IOP Conference Series: Earth and Environmental Science

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Flood adaptation impacts of blue-green infrastructure through hydrosocial framework.

To cite this article: Zul Azri Abd Aziz *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1274** 012044

Flood adaptation impacts of blue-green infrastructure through hydrosocial framework.

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Abstract. Modern dualisms between society and nature affect understandings of "what water is?" and "how water fits into society?", according to the hydrosocial cycle concept. Understanding the urban stormwater system within the tensions inherent in designing flood-resilient cities is crucial from a social, cultural, and ecological perspective. Therefore, it is essential to comprehend how the hydrosocial cycle altered the use of blue-green infrastructure over time and how these modifications reflect the values of urban waterscapes and urban flood adaptation. The purpose of this paper is to discuss and analyse historical and contemporary perspectives on correlations between the hydrosocial cycle and blue-green infrastructure networks, which are beneficial to water-sensitive urban design principles. A comprehensive literature review and comparative analysis of two case studies of waterscape impact on public space based on the hydrosocial framework were used to conduct the research. This study employs comparative case studies to evaluate the implementation of the hydrosocial cycle by examining the dynamics of social power and structure, technology and infrastructure, and the materiality of water at each respective site. The results of this study indicate that urban landscape and engineering systems that are influenced by ecological and social values are advantageous to the current state of flood adaptation and urban runoff management. The comparison demonstrated that the implementation of blue-green infrastructure that incorporates the symbiotic values of society and nature offers opportunities for urban flood adaptation. In a nutshell, the integration of the hydrosocial cycle in the context of reducing flood susceptibility contributes to the enhancement of the existing framework by incorporating an analysis of societal interactions and utilisation of urban waterscapes, alongside a transition towards urban flood adaptation.

1. Introduction

The "Water Sensitive City" era aims to lessen society's vulnerability by implementing dynamic adaptive measures based on the notion that nature and society are coevolving systems [1,2]. These ecosystem-based methods of environmental management, also known as the hydrosocial cycle, may offer robust solutions to the biophysical, social, and political implementation and planning issues associated with climate adaptation and mitigation [3]. The notion of a hydrosocial cycle explores the impact of contemporary dichotomies between society and nature on our comprehension of water as well as its integration within societal frameworks [4]. It highlights the socio-natural process by which water and society make and remake each other, especially in the contribution of technology toward adaptation.

Understanding the urban stormwater system within the tensions inherent in designing flood-resilient cities is crucial from a social, cultural, and ecological perspective. Consequently, it is crucial to comprehend how the hydrosocial cycle generated an effect that altered the use of blue-green infrastructure over time, and how these modifications reflect the values of urban waterscape and urban flood adaptation. As water management has been determined by the direction of political ecology and translated into technology application in response to water materiality, an overview of past innovations is significantly interpreted through urban heritage. Hence, culture and technologies rose with awareness of dynamic process of urban landscape [5].

The purpose of this study is to explore and assess historical and current viewpoints on correlations between the hydrosocial cycle and blue-green infrastructure networks that enhance water-sensitive urban design principles. The study is keen to explore the symbiotic relationship between the hydrosocial framework of two case studies focusing on urban parks and public spaces with adaptation to floods. The caretaking and conservation of such spaces by state and local policymakers also leads to the paradigm in which stormwater is not seen as a hazard or problem to be solved but as a natural resource that benefits society and the environment [6]. Therefore, the characteristics led to the selection of heritage town which has significant bonding between the people and blue-green infrastructure as the case study.

2. Hydrosocial Cycle

The hydrosocial cycle is a socio-natural phenomenon that describes how water and society shape and reshape one another across time and location. The hydrologic cycle, first introduced as a framework for the hydrologic sciences, has since taken over as the most widely used metaphor for describing water flows in the hydrosphere. In contrast, the hydrosocial cycle pays attention to both the social aspect of these flows and the agential role performed by water, while emphasising the dialectical and relational processes through which water and society interact [7,8].

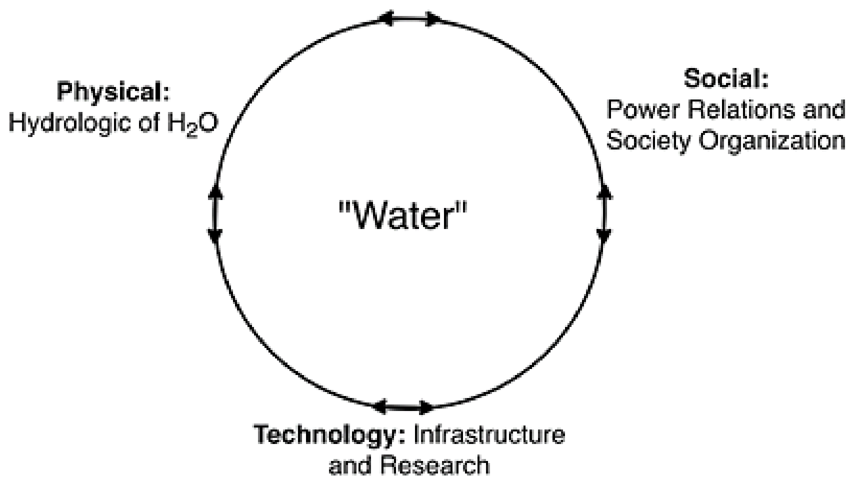

Figure 1. Conceptual diagram of the hydrosocial cycle by which the materiality of water, social power and structure, and technology and infrastructure make and re-make "water" [8].

