Shifting the Paradigm Toward Integrated Management of Urban River in a University Campus

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Abstract

Urbanization has maximized the land use, causing natural rivers being concretized into urban rivers to accelerate excessive runoff as well as stabilize soil structure, which in turn expose to water pollution. Hence, urban river water is not seen as a valuable water resource. Alur Ilmu is an urban river in Universiti Kebangsaan Malaysia (UKM) that has been exposed to various sources of pollution in which existing management may not be effective in revitalizing and conserving the urban river. In this chapter, an integrated management framework has been proposed, consisting of structural and nonstructural approaches in revitalizing and conserving the water resource. Physical and biological treatments have been employed in structural approach to remove pollution at source, and this approach has successfully improved the water quality from Class II to Class III in less than a year, whereas initiatives in enhancing knowledge, attitude and practice as well as strengthening the participation of campus stakeholders have been employed in nonstructural approach. Combining structural and nonstructural approaches not only develops on-site treatment for the revitalization of the urban river, but also promotes social learning for the conservation of urban river. This integrated management framework is expected to shift the paradigm for the restoration and conservation of urban river to attain sustainability of water resource for the benefits of economic growth, social well-being and environmental protection.

Keywords

Urban river • Integrated management • Structural approach • Nonstructural approach • Water resource

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1 Urban River

Urbanization increases the population working and living in urban areas as well as their socioeconomic activities. Hence, more areas are being developed to accommodate the needs of the population, such as roads, residential areas, public utilities, including rivers. Beginning in the twentieth century, urban population have increased more than 100% worldwide and reached 200% in less developed countries (Gupta 1984). In 2001, the world's largest city, New York, has a population of about eight million people; additionally, 17 cities have eight million inhabitants and Shanghai has more than 14 million inhabitants (United Nations 2004). According to the World Bank (2015), Malaysia is among the East Asian countries with fast growing development and population in urban areas; additionally, Malaysia was the fourth largest country in infrastructure development in the East Asia in 2010 with area development from 3900 to 4600 km^2 from 2000 to 2010.

As expected, urbanization is an inevitable process due to the development of infrastructure and socioeconomic activities to accommodate growing populations. Therefore, this effect has caused demands in making significant changes to the river system either directly or indirectly (Eyles 1997; Douglas 2005). These changes are permanent and may continue in the future; hence, it is feared that the water resource of the river in the urban area will be vulnerable to infrastructure development and socioeconomic activities along the river which could contribute to the pollution of the river, considering urbanization will have a significant impact on water drainage in terms of physical characteristics of river, socioeconomic functions and activities undertaken by stakeholders around the river.

Urban river is defined as a channel of water that has been concretized from either natural river or man-made river, located within urban area for the purposes of irrigation, water runoff as well as socioeconomic activities. Initially, the urbanization process set the conventional management

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paradigm of urban river for channeling excessive stormwater from upstream to downstream to avoid flood (Reese 2001; Zakaria et al. 2004; Mokthar et al. 2005). Due to the lack of environmental protection awareness, people tended to discharge all liquids including wastewater into the urban river, and this has led to pollution of water resources and caused detrimental effects to human and environment health. The focus of urbanization was given to economic development, and less emphasis was given to environmental protection because it was considered to be less cost-effective to the national economy (Thomas and Reese 2003); hence, it has resulted in poor management of urban river. The restoration and conservation of urban river within the post-development area are major challenges to conventional urban river management when attempting to radically shift the paradigm of urban river management to an alternative paradigm. In addition, efforts to conserve urban rivers within the post-development area require a high budget (Martin et al. 2007; ETP Annual Report 2012).

The restoration and conservation of urban rivers have gained the attention of developed and developing countries as rising demand from the public for better environmental health (EPA 2016), aesthetic appreciation and natural aesthetic gentrification, wishing to live in a healthy neighborhood, efficient and 'green' (Lim et al. 2013; Reese 2001) and improving the quality of life (Zakaria et al. 2004). In addition, the restoration and conservation efforts of urban rivers provide economic returns as well as potential as a source of local economic growth (ETP Annual Report 2012) and being a valuable water resource (Wong 2011; Lim and Lu 2016).

The evolution of urban river management in Malaysia is influenced by how the runoff and pollution control are determined based on the socioeconomic changes. It is undeniable that controlling the risks of flood for unusual heavy rain is the priority of the existing urban river management. This is due to the increase in the volume of running water as a result of intensive urbanization. However, the lack of consideration for pollution control and water quality will lead to chronic problems in the future. Hence, the balance of both functions in avoiding flood risk and controlling pollution is required in tandem with sustainable urban river management.

1.1 Features of Urban River Physical Landscape

Earth geomorphology is the physical state of the earth's surface, and it links to the urban geological structure and concrete water drainage to the surrounding area. It is influenced by runoff and discharge as well as human activities running at the riverside of the city (Toriman 2005). Factors affecting runoff and discharge are rainfall intensity, tree species in riparian areas, physical characteristics of river basins and land use in changing river structures (Wuriyati 2007). Physical features of the city's river and concrete water drainage are influenced by municipalities with paved surfaces. Due to the flow of urban rivers that are set in accordance with the norms set by humans, therefore the soil structure is more stable but it is prone to more runoff due to the surrounding paved surfaces (Nakamura et al. 2006) which carry pollutants into the river body (Din et al. 2012a, b) due to lack of canopy interception that allows water to infiltrate into the soil during rain events (Xiao et al. 1998). Due to surface pavement around the urban riverbank, it causes the lack of areas that can be used for aquatic and riparian habitats, therefore lack of flora and fauna species along the urban river and drainage (UKM 2013). These aforementioned factors result in changes of water flow patterns (hydrology), water quality of the river, exposure of urban river drainage system to runoff and land use from the surrounding areas that carry pollutants into the river body (Din 2012a, b). Thus, the functions and benefits of the urban rivers are still limited whereby it can only cater for irrigation purposes.

1.2 Functions of Urban River

The functions of rivers, urban rivers and concrete water drainages change according to respective purposes. Generally, urban rivers and concrete water drainages collect and channel runoff from the nearest water bodies, such as larger rivers, lakes, seas and dams (Mokthar et al. 2005; Department of Irrigation and Drainage Malaysia (DID) 2012; Chin 2006; Wohl and Merritts 2007; Speed et al. 2016) to avoid flooding. To date, most of the urban rivers and concrete water drainages maintain the same function and no other functions, such as recreation or as an alternative source of water, have been added. When the development of a city is the result of population growth, the function of urban rivers and the concrete water drainages also change and resemble a function like a natural river. Demands by the stakeholders within the city revolve around the gratification and appreciation of nature, the demand for safe, efficient and green areas (Reese 2001), improving the quality of life (Zakaria et al. 2004), demand for better environmental health (Environmental Protection Agency of Ireland 2011) and as a potential source of valuable resources that can give benefit directly and indirectly, such as harvesting runoff water and recharging underground water (Wong 2011, Lim and Lu 2016). Therefore, concrete water drainages, such as trenches or drains, are increasingly functioning and have a function and importance that are almost identical to the natural rivers. Therefore, the definition of concrete water drainage needs to be changed to urban river due to its increasing function.

