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Urban Flood Resilience Development Through Architecture Landscape Design in Vinh River's Banks

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Abstract

Vinh City is the political, economic, and cultural center of Nghe An province, Vietnam. Due to Vinh City's location right at the mouth of the Lam River, the city is often flooded by its extensive waterway system. In this research, focused on evaluating the data obtained through surveying the current status of Vinh City's drainage system; Hydraulic models are built to calculate the hydraulic parameters of rivers (river width, river bottom elevation, river water level). This experiment aims to provide information on the flood resilience of Central Vietnam while also creating a new scenario that includes public locations and communities near rivers. Our top goal is to create landscape architecture along both banks of the Vinh River, increase Vinh City's ability to withstand climate change, promote synchronous infrastructure development, and contribute to urban expansion. sustainable city and act as a catalyst for the socio-economic growth of Vinh City and Nghe An province in general. The project improves people's living standards, improves waterway ecosystems, and reduces the pain caused by annual floods. It also adds to the local science and landscape architecture community. This work exemplifies a comprehensive and integrated river restoration strategy. In this regard, the concept can simply be used as a methodology in other Vietnamese cities with similar characteristics.

1. Introduction

Vinh City is located in the Central region of Vietnam. Vinh City is 295 km north of Hanoi, 16 km northeast of Cua Lo town, 1,424 km south of Ho Chi Minh City, and 456 km west of Vientiane (Laos). Vinh City is the economic, political, and cultural capital of Nghe An province, which the government intends to develop into the economic-cultural core of the North Central area, as well as a class-1 urban and provincial city. [1]

However, the pressure on the drainage systems has increased recently due to numerous changes in the local environment as well as effects of socioeconomic development, including the restructuring of crops and livestock, climate change as well as sea level rise, urbanization, and industrialization in the area, etc. As a consequence, the drainage system has evolved, causing conflicts to arise throughout the drainage process and overload. This resulted in flooding and had an impact on the area's biological ecosystem [2]. In Vinh city, Vinh river plays the role of the main agricultural water supply and drainage river of Vinh city, and is also the place that creates a very important landscape and climate water surface space of the city. [3]

Assessing the importance of Vinh River in draining flood water, responding to flooding in Vinh city and contributing to the general landscape of the city. Previously, there have been many articles and research papers on flood response design. Landscape design projects to respond to climate change have also been implemented a lot in the world and have proven successful in practice [4]. However, there has not been any specific research on landscape design solutions to respond to floods. In Vinh city, Vinh River not only plays a role in transferring and draining flood water but also plays a very important role in the urban landscape. Therefore, the research question here is whether landscape design solutions on both sides of the river contribute to flood mitigation and flood response?

The objective of the study is to answer the above question through the method of evaluating landscape design solutions for their effectiveness in flood protection, specifically applied to the case of Vinh River. The study begins by studying the current status of the Vinh River system to provide the most general assessment of the flood drainage status, and the current status of landscape architecture on both sides of the Vinh River, combined with the experience of practical projects considered successful in the world to provide a toolkit of solutions in landscape design on both sides of the Vinh River. The design solutions will be tested by field survey toolkits and expert opinions.

The results of this experiment aim to provide knowledge about flood resilience in Central Vietnam and create a new scenario of open public space around waterways. The most focused part is the landscape architecture design along the two banks of Vinh River, an area rich in historical, cultural and social values of the city. The research contributes to the local science and landscape architecture, improves the waterway ecosystem, raises the living standards of people and reduces the impact of annual floods.

2. Background

2.1 River System and Rainwater Drainage System of Vinh City

The following are the principal rivers and canals in Vinh City: The Vinh-Ke Gai river system. Hoang Can canal is a tributary of the Vinh river system. From Vinh City's north to its south and southeast, the Rao Dung River flows into the Lam River. [3]

According to its natural geography, the city is separated into four primary drainage basins: The Southern basin, which includes the Vinh River, the Western basin, the Eastern basin.
Vinh city's urban drainage system includes: [11]

- The first-grade ditch system includes: North Canal, ditch No. 1, ditch No. 2, ditch No. 3, Hong Bang ditch and Dong Vinh ditch.
- Dense system of ditches and culverts with 47km of secondary ditches (B>800mm) and about 147km of grade 3 ditches (B<800mm).
- Regulatory lakes in the city area: Goong Lake (5.34ha), Central Park Lake (7.31ha), Cua Nam Lake (3.6ha), Vinh Tan Lake (10.1ha), conditioning lake Hung Hoa 1 (38ha), etc.
- Drainage pumping stations in the city include: Southwest pumping station: capacity 18,660 m3/h; Southern pumping station: capacity 56,000 m3/h; Southeast pumping station: capacity 20,000 m3/h.

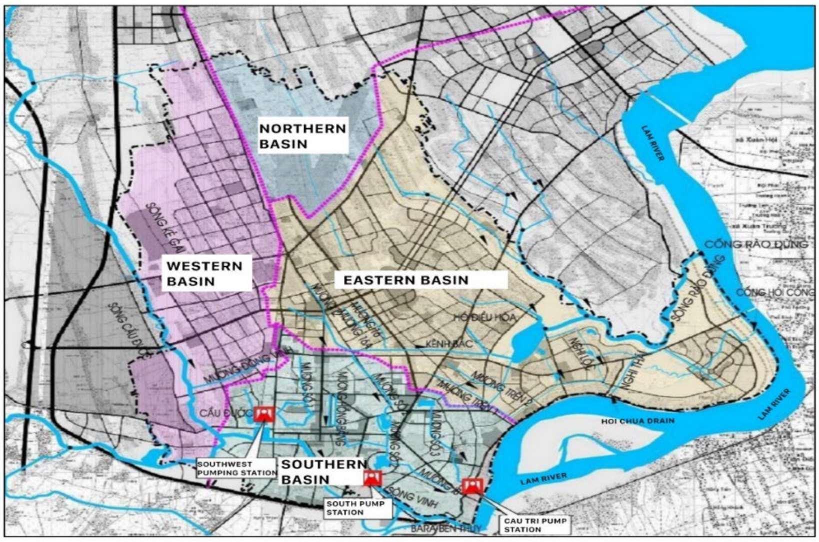

Fig. 1 *City drainage basins distribution map. (Source [5])*

2.2 Flood Situation in Vinh City

Recent years have seen an increase in the frequency of flooding in Vinh City, which has had major effects and hindered growth. Some major floods that affect the city include the following: [3]