This study's hydrosocial cycle provides a framework to examine urban water management through human redesign and reorganization highlighting hydrosocial relationships [3]. Hence, the framework of the study will be based on the components of hydrosocial cycle that will be translated into a guide for several key aspects of the research:

a. Water: Represent the "type of water". In this study, it will be focusing on the question of either water was perceived as a resource or hazard regarding urban flood adaptation.

b. Social Power/ Structure: Represent the act of governance toward water/ flood management related to policy, regulation, and community engagement.

c. Technology/ Infrastructure: This study will focus on blue-green infrastructure as part of landscape engineering that benefits urban flood reduction in heritage towns.
d. Materiality of Water (H^2O): In this study, the materiality of water regarding urban flood adaptation will focus on water discharge of peak flow and surface run-off. In conclusion, the hydrosocial cycle breathes new life into scientific methods by preparing the framework for the promotion of studies of ecosystems that include social effects, adaptive ability, and resilience [9].

2.1. Hydrosocial Framework as Assessment Tools
Instead of integrating water and socio-political factors, the assessment through the lens of the hydrosocial cycle seeks to clarify how water is produced through social and political processes, how it shapes social structures, relationships, and identities, and with what effects over space and time. We can progress assessments of the political ecology of water from the (external) relationships between people and water to the (internal) co-constitution of water itself through social and political processes by focusing on hydrosocial relations rather than the water itself [10].

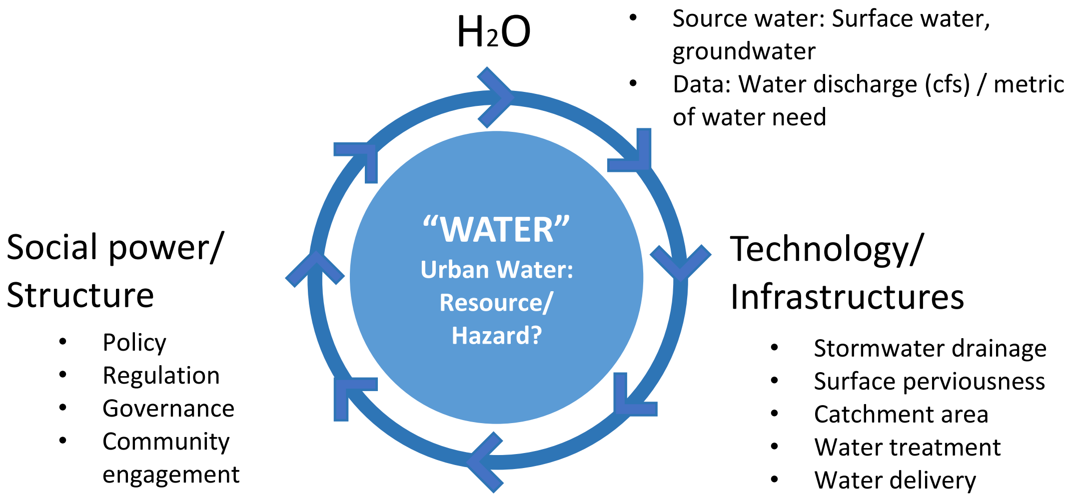

Figure 2. Hydrosocial cycle applied to "urban water" flood adaptation [3].

The hydrosocial cycle provides a framework for examining urban runoff management by emphasising hydrosocial relationships through human redesign and reorganization. Examining urban water through the lens of the hydrosocial cycle allows us to consider how power relationships inform urban landscape and engineering design to determine the effectiveness of local urban flood adaptation. Figure 2 illustrates the hydrosocial cycle that has been translated as a framework that focuses on "urban water" [3]. The hydrosocial cycle can be a powerful framework for analysing water-society relationships' social, political, and historical dimensions.

Table 1. Summary of previous studies utilizing hydrosocial cycle as a framework.

Authors	Area of Study	Concern Issue	Framework Assessment
[11]	South Africa	Water Resource Management	Advocates utilizing the hydrosocial cycle as an analytical framework for designing new institutional arrangements and acknowledging legitimate local interests.

Table continues.

[12]	Southeast of Spain (Mediterranean)	Water Resources Demand	The theoretical analysis is corroborated by the study of the hydrosocial cycle evolution of three cities, and the adaptive measures that the different stakeholders involved in the cycle has developed in each of them.
[13]	Salween River Basin, Hpa An, Myanmar	Flood Adaptation	Focus on hydrosocial approach and emphasise the practices of residents in local water management and responses to flooding.
[14]	Northeast London, England	Open Space and Wetland Management	Analyzed the hydrosocial relation through the argument generated from the expansion of Corporate Social Responsibility (CSR) initiatives which have developed spatially fixed forms of human-environment relationships that been termed as “hydrocitizenships”.
[3]	Nairobi River Basin, Kenya; Citarum River Basin, Indonesia; and Addis Ababa River Basin, Ethiopia.	Water Management and Security	Using the hydrosocial cycle as an organizing framework, all three watersheds are examined to highlight how water security underpins water justice. Projects were compared to assess the implementation of the hydrosocial cycle through a discussion of social power and structure, technology and infrastructure, and the materiality of water in each location.
[4]	City of Tuscon, Arizona and City of Pittsburg.	Stormwater Management and Water Harvesting	Two hydrosocial case studies centred on rain and stormwater are investigated to highlight how stormwater management can benefit from a hydrosocial approach.
[15]	Southern Sydney, Australia	Cultural-Society Environmental History	Develop a critical analysis of the historically changing relationship between urban communities and water infrastructures which focused on bringing together past and current perspectives, engaging with the formation of diverse hydrosocial behaviours entangled with water infrastructures.