1.3 Socioeconomic Activities of Stakeholders Around the Urban River

The human socioeconomic activities around urban rivers are dependent on urban river functions that are conceptualized by stakeholders. For example, Lim et al. (2013) found a socioeconomic change along the Cheonggyecheon River, South Korea, when it successfully conserved and preserved the river. Initially, the river was a concrete drainage under the highway. Due to the highway causing traffic congestion and air pollution to the nearby area, businesses in the area are experiencing difficulties due to the lack of visitors. But when the highway was demolished to conserve and preserve the water quality of the Cheonggyecheon River, the river was beautified, and the business in the area grew and became a tourist attraction for both locally and abroad. In this regard, the links between urban rivers and socioeconomic activities of stakeholders are very much related to each other.

1.4 Redefining Urban River

There are numerous studies related to the urban rivers (Douglas 1974; Douglas 1985; Wohl and Merritts 2007; Zakaria et al. 2004; United Nations 2018). However, the term 'water drainage' used by researchers is very loose whether the river, urban river and stormwater drainage or trench describing the same water drainage as having similar physical landscape features, functions, socioeconomic activities. Hence, the definition of urban river is still vague due to the existing definition inclining toward trench and drain systems (Gobster and Westphal 2004) or natural river (Wohl and Merritts 2007). Consequently, the definition of urban river is influenced by human perceptions and produces differences in function, water and environmental quality as well as social and economic development (Chin 2006; Gobster and Westphal 2004; Lim et al. 2013). The definition of an urban river is important as it determines whether the urban river should be conserved and preserved or otherwise (Gobster and Westphal 2004).

The definition of natural and modified rivers (by humans and natural events) is still debatable by researchers to date as the physical characteristics of the two types of rivers are almost identical (Wohl and Merritts 2007). This is because the effect of indirect modifications by the socioeconomic activities of the earlier civilization still preserves the nature of the river until to date and the effect of the river stabilization process also takes a very long time (Chin 2006; Wohl and Merritts 2007). However, concretization is a direct river modification that can be distinguished from natural river because of the different physical landscape features that do not have or maintain the characteristics expected for a natural river (Wohl and Merritts 2007).

Urbanization leads to the development of infrastructure and the vibrancy of economic activities in a given area leading to the construction of concretized rivers. The features seen from the stormwater drainage, trench, drain and urban river are almost identical. Its permanent construction works to channel runoff water rapidly to avoid flooding. However, many studies have shown that urban river is different from the drainage system in terms of function, physical landscape features and socioeconomic activities of the surrounding because humans receive many benefits from the urban river directly and indirectly other than channeling runoff water rapidly to avoid flooding.

As a result, urban river is defined as a river that has been concretized from either natural flow or man-made flow and it is located within urban area for the purpose of irrigation, water runoff as well as socioeconomic activities within the area. Therefore, water pollution resulted from urbanization has limited the functions and services of urban rivers in providing services for human and environmental purposes. In this regard, the sources and effects of urban river water pollution need to be identified to conserve and improve the functions of urban river.

2 Pollution and Pollution Control

In pursuing economic growth and urbanization, issues and problems related to the urban river environment are getting worse. Factors, such as aging of building and permanent infrastructure, rapid land clearing for infrastructure development and climate change, have put pressure on urban rivers, resulting in water quality deterioration (Keong 2006; Marsalek and Schreier 2009; University of British Columbia 2014). This is due to urban river being exposed to point-source and nonpoint-source pollutions.

Point-source pollutions are any sources of pollution that can be identified from which the pollutants are released, such as pipes, drains, boats or refineries (Hill 1997). The pollutants are produced by human activities, contributing to the deterioration of water quality of urban rivers and lakes (Thomas and Reese 2003). Nonpoint-source pollutions mean pollutions arising from soil runoff, precipitation, atmospheric deposition, drainage, seepage or hydrological changes. Nonpoint source pollutions, unlike pollutions from industrial and sewage treatment plants, where it comes from mixed sources. Nonpoint-source pollutions are caused by rain or runoff that move on the surface of the pavement and do not infiltrate into soil, but bring along pollutants which will eventually enter into lakes, rivers, wetlands, nearby coastal waters (Brezonik and Stadelmann 2002; Marsalek et al. 2008; United States Environmental Protection Agency 2018).

Water resources including urban rivers in Malaysia are exposed to point-source and nonpoint-source pollutions. Point-source pollution occurs in the urban river of Malaysia when the waste is released directly into the urban river. Domestic sources are usually derived from slaughterhouses, wet food shops, animal farms, household waste, cottage industry, domestic sewerage and agriculture. Malaysia has a tropical monsoon climate that is receiving hot and rain seasons only throughout the year. Due to the abundance of rainwater throughout the year, rivers including urban rivers in Malaysia face deterioration in water quality due to floods, flash floods, droughts, deposition of rivers due to soil erosion, sedimentation and solid waste. The root causes of nonpoint-source pollutions in urban rivers of Malaysia are from logging, land clearing for agriculture and development, sand mining, river reserve invasion, squatters and garbage collection centers (Keong 2006).

Point-source and nonpoint-source pollutions in urban river water not only affect water quality as a resource for human, but riparian and aquatic life is also affected. The effects of pollutions from sedimentation, organic matter, inorganic matter, nutrients, solid wastes and microorganisms have an impact on urban rivers and surrounding areas. Sedimentation has an impact on the quantity and quality of urban river water when suspended solid concentration is too high, causing turbidity to water especially in equatorial countries that receive high intensity of rain and hot weather throughout the year (Douglas 1974; Din et al. 2012a, b). When an urban river is concretized and receiving sedimentation throughout the year, it affects the depth of the urban river as a result of sedimentation (Chin 2006). Due to the deposition of suspended solids, sediments, soils and so on in the urban river, it causes urban river to become shallow. In addition, sedimentation causes urban rivers to lose their aesthetic and recreational values and alter aquatic and riparian habitats of urban river (Environmental Protection Agency of Ireland 2011).

In addition, pollutants from inorganic matters are highly toxic chemicals and can affect the health of humans and other organisms if they consume it. It affects the reduction of aquatic species, such as algae, invertebrates and fish communities causing riparian degradation (Paul and Meyer 2001; Meyer and Wallace 2001; World Bank 2006; Zhou et al. 2012). Additionally, inorganic substances, such as pesticides, and other highly toxic substances tend to accumulate in aquatic life and go into human and animal feedstock if they are controlled properly (Carson 2002; Atlanta Regional Commission 2002). Organic matters and high nutrients make an ideal condition for algae to bloom leading to eutrophication and reduction of dissolved oxygen, making it difficult for aquatic organisms' respiration processes to take place (Colangelo and Jones 2005; Speed et al. 2016). Moreover, the lack of dissolved oxygen will cause an anaerobic environment for the decomposition of organic matters and this gives an unpleasant odor to urban rivers (Atlanta Regional Commission 2002). Solid wastes and microorganisms entered into urban river water bodies will result in the loss of aesthetic and recreational value as well as causing riparian habitat degradation (Atlanta Regional Commission 2002) and vulnerability to various dangerous diseases when using water for drinking and recreational purposes (Thomas and Reese 2003).