- In 2010: Typhoon Megi's effects caused torrential rain to fall across a vast area. In Yen Giang block, Vinh Tan ward, 1,650 households are isolated, 90% of which are flooded from 0.4 m to 1.4 m; in Hung Chinh commune, more than 100 homes are submerged in flood waters. [11]
- Many residential areas had some flooding beginning in the early hours of September 22, 2014, due to heavy rain. There were many highly inundated roadways, some of which were up to 0.5 meters deep. [11]
- In 2016: The weather in Nghe An province experienced heavy to very heavy rain from October 13 to October 15, 2016, in the lower reaches of the Ca river basin, due to the enhanced cold high pressure and the edge of the low pressure crossing through the Vietnam Central region and connecting with the center of the low-pressure area on the mainland. Many highly inundated roadways, some of which were up 0.5m to –1 meter deep.
- In 2017: Vinh city was entirely flooded as a result of the tropical depression's influence. Many homes in the Ben Thuy ward region were submerged more than one meter deep. Vinh Ngap market is partially under 1.5 m of water. Because the rear drainage ditch system was too small, measuring just 1.6 meters, and was not yet connected to the Hong Bang ditch, the Vinh market was severely inundated. Even though there is too much soil and debris underground, the city does not engage in dredging. Draining water from the market to the Vinh River is highly challenging since the infrastructure behind the market is around 70 cm lower than the Vinh River and the canal system flowing from Vinh market through the urban area of Vinh Tan must be 70 cm higher. [11]
- In 2018: Rain fell from the evening of December 7 to the afternoon of December 8, 2018, flooding numerous roadways in Vinh City. Some areas had 50–70 cm of flooding. [11]
- In 2019: Rain fell in the North Central area of Vietnam from 19:00 on October 14 to 1:20 on October 16 in the amount of 359mm (Vinh), 290mm (Son Diem), and 284mm (Chule) owing to the effect of cold air and disturbances in the high-altitude East wind zone. It reached 950 mm in Vinh City, the most in 30 years, which prevented pumping stations and drainage ditches from connecting, leading to significant flooding. Statistics revealed that 5,680 homes were flooded, 250 homes had to be evacuated, 20,000 chickens perished, 370 hectares of ponds and lakes for aquaculture were submerged, 54 hectares of rice were destroyed, and 195 hectares of vegetables were destroyed. The total loss is estimated to be around 80 billion VND. [11]
- In 2020: Three significant downpours occurred between September and November, specifically: heavy rains of 484 mm (in Vinh) and 438 mm (in Cho Trang) between September 17, 2020, and September 20, 2020, caused severe flooding throughout the city. Pumping stations were at full capacity as many regions, including Trung Do, Ben Thuy, and others, were submerged between 0.5 and 1 meter deep. [11]
- From October 14, 2020, to October 20, 2020, there was intense rain, with 527mm (in Vinh) and up to 1164mm (in Cho Trang) of precipitation. Many locations flooded up to 0.8m - 1.5m deep like Trung Do, Ben Thuy, etc. Pumping stations functioned at full capacity. [11]

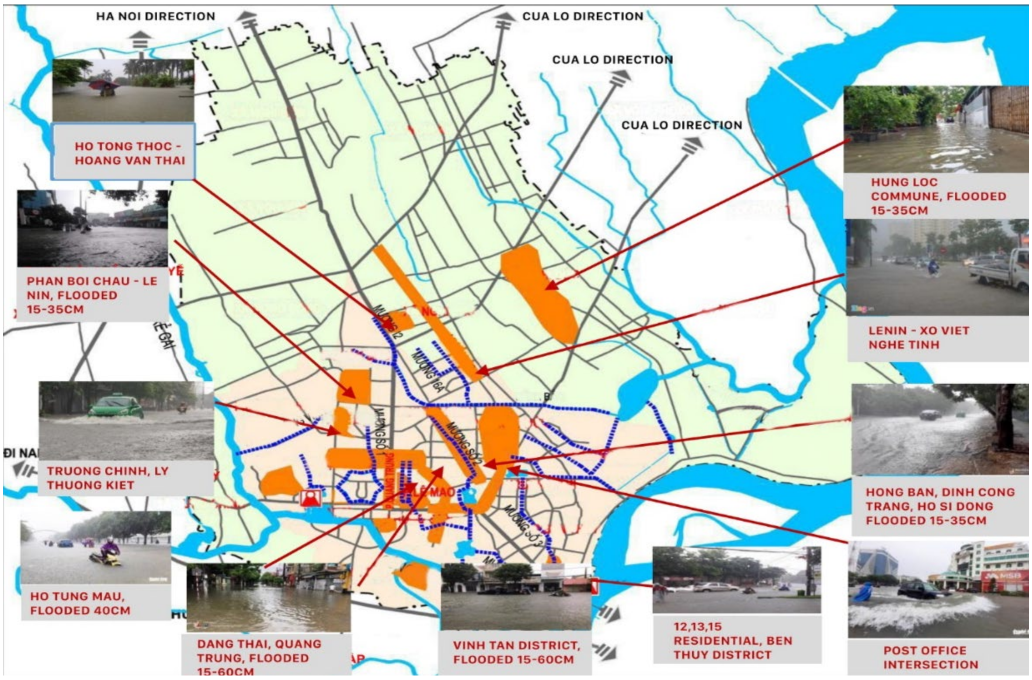

Fig. 2 *Map of the city's flooded areas (Source [5])*

2.3 Preliminary Analysis of Some Major Flooding Causes in Vinh City

The preliminary estimate of the number of flooding causes in Vinh city and the area is as follows, based on the results of the initial investigation:

Result of the flood outside the city: A preliminary analysis reveals that Vinh City frequently floods despite receiving little to no rain. Vinh City is impacted by floods from the Ca/Lam River upstream due to its location on its banks in the downstream region close to the sea. Floods from upstream areas (from the high mountainous terrains to the west and northwest of the city in the Hung Nguyen, Nghi Loc, and Nam Dan districts) overflow the surface of the city, in particular the Ke Gai major river, and generate this phenomenon of urban flooding.

With this characteristic, urban drainage research in Vinh City must study the overall problem of both the flood from the upstream Ca/Lam river system and the overflowing flood water from the upstream city, including Hung Nguyen and Nghi Loc, Nam Dan districts, before being in-depth with the drainage system in the city.

Result of the flood inside the city: As a result of intense rainstorm events that have increased in intensity, frequency, and pattern over the past few years and as a result of sea level rise, Vinh City now faces a high danger of flooding. When the Ca/Lam river had a high water level due to prolonged heavy rain and an inadequate rainwater drainage system, Vinh City experienced very slow drainage, which resulted in flooding in urban areas and the surrounding areas.

Additionally, because of the shift in river flow, the riverbeds that serve as natural drainage axes are winding and meandering. As a result, the drainage cross section is constructed and has been accreted, which reduces its drainage capacity. There have been local floods in many parts of the city as a result of the building of works and the quick growth of infrastructure, including transportation and housing.

The lack of awareness in some populations makes it possible for waste to be thrown into drainage systems without regard for how it would affect the flow or even block the drainage. The amount spent annually on dredging, treating, repairing, and upgrading drainage systems does not equal the scale and difficulty of the work.

It is feasible to draw some preliminary conclusions regarding the primary reasons for flooding in Vinh City at the moment by taking into account the fact that the city and its surroundings frequently flood during periods of heavy rain in recent years, as follows:

- Result of urbanization
- Result of an unsynchronized drainage system
- Result of unguaranteed pumping stations capacity
- Result of traffic routes acting as 'dikes' to prevent flood drainage

2.4 Local Drainage Conditions in Vinh River

Vinh River passes through Cua Nam, Vinh Tan, and Trung Do wards, measuring 30-70 meters in width. The Vinh River serves as the primary drainage axis for the southern region, which is its primary role. The Vinh River is not yet embanked, and some of its portions have been eroded and encroached upon. It is also not being dredged, and as a result, several of its sections have accreted, which affects the river's flow. On the other hand, as urbanization has advanced, there has been a noticeable increase in the population density living near rivers. This has been accompanied by people's disregard for littering and indiscriminate discharge into rivers, as well as a significant amount of wastewater discharged into rivers, which has led to the pollution of rivers. The volume of water flowing through rivers during the rainy season is increasing quickly due to the effects of climate change and unusual weather variations, exceeding the rivers' ability to discharge water. As a result, the neighborhood experiences flooding more regularly.