Previously, it is known that different researchers had conducted diverse studies utilizing hydrosocial cycle as their framework (Table 1). Most studies attempt to analyse the society- environment relation that manifests political and community influences toward defining the materiality of water and technological infrastructure application.

3. Blue-Green Infrastructure (BGI) System to Flood Adaptation

Blue Green Infrastructure (BGI) is a method or instrument for achieving sustainable urban stormwater management and climate-resilient settlement. Stormwater quantity and quality are managed using BGI, an ecosystem-based approach that relies on biophysical processes including detention, storage, infiltration, and biological uptake of pollutants [16]. This is one of the methods used to minimize the negative impact of extreme weather, which include droughts and floods, on a community. The effects of recent climate-related extremes show how many natural ecosystems, including human systems, are exposed to and vulnerable to present climatic variability and change [17,18].

Standard BGI System is that BGI incorporates several ecosystem-based landscape systems installed alone or in combination to regulate the volume and quality of stormwater runoff on-site. These systems are also created to replicate natural hydrology. The most widely utilized BGI systems include green roofs, rain gardens, bioswales, retention and detention basins and artificial wetlands. For example, a rain garden is a vegetated, shallow depression designed to collect and treat stormwater runoff from nearby impervious surfaces. How the rain garden system works is that the stormwater runoff is treated through filtration, sedimentation, adsorption, and plant and microbial uptake [19]. Not only does the soil serve as a filter medium for plant growth, but it also treats the water.

Table 2. Summary of the effects of blue-green infrastructure-based literature.

BGI Elements	Effect	Results	Reference
Storage Pond	Rainwater management	Runoff reduction by 30-100% Peak flow reduction by 38-86%	[22,23]
Rain Gardens	Rainwater management	Runoff reduction by 42% Runoff reduction by 12.7-19.4%	[24]
		Runoff reduction by 1.93-9.69%	[25]
		Peak flow reduction by 70%	[26]
		Peak flow reduction by 7-56%	[24]
		Infiltration: 60%	[27]
		Evapotranspiration: 19-84%	[28]
Green Roofs	Rainwater management	Runoff reduction 50-100%	[29]
		Runoff reduction 2-100%	[30]
E-extensive, SI-semi-intensive, I-intensive		Runoff reduction 40-80%	[31]
		Runoff reduction 5-69% compared to standard roofs	[25]
		Evapotranspiration: 51.5%	[32]
		(E) Evapotranspiration: 83% Retention of rainfall: 30-86%	[28]
Permeable pavements	Rainwater management	Runoff reduction 1-40%	[33]
		Peak flow reduction by 42.9-57.2%	[34]
		Peak flow reduction by 7-43%	[32]
		Total outflow reduction by 10-20%	[34]

BGI has positive benefits in managing rainfall and improving water quality. However, the literature research revealed that various methods have different degrees of improvement in the structure of urban water balance. The literature cited in Table 2 indicates that the storage pond provides the best effectiveness can reach 100% and the lowest rainfall reduction can reach 86%. According to reports, rain gardens offer the second most tremendous potential for reducing peak flow (by 70%). Additionally, rain gardens seem effectively to increase infiltration rates (by as much as 60%). The research on evapotranspiration from BGI reported a wide range of results: from 19% to 84% of rainfall for rain gardens, and 51.5% to 83% for green roofs. In order to purify rainwater, BGI elements efficiently absorb pollutants from rivers, lakes, and other water reservoirs as well as directly from the rain. They can remove between 80% to 90% of a variety of heavy metals such as Cu, Cd, Pb, Zn, and Cr, 65% of phosphorus, and 90% of total suspended particles. Additionally, it has been discovered that BGI drastically lowers the danger of erosion and sedimentation [20,21].

4. Methodology

A mixed method was employed by using both qualitative and quantitative methods to conduct this study. Firstly, qualitative method was undertaken by conducting a comprehensive literature review and performing a comparative analysis of two case studies. The focus of the investigation was to examine the influence of waterscape on public space within the context of blue-green infrastructure by utilising a hydrosocial framework. Case studies are compared to assess the implementation of the hydrosocial cycle through discussion of social power, technology, and the materiality of water [3] in each location (refer Figure 3).

Secondly based on these comparative results, quantitative method through rational method equations applied that lead to the indication of BGI impacts on storm runoff volume and peak flow reduction. Finally, through sequential content analysis of each hydrosocial cycle component, the justification of flood reduction will reflect "type of water" regarding flood adaptation in both case studies.

