Water Sensitivity in Historic Vernacular Urban Settings: A Review of Current Knowledge and a Theoretical Framework for Assessment

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Abstract

Conservation or regeneration of the hydro-systems of a historic area is dependent primarily on its water sensitivity, defined as the degree to which water can be harvested from the area. It is also influenced by the context of the area among other aspects such as the topography, historical use and periods of decay or abandonment. This paper examines the facilitators and challenges for their conservation or regeneration, and identifies the specific context variables to assess water sensitivity in historic, vernacular urban areas. It constructs a theoretical framework based on these variables to ascertain water sensitivity of a historic setting.

It employs a review of literature as a research method involving a systematic search of Scopus, ScienceDirect and Taylor and Francis databases. The search revealed 129 original records, of which, 16 articles were eligible for review.

The review finds that ecology, environment, spatial and built environment patterns, society, culture, economy and infrastructure play significant roles in the assessment of water sensitivity, the assessment of which requires the juxtaposition of all these aspects. However, uncontrolled growth, unregulated tourism, dependence on state provided water and non-integrative planning and conservation approaches pose challenges. Availability of traditional water systems, public-private partnerships and community participation are facilitators. Natural disasters both challenge and a facilitate water sensitivity.

The theoretical framework to assess water sensitivity employs water-sensitive urban design, culturally inclusive water-based urban design and historic urban landscapes, as concepts with context as a central tenet. This paper concludes that many historic cities have been traditionally water sensitive and continue to be so.

Keywords: Water urbanism, Water sensitivity, Context, Historic Urban Landscape (HUL), Water Sensitive Urban Design (WSUD), Vernacular

Introduction

Water and its management are the main drivers that produce cultural, spatial and economic identity of most human settlements (Willems and Schaik, 2015; Hein, 2019; Simic, 2020; Bansal, Jagadisan and Sen, 2022). It is more so in vernacular historic areas where evolution and growth are subject to developmental pressures and changing lifestyles. Amid such transformations, however, the hydro-systems of a place are often either neglected or exploited, leaving the historic fabric prone to ecological, social and environmental degradation. Therefore, conservation, preservation and regeneration of hydro-systems in such settings are of prime importance (Ramineni, Bhardwaj and Tejaswini, 2023; Youssef and Esaam, 2023). However, before any interventions, an assessment of water sensitivity must first be conducted.

Van der Meulen, Van Dorst and Kuzniecow Bacchin (2023) point out, that sensitivity of people to water is shaped primarily by its context. Therefore, in the assessment of water sensitivity of an area, the role of context must be evaluated and the specific context variables must be identified. Interestingly, most existing literature reviews the management and conservation of historic urban areas (Santander, Garai-Olaun and Arana, 2018; Ginzarly, Houbart and Teller, 2019; Rey-Pérez and Pereira Roders, 2020) or assesses the achievements and pitfalls of water-sensitive design and planning (Wong, 2006; Rashetnia et al., 2022; Kumar et al., 2023). However, none of them evaluate the significance of the contexts for assessing water sensitivity in historic urban areas. In this situation, this paper examines the published literature to first ascertain the current level of knowledge on this issue and to construct a theoretical framework to assess water sensitivity of a historic area. Its aim is to facilitate the conservation and regeneration of water sensitive historic areas. Its objectives are:

1. To evaluate the status of current knowledge regarding the relevance of context when assessing water sensitivity of historic urban areas.
2. To identify specific context variables that can be used to assess water sensitivity of such historic urban areas.

To achieve these objectives, the paper asks the following research questions:

1. Which context variables affect water sensitivity in historic urban areas? and
2. What are the facilitators and challenges of water sensitivity in historic urban areas?

Research Methodology

This review uses the 2020 PRISMA flow diagram (Page *et al.*, 2021) to systematically screen literature (Fig. 1) and answer the above questions.

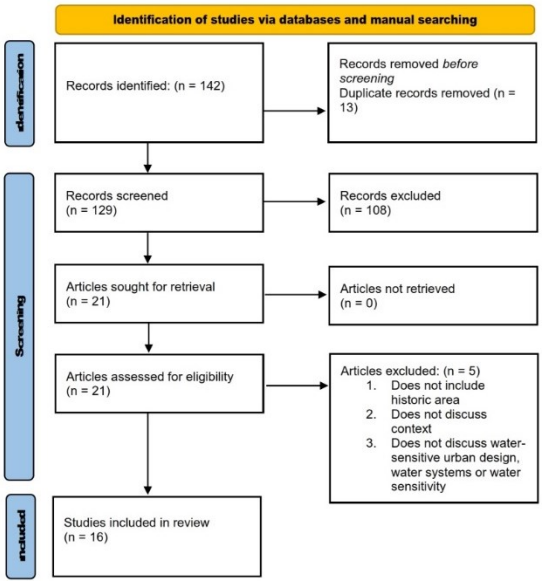

Fig. 1: PRISMA Flow Diagram, 2020
Source: Jacob (2024) adapted from Page et al. (2021)

The research first begins with a systematic search for relevant peer-reviewed literature in Scopus, ScienceDirect and Taylor and Francis databases using a combination of search terms 'water', 'sensitive', 'context', 'historic', 'vernacular' and 'urban' with the Boolean operators 'AND' and 'OR'. Further manual search of peer-reviewed and grey literature was conducted to retrieve relevant books, book chapters or conference papers. 142 articles were retrieved, and 13 duplicates were identified and removed. The abstract, title and keywords of the remaining 129 articles were screened, and 21 full-text articles were retrieved. Further screening of the full text was conducted, and 16 articles are included in the review. Only English language articles that discuss water sensitivity or water-sensitive urban design and systems, with reference to the context are included. Data extracted from the articles are used to answer the research questions. Following this, a theoretical framework is developed from the theories and concepts that identify specific context variables that affect water sensitivity in historic vernacular settings.

Findings and Discussion

Research Question 1: Which context variables affect water sensitivity in historic Vernacular urban areas?

This question is best answered by discussing the literature evaluating and identifying the role of specific context variables from the historic regions and cities. The review uncovered specific cases that have been studied by several scholars and for that reason, data is presented in terms of these case studies, In each case, the paper has examined several context variables which affect water sensitivity, which have been identified through this research. The articles from which data has been extracted are listed in the Table 1 and the specific variables are mapped out in the Table 2.

