai Ngai station), and a negative relationship with up-stream (Chau Doc station). It means that sea level rise has increasingly affected the water regime in Can Tho. Heavy short duration rainfall also contributes to urban floods. Moreover, social drivers as human behaviors and uncontrolled urban development also increase the risk. Therefore, to minimize the impacts of water-related hazards it is necessary to take into account a combination of hard measures and soft measures. Green urban development which shows potential for improving the quality of ecosystem services and provide opportunities for urban dwellers to reconnect with nature should be promoted for disaster risk reduction.

1. INTRODUCTION

Water-related hazards which arise from too much water, too little water, or polluted water are considered among the most complex phenomena, especially under a changing climate. According to the World Water Development Report 4, water-related hazards include floods, mudslides, storms, and related ocean storm surges, heat waves, cold spells, droughts, and waterborne diseases (United Nations-UN, 2012). Floods, droughts, and windstorms are the most frequently occurring natural disaster events and account worldwide for almost 90% of the 1,000 most disastrous events since 1990 (UN, 2015). An estimation by the UN (2015) showed that floods, droughts and storms have affected 4.2 billion people, accounted for 95% of all people affected by disasters and caused USD 1.3 trillion of damage, equally to 63% of all damage since the Rio Earth Summit in 1992. In terms of fatalities, the total number of deaths caused only by floods and droughts exceeded 166,000 persons between 2001 and 2018 (UN-Water, 2020). Among continents, Africa and Asia are the most impacted on all counts such as a number of deaths, people affected, and economic losses (UN-Water, 2020). Many studies reported that water-related disasters (i.e. flood, drought, erosion, salinity intrusion, health risks, etc.) will increase in both frequency and severity as a consequence of climate change on the global water cycle and unplanned socio-economic development including rapid urbanization, especially in developing countries and low lying deltas (UN, 2015; Chinh et al., 2017; Hoang et al., 2018; Nguyen et al., 2021).

Located in the tropical monsoon area of South East Asia, Vietnam is one of the most disaster-prone countries in the world (Eckstein et al., 2021). The country has a long coastline of over 3,200 km, coupled with high concentrations of populations and economic assets located in river deltas and other low-lying areas, which exposes these areas to multiple hazards such as floods, storms, whirlwinds, flash floods, coastline erosion, droughts, salinity intrusion, and landslides (Binh, 2015; Nguyen et al., 2021). According to the World Bank report, annual losses to people's well-being from natural disasters are estimated at around USD 11.0 billion in purchasing power parity (Rentschler et al., 2020). The losses vary by region, with coastal areas and deltas being the most impacted. Additionally, population growth, rapid socio-economic development, urbanization, and climate change will all increase the exposure and susceptibility to water-related hazards in the future (Chinh et al., 2017; Nguyen et al., 2017; Rentschler et al., 2020).

The UN-Water Country Brief assessed water-related hazards as follows: Vietnam is exposed mainly to landslides and floods triggered by tropical storms and monsoon rains, although storm surges, whirlwind, river banks and coastline erosion, hail rain and drought are also prevalent. The trend in the number of water-related hazards has been increasing. Economic loss and the number of affected people have also been on the rise (UN-Water, 2013). Recently, during the dry season of 2015-2016, the Vietnamese Mekong Delta suffered the worst historic drought and salinity intrusion on record. All 13 provinces of the delta were affected with a total damage of up to 360 million USD (Ngoc, 2017).

Can Tho City (CTC) located in the Vietnamese Mekong Delta, which is one of the five cities controlled directly by the national government plays an important role in regional socio-economic development but faces an array of water-related issues. Due to its low-lying topography and only 80 km from the sea, CTC is influenced by fluvial/river floods from upstream flow, pluvial floods in urban areas, and coastal floods caused by high tides, typhoons, and storm surges. Additionally, uncontrolled urbanization and a low drainage capacity and infrastructure further increase flood risks; for instance, the flood in 2011 inundated about 27,800 houses and caused a loss of USD 11.3 million in CTC (Can Tho Committee for Flood and Storm Control, 2011; Chinh et al., 2017; Nguyen et al., 2017; Nguyen et al., 2021).