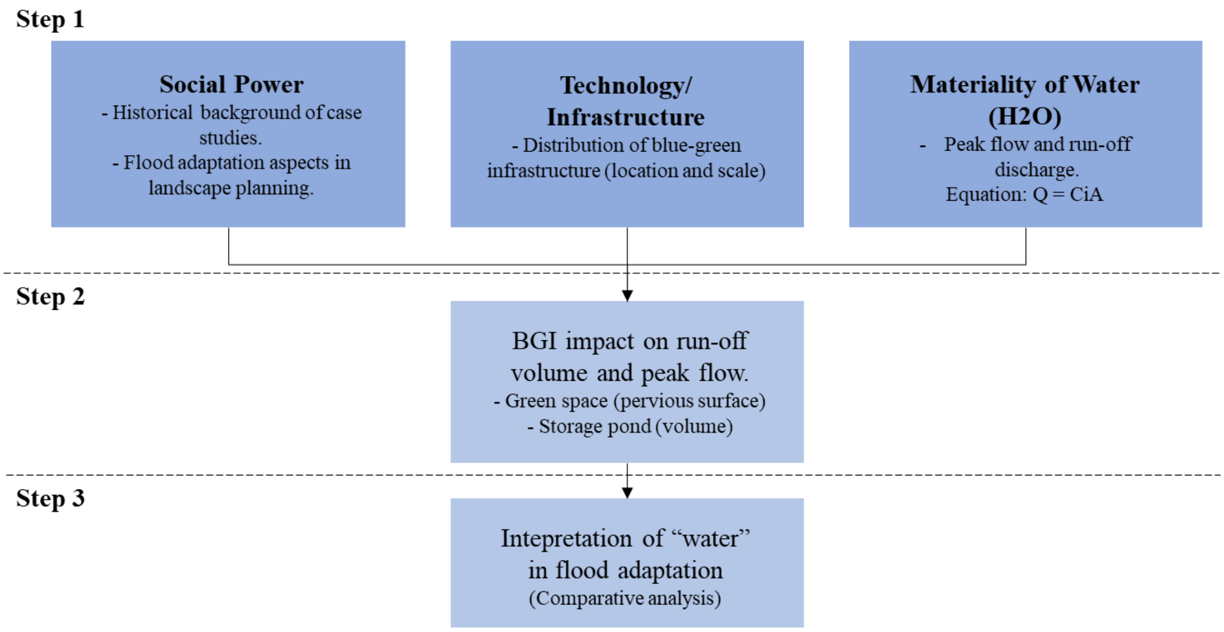

Figure 3. Sequential study process utilizing hydrosocial framework toward a comparison of case studies.

4.1. Case Studies

In this paper, the study process covers two selected heritage towns as case studies to be compared. Firstly, both towns were selected based on criteria obtained from the Operational Guideline for Implementation [35,36]. The criteria available on the heritage towns selected in Malaysia; a city that highlights the importance of the changes in human values over time or within the scope of world cultures, such as architectural or technological developments, unique monuments, town planning and landscape design. Both selected towns represent the most comprehensive pre-independent planning system which responded to natural disasters that led to redevelopment of the current state. They were also selected based on conservation practices and effort that significantly affect the preservation of original urban landscape settings. Study areas in these towns were focusing on the town center area which mostly indicated the origin of its formation.