To ensure the sustainability of the quantity and quality of urban river water and its environment to remain clean and healthy, pollution controls must be included in urban river management to prevent any form of pollution from entering urban river water bodies as well as removing pollutants in the water bodies. Best management practices are introduced to prevent any form of pollutions from entering nearby urban river water bodies, whereby best management practices apply control either physical or cultural functioning individually or as a group, in line with the source, location and climate of the area (United States Environmental Protection Agency 1993; Marsh 2011) for the restoration and conservation of urban rivers. Integrated management practices are divided into two parts: structural and nonstructural approaches (United States Environmental Protection Agency 1993). Structural approach focuses on reducing sources of pollution that have entered urban river by using technical capacity that includes scientific analysis and design of engineering systems to identify pollution sources and apply water treatment system as close as possible to the sources of pollution. Meanwhile, nonstructural approach focuses on preventing and controlling pollution before entering urban river (Thomas and Reese 2003) through changing stakeholders' attitudes toward environmental protection. Integration of both structural and nonstructural approaches to urban river management is expected to provide a paradigm shift that can link environmental protection, social empowerment and economic benefits to urban communities.

3 Current Urban River Management

Various studies have shown that the evolution of urban river management is reactive which relies on short-term solution to current problems and is not proactive (Reese 2001; Martin et al. 2007). Proactive solutions examine current issues, anticipate future problems and generate integrated solutions to address those problems. For the restoration and conservation of urban rivers for improved water quality, existing urban river management requires a paradigm shift toward a holistic and integrated approach due to the complexity of interrelated problems.

Pre-development paradigm that has less emphasis on environmental protection in urban river development planning has led to water quality deterioration. Therefore, current urban river management requires a new approach to restore and conserve urban river's water quality. The evolution of urban river management includes natural rivers, drainage systems, stormwater drainages and drains that are highly impacted by human practices from either urbanization or socioeconomic activities in the surrounding areas. In general, residents and urban planners still consider that stormwater channels are the final destination of waste disposal and affect the quality of human health, environment and security (Department of Irrigation and Drainage 2012; Lim et al. 2013). Hence, it is extremely difficult for the restoration and conservation of the urban environment when urban planning fails to incorporate environmental care elements, especially in urban river water quality.

Presently, the restoration and conservation of urban river are different from the previous management paradigm. According to Speed et al. (2016), the challenge of restoration and conservation of urban river is to balance between the natural functions of urban river and specific human needs. Furthermore, the complexity and scale of the restoration and conservation project lead to the failure to resolve pollution issues because of failing to take into account the processes at the basin level. Operations at a large scale require issues, consideration and participation of various stakeholders as well as planning and management tools. As such, it increases the uncertainties like climate change, land use, population growth and urban development toward the challenging future conditions to ensure that urban river is suitable for restoration.

The issues faced by urban river management are the best approaches to achieving the objectives, approaches and constraints of implementation, operation and maintenance, the diversity of issues to be addressed, the best way to conserve and the external problems resulting in the effectiveness of treatment. Aspects seen in the selection of the best approaches to achieving the objectives are the effectiveness of the water treatment system in the selected field (National Audit Department of Malaysia 2017). As funding has been spent on the development of high-cost water treatment system (National Audit Department of Malaysia 2017), it is desirable for the system to treat urban river effectively and the period of treatment does not take long to restore urban river's water quality (Chan 1999; Weng et al. 2003; Department of Irrigation and Drainage Malaysia 2012). In addition, there are constraints in the implementation of water treatment system whereby the feasibility of the treatment system varies depending on the condition of urban river and this complicates the installation of on-site treatment systems due to inadequate treatment system specifications (National Audit Department of Malaysia 2017; Thomas and Reese 2003). When water treatment system in the field has been financed, it is probable that it will not return the cost and value returned from the water treatment also takes a long time (Weng et al. 2003).

Operation and maintenance play an important role in the sustainability of water treatment in the field where costs are needed to repair water treatment system in the field to operate optimally, as a result of aging, damage caused by vandalism or clogging (Marsalek and Schreier 2009; Martin et al. 2013). In addition, urban river conservation needs to address various issues as it requires a comprehensive treatment scale, whereby if it is not sufficient, that water treatment system cannot improve water quality to a better level (Marsalek and Schreier 2009). In addition, external problems can affect the effectiveness of water treatment especially during flash floods and landslides that originate from natural disasters or anthropogenic incidents happened at the upstream are often ignored in urban river conservation (Marsalek 2003).

In addition to the issues faced to conserve urban rivers, the process of maintaining urban rivers also has its own unique aspects and issues. Among the issues faced are budget issues, socioeconomic and institutional mandates, defined returns from urban river care, inadequate planning, inefficient in enforcement and changes in stakeholders' practices. Urban river conservation issues such as budget, socioeconomic and institutional mandates as well as defined returns from urban river care are due to constraints and balancing interests and demands. This is because master plan planning and analysis use high cost (Marsalek and Schreier 2009; Chan 1997; Lim et al. 2013). In addition, the discomfort of squatters should be taken into account as they need to get out of their own homes when the government directs their relocation to another area. Hence, balancing stakeholders' needs and environmental care needs to be done fairly and equitably.

Planning failure is a matter of concern when there is less value in the formation of urban river master plan. Additionally, inefficient acts and enforcements as well as changes in stakeholders' practices are major issues when the failure of enforcement in regulating various acts to prevent pollution (Meenakshi and Mageswari 2002). Changes in stakeholders' practices have no apparent value because the practice changes based on small-scaled programs have less significant impact and it is difficult to evaluate their effectiveness (Weng et al. 2003).

Similarly, the management of river basins has undergone a change from the main purpose and use. Reyhan (2013) has summarized the management of river basins from the 1970s to the 1990s. Beginning in the 1970s, basin management aims to protect the infrastructure of local areas and resources at the downstream. This reflects the structural equation of the paradigm of river basin and urban river management that stated by Reese (1991). As stated by Mokthar et al. (2005), the use of river basin management is to stabilize the soil structure to prevent landslides. To address current problems, in the 1980s, the management has changed to an approach other than engineering and collaborates among other organizations. This change was made to manage resources, such as land, water and plants sustainably. However, cooperation between other organizations is difficult to build and technical approaches clearly fail to resolve the problems. In the 1990s, river basin management took into account the conservation of resources as well as enhanced the lives of local stakeholders by identifying and implementing integrated interventions and using approaches in prioritizing the involvement of local stakeholders in addressing local river basin problems with the help of technical methods. Management that integrates both science and social approaches is seen to be able to solve the problem of managing the local river basin and improve the lives of stakeholders that depend on the river basin. Therefore, the implementation of integrated management is necessary to manage urban river.

4 Integrated Management of Urban River

The Dublin Principles have stated in its first principle that freshwater is a limited and endangered source, essential for survival, economic development and the environment (Principles 1992). The population of the world increased by a factor of three during the twentieth century but the use of water resources increased by a factor of seven. It is estimated that one-third of the world's population reside in countries experiencing moderate to high water stress. This ratio is expected to increase to two-third by 2025 (Global Water Partnership 2000). In Malaysia, urban migration is a new challenge and complicates the formation of integrated management plans to incorporate elements of social unity and create economic opportunities. Furthermore, demand for domestic water supply is increasing and is expected to reach 16,176 million liters/day by 2050 (Keong 2006). No matter where the freshwater sources come from, either from rivers, lakes, dams and seas, these precious water resources need to be seen as a basin (Reese 2001). Consequently, the sustainability of water resources depends on how it is managed and water resources should be managed holistically and integrated by involving all levels of society.