Table 1: List of Articles Reviewed
Source: Jacob, 2024

No.	Source	Title
1	Hang, 2015	Water and heritage in Angkor, Cambodia: The monuments, the ancient hydraulic network and their recent rehabilitation
2	Bensi, 2020	The Qanat System: A Reflection on the Heritage of the Extraction of Hidden Waters
3	Van der Meulen et al, 2023	Reviewing Historic Urban Water Transitions to Advance Water-Sensitive Urban Design for Bhuj, India
4	Loen, 2020	Thirsty Cities: Learning from Dutch Water Supply Heritage
5	Van der Meulen, Bacchin and van Dorst, 2023	The hydro-cultural dimension in Water-Sensitive Urban Design for Kozhikode, India
6	Hasan and Ghafoor, 2023	Applying Water Sensitive Urban Design Strategies in the Historical City Center of Baghdad, Iraq
7	Grimes, Bouchair and Tebbouche, 2017	Sustainability of the Expansion Areas for Coastal Touristic Sites "E.A.C.T.S" Such as the case of El-Aouana in Algeria: Indicators for considering biodiversity
8	Bansal, Bansal and Sen, 2020	Assessing the role of urban design in a rapidly urbanizing historical city and its contribution in restoring its urban ecology: the case of Varanasi, India
9	Bansal, Jagadisan and Sen, 2022	Water Urbanism and Multifunctional Landscapes: Case of Adyar River, Chennai, and Ganga River, Varanasi, India
10	Coyne et al, 2020	Culturally inclusive water urban design: A critical history of hydrosocial infrastructures in Southern Sydney, Australia'

11	Samant, 2007	An exploration of the historic core along Lake Pichola in Udaipur
12	Ramineni and Bharadwaj, 2021	Integrated Water Systems in Vernacular Settlements: Temple City of Melukote, Karnataka, India
13	Bharne, 2020	Conserving Asia's Vernacular Water Urbanism
14	Sharma and Ji, 2024	Linkages between Traditional Water Systems (TWS) and Sustainable Development Goals (SDGs): A case of Govardhan, India'
15	Davis et al, 2023	Flood vulnerability and risk assessment of historic urban areas: Vulnerability evaluation, derivation of depth-damage curves and cost–benefit analysis of flood adaptation measures applied to the historic city centre of Tomar, Portugal'
16	Yu, Lei and Dihua, 2012	Living with Water Flood Adaptive Landscapes in the Yellow River Basin of China

Case Study 01: Angkor Region, Cambodia - Hang (2015)

One of the most noteworthy of these studies is that of Hang (2015) who examines the natural environment and ecology of Angkor, in Cambodia. He points out that these aspects are central to the establishment of it as a historic region. According to him, this settlement is dependent on an evolved understanding of the local soil, geology and hydrology. In fact, Hang (2015) identifies that these elements of the context have in turn led to the development of water sensitive infrastructure, hydro-cultural practices and an economy based on tourism which sustains the region presently.

Natural soil available in the region, however, has been historically unstable for the construction of large structures. In fact, the knowledge of this context variable has led to the introduction of sand as a top layer and the construction of a moat to store, harvest water and increase the groundwater recharge. This has ensured that sand that formed the foundation for the structures has remained compact and strong enough to support the stone temples. The moats have later gained religious significance and have played a role in controlling the floodwaters. Hang (2015) argues that it is through the rehabilitation of the ancient water system that the region has been protected from the natural disasters and has now become a major source of tourism, therefore playing an important economic role in the country. This study thus illustrates the significance of the natural environment and ecology as well as the geological characteristics being significant variables of water sensitivity.

Case Study 02: Qanat System, Iran

While tourism may be of contemporary economic benefit, the management of the natural landscapes has also historically benefited the local economies. The *qanat* water system used in the semi-arid regions of Iran is a classic example of this as unravelled by several research articles (Jomehpour, 2009; Crook, Tripathi and Jones, 2015). Beaumont (1971) as well as Joji, Gayen and Saha (2021) show how it supports agriculture and farming practices in the semi-arid regions of Iran. The system uses tunnels and gravity to bring groundwater through hilly landscapes and over long distances to agricultural areas. They point out that tunnels are carved into alluvial soil to achieve this. Adding to this, Bensi (2020) shows that access to water through *qanats* could also determine the spatial landscape of the settlement and its social structure, often bringing the community together for its management. This is also supported by Jomehpour (2009) as well as Raie, Khakzand and Motemasek (2024). Bensi (2020) also views the *qanat* system as a technological advancement and argues that the understanding of the system could progress a deeper knowledge society, culture and economy of the region.

Indeed, this case study amply illustrates that natural landscapes that enable articulated interventions can facilitate water sensitivity of a region. They support agriculture and farming practices while determining the spatial landscape of the settlement and its social structure. As said, they bring the communities together for their management.

Case Study 03: Bhuj, India

In the hot arid desert climate of Bhuj in India, Van der Meulen et al. (2023) trace the influence of the hydro-ecology of the city, history, natural disasters, traditional knowledge and planning practices on water sensitivity. The origins of Bhuj as a 16th century fortified city and the legacy of its kings, who had a deep knowledge and reverence of the local hydrology, has had a sustaining effect to the extent that the communities still celebrate the rising water level of the nearby lake. Van der Meulen et al. (2023) identify that a combination of techniques such as rainwater harvesting, redirecting and connecting water from the nearby watersheds, the construction of canals, and a dam and *qanat* system have been used to ensure sufficient water in the Hamirsar Lake, the city has been dependent on.

Indeed, these strategies have been essential in the desert climate with marshy land that has been periodically affected by coastal salination. These systems have been however, changed by the then ruling British who have imposed their own systems following earthquakes that have altered the flow of water. This degrading legacy of colonial water systems have profoundly affected the choices and attitudes of the government authorities who have managed the water systems in Bhuj after India gained independence from the British.

It is to be noted that the focus has shifted from the hydro-systems of the city to land, economy and much later infrastructure, with the major changes to the hydro-systems being responses to post natural disasters such as floods and earthquakes. According to Van der Meulen *et al.* (2023), while the infrastructural adaptations of the redevelopment aim to improve the supply and drainage of water, none of these changes have considered the ecological effects or the use of traditional knowledge systems.