Vinh River confluence


Railway bridge on Vinh River


Cao Xuan Huy bridge on Vinh River


Southern pumping station on Vinh River

Fig. 3.1 *Current status of Vinh river drainage (Source [2,5])*

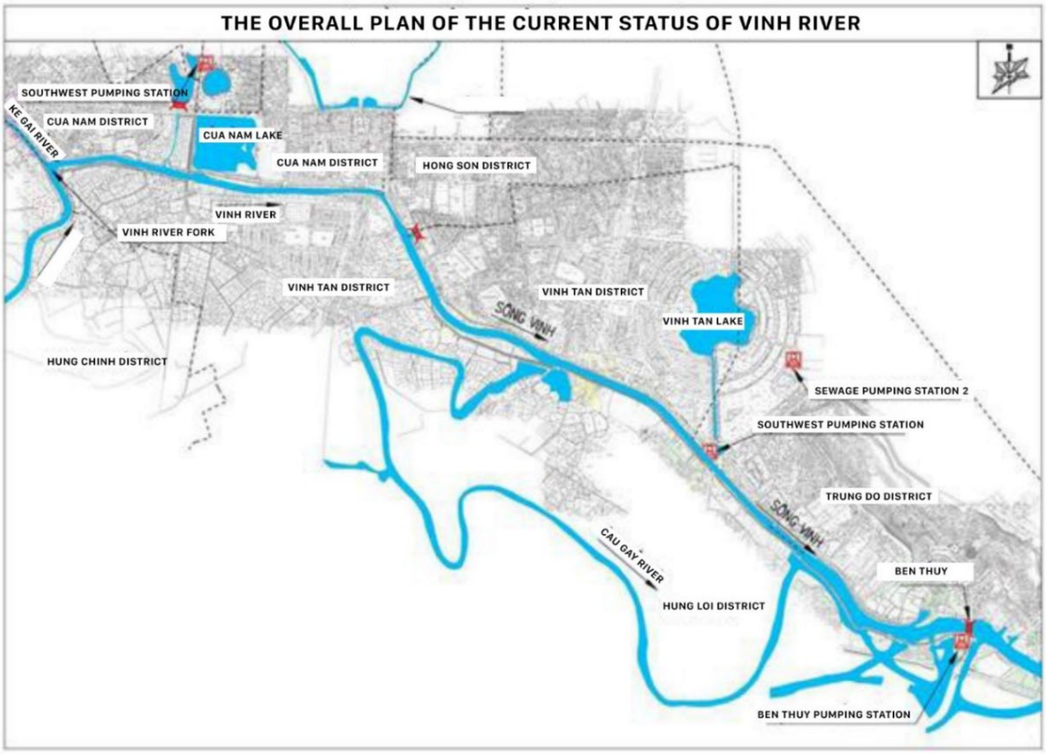

Fig. 3.2 *Current status of Vinh river drainage (Source [2,5])*

2.5 Current Status of Landscape Architecture on Both Banks of Vinh River

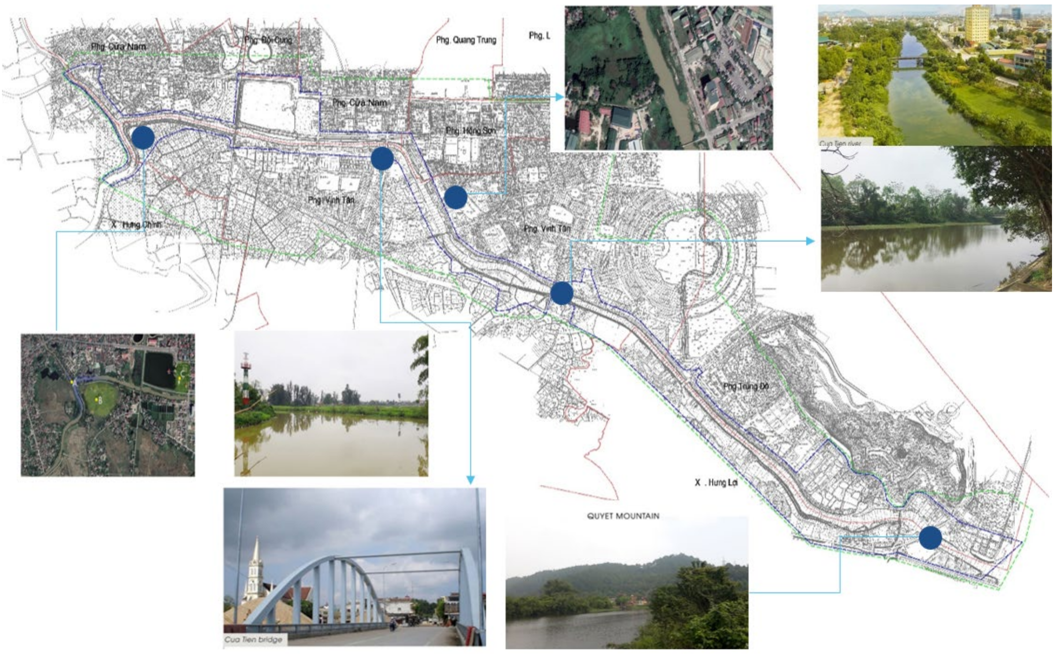

Fig. 4 *Vinh River area's current situation plan (Source [2,5])*

Landscape current situation includes major landscape types:

- Landscape of agricultural exploitation in the West (Rice production area in Cua Kenh Field, Bien Vinh Field, channel surrounding Ke Gai River confluence), in the East (Bien Day field, aquaculture ponds and fields in Hung Loi commune). These are important characteristic landscape areas, especially when the city rapidly urbanizes and the green spaces gradually get smaller.
- Surface water and vegetation: The Vinh River's water quality is typically unpolluted. The river cross-section is quite small (16–20 m) between Duoc Bridge and the junction of the Ke Gai River, and it is particularly small (25–30 m) between Cau Den and Tan Phuong Bridge, with a strong embankment on both sides. The remaining cross-sectional breadth in the other sections ranges from 30 to 40 meters, and from Ben Thuy bara to the mouth of the Lam River, the flow widens to a maximum of roughly 90 meters. This area's scenery is a valuable blend of natural water surface (the confluence of two rivers) and artificial water surface (an aquaculture pond), with one side facing the mountain and the other facing the lake.
- The area's green spaces are not interconnected or systematized, and the riverfront vegetation is not diversified. The embankment form is not appealing.
- The area that can be utilized or developed is quite small due to the lack of entertainment and public space on both sides of the river (currently just Cua Nam Lake Park in the project's western region). Outside of the dyke, there are only a few small alluvial plains.
- Landscape of residential areas and new urban areas: New urban areas are helping Vinh's urban area become more contemporary, but they haven't had much of an impact on the looks of the two banks of the river yet.

Fig. 5 *The current situation photos of the Vinh River landscape (Source [2,5])*

- Landscape of agricultural exploitation in the West, in the East. These are important characteristic landscape areas, especially when the city rapidly urbanizes and the green spaces gradually get smaller.
- Surface water and vegetation: The Vinh River's water quality is typically unpolluted. Vinh River, which connects to the Rao Mang River and the system of regulating lakes (Cua Nam, Vinh Tan), has an important function.
- The area's green spaces are not interconnected or systematized, and the riverfront vegetation is not diversified. Embankment form is not appealing. The area that can be utilized or developed is quite little due to the lack of entertainment and public space on both sides of the river.