Integrated water resource management (IWRM) (Global Water Partnership 2000) is an approach that promotes the coordination of development and management of water resources, land and related resources, to maximize economic and social welfare in a fair manner without affecting ecosystem conservation. IWRM covers the linkages between water resource managements including freshwater and saltwater, groundwater and surrounding life as well as the relationship between human and environmental systems. The concept of IWRM has been widely debated, and existing definition for the use of water bodies in cities, such as urban rivers, is still unclear. Therefore, regional and national institutions must develop the definition of their own IWRM practices that adopt the Global Water Partnership (GWP) 2000 framework. IWRM uses the best management practices in water resource management. For the restoration and conservation of urban river, IWRM is based on pollution control at its source. Any water received in the area should be controlled using best management practices and not directly releasing into urban river. Best management practices can be classified into two approaches, namely structural and nonstructural approaches (Micheal et al. 2004), whereby best management practices' goal is to provide pollution control from point-source and nonpoint-source pollutions to comply with the standards and guidelines set by the authorities (Thomas and Reese 2003).

Previous researches on the restoration and conservation of urban rivers in post-development areas emphasize integrated and holistic water management in addressing local problems and have their own perspective goals. However, contemporary research frameworks are complex, extensive and unique to each other, to support the institutionalization of urban river management according to their social and economic demographics and geomorphology (Martin et al. 2007; Al Bakri et al 2008; Wong 2011). It challenges decision-makers, engineers, urban river basin managers, local communities and stakeholders to build and implement their own approach based on existing research because broad principles need to be considered and uncertainties need to be taken into account and still lacking or do not have multi-discipline integration for solutions to complex problems, for example, feasibility study of effective water treatment system, stakeholder's participation and economic benefits of urban river management (Martin et al. 2007; Barbosa et al. 2012). Moreover, these approaches are specific to individual local issues, for example, stormwater management for industrial sectors (Wong et al. 2002), water harvesting as a water resource (Yang and Cui 2012), etc. However, it provides an unclear picture of the holistic main principle and must be included in the restoration and conservation of urban river. It is undeniable that various factors, such as restoration and conservation goals, types of approaches used and constraints as well as uncertainties, arise during the course of restoration and conservation processes of the urban river. Therefore, the central approach is to prevent pollutants from entering the urban rivers' water bodies. In this regard, decision-makers, engineers, river basin managers, local communities and stakeholders are required to empower integrated management to shift urban rivers that have only one function toward the restoration and conservation in the best possible way for the environment to be properly maintained as well as adding value to the socioeconomic status of locals.

4.1 Structural Approach

For the restoration of urban river water quality, structural approach is one of the best management practices to remove pollutants from water bodies (Lim and Lu 2016; Thomas and Reese 2003). Structural approach focuses on the removal of pollutants that have entered the urban river and provides quality and quantity control of water using technical capacity that includes scientific analysis and engineering-designed systems to identify sources of pollution and to apply the water treatment systems closest to the source. These include interpolation analysis (Murphy et al. 2009) and extrapolation (Wong et al. 2002) of water quality monitoring data for the spatial distribution of pollution sources.

Similar to many developed countries, the Malaysian government has outlined the National Water Quality Standard for freshwater, namely the Water Quality Index to identify and classify the level of water quality acceptance for human consumption and environmental health (Department of Environment 2006). The Water Quality Index consists of six water quality parameters, namely dissolved oxygen (DO), pH, ammoniacal nitrogen (NH_3–N), total suspended solids (TSS), chemical oxygen demand (COD) and biological oxygen demand (BOD). The value of the six parameters will be calculated according to the subindex calculations together with the weightage for each parameter to get a value that combines all subindex values. Of these Water Quality Index values, it will be classified into five classes and their usage whereby the highest value will be classified as Class I, which shows clean water and is most suitable for human consumption. The increase in the Water Quality Index Class shows the water quality is more polluted based on the six parameters, which can be detrimental to human and the environment health.

After the sources have been identified, field treatment will be carried out, for example, permeable pavement walls, gross waste traps, constructed wetlands, etc (Department of Irrigation and Drainage Malaysia 2012). One of the ways in placing the field treatment is using treatment train that is a series of retrofitted field treatment systems (United States Environmental Protection Agency 2000) without changing the geomorphological state to remove certain pollution in the body of water. The treatment efficiency relies on the ability of field treatment systems to address the targeted water quality parameters in the urban river. Design criteria for the installation and development of water treatment system as well as field operations depend on the size and mechanisms involved. Water treatment specifications are a requirement for optimum efficiency and better performance for the suitability of water treatment management (Lim and Lu 2016; Thomas and Reese 2003; Murphy et al. 2009). Hence, structural approach is designed in a set of action plans using scientific analysis that optimizes both site's characteristics and selected water treatment systems by reducing pollution from its sources according to standards set by local authorities or governments.

4.2 Nonstructural Approach

Another approach to improving the quality of urban river water is through nonstructural approach, whereby this approach prevents and regulates pollutants from entering the urban river water body besides removing pollutants released into the urban river water body (Thomas and Reese 2003). Nonstructural approach focuses on changing the behavior of stakeholders or the practices that cause urban river pollution using social capacity. This approach includes social analysis and social convention to identify and understand the practices that cause pollution and apply appropriate intervention on the stakeholders in accordance with the area, thereby preventing any subsequent pollution to the urban river (Bartlett 2005; Sparkman and Walton 2017).

Nonstructural approach is divided into two stages, namely assessing the management paradigm of urban river and applying social convention. Assessing the current urban river management paradigm is to identify the level of knowledge, attitudes in reflecting the practices as well as participation of stakeholders in the restoration and conservation of urban river and assess their perceptions in water quality and quantity (Gobster and Westphal 2004; Bartlett 2005). This assessment requires a set of questionnaires and a series of consultations with urban river stakeholders to understand the current management paradigm of the urban river, aiming to dissolve the complexity of nonpoint-source pollution by identifying practices and challenges for change as well as methods to address the local problems.

Prerequisite to the aforementioned methods, social convention is the establishment of intervention on current practices and understandings of environmental protection and nurturing salient practices in the restoration and conservation of urban rivers by enhancing the social well-being of stakeholders and adding value to the economy that they are relied on (Taylors and Wong 2002; Sparkman and Walton 2017). It includes pollution control, establishing advisory committees, education as well as capacity building, regulatory and practice development designed to limit the conversion of rainwater to runoff (Thomas and Reese 2003; Martin et al. 2007). The baseline program focuses on joint planning and pollution management through the participation and capacity building of stakeholders involved. This includes educating the public on the disposal of solid wastes in a cleaner and efficient way, legal regulations for waste disposal, change in material usage, work practice change, substitution of materials, reconstruction of drainage into the urban river by diverting into separate water treatment.

4.3 Challenges of Structural and Nonstructural Approaches

The challenge of structural approach in best management practices is the combination of complex stormwater and runoff water contributing to various types of biological and chemical reactive pollution in the urban river. Despite careful planning of water treatment systems in the field, pollution reduction is still inconsistent (Thomas and Reese 2003; Brown and Clarke 2007; Lim and Lu 2016). Therefore, it is difficult to achieve replicated results in treatment efficiency because structural approach can only reduce identified point-source pollutions. However, urban rivers are still vulnerable to nonpoint-source pollutions that enter into the water body. The greater volume of pollutants, such as nutrients, heavy metals and toxic substances enter into the urban river, the more efficient and robust water treatment system in the field is required. As such, the cost of water treatment will be higher for long-term operation and maintenance.