Currently, there have been a number of studies on floods in Vietnam generally, and in Can Tho in particularly. A systematic review of 519 scientific papers related to flood risk in Vietnam shows that there are many drivers of flooding such as rainfall, storm, typhoon, climate change, sea level rise, degradation of wetland areas, urbanization, and operation of dams and reservoirs (Nguyen et al., 2021). Most of these studies are mono-disciplinary, looking at flooding from a researcher's professional perspective such as hydrology or sociology. Meanwhile, humans and the environment always interact with each other (Gallopin, 2006; Renaud, 2006; Biggs et al., 2021). The concept of socio-hydrology has been increasingly used by some scholars to study human-flood interaction in recent years has proved effectively (Sivapalan et al., 2012; Baldassarre et al., 2013; Herrera-Franco, 2021). Therefore, this study applies the socio-hydrological concept to explore the interaction between urban development and water-related hazards in Can Tho city. Then, an analytical framework is developed to develop improved strategies for disaster risk reduction in the future.

2. MATERIALS AND METHOD

2.1. Study area

The research was conducted in CTC, focusing on the urban districts of Ninh Kieu and Cai Rang (Figure 1). Ninh Kieu and Cai Rang are the two urban districts of CTC. Ninh Kieu has a total area of 2,890 hectares with a population of 284,729 people, whereas Cai Rang has an area of 6,782 hectares and a population of 107,500 people. The total areas of these two districts account for only about 6.7% of the CTC area, but the population accounts for 31.6% (Can Tho Statistics Office, 2021). This means that the population density in these two districts is very high compared to the average of the whole city. Table 1 shows that the population densities in Ninh Kieu, Cai Rang districts, and CTC are 9,741, 1,609, and 862 persons/km^2, respectively. Urbanization also occurs quickly in these two districts. Currently, the agricultural land area in these two districts accounts for only 40.9% of the area compared to 79.3% of the whole city. Some basic information on the natural and socio-economic conditions of the research site is presented in Table 1.

Table 1. Some basic information on the research sites, data as of 2020

Items	Ninh Kieu district	Cai Rang district	Can Tho city
Total land area (ha)	2,890	6,782	144,040
- Agricultural land	441	3,517	114,256
- Homestead land	1,075	985	8,647
- Special used land	923	1,113	12,173
Total population (person)	284,729	107,500	1,240,731
Urban population	284,729	107,500	868,839
Rural population	0	0	371,892
Population density (person/km^2)	9,741	1,609	862
Rice planted area (ha)	0	14	222,999
Planted areas of vegetables and beans (ha)	28	1,044	13,923
Fruit planted area (ha)	22	1,846	21,623
Cattle (head)	196	856	4,099
Pig (head)	413	1,901	121,062
Poultry (head)	0	39,234	2,126,671
Area of aquaculture (ha)	0	38	6,531
Production of fishery (ton)	5	692	221,091

(Source: Can Tho Statistics Office, 2021)

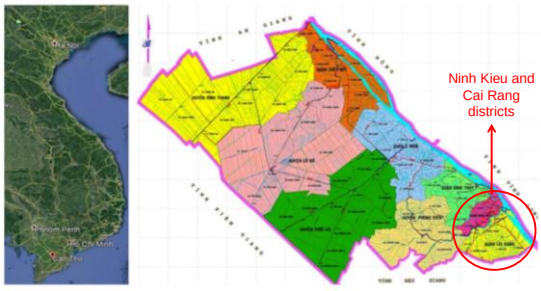

Figure 1. Map showing the study site

2.2. Research steps

The social analysis approach as described by the FAO (2011) was applied in this study. In particular, this handbook helps to guide the field survey including the research process and use of PRA (Participatory Rural Appraisals) tools. Primary data collection was done in October and November 2020. The main research steps are summarized as follows:

Step 1: A desk study was conducted to gain an understanding of the research topics such as water-related hazards (flood, storms, river erosion, etc.), weather conditions, parameters of hydrometeorology, demographic change, land use change, and urbanization process in CTC.

