A shared view of the integrated urban water management practices in Malaysia

K. Y. Foo

ABSTRACT

Urban water management remains a complex interplay between climate change, population growth, water scarcity, and the living environment. This agenda has called for an integrated, coordinated, ecologically-oriented, and participatory approach to the reliable protection of water resources. Malaysia, endowed with its rich natural resources and diversity recognizes the need to adopt a sound developmental framework to transform the country’s water management landscape to a high quality and excellent level. In parallel with this development, both government and non-governmental organizations continue to advocate national efforts to address environmental research for incorporating the sustainability of environmental literacy and conservation of ecosystems. The plan espouses the establishment of urban water recycling, bio-retention systems, and constructed wetlands to buffer the impacts of water pollution, and preserve ecosystems for the neighboring communities. The impetus is accompanied by the integration of water quality monitoring systems, and boosted by the implementation of expert analysis. The present work attempts to address the dynamic pressure, key challenges, and benefits of urban water management practices in Malaysia. The sustainable concepts of waterfronts, constructed wetlands, and implementation of water monitoring analysis are elucidated. In addition, the research breakthroughs, major obstacles, and co-operative ventures for the promotion of urban water management are outlined.

Key words | constructed wetland, storm water, urban water management, water resource

INTRODUCTION

Urban water management is an integrated activity undertaken to achieve sustainable water supply, hygienic collection, public health protection, waterway security, amenity and recreation, greenhouse neutrality, intra and inter-generational equity, and a demonstrable long-term living environment. Strategic urban planning is a continuous management process of cumulative learning, analysis, repetitive review, and updating. It represents a major challenge for human settlements, development, and management in the 21st century. The traditional paradigm of centralized urban water supply, sanitation, and drainage systems began in the 1800s, as a response to typhoid and cholera epidemics that swept European and American cities (Chocat et al., 2001). Up to 1976, a number of water related directives have been issued, aimed at protection of public health, nature, and wastewater pollution. The concept of sustainability in urban water management was extended to the international level as dictated in Agenda 21, with a clearly defined objective in 1992 (Lai et al. 2008).

Sustainable urban water management requires an inter-connection between the key design elements, particularly in relation to energy and carbon emission, water conservation, environment protection, biodiversity and the associated water scarcity, wastewater flows, and storm water runoff. A trans-disciplinary approach with active community engagement is an essential principle to buffer the impact of climate change, and to accommodate local opportunities and constraints from both physical and socio-economical perspectives.

It has been estimated that over 400 million of the developing world’s population are facing severe water
shortages for the simplest latrines (Khatri & Vairavamoorthy 2007), and the urban fraction will increase to almost 33% by 2025 (Alwi et al. 2011). Unsustainable water management also affects urban communities at a macro-level. Unsafe water and poor sanitation are the primary causes for a vast majority of water borne and primarily diarrheal diseases, that kill at least 1.6 million children under the age of 5 years (WHO/UNICEF, 2006). The health threats associated with inadequate water at the household level, are exacerbated on a larger scale by heavily polluted surface and ground water from unregulated dumping of household and industrial effluents. The significant economic burden caused by the loss of productivity of the workforce and increasing national health care costs, has eventually brought into focus the urgent need for planned action to manage water resources effectively. This integrated thinking should be jointly developed, and translated into a strategic and flexible plan, rather than a blue-print design.

This biographic review was undertaken to address the dynamic pressures, gigantic approaches, and tremendous impacts of urban water management practices on the natural environment in Malaysia. Within this framework, the sustainable concept of constructed wetlands, with the root objective to create greener and healthier cities, integrated with economic viability, social stability, wise uses of resources and nourishing of the environment, was highlighted. The fundamental importance of urban water quality monitoring and application of expert analysis was emphasized. In addition, the benefits, key challenges, multi-disciplinary efforts, and institutional ethics of water resources management are outlined.