Figure 1 shows structural and nonstructural approaches in improving urban river water quality (Mahmud et al. 2017a). In a hypothetical situation, conventional urban river management is limited to functions of which irrigation and flood control cannot prevent and control pollution that are contributing to the deterioration of water quality by anthropogenic activities. It is because urban rivers receive pollutants from the upstream caused by natural events, economic development and anthropogenic activities that are difficult to control as it is beyond the capacity of conventional urban river management. Structural approach is designed to allow urbanization and economic development

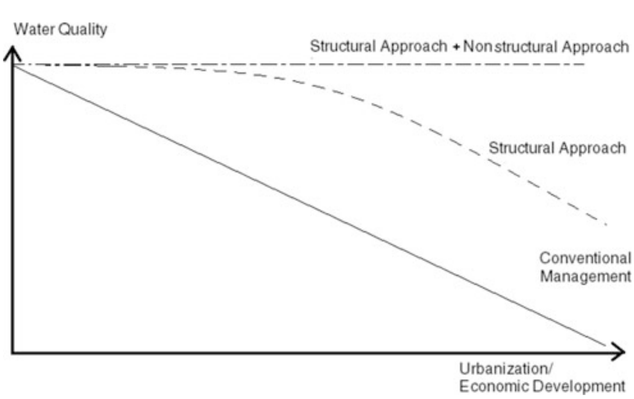

Fig. 1 Hypothetical water quality comparison of urban river using conventional management, structural approach and nonstructural approach (Mahmud et al. 2017a)

by reducing its impact on the environment (Urbonas 2001; Thomas and Reese 2003). With the rapid urbanization and economic development, anthropogenic activities contribute to the diversity of pollutants, the water treatment capacities in the field are limited to the amount of pollutants discharged and increasing pollutant load will cause water treatment in the field less effective. Besides that, urban rivers are still vulnerable to external factors and problems, such as oil spills or flood events that carry pollutants from nonpoint sources, such as sediment, silts and others from upstream catchment. Furthermore, the effectiveness of water treatment in the field is based on the types of pollutants found in the urban river water body. Additionally, urban rivers have slow recovery process in water quality due to several factors, namely slow exchange of chemical composition between the water and soil due to the concrete base (Chin 2006; Wohl and Merritts 2007). Hence, relying only on structural approach is unsustainable because water treatment systems in the field can only treat point-source pollution, whereas nonstructural approach encourages behavior change in stakeholders' consent and practice toward environmental protection whereby it prevents and controls all forms of pollutions before entering the urban river water body instead of removing pollution from the water body (Thomas and Reese 2003). It requires capacity building, regulation and time to change the behavior of which they have been practicing so far. Therefore, both structural and nonstructural approaches are needed in integrated management of urban river.

4.4 Concept

Integrated management of urban river is a complex program that combines both structural and nonstructural approaches to current management in supporting a wide range of disciplines, including ecology, aquatic biology, hydrology and hydraulics, geomorphology, engineering, planning, communication, economics and social sciences to solve the problems of urban river. The current urban river management is on the verge of revolutionary change in response to the growing demand for water resources in urban areas due to the rapid economic development and human activities (Global Water Partnership 2000; Bahri 2012). Current water resources management needs to be resilient to climate change, competitions, conflicts, deficiencies and pollution of water resources; therefore, rethinking the concept of conventional urban river management is important in order to shift the paradigm of managing urban water cycle separately to integrated water resource management in urban areas supported by all stakeholders (Global Water Partnership 2000; Bahri 2012).

Integrated urban river management is adopting the concept of IWRM which contributes to the security of water resources in river basins within urban areas or as water supplies for rural areas. In addition, this integrated management leads to the opening up of the diversity of urban river potential from the economic, social and environmental perspectives by coordinating urban rivers from the aspects of water resources, gentrification, value-added economies and more. Additionally, it can unite various entities and groups of stakeholders around the urban rivers while solving the problems to achieve the goals of economic, social and environmental sustainability.

There are four important factors in the concept of integrated urban river management, namely (1) structural approach, (2) nonstructural approach, (3) understanding the paradigm (Reese 1991) and (4) the capacity for paradigm shift (Wong 2011). Implementing this concept requires the current urban river management paradigm and the capacity for paradigm shift. It is important to understand the relationship between physical problems, the effects of pollution and social problems that become the source of pollution where the problem of water quality requires both structural and nonstructural approaches to form integrated management of urban river. A social science platform is required to form integrated management of urban river, whereby it includes restoration and conservation of urban river for paradigm shift in urban river management. The concept should begin simultaneously for both structural and nonstructural approaches, whereby it focuses on mutually complementary solutions to address the urban river pollution within a time frame for effective outcomes (Lim and Lu 2016). Both structural and nonstructural approaches complement each other on the socio-science platform in which through this platform, demonstration of successful structural approach, it builds stakeholders' confidence in accountable and credible science in helping to build capacity and encourage more stakeholders' involvement throughout the process (Wong 2011). It enables the change to occur with confidence through the technological propagation and stimulates the emergence of development in a socio-technical environment for the paradigm shift of urban river management. Guidelines, collaborative goals, master plans and water quality standards provide a basis of vision and direction for future transition scenarios and routes for sustainable urban river management.

5 Case Study: *Alur Ilmu*, the National University of Malaysia

Urbanization contributes to population growth by improving physical development and socioeconomic development of the population and building rural areas to cities. These changes also change geomorphological structures including rivers in the area to strengthening soil integrity to nearby infrastructure and channeling runoff during storm events to prevent flash floods. Sustainable urbanization processes emphasize environmental protection including the care of the quantity and quality of urban rivers and the surrounding environment for urban sustainability.

Alur Ilmu was originally a 1.79-km-long natural river that has been converted into an urban river, flowing through the main campus of the National University of Malaysia, Selangor, Malaysia, before flowing into the Langat River, one of the UNESCO HELP (Hydrology for the Environment, Life & Policy) River Basins. As shown in Fig. 2, *Alur Ilmu* receives water source from the Permanent Reserved Forest, stormwater and runoff water from paved surfaces, such as paved roads or cemented roads around the urban river. *Alur Ilmu* is surrounded by buildings and infrastructures, comprising faculties, residential colleges, tar and pedestrian areas, administrative buildings and other paved areas which are full of socioeconomic activities of campus stakeholders. *Alur Ilmu* works to strengthen the buildings nearby soil structure and serves as an irrigation system to drain excess stormwater in the event of rain to prevent flooding. However, its initial development of less emphasis on the environmental protection has caused *Alur Ilmu* to be exposed to point-source and nonpoint-source pollutions along the river (UKM 1979). In addition, the current management and programs that have been implemented are less effective in restoring and conserving the water quality of the urban river. Consequently, *Alur Ilmu* records a decline in water quality as a result of water pollution (Chong 1999; Mokhtar et al. 2005; Din et al. 2012a, b) and now such water quality makes the urban river neither regarded as a valuable water resource nor used for recreational purposes because of its low aesthetic value. According to the studies of the Water Quality Index, the water quality has decreased from Class I before the construction of the campus to Class II in 1999 (Chong 1999), Class III in 2003 (Mokhtar et al. 2005), Class IV in 2012 (Din et al. 2012a, b), and Water Quality Index is expected to decline further if no action taken as shown in Fig. 3.

Alur Ilmu is exposed to water pollution arising from natural events and nearby anthropogenic activities. During rain, runoff water flows and collects pollutants, such as sediment, organic matter, solid waste, oil and grease from the pavement and into the urban river. As a result, it contributes to the deterioration of the Water Quality Index. Although the upper Ghazali Lake has sediment trap, it has failed to prevent sediment to flow into *Alur Ilmu* during heavy rains. This is because the sediment trap has surpassed its capacity to cope with sediment load as a result of erosion brought by runoff water. In addition, nearby anthropogenic activities, such as the cafeteria and faculties, also discharge wastewater into the water body contributing to pollution (Din et al. 2012a, b).