Step 2: Secondary data from the Department of Agriculture and Rural Development, Department of Natural Resources and Environment, Statistics Office, and Hydrometeorology Station at the city level were collected. These data were used to analyze the natural disaster situation and trends of socio-hydrological drivers (i.e. rainfall, water level, land use, population, etc.)

Step 3: Key informant interview (KII) using semi-structure questionnaires were carried out with 12 experts who are knowledgeable on the research topics in CTC at different sub-departments such as water resources management, climate change adaptation, urban planning, water supply, aquaculture, agriculture, disaster risk reduction, irrigation, and hydrometeorology. The targets of KII concentrate on drivers of water-related hazards, challenges, and plans for better adaptation strategies. At this stage, secondary data at sub-department level such as annual reports, regulations, and planning were gathered. By secondary data analysis and interview of key informants, research sites were selected for the next step.

Step 4: The Focus Group Discussion (FGD) tool was used to collect information and data at the grassroots level. Key contents of FGD include the perception of local people on water-related hazards such as trends, drivers, and impacts on the lives. There were 2 FGDs with 18 participants involved in the two surveyed districts. They represent farmers, women, youth, and urban citizens in the research site. Each FGD spent about 2 hours at the district People's Committee Hall. After KII, FGD, and observation in the study sites, water-related hazards refer to water pollution, thunderstorms, heavy rain, river floods, urban inundation, riverbank erosion, and saline intrusion.

Step 5: Descriptive statistics and a social-hydrological conceptual framework were applied to analyze the data and information. In the social-hydrological theory, the hydrological regime is governed by both physical and social structures that depend on variations in human culture. The dynamics of both cultural drivers and natural systems are important in water governance (Luu et al., 2022). Therefore, data and information in this study are grouped into social and hydrological drivers to explain the water-related hazard situation in CTC. The research result is presented in the following section.

3. RESULTS AND DISCUSSION

3.1. Natural disaster situation in Can Tho City

Damage caused by natural disasters in CTC for the period of 2015-2020 is presented in Table 2. The results show that on average human losses are 6 persons per year and damage to 549 houses. Total damage is estimated at VND 14.3 billion annually, accounting for about 0.02% of the city's GRDP (Gross Regional Domestic Products) or it is about 11,711 VND per capita. The above results show that the amount of damage caused by natural disasters is relatively low compared to the total GRDP, as well as VND per capita. However, the results of FGDs (2020) in the community revealed that the damage is much higher. This disparity is due to the fact that many cases of damage that are not fully assessed and accounted for (KII, 2020). Indeed, using the flood loss model in CTC with 858 observations showed that flood damage accounted for approximately 2.5% of the total annual income of households in 2011 (Chinh et al., 2017).

The results of expert interviews and group discussions highlight that there are various types of water-related disaster risks in CTC including water pollution, thunderstorms, flooding caused by heavy rain, river floods, urban inundation, riverbank erosion, and saline intrusion. The natural disaster situation in 2020 is summarized as follows by the KII (2020) with staff at CTC in Search and Rescue Committee for Natural Disaster Prevention and Control and FGDs with local people:

3.1.1. Rain accompanied by thunderstorms

In 2020, there were 33 tornadoes (killing 2 people, injuring 5 people, collapsing 59 houses, breaking down 575 houses, and causing damage estimated at VND 5.07 billion). Compared to 2019, the number of heavy rains accompanied by thunderstorms occurred less, but the level of damage to people and houses was greater.

3.1.2. Lightning strikes

In 2020, there were 04 lightning strikes in CTC, killing 04 people. Compared to 2019, the number of lightning strikes in 2020 increased by a factor of, and the number of deaths increased by 3.

3.1.3. River bank erosion

In 2020, there were 30 landslide sites (11 houses completely damaged, 67 houses partially eroded and affected, total length affected by landslide 1,471 m). The number of landslide sites increased by 5 localities compared to 2019. The estimated damage caused by landslides in 2020 is 16.6 billion VND, an increase of 2.2 billion compared to 2019.