Thus, this case study amply demonstrates that there is a significant influence of the hydro-ecology of a place, history, traditional knowledge and planning practices on water sensitivity.

Case Study 04: The Dutch Water System

Loen's (2020) investigation of the Dutch water supply system stands as a testament to those cities that face over-exploitation of their hydro-systems. Like Coyne et al. (2020) and Van der Meulen et al. (2023), she too traces the historical role of context variables, more specifically the dependence of industries on water technologies, infrastructure and the transformation of cities spatially and ecologically through public-private partnerships. While geographically varying cities had diverse strategies of water supply, they historically relied on groundwater, surface water such as rivers, canals, brooks or rainwater harvesting. Loen (2020) also identifies that it was the growing demand of industries, residents, agriculture and the subsequent water pollution and stagnation of water, that have resulted in varying attempts to provide clean water across cities and ultimately the construction of centralised piped water supply systems in the 19th century. These attempts have changed the urban landscape of cities, such as the introduction of sluices and mills in Amsterdam or public wells that stored rainwater or groundwater, found in both urban and rural areas. The wells have become important spatially, as they serve as the landmarks and points of communal contacts. Large underground cisterns where rainwater has been stored have also been constructed to combat the demand for clean water and have been provided underneath some commercial or industrial establishments, public buildings and public spaces.

This case study clearly shows the complexity of demands of industry on water and how over exploitation can affect the urban landscape and the very supply of natural clean water. It also demonstrate various attempts and technologies developed to bring back the availability of clean water for modern civilizations.

Case Study 05: Kozhikode, India

Van der Meulen, Bacchin and van Dorst (2023) discuss the contribution of hydro-cultural practices to water sensitivity in the city of Kozhikode, India. They find that despite the harsh transformation of the natural landscape by the British during the colonial rule, places of

cultural and religious significance such as sacred groves and ponds play a role in ecological preservation and groundwater recharge. The authors have studied the Connolly Canal in Kozhikode and have found that this piece of colonial infrastructure dissects wetlands, causing harm to the local ecology by introducing weeds and wastewater from the nearby residences and commercial establishments. However, redundant spaces along the canal have become meeting places and have been appropriated for informal activities. Van der Meulen, Bacchin and van Dorst (2023) have also found that timber industries are reliant on the water in the canal. Although these harmful effects on water sensitivity exist, they have still found the city to have clusters of forests or groves of ritual and religious significance. These protected areas were found to recharge groundwater during the monsoon and the prevention of groundwater salinity. Similarly, temple ponds and ponds outside the temple premises are used for bathing and have become important landmarks, meeting places and recreational spaces for the residents. They too play a positive role in groundwater recharge and water sensitivity.

This case study demonstrates that the clusters of forests or groves of ritual and religious significance could immensely recharge groundwater particularly in such cultures where such amenities exist.

Case Study 06: Baghdad, Iraq

Hasan and Ghafoor (2023) apply water sensitive strategies to the city of Baghdad, located along the Tigris River to counter the degradation of its economic, environmental and spatial context. They study the relationship between the city and the river and identify the causes of the degradation to rising economic costs, the fragmented urban fabric, isolation from and lack of access to the riverfront, resulting in the non-optimal use of technologies and infrastructure. Aligning with the principles of water-sensitive urban design (Wong, 2006), they suggest an integrative approach to water sensitivity with authorities from varying disciplines integrating strategies and solutions at multiple scales. They also suggest recycling of water and the linking of spatial networks with the river, where activities for all ages are provided to prevent disuse of public space by the river.

This case study demonstrates that applying water sensitive strategies and water-sensitive urban design could rejuvenate water supplies.

Case Study 07: El Aouana, Algeria

Grimes, Bouchair and Tebbouche (2017) identify the unregulated effects of tourism in causing harm to biodiversity through the generation of polluting and untreated wastewater in the coastal city of El-Aouana, Algeria. While the positive economic impacts of tourism are acknowledged, their study suggests that practices adopted by the tourism industry need to be addressed first before any sustainable change can be brought about. Issues such as dumping of solid waste from hotels, disposal of untreated wastewater, unregulated buildings and the overconsumption of natural resources have resulted in coastal erosion, loss of wetlands, deforestation and degradation of water quality.

This case study shows the negative impact of tourism upon water in places. It also shows that mitigating strategies need to be put in place when industries begin to pollute the water supplies.

Case Study 08: Varanasi, India

Bansal, Bansal and Sen (2020) illustrate the impact of ecology, urban spatial structure and visual connection on the significance of hydro-infrastructure in the historic city of Varanasi located along the river Ganga. Along with the above authors, Bansal, Jagadisan and Sen (2022) also document two types of traditional hydro-infrastructure found in Varanasi i.e. *kunds* and *ghats*. Both structures have ecological, religious, and social significance. While the *ghats* form a stepped linkage between the river and the historic settlement, *kunds* are stepped tanks used for religious and domestic purposes. *Kunds* would welcome flood waters from the nearby Ganga River, which is considered sacred and hence have been used during the rituals. However,

both sets of authors find that due to colonial influence and uncontrolled development, the religious identity of the *kunds* is changing, thus representing a disconnect from ritual and hydro-cultural practices. However, as Bansal, Bansal and Sen (2020) discuss, *kunds* still maintain social importance and have now become recreational areas. Some *kunds* are more popular, while others have reduced importance due to low visibility when analysed by space syntax (Bansal, Bansal and Sen, 2020). Comparatively, the popularity and increased social activity at the ghat are ameliorated by increased physical and visual integration and also its ecological significance. Therefore, one type of hydro-infrastructure gains more importance than the other because of urban spatial connectivity and access.

This case study reveals that there is a significant impact of ecology, urban spatial structure and visual connection on hydro-infrastructure and water sensitivity in places, which could then be also transformed by other activities.

Case Study 09: Georges River Catchment, Australia

Coyne et al. (2020) use archival documents including maps, newspaper articles and journals to trace the historical influence of ecology, society, culture, politics and governance on water sensitivity in the Georges River catchment in Australia. Unlike Hasan and Ghafoor's (2023) strategies for Baghdad, Iraq, they move away from Wong's (2006) principles of water-sensitive urban design and rather further the concept by considering the role of history and culture when assessing water sensitivity. Like Bansal, Bansal and Sen (2020), they too find that the identity of an area's hydro-systems can change and is governed by the society's relationship with the Georges River. This relationship is in turn influenced by natural disasters, cleanliness of the river, infrastructural development and the level of ownership and control that the community could exercise over the river. The river which was initially identified as wild and dangerous has been transformed into a recreational and democratic place.