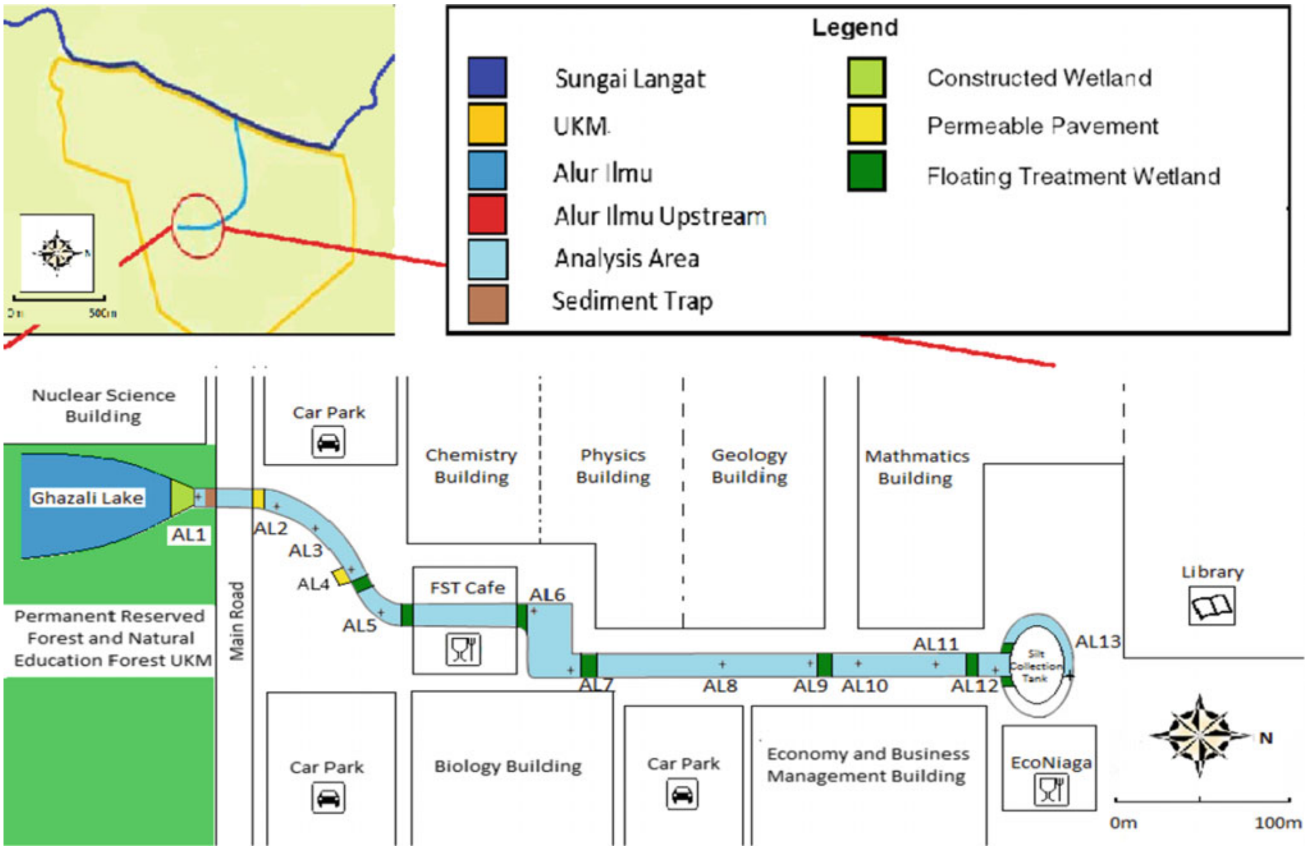

Fig. 2 Geographical location of *Alur Ilmu* within the National University of Malaysia campus

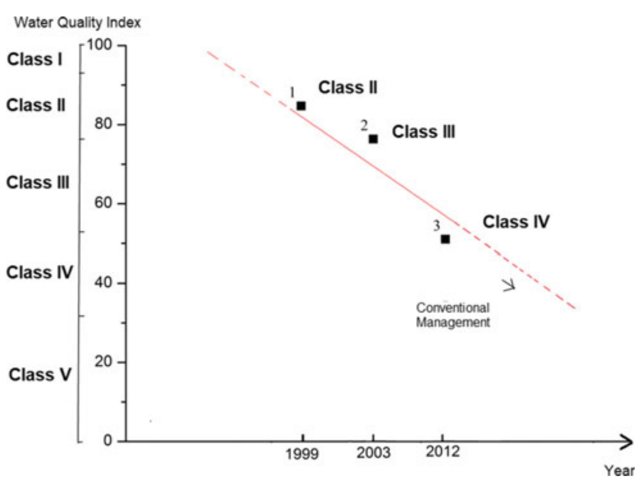

Fig. 3 Water Quality Index of *Alur Ilmu* from 1999 to 2012. [1]Chong (1999); [2]Mokthar et al. (2005); [3]Din et al. (2012a, b)

In addition, the knowledge of stakeholders in protecting urban river and the attitude toward the management practices play an important role in influencing the water quality as the amount of pollutants from point source and nonpoint sources entering into *Alur Ilmu* depends on the management practices in restoring and conserving the urban river. If the conventional management of *Alur Ilmu* continues, pollution brought by the campus could result in the degradation of the ecosystem and affecting the water quality of Langat River which is one of the local water resources. Consequently, *Alur Ilmu* requires an integrated management to restore and conserve its water resource. The paradigm shift toward sustainable management of urban river is expected to restore the water quality by adopting a structural approach, and the health and the quality of life in the campus can be addressed by adopting a non-structural approach. Hence, best management practices that integrate both structural and nonstructural approaches are needed for integrated management of urban river.

6 Shifting the Paradigm of Urban River Management

Figure 4 shows the integrated management framework for urban river focusing on *Alur Ilmu*. The integrated framework for urban river is divided into three stages in three different platforms (i.e., science, social and social science): Stage 1 co-framing the problem collaboratively; Stage 2 co-producing knowledge-based and transferable solutions by establishing integrated management of urban river; and Stage 3