WATERFRONTS, URBAN WATER RECYCLING, AND INTEGRATED WATER POLLUTION MANAGEMENT SYSTEMS

Waterfront areas have been an issue worldwide, due to their significant contribution in the historical development of main transportation routes, urban water management, and giving a sense of place through the quality of views, urban form, activity settings, and townscape effects (Bunce & Desfor 2007). From being the major nodes of a city, the riverfronts grew from settlements to trading areas, where many buildings were dilapidated, developed into ports, and signified a morphological development (Vayona 2011). The same situation was experienced in many cities in the Malaysian context. This phenomenon affected the waterfront area, which was once an important place for trading and the birth place of the city, requiring a positive approach for urban water management and recreation for city dwellers. Recently, Shamsuddin et al. (2008) have outlined the current scenario of waterfront development in Malaysia, and its potential for the sustainable city/urban development in the future.

The most prominent example is the Kuching waterfront, which turned the former port area along the waterfront into a recreational promenade. Melaka, which spent a significant amount of money to clean up the river, and constructed the pedestrian walkways along the river, has witnessed a thriving tourism industry in the city. Some other traditional market places along the river or sea can be observed in Kuala Terengganu, Kuching, and Kota Kinabalu. In Kuantan city, the river ceased to play a key role in commercial development, and it became the major feature that influenced the quality of views into and within the city. The river’s presence in Alor Setar, Ipoh, Johor Bahru, and Kangar appears to be a symbiotic relationship between both rural and urban parts of the riverfronts, and distinguishes between the old and historical, and the new commercial parts of the cities. Georgetown, a town built on Penang Island, was a former port ruled by the British for a significant number of years. Kota Kinabalu, a promenade with some recreational and leisure facilities built along the waterfront, provides a direct access to the most picturesque view of the city. In Johor Bharu, the river is considered to be the unique element that runs right through the city center parallel to its major streets and shopping complexes.

Kuala Lumpur is blessed with a river running through the city center which played an important role in the birth of Kuala Lumpur when the new tin mining area was explored. The river was the main lifeline of the city, where trading activities, houses, shops, and markets along the riverfront were developed. The awareness of the importance of rivers was outlined in the early 1990s in the ‘High National Priority’ in Chapter 18, Agenda 21 (Langeweg
Further acknowledgement was highlighted in the National Urbanization Policy, 2006, specifically focused on the conservation of historical buildings, natural heritage sites, and urban water management to achieve sustainability and improve the quality of urban life (Hashim & Rahaman 2005). Findings from the reconnaissance in the waterfront development in Malaysia implicated an impact in the continual management of water pollution, and complemented the balance between urban development with environmental sustainability.

An integrated sewer system with wastewater treatment plant design moves toward better, cost effective, and sustainable urban wastewater management. A conceptual understanding of the process allows the incorporation of operations, which are not only for the conveyance of water and pollutants, but also to obtain the required wastewater and effluent quality (Angelakis & Spyridakis 2013). One of the required tools is the in-sewer wastewater transformations model. Such models must be capable of predicting the changes of organic matter quality with respect to the subsequent treatment works. For this reason, in 2002, the WATS model, a new and validated tool for the in-sewer microbial process simulations was presented, and its application for the integrated sewer and treatment plant design was exemplified (Vollertsen et al. 2002). The concept of the integrated urban wastewater system is depicted in Figure 1. The process proceeds in four phases that are interconnected by mass transfer: bulk water, biofilms, sediments, and the sewer atmosphere. The layout of the intercepting sewer is optimized to meet the requirements of different treatment scenarios. An example of using the model was on wastewater from Taman Sri Pulai, Johor, Malaysia, a catchment which covers 70 hectares, and is occupied by 10,000 residents. At the inlet to the treatment works, 21 wastewater samples were collected at different time intervals, and analyzed within 30 min of sampling. It was seen from the simulations that the design allowed optimization with respect to different variations, with more than 80% of biodegradable organics to be removed. The study demonstrated the applicability of the integrated design in developing countries, with lower economic, construction, and operational cost for the urban wastewater system as a whole.

**Figure 1** The concept of the integrated urban wastewater system (Vollertsen et al. 2002).
Similarly, Mah et al. (2009) have explored a pilot project of gray water treatment for water reclamation, for both non-consumption uses and environmental needs in Kuching city (population 579,900). The philosophy of the project was targeted at lowering the pollutant loads, and diversifying the supply options so as to reduce the dependency on sole sources of water supply. The system was conceptualized as a flow-through system. Gray water, discharged from household appliances, was seen as a valuable resource to be recovered, rather than to be disposed of. The device connected to nine households of single-story detached houses, where constructed wetlands with integrated aerobic filters were adopted (Jenssen et al. 2005).