This case study clearly demonstrates two things: first, the fact that ecology, society, culture, politics and governance influence water sensitivity. Second, the identity of the hydro-systems of an area can change due to its presence and is indeed governed by the relationship the community has with the water source.

Case Study 10: Udaipur, India

Samant (2007) finds a close relationship between surface water bodies and the urban and architectural patterns that take advantage of the mediating micro-climate, created by the nearby lake in the hot-arid climate in Udaipur, India. Lake Pichola in Udaipur even influences the urban skyline, bringing coherence and harmony to the city, with large scale administrative buildings or important temples, palaces or memorial pavilions being located adjacent to the lake and continuous *ghats* binding the urban scene as in Varanasi (Bansal, Bansal and Sen, 2020). The *ghats* continue to be used by residents for domestic purposes. Samant (2007) finds that the pavilions built within or adjacent to the lake although previously hosted religious festivals or cultural performances have since become the main attractors of tourists with many palaces being converted to hotels. Although the streets have once been laid according to the natural topography to drain stormwater into the lake, the recent lack of suitable hydro-infrastructure has resulted in open drains and pollution.

This case study reveals that there is a close relationship between surface water bodies and the urban and architectural patterns. Indeed, they may influence the visual appearance of the place, and could lead to the production of attractive structures by the people.

Case Study 11: Melukote, India

Ramineni and Bharadwaj's (2021), investigation of Melukote, India finds that the town's traditional water system is both historically and presently greatly influenced by the region's geology, topography, hydrology, environment and the society's culture, religion and economic practices. The authors find that a system of interconnected tanks that are fed by both a perennial source and the overflow of rainwater, physically results in a combination of ponds,

temple tanks, wells and sacred water bodies called *tirthas* that make up the town's waterscape. Societal and spatial segregation exist within the town and so too in the access to hydro-infrastructure with each community being dependent on their own water tanks (Ramineni and Bharadwaj, 2021). Therefore, access to water also determines the spatial distribution of communities and the societal structure, a phenomenon seen with the *Qanat* system in Iran (Bensi, 2020). Some tanks use a traditional filtration system and harvest rainwater to support the domestic and economic activities of each community.

While there are numerous tanks in the area, each tank has its purpose. While some tanks are used purely for rituals, others may be used during festivals or for domestic purposes. In accordance with Samant's (2007) findings, Ramineni and Bharadwaj (2021) also find that some of the tanks in the town are facing degradation.

This case study shows clearly that geology, topography, hydrology, environment and the culture of a community, religion and economic practices influence access to water and also determines the spatial distribution of the community.

Case Study 12: Hiti System, Nepal

Unlike the segregated tanks of Melukote (Ramineni and Bharadwaj, 2021), Bharne (2020) finds that the Hiti water system in Nepal served multiple purposes and could be accessed by all. The construction of the system requires a keen knowledge of the region's hydrology, soil, geology and topography. Bharne (2020) discusses that although the outer appearance of the Hiti system at a location may be a spout in a vertical wall surrounded by ponds, wells and shrines, there exists a larger system of interconnected pipelines, canals, streams and groundwater that are partially hidden. The places where the outflowing spouts are located are at once sacred public shrines, sources of domestic water and communal gathering spaces. The spouts are usually made of stone and are decorative, with some that are in public places and even gilded. The construction of the system has often been sponsored by the rulers and the maintenance and management, sustained by families in the community.

This case study clearly demonstrates that the construction of any systems to harness water requires a thorough knowledge of the hydrology, soil, geology and topography of the region.

Case Study 13: Govardhan, India

Sharma and Ji (2024) consider the ecological and cultural context of Govardhan, India when assessing its traditional water systems. As in Melukote (Ramineni and Bharadwaj, 2021) and the Hiti system of Nepal (Bharne, 2020), the topography of the region, and the town's surrounding hills result in the natural flow and occurrences of water bodies in the form of ponds, lakes and wetlands. The traditional system of *kunds* is interconnected as in Melukote (Ramineni and Bharadwaj, 2021) and is influenced the ecology, architecture, culture and society of the historic area. In the semi-arid climate of Govardhan, Sharma and Ji (2024) find that the *kunds* are linked by channels which carry overflowing rainwater and can be characterised as two types based on the surrounding topography and nature of runoff. The first type found near the hill is fed by water from the catchment area, is multifunctional i.e. used for both religious and domestic purposes and recharges the groundwater. The second type is located away from the hill and is fed by the canals and streams that form during the rain. *Kunds* may also differ architecturally depending on the purpose of use.

This case study clearly shows that the topography of a region, particularly the surrounding hills if available could provide a natural flow and water bodies in the form of ponds, lakes and wetlands.

Case Study 14: Tomar, Portugal

Davis et al. (2023) discuss the disastrous effects of flooding from the Nabao River on the economy and the urban and built environment in the historic core of Tomar, Portugal. The authors have found that those buildings located near the river and along the central spine of the

city have been more vulnerable to flooding. Additionally, non-residential buildings, buildings with openings on the ground floor, buildings with higher heritage values, a building's concavity and the type of door and window frames also increase the risk of damage due to floods. However, Davis et al. (2023) also suggest that mitigation strategies where structural retrofitting of buildings such as replastering, decreasing the number of openings on the ground, changing to metal door and window frames, installing flood gates etc. can reduce the economic damage due to floods.

This case study clearly demonstrates how natural disasters such as floods can affect areas and as well buildings and how they need to be fashioned to withstand such challenges.