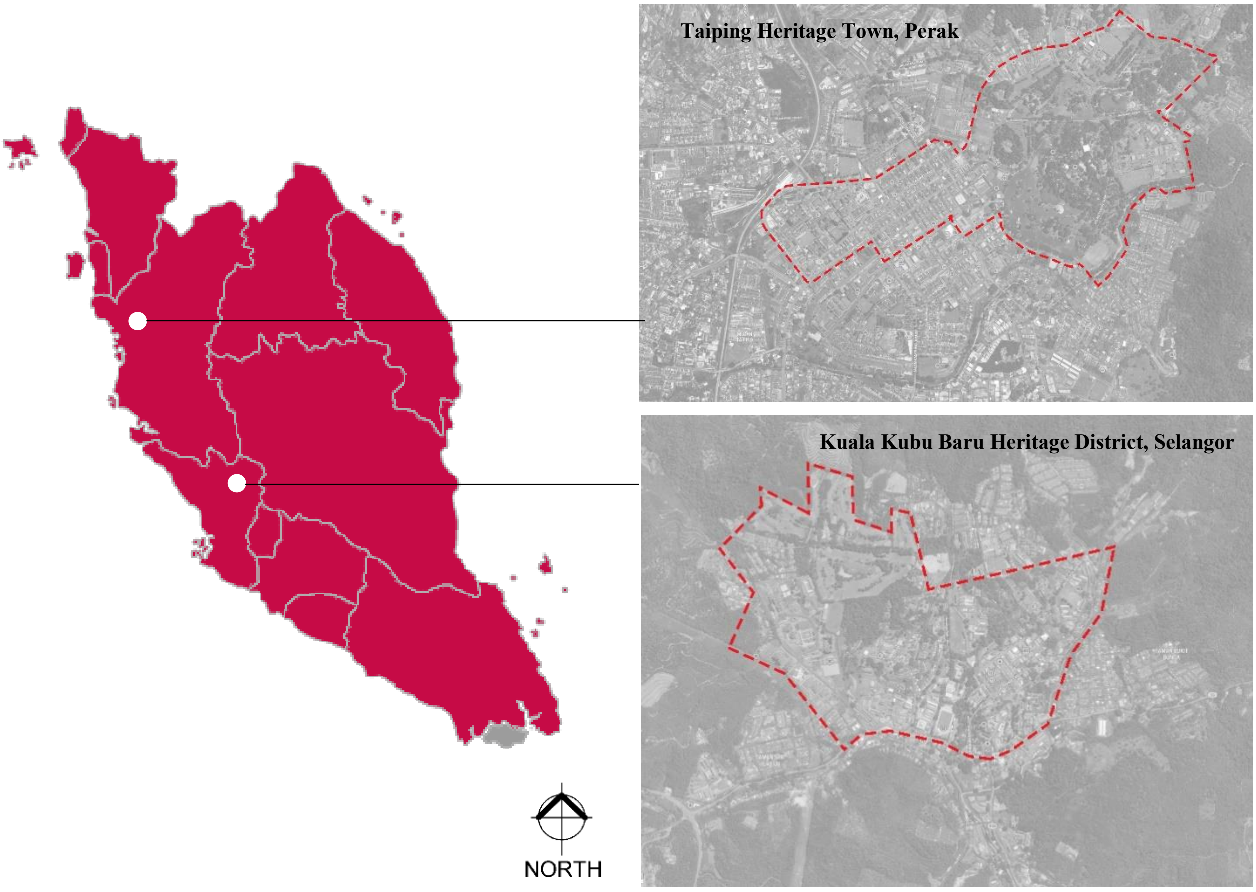

Figure 4. Case study locations- Taiping, Perak and Kuala Kubu Baru, Selangor.

The second criteria of this case study's selection are regarding responsive development of both heritage areas toward disaster. Historically, both town systems were developed from the implication of massive fire (Taiping Heritage Town) and constant flooding (Kuala Kubu Bharu) that lead to adaptive environment in spatial design (Table 3). The landscape engineering approach that provides efficient water flows and spatial sustainability became essential in comparing each unique case study. Therefore, both case studies will be indicated as follows:

a. Taiping Heritage Town Core Heritage Zone and Buffer Zone [37].
b. Kuala Kubu Bharu Heritage Conservation District [38].

4.2. The Impact of BGI System to Flood Adaptation

Wetlands, ponds, swales, rainwater tanks, vegetated filter strips, and filter strips all fall under the category of blue-green infrastructures. These facilities each keep a certain amount of precipitation "on-site" either by storing it in containers or by recharging the groundwater below them. In this study, we chose two typical blue-green infrastructures, which are more suitable for implementation in a heritage town environment. These infrastructures include storage ponds and green space coverage, and we evaluated their regulatory functions that they have regarding storm runoff. The BGI overflow calculation involves substituting the corresponding surfaces and then connecting the calculation with the runoff via coupling with hydrological processes.

4.2.1 The Impact of Green Space on Peak Flow Reduction. Green space coverage in developed areas impacts the runoff volume and peak flow through pervious surface that reduce ratio of runoff coefficients. The process will involve two steps of equations based on Rational Method [39]. The rational method typically applies to drainage areas that are no greater than 200 acres (other governing bodies allow this upper limit to be as high as 640 acres). In the case of both case studies, the area in applying equation toward watershed needs to be divided into smaller areas [40]. The rational method formula to identify rainfall volume (V):

$$V = iA \tag{1}$$

And rational method to identify runoff and peak flow (Q):

$$Q = CiA \tag{2}$$

Where:
A = the surface land use area
C = the runoff coefficient
i = the intensity of the rainfall
Q = the peak flow; and
V = the rainfall volume

4.2.2 Impact of Storage Pond on Peak Flow Reduction. The man-made lake and retention or detention pond, located near the storm water drainage outlet, serve as a storage pond to temporarily store the entire runoff and mitigate the volume of runoff. The methodology employed in this study will incorporate the Average End Area Method to calculate the runoff volume associated with the storage pond structure.

$$V = \left(\frac{A1+A2}{2}\right)\mathrm{L} \tag{3}$$

Where:
V = the discharge volume
A1 = the area of first cross section
A2 = the area of second cross section
L = the length between two areas

4.3. Data Analysis

In order to comprehend the phenomenon in Taiping Heritage Town and Kuala Kubu Bharu Heritage District, researcher did mixed-methods research by carefully looking for, evaluating, and putting together observation notes and other literature. A content analysis was conducted on stormwater management systems investigating flood adaptation categories and the type of measures implemented in the blue-green infrastructure network. In both case studies, a comparative analysis was then used to substantiate the flood reduction framework in terms of the effectiveness of urban flood adaptation. The very first impression and the evidence of the current circumstance were both presented by this method. It included a collection of site assessments that analysed their capacities and the resources for the purpose of this study.

5. Results and Discussion

The results of both case studies were based on the importance of preserving ecological-based infrastructure in the context of urban flood adaptation derived from conservation effort.

5.1. Taiping and Kuala Kubu Bharu setting based on social power.

Adaption or resilience of cities to extreme events such as urban floods is the complex ongoing process that demands cooperations of all stakeholders and governance in shaping and managing urban areas [18]. The development of both Taiping Heritage Town and Kuala Kubu Bharu were based on social power response toward disaster that translated into responsive environment values toward flood adaptation (refer Table 3). Furthermore, conservation efforts focusing on core and buffer zone [35] were actively applied in both case studies urban planning strategies [37,45] that include blue-green infrastructures within the area.

Table 3. Development background leading to flood adaptation in Taiping and Kuala Kubu Bharu.