In the work, the scope to reuse the treated gray water as an integrated part of the water supply system was made with the assistance of a model developed at Wallingford: InfoWorks Water Supply (WS) software. The model calculated 1,335 units of domestic houses in the housing estate, that contained 372 units (27.87%) of single-story terrace houses, 704 units (52.73%) of two-story terrace houses, 127 units (9.51%) of single-story semi-detached houses, and 132 units (9.89%) of two-story semi-detached houses. Such integrated analyses provided an understanding of the current water demands, and the application of available technologies. The water use data of different housing types were analyzed, and the modeling assumptions are depicted in a schematic diagram shown in Figure 2. The hydraulic modeling efforts have shown positive results to save about 40% of the water resources. This has achieved the objective of water supply sustainability, to reduce the pollutant loadings of waterways and rivers, and to facilitate this as part of the urban water supply system, rather than solely as a sanitation system.

Meanwhile, Eisakhani et al. (2011) have investigated the deterioration of the quality of the water in the Cameron Highlands, which plays a vital role in water supply in Peninsular Malaysia. The water has been polluted significantly, due to land clearing for agriculture, excessive use of pesticides and fertilizers, and construction activities in the rapidly developing urban areas. The point source (PS) pollutants were measured by in-situ and ex-situ methods (Eisakhani et al. 2009), while the non-point source (NPS) pollution, originating from urban runoff, construction, hydrologic modification, mining, irrigation return flows, solid waste disposal, atmospheric deposition, stream bank erosion, and individual sewage disposal was identified. An ArcView application has been developed for the assessment of land use, mapping characteristics, spatial distribution of contamination, and estimation of average annual pollutant.

Figure 2 | Schematic diagram of the integrated water supply and ecological sanitation recycling system (Mah et al. 2009).
loads, total nitrogen, total phosphorus, and biochemical oxygen demand (BOD₃).

Results of this assessment showed that urban development constituted the largest pollution load in the watershed, with the BOD₃ load of 1.31 × 10⁶ kg/yr. The study proposed the establishment of a technical advisory services unit, providing advice on soil erosion control, urban water monitoring, and sustainable land use and riparian management. In addition, the integration of extension programs to raise awareness, and facilitate the development of best management practice by government agencies and local authorities for urban water management was recommended.

CONSTRUCTED WETLANDS FOR URBAN STORM WATER MANAGEMENT

Wetland systems have been seen as an economically attractive and energy-efficient form of low-cost alternative technology specifically engineered for water quality improvement, flood control, and production of food and fiber (Khaki et al. 2014). A wetland system fits into the landscape, relying on renewable energy sources, wetland plants, and micro-organisms, which are the active agents in the treatment processes (Wang et al. 2013). A wetland can serve as a wildlife sanctuary to provide a habitat for wetland animals, aesthetically pleasing as an attractive destination for tourists and local urban dwellers, and a public attraction for visitors to explore its environmental and educational possibilities. It also provides a research and training ground for young scientists in this new research and education arena (Nivala et al. 2012). In Malaysia, wetland systems have been designed, built and operated as a significant contributor to storm water management and to emulate functions of natural settings for human desires and needs, which can tolerate both great and small volumes of water with varying contaminant levels (Mishra & Malik 2012). Specifically, wetlands offer the advantages of water storage and peak-flow attenuation, nutrient cycling and burial, metal sequestration, sediment settling, and breakdown of organic compounds with ancillary benefits as recreational facilities and wildlife habitats (Ibrahim et al. 2012).

As early as 2001, Shutes (2001) has illustrated the global trend to introduce sustainable methods of environmental management, and the role of plants for the treatment of urban surface runoff in the Putrajaya Lake, Malaysia. Putrajaya is a new federal government administrative center (consisting of government departments, commercial offices, residential premises, and recreational parks) located in the south of Kuala Lumpur, along the multimedia super corridor, with green space occupying approximately 30% of the land area. In balancing the ecosystem and the future population of Putrajaya, one of the most distinctive features is the development of a lake that covers a total area of 650 ha.