3.1.4. Saline intrusion

In Can Tho city, salinity has penetrated in the direction of the Hau river to Cai Rang district. The highest salinity level on Hau River in Rach Cai Cui station, Tan Phu ward, Cai Rang district reached 3.5 ‰ on the morning of February 10th, 2020. After reaching the peak, the salinity decreased to 3.0 and 1.8 ‰ in two consecutive days and continued to decrease with the tide.

3.1.5. Inundation and tidal impacts

Due to the influence of floods coming from the upstream Mekong River in combination with the tide in early September of the lunar calendar and rain due to the circulation of storm No. 7; there was a high tide with water level above Alert III, which occurred on October 19th, 2020 (on September 3 of the lunar calendar). During the days of high tide, a number of roads at low elevations were flooded, causing great obstacles to both economic and social activities, especially business and trade, traffic activities, agricultural production, environmental sanitation, and the face of the urban landscape in the city.

3.1.6. Land subsidence and sediment reduction

There is no data for land subsidence and sediment reduction. But in reality, some roads were broken due to land subsidence. People also mentioned about sediment reduction due to hydropower dams in the upstream Mekong River.

In short, various water-related hazards occur in Can Tho city. The hazards have tended to increase in terms of frequency and damage in recent years. As such, it is necessary to develop suitable strategies

with the view of socio-hydrology to minimize the hazard impacts. The section below (3.2) presents how interaction between social and hydrological drivers influences water-related hazards in the urban areas of the city.

Table 2. Natural disaster damage in Can Tho city 2015 to 2020

Items	2015	2016	2017	2018	2019	2020	Ave
Human losses (person)	13	9	1	0	3	8	***6***
- Deaths and missing	9	9	1	0	1	6	***4***
- Injured	4	0	0	0	2	2	***1***
House damage (house)	163	246	123	1771	345	645	***549***
- Collapsed and swept	50	70	27	1771	345	54	***386***
- Flooded, partly damaged	113	176	96	0	0	591	***163***
Total damage (billion VND)	9.44	5.62	4.00	33.30	8.40	25.3	***14.3***
Damage per capita (VND)	7,811	4,627	3,272	27,120	6,794	20,407	***11,711***
Share of total GRDP (%)	0.02	0.01	0.01	0.04	0.01	0.03	***0.02***

(Source: Data collected at Can Tho Statistics Office, 2021)

3.2. Water-related hazards from socio-hydrological perspective

There are many drivers affecting water-related hazards including social and hydrological factors which interact with each other (Figure 2); for example, the increase of rainfall over a short time combined with blocked of sewers due to garbage or/and a lack of green areas will increase the risk of urban flooding. The factors related to hydrology include rainfall, water level, and discharge. The survey confirmed that the increase in urban flooding was due to the change in the rainfall pattern, specifically because of heavy rain of short duration.

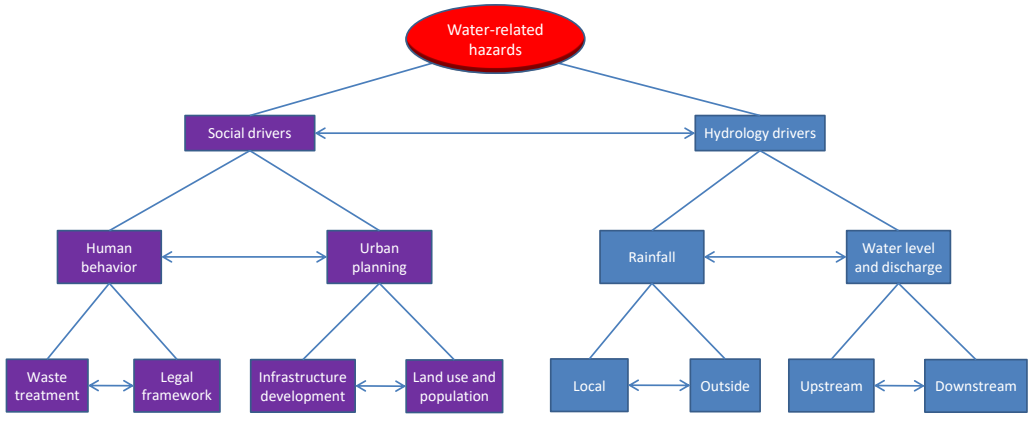

Figure 2. Water-related hazards from a socio-hydrology perspective

(Source: Authors, based on KII and FGDs in 2020)