Case study	Development background	Flood adaptation origin
Taiping Heritage Town, Perak	The town completed its redevelopment in 1882 from the implications of massive fire tragedy that almost burnt down the whole town in 1878 and 1880 [41,42].	The post-colonial urban water management and infrastructure consist of 10 man-made ponds as lake garden, canal and drainage system intended for Taiping heritage town systematically function to reduce flood vulnerability that ensures the health and well-being of community [41,42]. Taiping also imposed a garden city concept where Taiping Lake Garden were the first built public park in Malaysia [43].
Kuala Kubu Bharu, Selangor	In 1921, Old Kuala Kubu conditions became so bad due to constant flooding because of mining silt deposits from the Selangor River's upper reaches. Between 1923 and 1926 Kuala Kubu was flooded several times. In 1924 Charles Reade was allowed to plan a new township of Kuala Kubu Baru [44].	Kuala Kubu Bharu (KKB) is the name of the new town, with Bharu signifying "new" in Malay. Since the 1980s, residential housing has been constructed in the formerly abandoned old town of Ampang Pechah. With the implementation of Charles Reade's Garden City Concept, the redevelopment entailed the relocation of the upper elevation location [38]. Practically all new development were situated above the lowest level recommended by the Public Works Department to protect against future flooding and siltation. The sites accommodate hospitals, rest houses, schools, clubs, churches, subordinate accommodations, the layout, and commercial structures [44].

5.2. BGI distribution in technology conservation

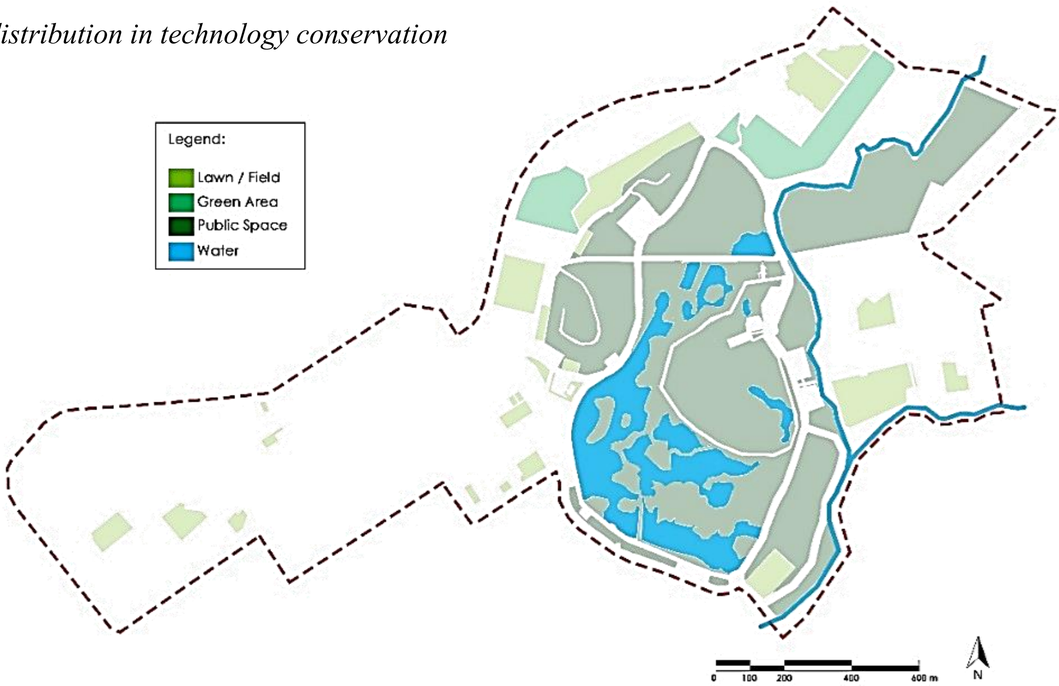

Figure 5. Distribution map of green space that contains BGI attributes in Taiping Heritage Town.

Impact from conservation efforts that maintain the use of green spaces around both case studies, distribution of BGI provides a pervious surface that allows infiltration, vegetation interception and evaporation that reduce stormwater runoff. Taiping Heritage Town preserved 343.5 acres of green space area which represent 49.3% of the total urban catchment area. Meanwhile, due to Kuala Kubu Bharu topographical features, green space area is only estimated at 34.9% of the total area with 205.1 acres in coverage. The concave landscape character of Taiping Heritage Town gives an advantage to green space preservation that also highlight special characteristic of Taiping Lake Garden as a storage pond.