3. Literature Review on Urban Flood Response Design

The risk of urban flooding is increasing worldwide due to changes in the natural environment, such as rapid urbanization, which leads to more extreme weather events. [6] Of all natural disasters, flooding is the most frequent and affects the largest number of people globally. [7] The risk of flooding is particularly severe in urban areas. [8]

Because of the seriousness of the problem, many studies have been conducted in the past to study urban flooding. A study conducted by Yinghong Qin, which included searching and cataloging more than 550 research articles with keywords on urban flooding conducted before and after 2018, found that most of the research articles reported on techniques that both reduced runoff and improved water quality. [9] The research articles only mentioned a very small part of the problem of urban flooding mitigation, and did not really mention specific solutions to deal with, overcome or minimize this situation.

In addition, through the keywords used such as "Urban flooding", we also found related studies and these studies also proposed preliminary solutions. Typical examples include the research of Matos Silva and Costa (2016). The importance of public space design solutions in implementing adaptation actions to urban flooding has been demonstrated through the study of Matos Silva and Costa (2016). [21]

In this study, the theory of flood adaptation by referring to public space design solutions, and also refers to the definitions of flood adaptation measures proposed by Matos Silva and Costa (2016). In the definition of Matos Silva and Costa, the solutions are divided into 6 groups: Harvest, Store, Infiltrate, Convey, Tolerate, Avoid. These solutions focus primarily on design solutions for urban public spaces, but also identify a taxonomy of elements of urban flood management.

Another study conducted by Yinghong Qin [9] also mentioned the engineering solutions used for dealing with urban flooding including: green roofs, non-vegetated roof, trees, permeable pavements, water-retaining pavements, infiltration trenches, rain barrels, rainwater tanks, bioretentions, soakaways, and underground tanks.

Through analyzing a large number of previously presented research papers and solutions, the author found that the above-mentioned techniques are quite similar to the NBS solutions published by the European Commission in 2019. Landscape design applying nature-based solutions has gradually achieved an important role in flood management and achieving post-flood resilience for urban areas. This has been demonstrated through the analysis documents on grey and green infrastructure of the European Union Commission (2019) [10]. As defined by the European Commission, nature-based solutions are "Solutions inspired and supported by nature that are cost-effective, while delivering environmental, social and economic benefits and helping to build resilience. Such solutions bring more and more natural and natural features and processes into cities, landscapes and seascapes, through systematic, resource-efficient and locally adaptive interventions." [11]

Up to this point, landscape design solutions to respond to climate change and urban flooding have only really begun. However, verifying the effectiveness of these solutions really needs further research to be able to demonstrate most convincingly.

Finally, all the above documents are synthesized by us to become a theoretical framework to consider the specific problem of flooding in Vinh city.

4. Research Methodology

The study started from an overview of previous research documents and models that have been conducted on flood resilience of urban areas, thereby providing basic criteria for responding to floods of an urban area. Through studies on NBS solutions, it is found that there is a possibility to solve the problem of urban flooding in Vinh city. However, these solutions need to be expressed in a more specific way, so we used expert methods, combined with practical experiences from projects that have been considered successful in the world, we proposed 6 tools in landscape design, which are concretized from NBS solutions that are capable of adapting and solving the problem of flooding in Vinh city.

These tools were studied and applied to the scale of the Vinh River area, the section flowing through the South of Vinh city. Through field research and survey methods, the tools were evaluated for their ability to respond to floods within the scope of the study. From there, design principles and perspectives in landscape design for the Vinh River area are proposed, aiming at the goal of sustainable landscape design, not only serving urban aesthetics and community activities but also supporting urban adaptation to floods and climate change.

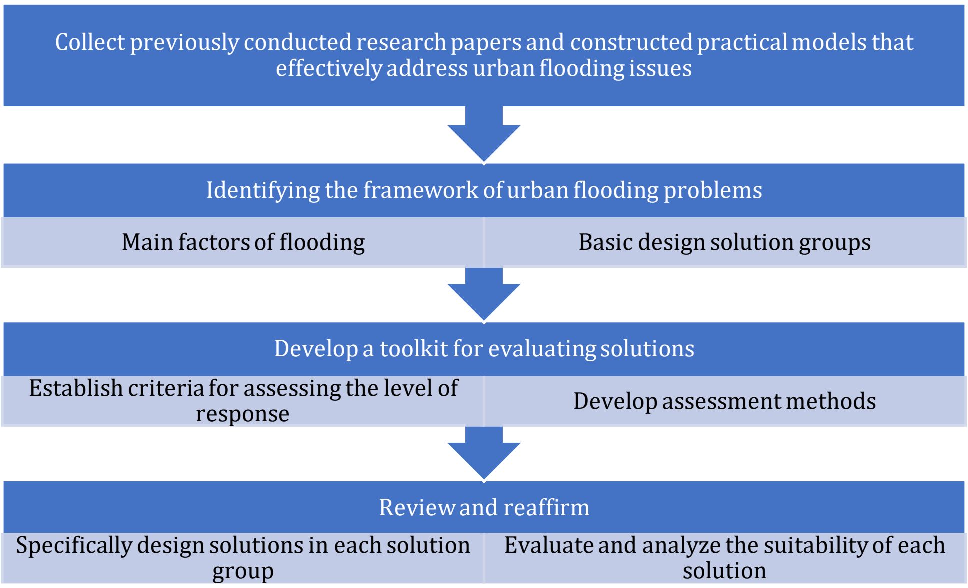

Fig. 6 *The research process*

5. Research Results

5.1 Identify Key Factors in Dealing with Urban Flooding from Practical Experiences

In this section, we examine global urban flooding coping factors by studying the cases of three cities: Haikou (China), Fengxi (China) and Singapore (Singapore). These practical examples were chosen because of their similarity in scale and natural and cultural climatic conditions to the study area, specifically Vinh city.

5.1.1 Haikou Meishe River Greenway and Fengxiang Park

For decades, the Chinese city of Haikou has suffered from monsoon-related flooding and water pollution from sewage and non-point source pollution from urban and suburban runoff. Rivers are channeled and flood-controlled with concrete, leaving the urban landscape lifeless and lacking ecological resilience. [12]

To address this, architects and urban planners have implemented NBS solutions to transform grey infrastructure into green infrastructure. Concrete flood walls were removed and replaced with environmentally friendly and flood-resilient waterways. In addition to maximizing the environmental restoration of mangrove areas, artificial wetlands were built along the river to collect and clean polluted water, and community recreational spaces were integrated into the ecological infrastructure [13]

The main design strategies implemented include:

1. Ecological infrastructure planning:
   Based on topography, land use planning and hydrological analysis, a network of green spaces and green sponges was planned. The goal is to separate storm water from wastewater before it enters the river. The green sponges are also integrated with an interconnected pedestrian and recreational network. [12,14]
2. Convert maximum gray to green:
   The design maximizes green space for water. Concrete flood walls were removed and replaced with environmentally friendly riverbanks. Blocked waterways were reconnected to the sea, allowing tidal waters to flood the city once again. Wetlands and shallow banks along the river were redeveloped to allow mangroves to repopulate them. Continuous elevated pedestrian walkways were designed to provide access to the riverbank.
3. Integrating diverse green landscape elements into urban technical infrastructure systems:
   The interconnected terraces of the wetlands are built along the riverbanks, which were formerly concrete flood walls and landfills. The terraces are designed as tools for water purification. Two types of water flowing into the wetlands need to be purified: Non-point source polluted runoff carrying high levels of nutrients and wastewater from local urban villages that cannot reach the centralized wastewater treatment system.
4. Developing community-oriented landscape spaces and promoting local culture:
   Integrated into this ecosystem is a system of community spaces and resting places to enjoy the landscape services, allowing visitors to have a unique experience of the designed ecosystem. The simply shaped pavilions distributed along the green walkways are designed to provide shelter and safe resting places, against the tropical monsoon storms and the summer sun. [13,14]