Located in the middle of Putrajaya, the lake provides a landscape feature and varied recreational activities for the population. An important aspect of the lake is the creation of 23 constructed wetlands that filter most of the pollutants in the river water before it enters the lake. The wetlands were designed using a multicell-multistage approach, with different water levels in each cell as the water flows across the wetlands. The bed slope was gradually increased from upstream to downstream to achieve a continuous flow by gravity. Each of the 23 wetland cells is separated by a weir, and 70 vegetation species have been selected, comprising mainly emergent macrophytes (large plants), rheophytes (floating plants), and freshwater swamp species. It provides good flow distribution, maximizes shallow areas required for the successful growth of macrophytes, and facilitates a cost-effective management of weeds and insects. Ultimately, it fulfills the development goal as a self-sustaining and balanced lake ecosystem set in the Garden City of Putrajaya.

Sim et al. (2008) have advanced the study to examine the nutrient removal in three wetland cells at the upper north arm of Putrajaya lake, located at 02°58.02–02°58.53 N, and 101°41.94–101°42.08 E. The water quality was monitored for two separate periods, from October 2001 to December 2002 at bimonthly intervals, and from April to December 2004 at monthly intervals. The water samples were analyzed weekly for chemical oxygen demand (COD), ammonical-nitrogen (NH₄-N), nitrate (NO₃-N), nitrite (NO₂-N), phosphate (PO₄-P), dissolved oxygen (DO), pH, temperature, conductivity, turbidity, total suspended solids (TSS), and total dissolved solids. The field results showed an improvement in water quality, with 82.11% removal for total nitrogen, 70.73% for nitrate-nitrogen, and 84.32% for phosphate, along the six wetland
cells. The findings ascertained the suitability of the selected plant species in a tropical climate.

Similarly, Sidek et al. (2002) have outlined a pilot ecological approach for the sustainable management of urban storm water runoff and water quality. The project was proposed with the following prime objectives: to introduce a new ecological drainage system for private and public buildings, to assess the potential application of integrated ecological drainage systems, to monitor the effectiveness of individual components, to develop a modeling procedure for the analysis, design, and optimization of the integrated systems, to evaluate the cost effectiveness and to provide guidelines on new ecological drainage systems for local use.

The study was conducted in the engineering campus of Universiti Sains Malaysia, which was established in 2001. The campus is located within the Nibong Tebal district at 100° 30.5 N, 5° 9.4’ E, 100° 29.5’ S, and 5° 8.5’ W on Penang Island, Malaysia. As a joint venture with the Department of Irrigation and Drainage (DID), Malaysia, the campus has been selected as the national pilot project for ecologically sustainable urban storm water management in the country. The project integrated the concept of urban drainage best management practices based on the Urban Stormwater Management Manual for Malaysia (MSMA), where the ‘control-at-source’ approach has been adopted.

Generally, the sustainable innovative bio-ecological drainage system (BIOECODS), which covers an area of 300 acres within the campus, is a method of storm water management that implements a series of key components, namely the bio-retention swale, dry pond, wet pond, detention pond, constructed ecological wetland, and recreational pond. In a broader context, the BIOECODS concept is an early attempt to solve three of the major problems commonly encountered in Malaysia, flash floods, river pollution, and water scarcity. This system was designed to combine infiltration, delayed flow, storage, and purification as pre-treatment of storm water before discharging to the constructed wetlands. In combination, these increase the runoff lag time and opportunities for pollutant removal through settling and biofiltration, and reduce the rate and volume of runoff through enhanced infiltration. This development is expected to reduce the surface runoff volumes by 65% and reduce solids, nutrients, and heavy metals loads by 85–100%.