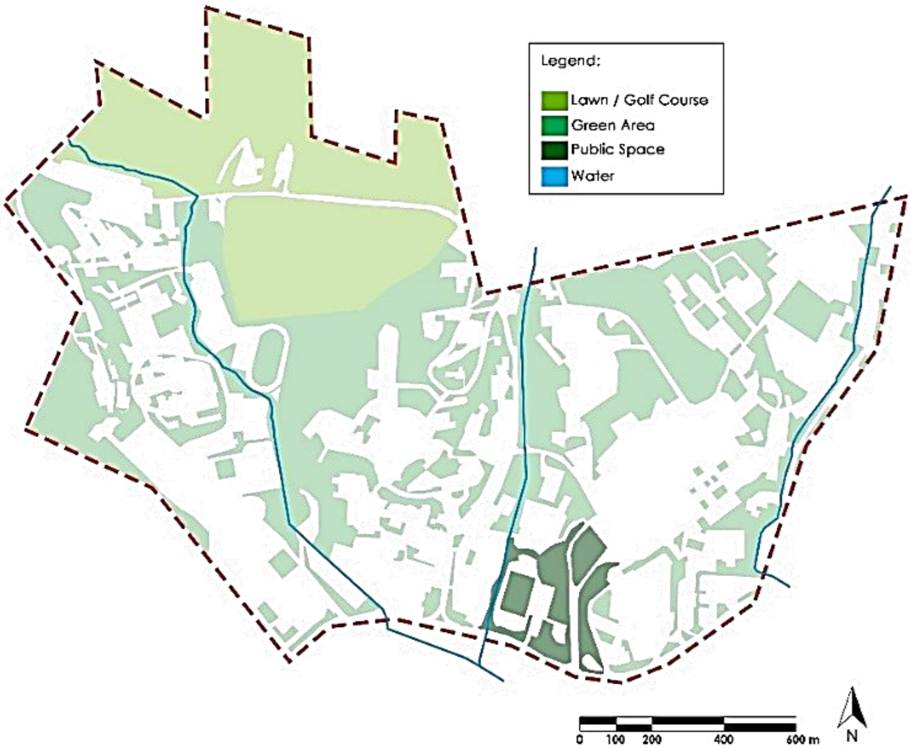

Figure 6. Distribution map of green space that contains BGI attributes in KKB heritage district.

5.3. Materiality of water toward flood reduction simulation

Similar in functionality to the flood reduction technique, previous BGI distribution mapping is the preliminary hydrological analysis that aim to compare the flow rate in the catchment area such as Taiping heritage town and Kuala Kubu Bharu heritage district. Table 4 will summarize the parameter values used for further simulation based on hydrosocial cycle information. Three storm events representing 2, 5 and 10-year of recurrence intervals are selected. However, the data will only provide focus simulation of two BGI typology and distribution around the case study regarding green space and storage pond.

Table 4. Parameters for runoff volume and peak flow simulation.

Parameters	Taiping Haritage Town	KKB	Source
Impact of Social Power			
Area of conservation zone	696.9acres	558.1acres	[37,45]
Percentage of impervious area	50.7%	65.1%	Based on local investigation
Percentage of pervious area	49.3%	34.9%	

IOP Conf. Series: Earth and Environmental Science 1274 (2023) 012044 doi:10.1088/1755-1315/1274/1/012044

Table continues.

Impact of Technology/Infrastructure			
Area of conserved green space	343.5acres	205.1acres	Based on local investigation
Area of downtown	234.8acres	316.3acres	
Area of road (asphalt)	59.3acres	61.8acres	
Area of road (bricks)	59.3acres	4.9acres	
Impact of materiality of water			
Overall rain volume	1657.7m^3/min	1327.5m^3/min	Q=CiA [39]
2-year storm intensity	1.4 in/h	1.4 in/h	IDF curves [43]
5-year storm intensity	1.8 in/h	1.8 in/h	IDF curves [43]
10-year storm intensity	2.2 in/h	2.2 in/h	IDF curves [43]
Volume of storage pond	210877.98m^3	0	[37]