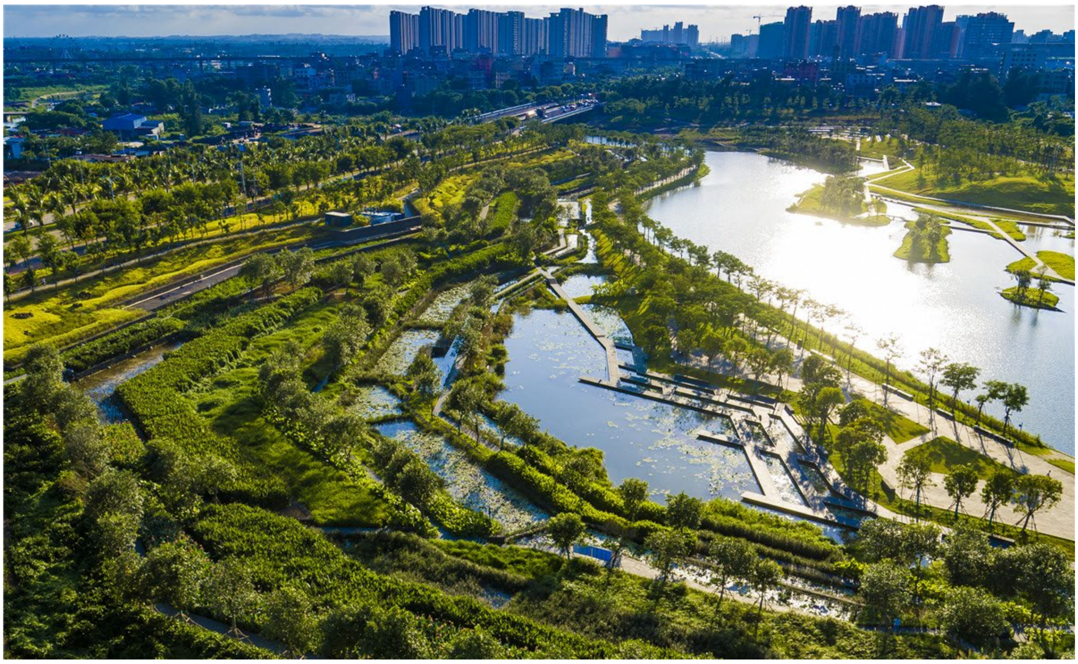

Fig. 7 *Haikou Meishe River Greenway and Fengxiang Park (Source [14])*

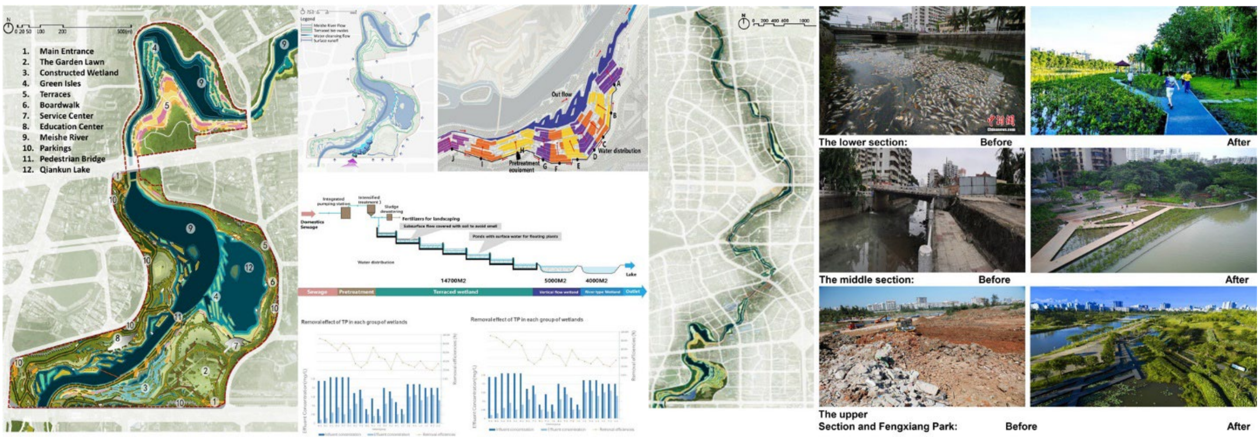

Fig. 8 *Master plan design and solutions (Source [14])*

5.1.2 Shanxi Fengxi New City Center Green Corridor

Fengxi Green Corridor is located in the center of Fengxi New City, with a total length of 7km and a total area of about 180ha. The current land is mainly agricultural land and rural residential areas. According to the general planning of the city, the green corridor passes through the core residential, commercial and cultural areas of the new city and is an important green corridor of Fengxi New City. [15]

Landscape planning and design strategies have been applied:

1. Adjusting the urban storm water drainage system around the green corridor:
   The land areas adjacent to the green corridor adopt decentralized drainage solutions, and the storm water pipe network is directly connected to the green corridor. Daily rainfall converges and percolates into the green corridor. In the event of heavy rain, the green corridor can act as a flood discharge corridor, and the accumulated rainwater is discharged into the Weihe River and Fenghe River through the pumping stations at the east and west ends of the green corridor. By adjusting the planning and making full use of the role of the green corridor in the urban storm water drainage system, the green corridor is used to solve the storm water drainage problem of nearly 60% of the urban areas. [16,17]

2. Design of a green flax structure suitable for rainwater collection:
   To ensure the collection and utilization of urban rainwater, green corridors need to adopt appropriate functional structures. Generally, a spatial structure with green spaces and east-west connections is adopted. Sunken green space: Excavate about 5 meters below the green corridor to become the low point of the area and the surrounding rainwater can naturally flow into. East-west connection: To cope with heavy rain, the green corridor needs to connect the Weihe River and the Fenghe River in an east-west direction to form a continuous flood discharge corridor, and pumping stations are located at the east and west ends to ensure that in the event of heavy rain, the pumping station can discharge into the river. [16,17]

Int. J. of Sustainable Construction Engineering and Tech. Vol. 16 No. 1 (2025) p. 102-121

Fig. 9 *Shanxi Fengxi New City Center Green Corridor*

5.1.3 Kallang River - Bishan Park, Singapore

The Kallang River is the longest river in Singapore and flows through the heart of the island for 10km from the Lower Peirce Reservoir (located at the geographical centre of Singapore) to the Marina Reservoir (formerly a bay). [18,20]

In the 1960s and 70s, concrete channels and culverts, including the Kallang River in Bishan Park, were built to alleviate widespread flooding. Today, as in other cities around the world, this "faster is better" approach to stormwater drainage (downstream) must be complemented by a more comprehensive set of solutions to the design to meet the challenges posed by unpredictable weather and increasing urbanisation. [18,19]