Case Study 15: Yellow River Basin, China

Yu, Lei and Dihua (2008) find that settler's sensitivity to water has influenced the urban form of historic cities in the Yellow River Basin of China, with the cities adapting according to flooding patterns of the river. Three main strategies to combat flooding i.e. living on high land, circumvallation with circumvallating levees and retention ponds have given way to three typologies of urban form which the authors name as 'water-within-city', 'city-in-water' and 'Ying-yang-city' or 'dead and living city'. In contrast to the interconnected flowing systems seen in Melukote (Ramineni and Bharadwaj, 2021), Govardhan (Sharma and Ji, 2024), the Qanat system (Bensi, 2020) or the Hiti system (Bharne, 2020), the water bodies here are separate, forming unique waterscapes of ponds and lakes located within or outside the cities. The authors define those cities that have water bodies, namely ponds or lakes within the city as the 'water-within-city' type. Those cities with water between the circumvallating levees and the inner-city walls are defined as 'city-in-water'. The circumvallating levees are circular and form a protective layer against floods around the square city. In cases where such defensive structures are not able to withhold the flood waters, the city may get submerged, and a new city later built adjacently, forming the 'Ying-yang city' or the 'dead and living city'.

This case study clearly demonstrates how people's sensitivity to water influences the urban form of historic cities.

As can be seen, the fifteen case studies have divulged numerous contextual aspects that affect water sensitivity of places. They show that understanding water sensitivity and providing clean water for communities either rural or urban vernacular or otherwise, require a complex analysis of the variables involved.

With these case studies, a number of variables could be identified as follows.

- Climate
- Soil
- Topography
- Geology
- Hydrology
- Culture
- Religion
- Society
- Technology
- Infrastructure
- Tourism
- Agriculture
- Economy
- Spatial Patterns
- Architecture
- Politics
- Governance

Table 2: Mapping of Context Variables that Affect Water Sensitivity Across Historic Urban Areas
Source: Jacob, 2024

Source		Context Variables																
		Climate	**Soil**	**Topography**	**Geology**	**Hydrology**	**Culture**	**Religion**	**Society**	**Technology**	**Infrastructure**	**Tourism**	**Agriculture**	**Economy**	**Spatial Patterns**	**Architecture**	**Politics**	**Governance**
Hang, 2015	**Cambodia**	x	x		x	x	x	x	x	x	x	x	x	x	x			x
Bensi, 2020	**Qanat System,**	x	x	x	x	x	x		x	x			x	x	x			
Van der Meulen et al, 2023	**Bhuj, India**	x				x	x		x		x			x	x			x
Loen, 2020	**Dutch System**		x	x	x	x			x	x	x		x	x	x			
Van der Meulen, Bacchin and van Dorst, 2023	**Kozhikode, India**					x	x	x	x									
Hasan and Ghafoor, 2023	**Bhagdad, Iraq**					x			x	x								
Grimes, Bouchair and Tebbouche,	**El Aouana, Algeria**					x						x		x				
Bansal, Bansal and Sen, 2020 & Bansal, Jagadisan and Sen, 2022	**Varanasi, India**					x	x	x	x		x				x			

	Coyne et al, 2020	Samant, 2007	Ramineni and Bharadwaj, 2021	Bharne, 2020	Sharma and Ji, 2024	Davis et al, 2023	Yu, Lei and Dihua, 2012
	Georges River catchment,	Udaipur, India	Melukote, India	Hiti System,	Govardhan, India	Tomar, Portugal	Yellow River Basin, China
	x	x			x		
				x	x		
	x	x		x	x	x	x
	x			x	x		x
	x	x	x	x	x	x	x
				x	x		
	x	x	x	x	x	x	
	x	x	x	x	x	x	
	x	x	x			x	x
			x		x		
	x		x			x	
	x	x	x		x	x	x
				x	x		
	x			x			
	x			x			

Research Question 2: What are the facilitators and challenges of water sensitivity in historic urban areas?

While the cases presented in the literature are by no means comprehensive in the evaluation of all possible context variables affecting water sensitivity, it is still possible to evaluate and synthesise the main facilitators and challenges to water sensitivity in historic urban areas. While certain challenges and facilitators are common across cities, the distinction between the two is not always evident. As we shall discuss below, what is perceived as a challenge in some historic areas can become a facilitator in others, giving a dual status for some indicators.

Facilitators

Public-Private Partnership and Traditional Water Systems

The Dutch water system serves as a unique example of a successful public-private partnership for the management of water. Loen (2020) finds that this kind of partnership can

facilitate water sensitivity and positive hydro-practices. This approach could serve as a solution to the challenge of mitigating cost, as identified in Baghdad, Iraq (Hasan and Ghafoor, 2023).

Traditional knowledge and hydro-practices can deeply affect the conservation and management of water in a community (Agarwal, 1997; Murthy, Srikonda and Kasinath, 2022; Van der Meulen, Van Dorst and Kuzniecow Bacchin, 2023) and thereby improve water sensitivity. Sharma and Ji (2024) even find links between the traditional systems and sustainable developmental goals (SDGs) and suggest that the conservation of the traditional water systems could help achieve SDGs. Van der Meulen et al. (2023) suggest that the ecological and environmental determinants to water supply can be overcome by traditional knowledge. While systems of ownership could be complex (Bensi, 2020) or straightforward, segregated (Ramineni and Bharadwaj, 2021) or public (Bharne, 2020), there is no doubt that the communities that depended on these hydro-systems historically, took ownership and ensured its management and preservation for their survival. However, this is challenged by two concerns in the contemporary historic urban area. The first is the breaking of communal bonds and the other, the dependence on state provided water systems.

Challenges and Facilitators with Dual Status

Communal Bonds and Community Participation

It is identified that maintaining hydro-systems together as a community can develop strong bonds. Although the loss of communal bonds with the transformation of historic urban areas is challenging to water sensitivity, the continuing tradition of cultural practices indicates that communities still come together to participate in festivals that celebrate water or perform rituals that include water. This trend is found in Nepal, Varanasi, Melukote and Bhuj (Bharne, 2020; Bansal, Bansal and Sen, 2020; Ramineni and Bharadwaj, 2021; Bansal, Jagadisan and Sen, 2022; Van der Meulen et al., 2023). This aspect could be used as a major facilitator to overcome the challenge and make inroads towards water sensitivity through participatory water management and planning. The inclusion of multiple stakeholders during the planning process has been shown to result in the successful regeneration of historic areas (Boyacioglu, Gocer and Karahan, 2023; Tanrıkul, 2023). Coyne et al. (2020) find that participatory approaches transform an area and its citizen's relationship with their hydro-systems. They find that the identity of Georges River has shifted from a 'menacing' river to a 'stakeholder' river by involving community participation and the inclusion of recreational activities. People have developed a new respect for their area's hydro-systems and perceive them more positively. Coyne et al. (2020) even claim that people develop an emotional bond with their waterscapes, thereby benefitting the rivers ecologically and improving water sensitivity.