The rainfall data at Can Tho station shows that annual rainfall did not change much in the period of 2000-2019 (Figure 3). However, heavy rains tended to increase. Statistics of hourly rainfall in the 6 years of period 2007-2012 showed that there are 49 cases with rainfall over 20 mm per hour, but in the next 6 years of the period 2013-2018, there were 85 cases. The water level in Can Tho also tended to increase. Figure 2 shows that the water level at Chau Doc station (upstream) tended to decrease but at Can Tho station (middle source) it increased. This is due to the effects of climate change and sea level rise, as shown by the trend of rising water levels at Dai Ngai station (downstream) over the past two decades. From August to October every year, when water discharge from the upstream increase, if local rainfall is heavy, occurring in combination with high tide days, then the risk of flooding is very high.

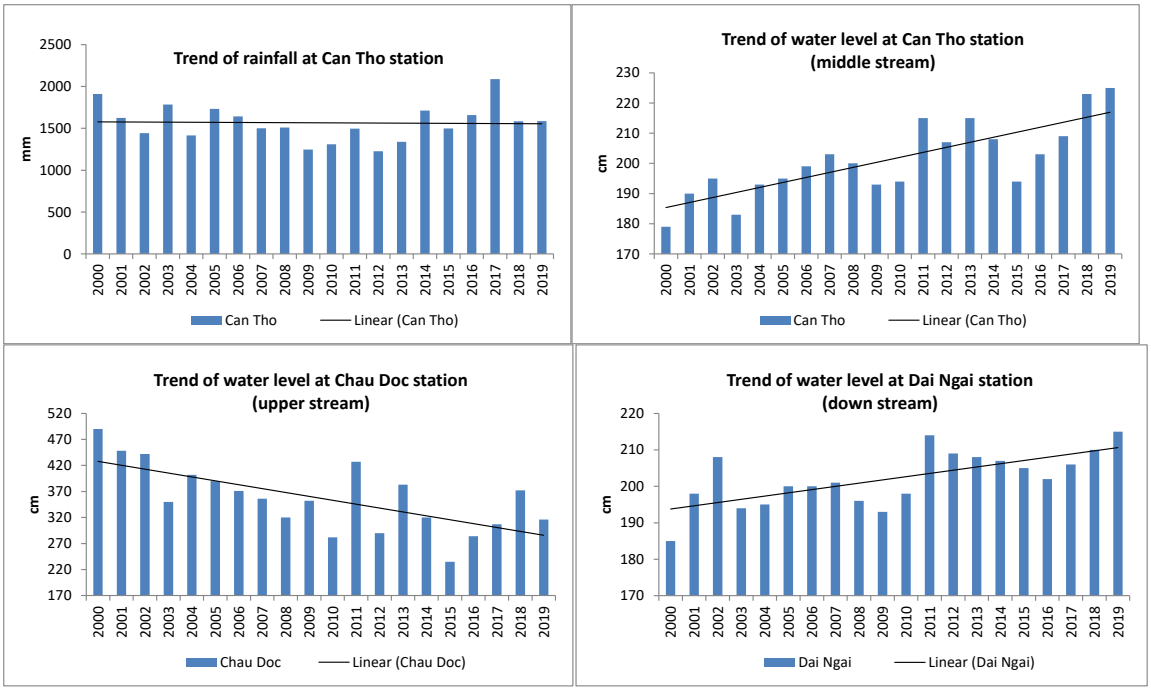

Figure 3. Change in the hydrological drivers of water-related hazards

(Source: Authors, based on available data collected at the research site)