Right at the Kallang River – Bishan Park, the unique plan to remove the concrete channels and create natural flows was conceived for the first time in Singapore. Designed around the idea of a floodplain (depending on the rainfall pattern), people can get closer to the water and enjoy and participate in activities along the riverbank when the water level is low, and during heavy rains, the low-lying riverbank becomes a flooded channel. The increased roughness of the riverbed with gravel and rocks means that the flow velocity of the Kallang River is reduced, thus less solids are carried downstream to the Marina Reservoir, where they have to be separated from the water through filtration. The increased volume of the river and reduced flow velocity also means that the high-density urban area surrounding the park is protected from flooding. In addition, the park is complemented by large open spaces for recreation and relaxation, and the vegetation along the riverbank allows people to get closer to the water. In the event of heavy rain, the green areas on both sides of the river will be flooded to act as a large channel to transport water downstream. Bishan Park is an inspiring example of how an urban park can function as ecological infrastructure, a smart combination of water resources, flood management, biodiversity, recreation, and through human contact and connection with water, increasing civic responsibility towards water. [18,20]

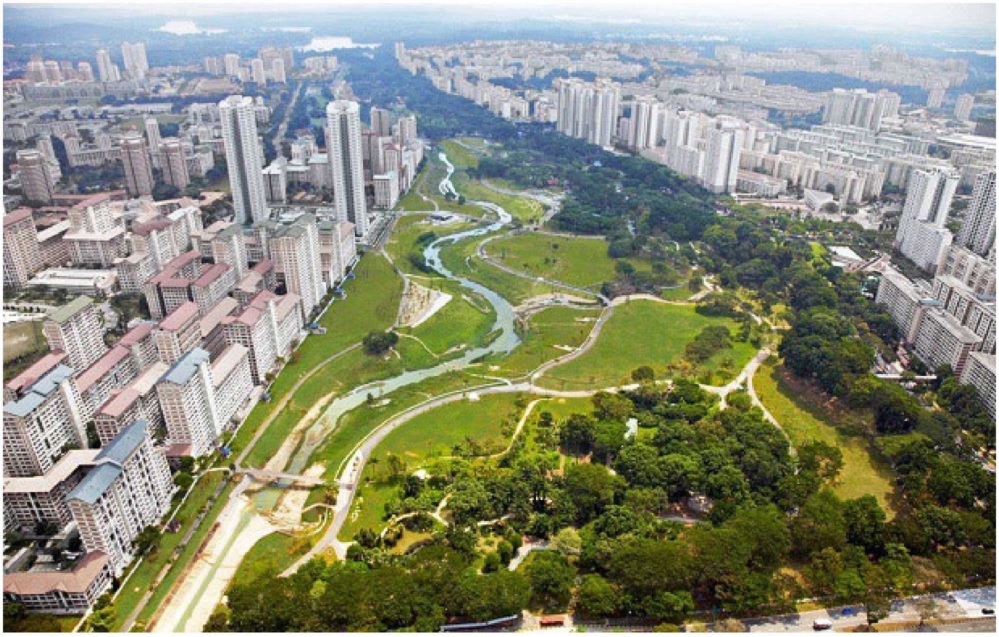

Fig. 10 *Kallang River - Bishan Park, Singapore*

5.2 Identify the System of Factors of Urban Flooding

From the theoretical foundations of flood-adapted urban areas, combined with definitions and main characteristics of selected NBS that have been analyzed, and with the practical experiences analyzed at the research site, we propose the following basic characteristics of water treatment in flood control based on [11, 21] as presented in Table 1.

Table 1 *Basic characteristics of water treatment in flood control*

No	Elements	Description
1	Permeate	Permeate is the process by which rainwater seeps into the ground to maintain the natural flow of water, replenishing water to the soil layers below. To achieve infiltration, there are many measures that can be applied such as using surfaces with biological drainage grooves, infiltration tanks. This solution will help control the natural flow in urban areas, reduce erosion and replenish groundwater.
2	Purification	Purification is the process of removing pollutants from the flow. There are many methods to achieve this goal such as settling tanks, aeration, evaporation, and phytofiltration. Among them, phytofiltration is highly appreciated in nature-based design solutions while helping to achieve landscape effects.
3	Orientation	Orientation is a measure to divert water flow from the source to the final discharge point (river basin, reservoir). The transportation needs to be determined precisely to avoid the risk of water stagnation in residential areas, leading to urban flooding. During the transportation process, it is possible to combine infiltration and purification solutions in parallel.
4	Maintenance	Water conservation is an important process that requires storing water for a relatively long period of time. Natural water surfaces in urban areas are the most effective tools for water conservation, including wetlands, ponds, lakes, etc.
5	Storage	Storage is the process of retaining rainwater for a short period of time. Urban green spaces are spaces that store water for a short period of time, including trees, grass, sandbanks, etc.
6	Reduction	solutions to reduce the velocity of water flows by artificial means such as using barriers, ditches, dikes, spillways. Slowing and controlling water flows will help manage floods and reduce landslides and erosion.

Int. J. of Sustainable Construction Engineering and Tech. Vol. 16 No. 1 (2025) p. 102-121

To consider measures to address the above factors, combined with the theories of NBS and practical experiences from cities around the world analyzed, and realize the importance of urban drainage systems in dealing with flooding, and above all, sustainable urban drainage systems. In the documents on water-sensitive design, focus on SUDS solutions including a set of water management solutions, adjusting the drainage system according to the natural cycle to aim for the most efficient and natural urban drainage. [22]

From there, propose 6 appropriate and effective natural design tools in dealing with urban flooding as shown in Table 2, including:

Table 2 *Solution groups in dealing with urban flooding*

No	Solution group	Description
1	Green surface	Green surfaces are defined as including all layers of the surface including the vegetated surface and the natural geological subsoil. Green surfaces are effective in managing stormwater through their ability to retain and infiltrate water, and also contribute significantly to slowing runoff. [22, 23,24]
2	Bioretention systems	Bioretention systems are one of the most widely used and versatile SUDS tools. Urban bioretention systems are defined as areas of special geological background that are characterized by high permeability and rich organic matter. Bioretention systems must maximize infiltration capacity, drain within hours, and support plant growth. [25,26]
3	Buffer and vegetated filter strips	Green buffers are gently sloping areas adjacent to watercourses (rivers, streams) that separate the watercourse from an impervious surface (road, parking lot). Green buffers function to filter water, reduce pollution and prevent stormwater runoff, slowing the flow of water from these impervious surfaces before it reaches the main watercourse. [27,28]
4	Drainage ditch with plants	Drains are defined as wide, shallow, linear depressions that are vegetated and carry stormwater away from impervious surfaces. [22,26]
5	Wetlands	Wetlands are areas of permanent water storage, which reduce runoff and treat it through natural processes. Typical types of wetlands adapted to NBS include marshes, swales and marshes. Wetlands that allow free-flowing surface water are frequently used in urban areas due to their green space and urban landscape value.[29,30]
6	Permeable pavements	There are two types of permeable pavement: porous pavement and permeable pavement. Both types of construction allow rainwater to seep through the surface, but are still suitable for pedestrians or vehicles in parking lots and on low-traffic streets. Rainwater will either seep into the soil below or can be discharged into a stormwater collection system with a delay. [31]