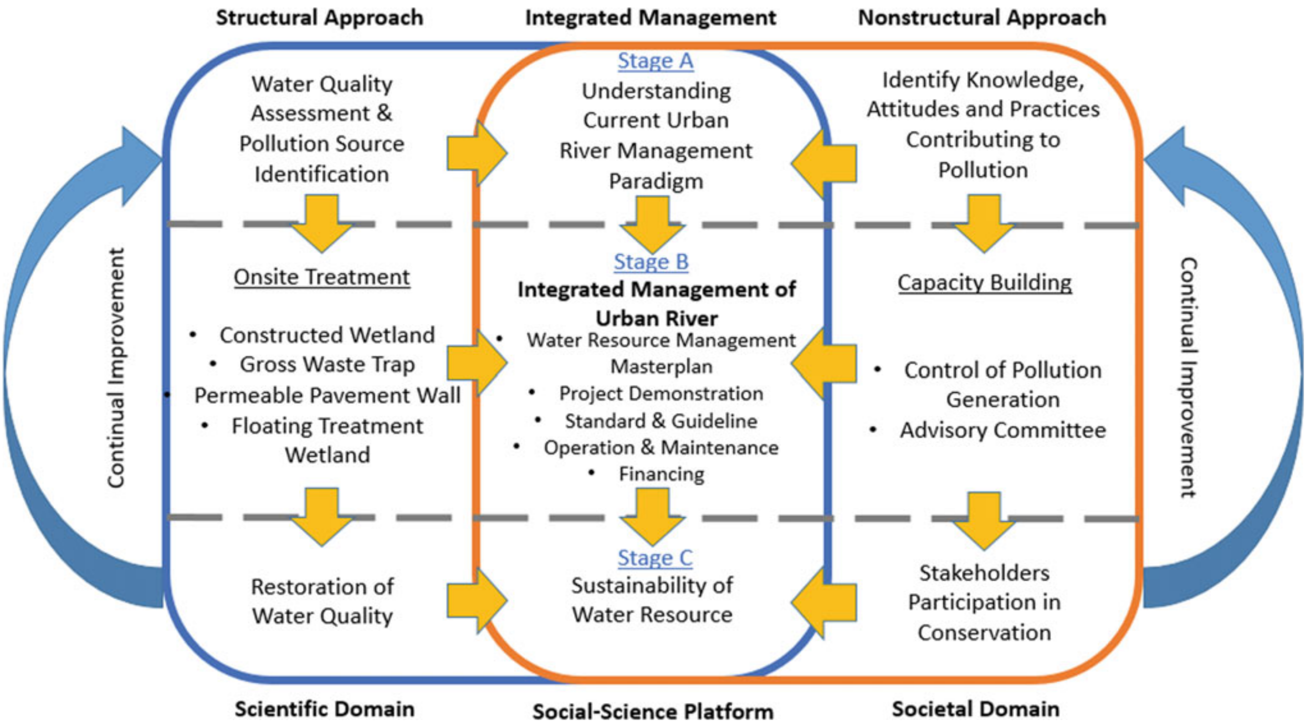

Fig. 4 Integrated management framework for urban river focusing on *Alur Ilmu* (Lee et al. 2018)

co-implementing the knowledge-based solutions generated by both scientific and societal domains.

(i) Stage 1: Co-framing the problem collaboratively

The first stage of integrated management of urban river begins with co-framing the problem collaboratively for *Alur Ilmu* among the scientific and societal domains which consist of related multi-disciplines and multi-stakeholders with experience, expertise or any other aspects that are relevant to the problem (Pohl and Hadorn 2008). This group of stakeholders will form a committee to understand current urban river management paradigm in *Alur Ilmu* by conducting water quality assessment and pollution source identification through structural approach by scientific domain, and identifying knowledge, attitudes and practices contributing to pollution through nonstructural approach by societal domain. Setting up this working committee with a structured organization is important where responsibility, efficiency and decision-making are clearly defined, whereby this is to establish a balance between the scientific domain (researchers) and societal domain (stakeholders) at every level to form a shared leadership for paradigm shift in urban river management (Scholz et al. 2006). Understanding the current urban river management paradigm of *Alur Ilmu* needs to define complex sustainability issue as a relevant social issue and raise questions for scientific research (Lang et al. 2012; Siebenhüner 2004; Wiek et al. 2012), and it will be instrumental for the formation of integrated management that balances the scientific and societal importance in knowing and solving the real problems of *Alur Ilmu*.

(ii) Stage 2: Co-producing knowledge-based and transferable solutions

In order to develop collaborative knowledge-based and transferable solutions for *Alur Ilmu* (Lang et al. 2012; Lee et al. 2018), the integration of concepts and findings throughout the collaborative research is essential to make pragmatic research a success. Therefore, the responsibility of each stakeholder at all different levels must be determined first as this is to implement transparent management taking into account inertia, reluctance and structural barriers (Maasen and Lieven 2006; Wiek 2007). There are different levels of engagement of stakeholders, including tasks, responsibilities, technical skills, levels of concern and willingness to contribute time and energy (Thomas and Reese 2003). In addition, to enable transdisciplinary integrated management, cognitive-related leadership (providing a way to integrate stakeholders' epistemic differences), structure (addressing the need for coordination and information exchange) and procedure (resolving conflicts during the process) are important elements that must be present in such management (Gray 2008).

Integrated management of *Alur Ilmu* requires the integration of structural and nonstructural approaches on the social science platform that includes water resource management master plan, project demonstration, standard and guideline, operation and maintenance and financing. Water resource management master plan that set by an advisory committee aiming to control pollution is able to give an impact not only to restore but also to conserve *Alur Ilmu*. The relationship between structural and nonstructural approaches conducts not only on-site treatment through gross waste traps, constructed wetlands, permeable pavement walls and floating treatment wetlands but also capacity building for enhancing knowledge, attitudes and practices and strengthening stakeholder participation (Gobster and Westphal 2004; Ison et al. 2007; Pahl-Wostl et al. 2008). The integrated management of *Alur Ilmu* has also opened up a new dimension to the impact of project demonstration in which social learning can impact on natural values, gentrification and aesthetics (Gobster and Westphal 2004; Marsalek et al. 2008; Lim et al. 2013; Viswanathan and Schirmer 2015). Project demonstration can be a catalyst for improvement of knowledge, attitudes and practices of stakeholders toward the importance of *Alur Ilmu* (Gobster and Westphal 2004; Lim and Lu 2016). As such, project demonstration is imperative to any river restoration and conservation efforts that are either proactive or reactive because they can trigger a change in stakeholder practices toward river restoration and conservation. Finally, integrated management of *Alur Ilmu* should set standard and guideline to control pollution to prevent any pollution to happen (Thomas and Reese 2003) and should be supported by operation and maintenance as well as financing to cover the costs of managing *Alur Ilmu*.

(iii) Stage 3: Co-implementing knowledge-based solutions generated by both scientific and societal domains

The final stage of integrated management of *Alur Ilmu* is to shift the management paradigm toward ensuring the sustainability of water resource through establishing the principles for the integration and application of knowledge-based solutions, namely (1) continual improvement based on the outcome, (2) generating science and social values, and (3) assessing science and social impacts. Continual improvement is reflected in the results obtained from structural and nonstructural approaches in managing *Alur Ilmu*. For structural approach, the review on the restoration of *Alur Ilmu* is based on the Water Quality Index and it is proposed with the addition of other water quality parameters, namely oil and grease and heavy metals, whereas for nonstructural approach, the review of the participation of stakeholders in the conservation of *Alur Ilmu* should be made on their knowledge, attitudes and practices toward pollution control and participation in management. Likewise, shared learning between science and social domains through project demonstration has a high visibility value and it is important to carry out different criteria in the review of contributions as both perspectives adhere to the quality of criteria, such as scientific credibility or practicality (Wiek 2007; Jahn 2008). The contributions to solve *Alur Ilmu*'s problem by stakeholders take into account both scientific and social aspects (Defila et al. 2006) and can be used as a transformation to scientific innovation and social progress (Pohl and Hadorn 2008). Figures 5 and 6 show the improvement of *Alur Ilmu*'s water quality before and after implementing structural approach that consists of gross waste traps, constructed wetlands, permeable pavement walls and floating treatment wetlands, whereas Fig. 7 shows the need to have integrated management through combination of structural and nonstructural approaches for the restoration and conservation of *Alur Ilmu* by improving Water Quality Index further. Believing *Alur Ilmu* as a water resource, integrated urban river management helps in sustainable management and development of water resource by taking into account social, economic and environmental benefits whereby it recognizes the differences and requirements of each stakeholder and entity that use or abuse water and environment (GWP and INBO 2009). Hence, uplifting *Alur Ilmu* as part of the IWRM will ensure the sustainability of water resource, not only for the use of campus stakeholders but also for environmental and habitat protection despite rapid urbanization and economic development.