From the social viewpoint, the factors affecting water-related disasters include human behavior towards the environment and urban planning. Water pollution is directly related to the way people dispose of domestic waste. Although the garbage collection service has improved throughout the urban districts, people still maintain the habit of littering trash to the canals or rivers. The inadequate implementation of the law on environmental protection in daily life, agricultural production, and industry also increases the risk of water pollution. In addition, the habit of leaving garbage on the street, especially at sewer mouths, reduces the ability to drain water when it rains. Urban planning through land use change and urban infrastructure development is also associated with disaster risk. The KII survey reveals that urban infrastructure development has not met the urban planning; for example, lack of investment in wastewater treatment in Tra Noc Industrial Zone 1 and Zone 2, or inadequate urban wastewater collection systems in Ninh Kieu and Cai Rang districts. Figure 4 shows that there is a difference in land use between the urban districts such as Ninh Kieu and Cai Rang compared to the general level of CTC. The percentage of agricultural land to the total land area in urban districts is always high and tends to decrease because of the conversion to residential and public special uses d. The ratio of agricultural land in Ninh Kieu district decreased sharply, from 35% in 2005 to only 15% in 2020. Meanwhile, in Cai Rang district agricultural land has only decreased from 55% to 52% in the past 15 years. However, the survey shows that the percentage of agricultural land decreased even faster than this statistical data because most of the agricultural land has been converted to non-agricultural land but it has not been updated in the land use registry. This can be determined indirectly through the statistics of the rice planted area in Ninh Kieu and Cai Rang, which has decreased very rapidly over of the past. By 2020, the rice cultivation area in these two districts was almost zero. The spontaneous conversion of agricultural land to urban residential land causes the loss of room for water (reservoirs, canals, and paddy fields) while the infrastructure (i.e. wastewater collection systems, technology for wastewater treatment, parks, or green area) is not fully invested, this causes increasing risk of urban flooding.

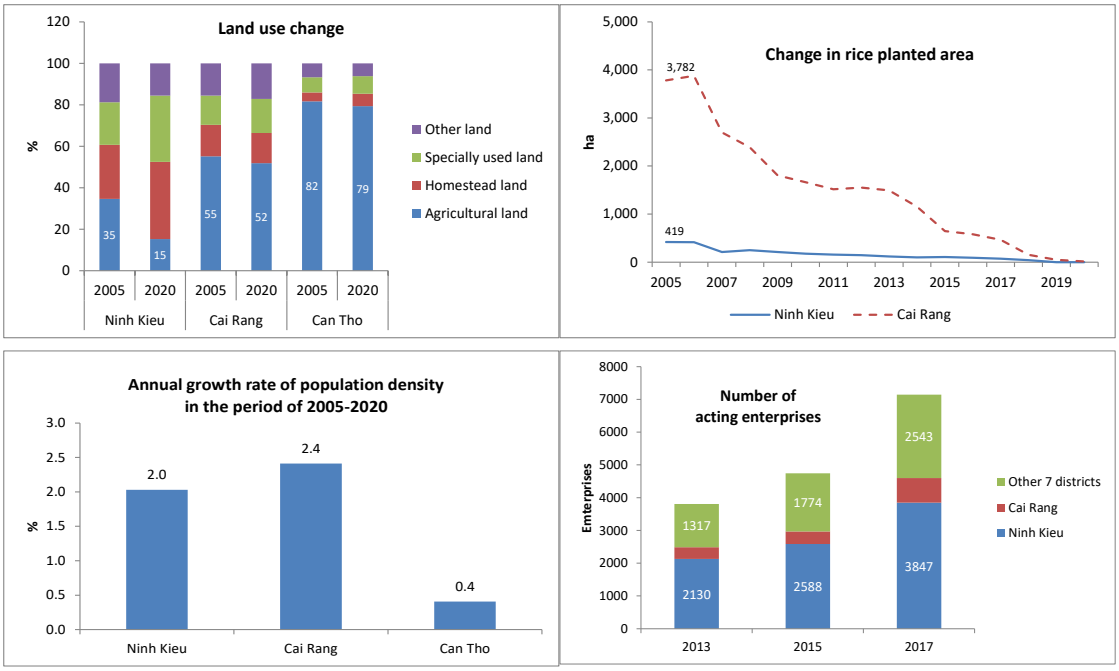

Figure 4. Change in the social drivers of water-related hazards

(Source: Authors, based on available data collected at the research site)