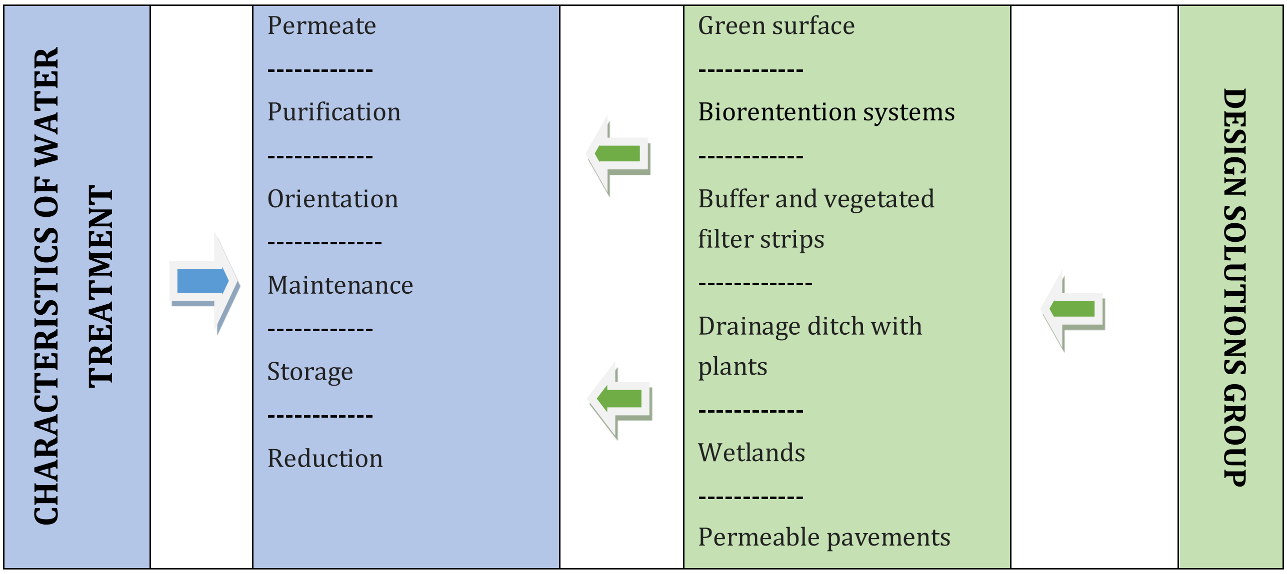

Fig. 11 *The correlation between factors of urban flooding and landscape design solution*

6. Techniques for Analyzing The Responsiveness of Design Solutions in Responding to Urban Flooding

A technique is developed to reflect the criteria in analyzing the adaptation of landscape design solutions to flood resilience in the Vinh River area, Vinh City. This technique used the Likert scale of five levels to determine the importance of each criterion through a sociological survey table. The levels include fully responsive, relatively responsive, partial responsive, not responsive and completely unresponsive (Table 3).

Table 3 *Likert scale point*

Level	Range
fully responsive	80 - 100 Point
Relatively responsive	60 - 80 point
Partial responsive	40 - 60 point
Not responsive	20 - 40 point
Completely unresponsive	0 – 20 points

Research sample: To objectively assess the responsiveness of the solutions, the author conducted a survey of 100 participants including architects (urban designers), urban managers, environmental engineer and local residents.

The architectural group will evaluate the urban landscape and waterscape capabilities of the solution. The environmental engineering group will evaluate the effectiveness of the solution in regulating water flows. Urban managers will evaluate the overall and total effectiveness of the solution on the urban and legal scale. Finally, local people will play a role in verifying the effectiveness of the solutions through practical experiences and experiences. The research subjects were selected to participate in the study using the convenience sampling method. General information about the sample is shown in Table 4.

Table 4 *Participants evaluated the responsiveness of design solutions*

Types of Participants	Symbol	Quantity (pers)	Percentage %
Architect (urban designers)	D.KTS	30	30.00
Environmental engineer	D.KS	30	30.00
Urban management	D.QL	20	20.00
Local residents	D.ND	20	20.00

Method of scale evaluation: Before analyzing the survey results, the researcher evaluated the Likert scale used using the Cronbach's alpha reliability coefficient with the criterion that the questionnaire has good reliability if the Cronbach's alpha reliability coefficient is greater than or equal to 0.6. The results of the group of questions on natural conditions, the group of questions on socio-culture and the group of questions on technical economics have Cronbach's alpha values of 0.81; 0.78 and 0.77 respectively. This result shows that the technique is reliable.

7. Confirm Landscape Design Solutions on Both Banks of Vinh River to Respond to Urban Flooding Problems in Vinh city

7.1 Proposing Landscape Design Solutions Applied on Both Banks of Vinh River

The design solutions applied in the landscape design of the two banks of the Vinh River are based on practical experiences from successful urban areas, and are divided into groups of solutions according to the classifications made above. The design perspectives and principles include:

(1) Green surface:
- Maximum respect for terrain and natural geology
- Minimize concrete surface areas
- Design of water squares
- Use native plants and trees

(2) Bioretention systems
- Building diverse landscapes, combining lagoon areas, riverside sand landscapes
- Stepped landscapes, diverse spaces and functions depending on the level of river surface change

(3) Buffer and vegetated filter strips
- Constructing riverside park entrances at different elevations
- Teramesh green embankment solution ensures Vinh River water surface
- Improving existing embankments, in the direction of combined soft and stone embankments

(4) Drainage ditch with plants
- Between landscape subdivisions with different material surfaces, surface drainage slots are arranged in combination with vegetation.
- Drainage slots are designed along all landscape paths.

(5) Wetlands
- Building an agricultural park model, based on exploiting the current agricultural model of the area
- Building ecological village models
- Building a floating market model

(6) Permeable pavements
- Maximize access to the waterfront
- Sidewalks and walkways using durable bricks or stones, with open drainage channels
- Use scenic bridges over water
- Use local, sustainable and environmentally friendly materials

7.2 Using The Proposed Technique to Evaluate Solution Sets in Response to Urban Flooding Problems in Case of Vinh City

The evaluation form scores each survey object based on the average coefficient according to the formula and as presented in Table 5

$$DTB = D.KTS*0.3 + D.KS*0.3 + D.QL*0.2 + D.ND*0.2$$

Table 5 *Assessing the responsiveness of landscape design solutions to flood resilience*

No	Solution group	Detail solution	1.Infiltration	2.Purification	3.Conveyance	4.Retention	5.Detention	6.Attenuation	Average score
1	(1) Green Surface	Maximum respect for terrain and natural geology	75	85	80	80	75	85	80.0
2		Minimize concrete surface areas	87	72	57	92	82	82	78.7
3		Design of water squares	81	86	86	76	76	86	82.8
4		Use native plants and trees	87	87	71	91	91	76	83.5
Average score									81.25
FULLY RESPONSIVE									

7.3 Results of Ranking Solution Groups and Evaluating Specific Solutions for the Case Study in Vinh City

Other solution groups are also evaluated based on the results Table 6. It can be seen that the green space solution group has the highest score and optimally solves the problems of urban flooding. Next is the solution group on Water garden landscape and using green corridors. The biological garden solution group partially meets the requirements.

Table 6 *Solution group evaluation table*

Solution Group	(1) Green surface:	(2) Bioretention systems	(3) Buffer and vegetated filter strips	(4) Drainage ditch with plants	(5) Wetlands	(6) Permeable pavements
Score	81.25	75	80	78	76.1	81.5
Evaluate	**Fully responsive**	Relatively responsive	**Fully responsive**	Relatively responsive	Relatively responsive	**Fully responsive**

The above results have once again confirmed the research question posed in the first part of the research paper. After the results as collected above, the author reaffirms that appropriate landscape design solutions will help effectively respond to the risk of urban flooding, especially landscape design solutions along major urban rivers and integrated with elements of nature-based design.