Natural Disasters as Facilitators and Challenges

Research reveals that natural disasters can become both a challenge and a facilitator of water sensitivity. Although earthquakes challenge Bhuj, and Tomar has a history of flooding, post-disaster redevelopment has ignored the role of ecology and hydrology in Bhuj (Van der Meulen *et al.*, 2023) and only recently has an assessment of flood vulnerability and risk on built heritage been conducted in Tomar (Davis *et al.*, 2023). In this regard, the evolving and diverse typologies of historic cities in China's Yellow River Basin, speaks of the struggling nature of the resident's relationship with water. Even in the Georges River Catchment of Australia, people's perception of their waterscape is influenced by river flooding (Coyne *et al.*, 2020). However, natural disasters do not always have to be a challenge, as proved in the Angkor region of Cambodia, where the need to mitigate and manage flooding has become a facilitator for the revival of its ancient hydraulic system.

Challenges

Uncontrolled Growth and Unregulated Tourism

Nearly all the literature reviewed, show that uncontrolled growth is a challenge to water sensitivity (Samant, 2007; Bansal, Bansal and Sen, 2020; Bansal, Jagadisan and Sen, 2022;

Bensi, 2020; Bharne, 2020; Hasan and Ghafoor, 2023; Van der Meulen, Bacchin and Van Dorst, 2023; Van der Meulen et al., 2023; Sharma and Ji, 2024). Historic urban areas face developmental pressures in the contemporary era, with changing ways of living and spatial growth resulting in the informal appropriation of space, lack of suitable planning practices or contrasting planning practices being forced upon the area. In addition to the challenge of supplying daily water needs (Hang, 2015), the need to support tourism activities can prove challenging. Samant (2007), Hang (2015) and Grimes, Bouchair and Tebbouche (2017), find that unregulated tourism can have detrimental effects on the hydro-systems and the environment that supports them.

Non-Integrative Planning and Conservation Approaches, Limited Data and Focus, Dependence on State Provided Water

The process of planning and conservation in historic areas are further challenged by the non-integrative planning practices (Bensi, 2020; Hasan and Ghafoor, 2023; Van der Meulen et al., 2023) where government agencies rarely share data and information, but rather function within silos and as separate entities. Additionally, the limited availability of data can prove challenging to make informed planning and management decisions (Van der Meulen *et al.*, 2023).

Water sensitivity is also challenged by conservation and planning practices that do not focus on water and ecology or consider traditional systems, but rather focus primarily on land, economy and built heritage (Bansal, Bansal and Sen, 2020; Bansal, Jagadisan and Sen, 2022; Van der Meulen *et al.*, 2023; Sharma and Ji, 2024). In Govardhan, this approach has resulted in the degradation of the ecological, cultural and social context and depletion of water resources (Sharma and Ji, 2024). In fact, as Bansal, Bansal and Sen (2020), Bansal, Jagadisan and Sen (2022), Van der Meulen, Bacchin and Van Dorst (2023), Van der Meulen et al. (2023) recognise, the ignorance of traditional water systems continues the legacy of colonial planning practices.

Transformation of historic cities is also the transformation of systems of water supply. A new dependence on state provided water means that traditional systems become redundant (Loen, 2020; Van der Meulen et al., 2023). In many cities, water has been managed through communal co-operation, a system disrupted by the provision of a centralised system of water supply and sewerage (Bensi, 2020; Loen, 2020).

To summarise, water sensitivity in historic urban areas is influenced by a diverse set of context variables ranging from climate, soil, topography, geology, hydrology, culture, religion, society, technology, infrastructure, tourism, agriculture, economy, spatial patterns, architecture, politics and governance. While the consideration of the inter-connectedness between the variables can facilitate water sensitivity, challenges do exist. The most common challenge is the forced transformation of historic areas and the resulting uncontrolled growth. A consequence of this is unregulated tourism which can be detrimental to ecology, built environment and hydro-systems. The challenges to water sensitivity are perpetuated by fragmented planning and conservation frameworks, lack of ecological focus, insufficient data, and the dependence on state provided hydro-systems.

More positively, a beacon of hope lies in the strengthening of the presently disintegrating communal bonds and the application of participatory planning approaches to transform water sensitivity. Areas that are historically challenged by natural disasters can use these occurrences to their advantage, by facilitating a more sensitive approach to the planning and management of hydro-systems. Undenibaly, preservation of traditional water systems and partnerships between public and private organisations can further facilitate water sensitivity in historic urban areas.

Development of a Theoretical Framework

From the review of literature, it is evident that context plays an important role in a historic region's sensitivity to water. However, each article includes several, but differing

context variables (Table 2) for the understanding of water sensitivity in the historic city, revealing a fragmented picture and making it difficult to compare across cities. Therefore, in order to generate an exhaustive list of context variables, we combine multiple theories and concepts related to historic cities and water urbanism, which include the historic urban landscape approach or HUL (UNESCO, 2011), water sensitive urban design or WSUD (Wong, 2006; Abbott, 2013; Van der Meulen, Van Dorst and Kuzniecow Bacchin, 2023) and culturally inclusive water urban design or CIWUD (Coyne *et al.*, 2020). These theories are included, as the role of context is central in each (Fig. 2). While each can be discussed as standalone frameworks, we shall demonstrate that the integrative approach that all three concepts follow and the parallels and overlaps between the context variables that govern them (Fig. 3), can progress a critical analysis of water sensitivity in historic settlements. We shall further group the context variables into categories (Fig. 4) for easier applicability to historic settlements.