Figure 4 also depicts that the population density growth rate in Ninh Kieu and Cai Rang is very high compared to the average of CTC. This increases the pressure of pollution on the water environment when rural people move to urban areas, as well as the habit of littering indiscriminately as mentioned by the key informants. In addition to population growth, the number of enterprises and industrial production companies in Can Tho are also concentrated mainly in Ninh Kieu and Cai Rang. Infrastructure development, especially waste treatment plans, has not kept pace with socio-economic development, which increases the risk of water-related disasters, especially pluvial floods and pollution in urban areas. Thereby, it shows that water-related disaster risk is not only due to changes in hydrometeorology but also correlates with social factors.

3.3. Strategy for disaster risk reduction

Green urban development has the greatest potential for improving the quality of ecosystem services and providing opportunities for urban dwellers to reconnect with nature (Stobbelaar et al., 2021) may be an appropriate strategy for disaster risk reduction (Figure 5). Green urban development can reduce disaster risks by strengthening resilience. The same approach has been proposed as a message from the CTC leadership mentioned in the Can Tho Resilience Strategy until 2030 that "develop Can Tho as a green, sustainable, proactive and integrated river city where people enjoy prosperity and safety from shocks and stresses, and no one is left behind". Based on the analysis of water-related hazards from a socio-hydrological view, it is important to change human behavior. Local people must be equipped with knowledge about the reasons for climate change and the relationship of climate change to natural disasters in order to interact well with the environment. The current linear economy should shift to a circular economy which is a way to promote industry sustainably, while making use of scientific advances, innovations, and new technologies. Additionally, infrastructure development must be greener. Moreover, urban planning should be implemented effectively at the local level to avoid spontaneous residential areas. The planning has to take into account better rural – urban linkages in terms of land use and population distribution, as well as more space for water to improve ecological services. Finally, the governments at different levels need to play an important role to develop a strong legal framework to support this green strategy for disaster risk reduction. On the other hand, when disasters reduce and people see the benefits of green urban development, they will return to invest in green infrastructure again.

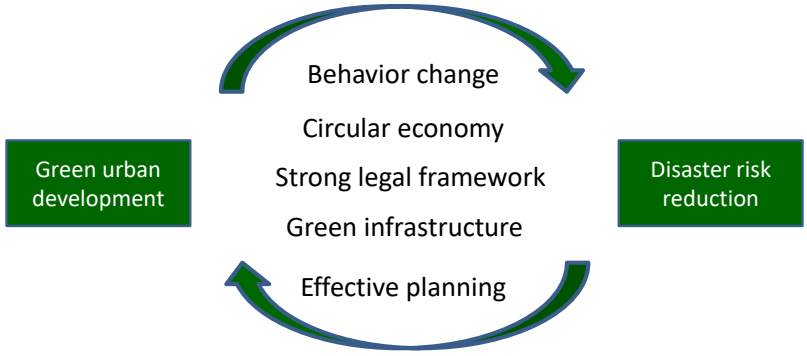

Figure 5. Framework for green urban development and disaster risk reduction

4. CONCLUSION

Water-related hazards have tended to increase in the urban district of Can Tho city. Using the socio-hydrological approach highlights that these hazards are not only caused by hydrological factors but also by social factors. Therefore, for sustainable urban development in the future, it is not only solved in terms of hard infrastructure development but also addressing the other social drivers. The green urban development strategy is a suitable approach to reduce natural disaster risk. To achieve this dual goal, the government and the people must agree to effectively implement these policies at the local level, contributing to the achievement of the common sustainable development goals.

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