5.4. BGI impacts on storm runoff volume and peak flow.

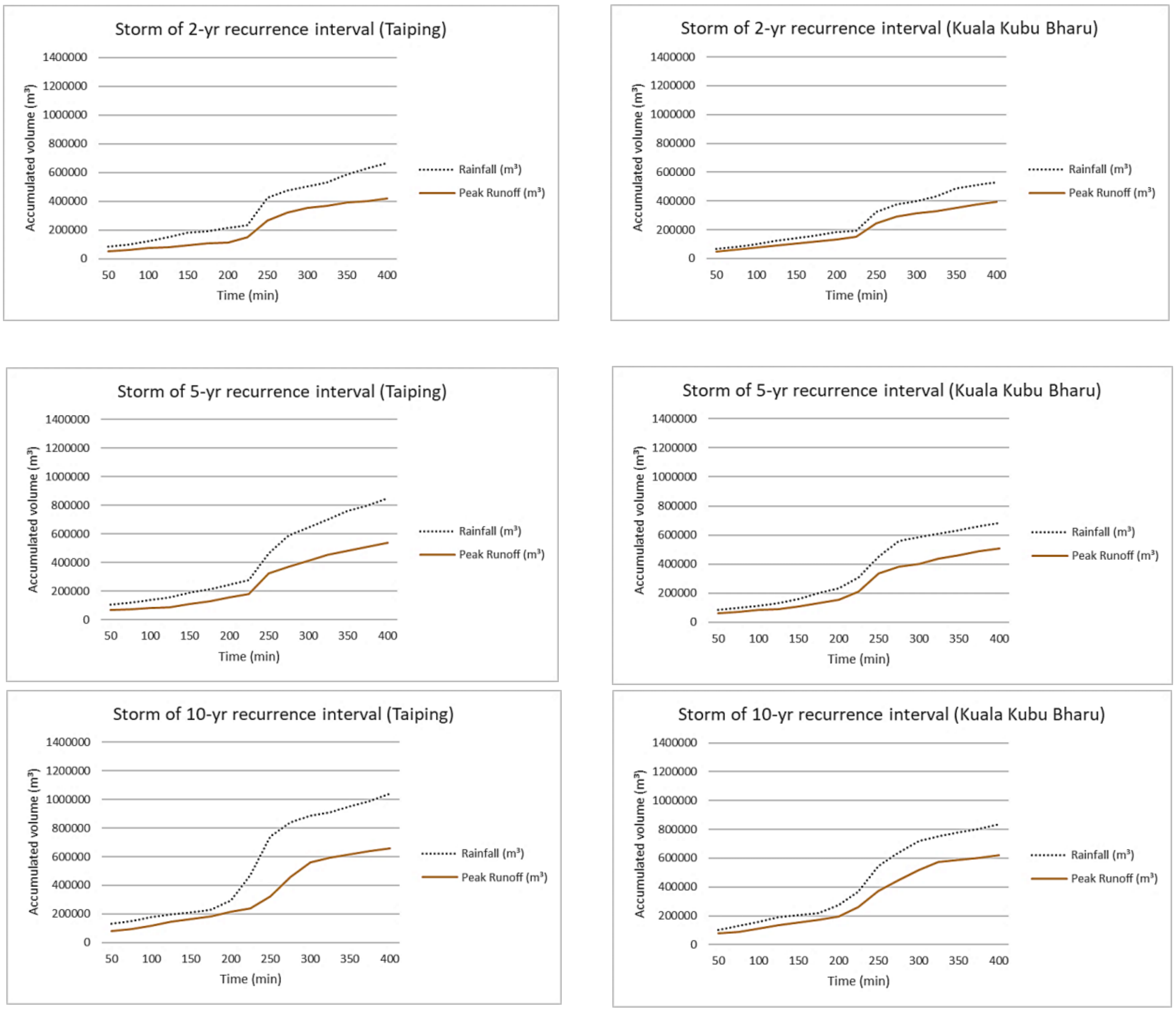

Figure 7. Influence of cumulative green space coverage on the precipitation patterns, specifically in terms of rainfall and runoff, during storms with recurrence intervals of 2, 5, and 10 years.

5.4.1 Green space. Conservation of blue-green infrastructure and/or expansion of green spaces would have a significant effect on urban flood adaptation. In Taiping heritage town, with a green area coverage of 49.3% of the surface, the base scenario would reduce runoff volumes by 37–28.5%, and peak flows would be 1,044.7, 1343.2, and 1,641.7 m3/min, indicating 22.2–18.2% reductions for the 2-, 5-, and 10-year storm events, respectively. Compared to Kuala Kubu Bharu, which has an average green space coverage of 34.9%, discharge volumes would be reduced by 25.7–20.3% and peak flows would be reduced by 17.4–13.2% for 2-, 5-, and 10-year storm events, respectively (Refer Figure 7).

According to these findings, the effectiveness of increasing the amount of green space in reducing the volume of storm runoff and the peak flow was quite moderate across the board for all of the storm events. As a result, the risk of urban flooding may be reduced if the amount of open space in the town area is greatly increased. It was not possible to solve the problem of storm runoff and flooding by relying solely on this strategy because there are so few opportunities to increase the amount of green space in the urban environment at the present time.

5.4.2. Storage Pond. In Taiping heritage town 10 man-made lake been preserved and designed to be a lake garden and function in capturing the storm water thus reduce the runoff. With 84351.2 m3 of runoff storage capacity, it reduced the runoff volumes by 84.8%, 66.2%, and 53.9%. Meanwhile, the peak flows were 1657.7, 2131.3 and 2604.9 m3/min, reduced by 83.2%, 70.7%, and 37.7%, respectively, under 2-, 5-, and 10-year storm events (Figure 8).

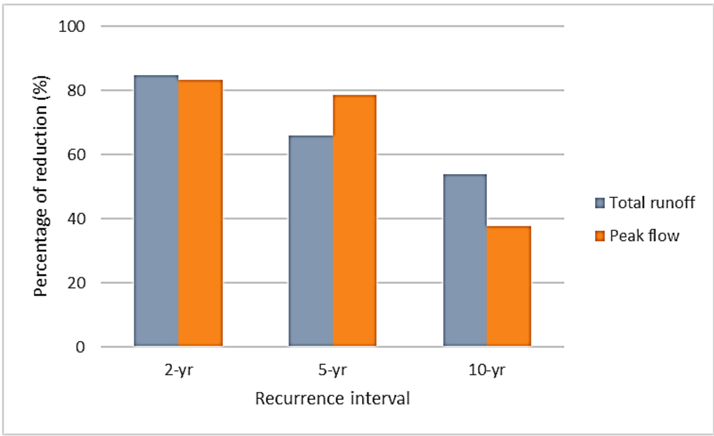

Figure 8. Influence of cumulative storage pond coverage on the distribution of rainfall and runoff during storms with recurrence intervals of 2, 5, and 10 years.

The results implied that the flooding reductions of storage ponds were effective in small and large storms despite decreasing the advantage. The storage pond is the distinctive difference between BGI characteristic of Taiping and KKB. For a storm of 1-year recurrence interval, almost all the storm water of the community may be retained in the storage pond, highlighting essential feature toward flood adaptation.

6. Conclusion

The results of this research indicate that the existing level of flood adaptation and urban stormwater management can benefit from urban landscape and engineering systems that are inspired by ecological and social values. The comparison demonstrated that there are chances for urban flood adaptation to be found in the application of blue-green infrastructure, which considers the symbiotic values shared by civilization and environment. In a nutshell, the hydrosocial cycle that pertains to the reduction of flood vulnerability encourages the advancement of existing framework to include a consideration of societal connections and uses of urban waterscapes, as well as a shift towards urban flood adaptation. This is accomplished by advancing the present framework to include a consideration of urban waterscapes.

Acknowledgments
This research work was funded by the Ministry of Education Malaysia and Universiti Teknologi MARA (UiTM) through its KPT (B) SLAB/SLAI Scholarship Scheme. The authors also gratefully acknowledge the use of postgraduate's facilities at Universiti Teknologi Malaysia (UTM).

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