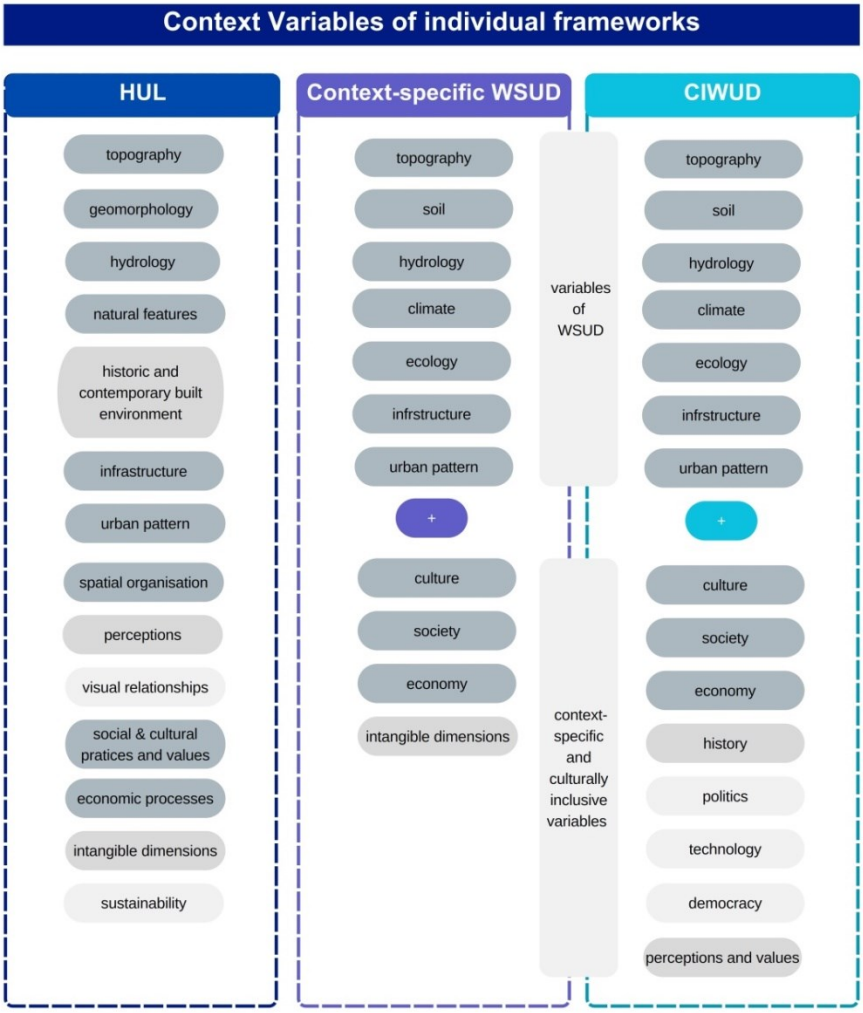

Fig. 2: Context variables of HUL, WSUD, context-specific WSUD and CIWUD
Source: First author. Based on Wong (2006), UNESCO (2011), Coyne et al. (2020), van der Meulen, van Dorst and Kuzniecow Bacchin (2023)

The contemporary historic city can be understood and analysed through the lens of the historic urban landscape approach; a concept developed by UNESCO. The organisation's recommendation (UNESCO, 2011) considers the historic city as a layered entity unconstrained by time or space, extending beyond the immediate to include the broader context's natural, man-made and built environment and is inclusive of contemporary and historic processes and practices. This panoptic conceptualisation dissuades the objectification of heritage as artefact

(Bharne, 2020) and allows for a more comprehensive "identification, assessment, conservation and management" of the historic area (UNESCO, 2011:3). The setting's ecology including topography, geomorphology, hydrology and biodiversity plays a significant role in this assessment. The relationship between these elements of the natural environment and those of the built environment such as infrastructure, land use, spatial organisation, are mediated by social, economic and cultural values and practices and intangible aspects of heritage that have developed through time and continue to shape and in turn be shaped by the city and its context (Fig. 2).

Historically, a settlement's relationship with water could affect its safety, security and survival. Traditional knowledge of water has been used to avert natural disasters such as flood or drought, sustain livelihoods through continuous access and storage of water and has even been used to alter local conditions for the creation of new settlements (Willems and Schaik, 2015). In the light of the value of water as heritage, its use and conservation in the historic urban landscape has gained new interest amidst social, political and cultural transitions in settlements (Bharne, 2020) and thereby the need to assess water sensitivity for its successful management.

Considering this need, the concept of water sensitive urban design (WSUD) becomes a useful framework. While WSUD has some overlaps with concepts such as sponge cities, Nature-based solutions, green-blue infrastructure, and its integrative approach to urban water cycle management lies at the heart of its predominant applicability in the historic urban landscape. The WSUD approach as described by Wong (2006) calls for integration at three intersections, to implement objectives of water sensitivity:

i) The first is the integrative management of three types of urban water systems i.e. potable water, wastewater and stormwater,

ii) ii) integration across spatial and geographic scales, i.e. regional, precinct, site and building &

iii) iii) integration across disciplines, industries and institutions- arts, social and physical sciences, engineering, architecture, urban studies and the design of policies and performance indicative indices (Wong, 2006). The climate, topography, ecology, soil, urban patterns and infrastructure of the context are important considerations when implementing WSUD (Fig. 2).

Despite the larger noble goals set out by WSUD, the concept, having been developed in the Australian context, is still critiqued for its lack of sensitivity to all dimensions of the context and hence its transferability to other contexts is questioned (Coyne et al., 2020; van der Meulen, van Dorst and Kuzniecow Bacchin, 2023). The concerns related to the specifics of the context includes, the existing use of traditional knowledge and systems of water management that are rooted in the local culture, varying governance structures, non-availability or inaccessibility of data, informal urban patterns, varying socio-economic structures and intangible aspects of society, economy and culture (Coyne et al., 2020; Rashetnia et al., 2022; Kumar et al., 2023; van der Meulen, van Dorst and Kuzniecow Bacchin, 2023). The consideration of these context variables along with the variables of WSUD discussed earlier, could facilitate the implementation of context-specific WSUD (Fig. 2). However, this consideration also implies that the scope and path to water sensitivity in the city is directed by the prevailing context and would vary from city to city (Wong, Rogers and Brown, 2020; van der Meulen, van Dorst and Kuzniecow Bacchin, 2023).

Amongst the need for contextually driven responses to water urbanism is the framework of culturally inclusive water urban design or CIWUD (Coyne et al., 2020). This theoretical framework is an outcome of the historical evaluation of a city's waterscape. Like WSUD, water sensitivity is the main aim of CIWUD. However, the hydro-social and hydro-cultural components along with the values and the perceptions of the community also have a strong significance. The need to understand cultural practices and knowledge concerning water is at the forefront of its transcendence to multiple contexts. This framework, therefore, rejects

a purely technocratic approach and insists on the consideration of the context's social, political, economic, cultural variables for successfully achieving water sensitivity (Fig.2).