Returning to the specific case of Vinh River and Vinh City, found that there was a difference in scores between the solution groups. This is explained by the differences in natural climatic characteristics, as well as the socio-cultural characteristics of each urban area. In Vinh City, the landscape design of the two banks of Vinh River to cope with flooding must focus on 3 groups of solutions that have given results that fully meet the requirements for coping with flooding in the city.

(1) Green surface
(3) Buffer and vegetated filter strips
(6) Permeable pavements

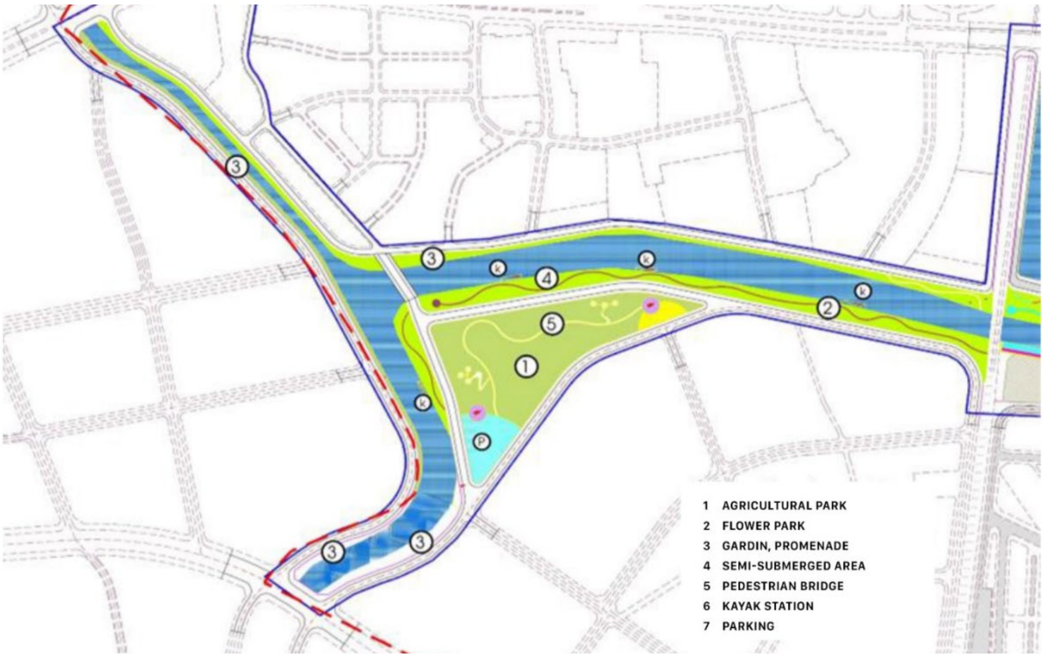

Fig. 12 *Landscape design applies solutions to maximize green space (1-Green Surface) in the area at the western end of Vinh River (Source [3])*

Fig. 13 *Maximize the design of soft embankment and green embankment landscape (3 - Buffer and vegetated filter strips) close to the water surface in the middle of the river. (Source [3])*

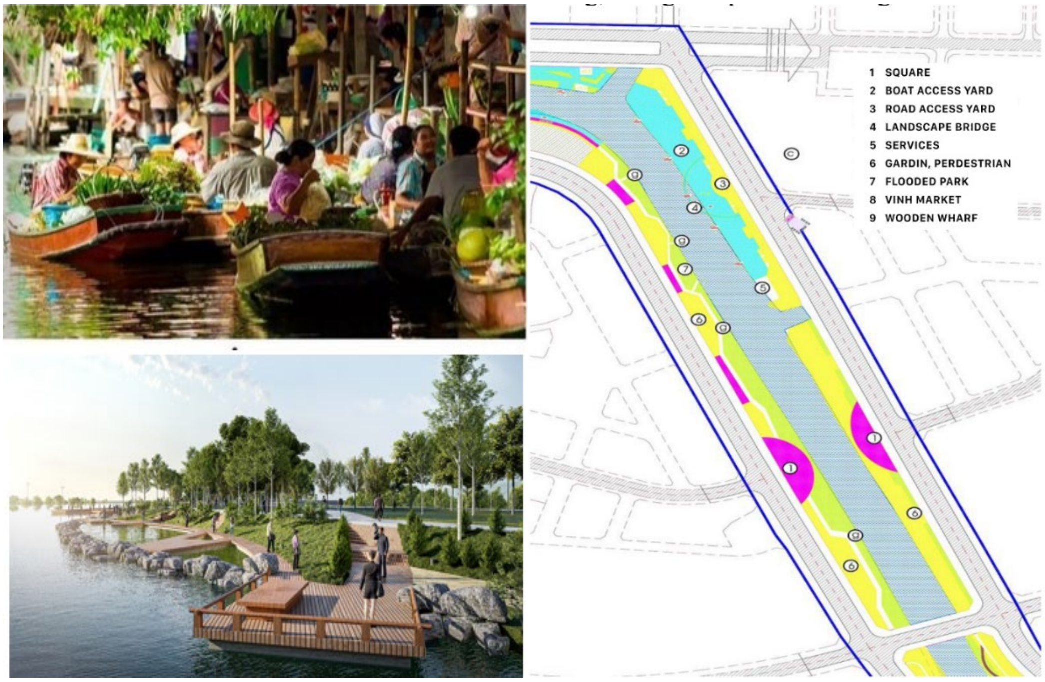

Fig. 14 *On the east side of the river the floating market area is designed with piers to maximize surface access with drainable surface material. (6 - Permeable pavements) (Source [3])*

The remaining groups (2) Bioretention systems, (4) Drainage ditch with plants, (5) Wetlands, which partially respond to the flood risk will be considered and integrated harmoniously and reasonably in the overall landscape design of the entire route, arranged in special locations to maximize design effectiveness.

8. Conclusions

The quality of life and living conditions of the population have significantly improved in comparison to earlier years along with the socioeconomic development of the city. The economy has grown, the standard of living has increased, the rate of urbanization has accelerated, and the social and technical infrastructure has gradually improved. The creation of a technical infrastructure system, however, has not complied with the needs of the city's socioeconomic development. The city is currently dealing with pressure from urban traffic caused by flooding and environmental pollutants brought on by climate change.

The study provides knowledge about flood resilience not only in Vinh city but also in all urban areas in the Central of Vietnam and creates new scenarios in public space design. The study has proposed a set of tools to assess the responsiveness of landscape design solutions in responding to urban flooding problems.

The solutions are evaluated purely based on technical and environmental factors. However, in practice, landscape design or urban design solutions are also affected and related to other urban issues such as culture, economy and society. Therefore, to objectively evaluate truly effective solutions, it is necessary to evaluate them in many aspects. Those aspects can also apply the evaluation techniques mentioned in the research and open up future directions for the research, from which to propose solutions that bring the most comprehensive effectiveness.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *THLV, VHN, DTD;* ***data collection:*** *THLV;* ***analysis and interpretation of results:*** *VHN, THLV;* ***draft manuscript preparation:*** *THLV, VHN, DTD. All authors reviewed the results and approved the final version of the manuscript.*

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