7 Conclusions

The effects of urbanization on urban rivers have changed the geomorphological structure of the land by strengthening the integrity of the soil to the nearby infrastructure besides the runoff during storm events to prevent flash floods. In addition to its permanent structure of urban river which did not emphasize on environmental protection, the rapid growth of socioeconomic activities, the construction of buildings and the opening of the surrounding land have made urban river susceptible to various types and forms of pollution from point-source and nonpoint-source pollutions throughout the urban river. As a case study, *Alur Ilmu* of the National University of Malaysia has been adopted as an example of urban river in this study. Although many efforts have been undertaken to restore and conserve *Alur Ilmu*, the water quality has continued to decline to an alarming and unsustainable level. Hence, the current management of the urban river needs to be addressed in order to resolve the problem.

Integrated management of *Alur Ilmu* has been proposed, whereby it consists of structural and nonstructural approaches on the social science platform. Treatment taken place in

Fig. 5 Comparison of Alur Ilmu before (top) and after (bottom) implementation of structural approach (Mahmud et al. 2017b, c, 2018)

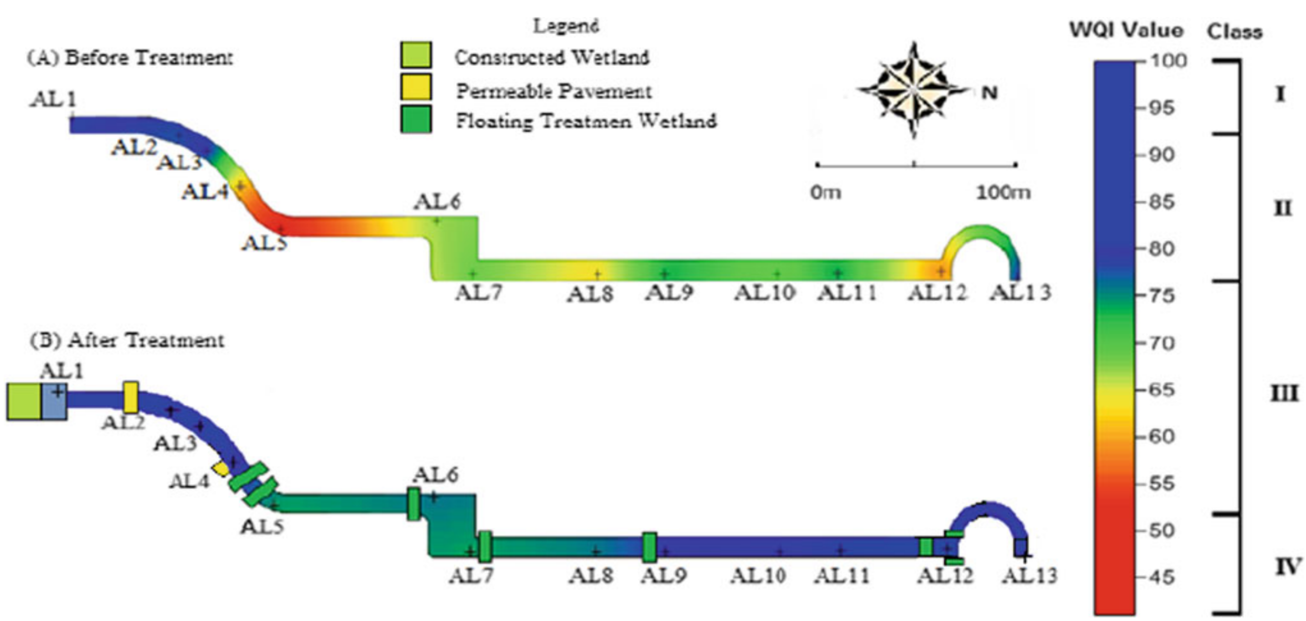

Fig. 6 Comparison of Water Quality Index before and after the implementation of structural approach (Mahmud et al. 2017b, c, 2018)

the field through structural approach is gross waste traps, constructed wetlands, permeable pavement walls and floating treatment wetlands. Due to the location of *Alur Ilmu* is surrounded by buildings and infrastructure, hence most of the areas are paved and have very limited space. Therefore, selected water treatment infrastructures are of low-impact development without changing the physical landscape and geomorphology of the urban river. Structural approach taken has successfully improved from Class III to Class II in less than a year. Nonstructural approach taken focuses on enhancing knowledge, attitude and practice as well as strengthening the participation of campus stakeholders.

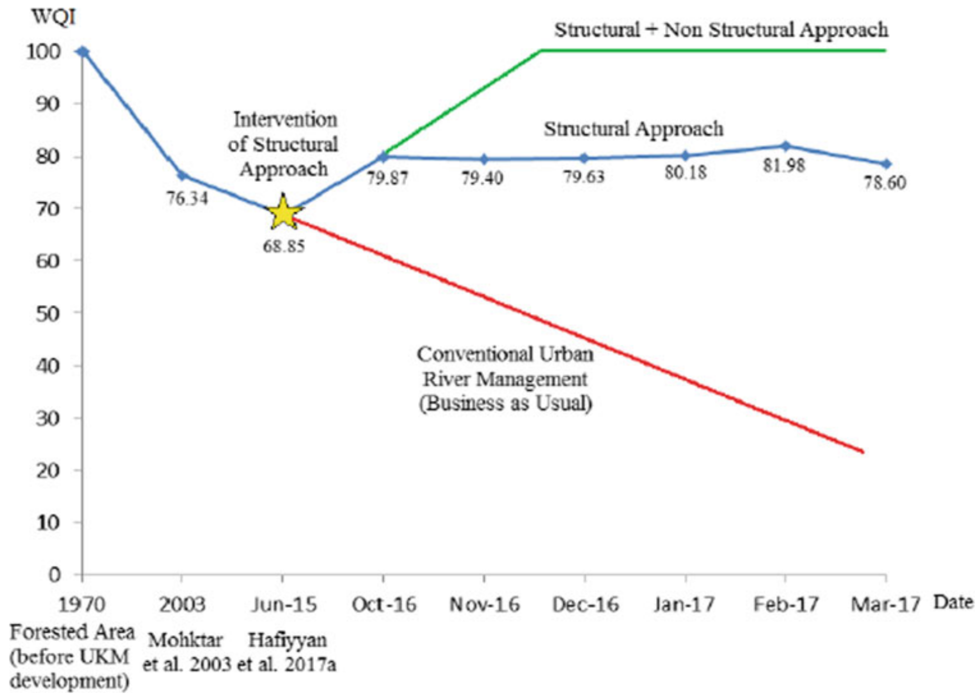

Fig. 7 Water Quality Index of *Alur Ilmu* and hypothetical structural and nonstructural approaches in improving water quality

Combining structural and nonstructural approaches not only develops on-site treatment for the restoration of urban river, but also creates social learning for the conservation of urban river through stakeholders' participation to avoid pollution from occurring. This study is expected to be used as a model for the restoration and conservation of urban river to attain sustainability of water resource for the benefits of economic growth, social well-being and environmental protection.

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