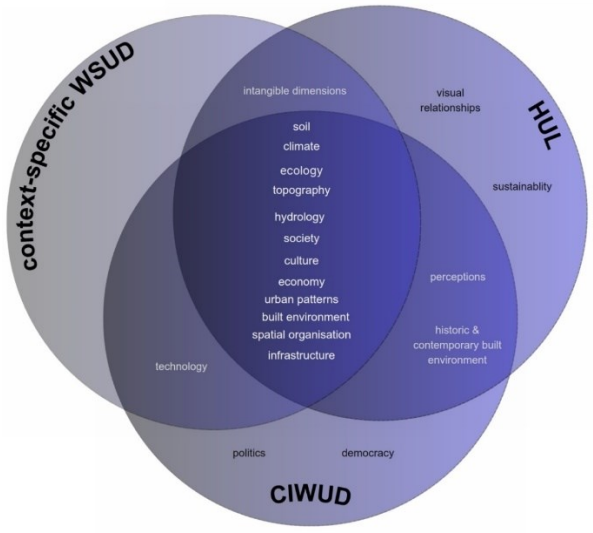

Fig. 3: Overlapping variables between HUL, context-specific WSUD & CIWUD; Context variables for assessing water sensitivity in the historic urban landscape
Source: Jacob (2024) Based on Wong (2006), UNESCO (2011), Coyne et al. (2020). van der Meulen, van Dorst and Kuzniecow Bacchin (2023)

The overlapping context variables that have been evaluated among the three frameworks of HUL, WSUD, context-specific WSUD and CIWUD are soil, climate, ecology, topography, hydrology, society, culture, economy, urban patterns, built environment, spatial organisation and infrastructure (Fig. 3). In addition, the intangible dimensions are included as they are a part of assessing society, culture, economy and heritage (Nhu, Nguyen and Chi, 2024). These variables are further grouped into categories of ecology and environment, spatial context, economy, society and culture and finally infrastructure (Fig.4) for a more comprehensive assessment of water sensitivity in the HUL.

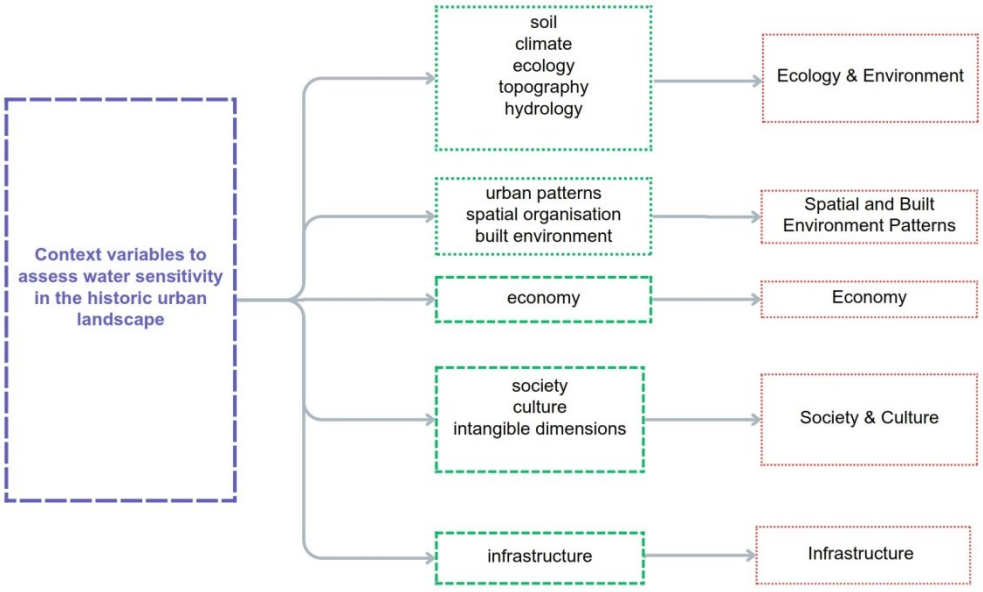

Fig. 4: Categorisation of context variables for assessing water sensitivity in the Historic Urban Landscapes
Source: Jacob, 2024

Conclusions & Recommendations

While this review has addressed the need for the application of context variables when assessing water sensitivity in historic urban areas, it is not without its limitations. Only English language articles are included. The inclusion of records published in other languages may have generated a more exhaustive list of variables. We have tried to remedy this by the synthesis of the theoretical framework. although a manual search was also conducted to include relevant articles, it is possible that many records that are not available in the identified electronic databases may not have been included.

The first insight from the research is that context plays a significant role in the assessment of water sensitivity in the historic urban areas. The synthesis of data to answer research the question 1, reveals 17 individual context variables that influence water sensitivity in the historic areas (Table 2). These variables are climate, soil, topography, geology, hydrology, culture, religion, society, technology, infrastructure, tourism, agriculture, economy, spatial patterns, architecture, politics and governance. However, the occurrences of these variables in the cases evaluated are unequal, signifying a need for a more extensive assessment of water sensitivity and a limitation of the existing literature. the frequency of a variable's occurrence in a historic area also does not determine its relative importance. Rather, while each variable has significance individually, it is through the interplay between the variables that water sensitivity is truly achieved.

This means that each historic area must be evaluated as a unique case when assessing water sensitivity and therefore a comprehensive framework (Fig. 4) of context variables is developed using the theories and concepts of HUL, WSUD, context-specific WSUD and CIWUD. The application of the theoretical framework developed in this paper can uncover findings that are transferrable to other contexts and reveal patterns of water sensitivity that are comparable across varying historic urban landscapes. It would therefore be worthwhile for future researchers to conduct comparative case studies exploring trends in water sensitivity or water-sensitive urban design in the HUL using this theoretical framework.

From the findings and discussion of the research question 2, it can be concluded that many historic cities have been traditionally water sensitive. However, because of the pressures of development, uncontrolled growth, unregulated tourism, changing dependencies of access to hydro-infrastructures and the degradation of communal bonds and traditional knowledge, water sensitivity has become a growing concern in the HUL. It therefore becomes important to assess the present state of water sensitivity in a HUL using the comprehensive theoretical framework developed, before any interventions can be made.

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