Another study presenting the design and performance of a pilot scale constructed wetland in treating a mild domestic wastewater generated from the Faculty of Engineering, Universiti Putra Malaysia, has been carried out by Katayon et al. (2008). This investigation was directed at determining the effectiveness of constructed wetlands by measuring the influent and effluent quality to obtain an optimum hydraulic retention time for the desired performance. The constructed wetlands cells were built in equal dimensions of 3 × 1.5 × 0.4 m, based on the influent BOD₅, TSS, and nitrate (NO₃⁻) concentrations. Two cells were planted with Lepironia articulata, an indigenous Malaysian plant, commonly known as tube sedge, and one cell was left unplanted.

The constructed wetlands were fed with wastewater generated from the campus, with the influent concentrations for BOD₅, TSS and NO₃⁻ of 150, 40 and 2 mg/L, respectively. These cells were operated at four different hydraulic retention times in two phases ranging from 0.5 to 7 days. The significance of the constructed wetlands in treating domestic wastewater was analyzed using one way analysis of variance. Tukey’s test (p < 0.05) was used to examine the differences between the means, while the effect of hydraulic retention time was investigated using the post hoc test. Results showed that the constructed wetlands were capable of removing 56–77% of COD, 50–88% of TSS, 20–88% of TP, 27–96% of NH₄⁺ and 99% of total coliforms, to meet with the requirement of the river class III standard level.

Meanwhile, Lai & Mah (2012) have investigated the field measurement of a dry pond at Taiping health clinic, Perak, Malaysia that has been functioning well for 5 years. The data were simulated using computer simulations to further explore the functionality of the dry pond, including: storage capacity, variation of infiltration rate, response to rainfall, and drying-up period. The project consisted of a public health clinic and a state-of-the-art environmentally friendly drainage system, designed according to the Urban Stormwater Management Manual produced by the Malaysian DID. The pond has a maximum depth of 320 mm and surface area of 194.62 m², with a storage volume of 51.88 m³, while the pond outlet consists of small aggregate, of 3–10 mm diameter, to facilitate
the infiltration of stormwater from the pond to subsurface detention storage in less than 24 h.

The rainfall and water-level data were collected for a period of 9 months, from July 2009 to March 2010, which included the monsoon season with frequent and heavy rainfall from November to January. Overall, more than five complete data sets, including a 10-year average return interval (ARI) rainfall, were collected for the analysis. The Green–Ampt equation was selected to quantify infiltration, and a public domain storm water management model was employed to execute the underlying mathematics. The maximum capacity of the dry pond was found to be 31.88 m³, and a complete data set, including a 10-year average return interval (ARI) rainfall, were collected for the analysis. The Green–Ampt equation was selected to quantify infiltration, and a public domain storm water management model was employed to execute the underlying mathematics. The maximum capacity of the dry pond was found to be 31.88 m³, and when the depth reached 32 cm, the pond dried up through infiltration in less than 5.5 h. The hydraulic conductivity, \( K \), was 125 mm/h and the suction head was identified to be 55 mm. These results led to a better understanding of the system, and allowed duplication of such drainage design for other dry ponds.

In the same vein, Liew et al. (2012) have conducted research to evaluate the effect of dry detention ponds on water quantity using a numerical modeling approach with InfoWorks Collection System software. The study was aimed to determine the hydrological and hydraulic parameters of the catchment, to analyze the performance of the existing dry detention pond and to assess compliance with design requirements in MSMA. The research site is located at Kota Damansara, Petaling district, Selangor, Malaysia, which is about 10 km from Sungai Buloh, North–South Highway toll. The dry detention pond is an on-line pond which was built in 1996 with an area of 6.55 hectares. The land use within the catchment area was divided into four main categories, bungalows or schools (7.3%), impervious (housing or shops) (43.2%), fields (landscape or open space) (12.3%), and pervious (forest or ponds) (37.2%), with almost 50% being a moderately developed housing scheme.

Hydrological and hydraulic data were collected for model calibration and verification. The necessary data for model development are catchment hydrological parameters, which include the amount of rainfall, catchment characteristics, contour, land use, hydrologic soil groups and soil type, and catchment hydraulic parameters, such as river cross-sections, water level, discharge, and Manning's n coefficient. Rainfall and water level data were obtained from MyTelelogger wireless Short Messaging Services telemetry system, with a rain gauge and an on-site ultrasonic water level instrument. Results indicated that the dry detention pond could attenuate the flow at 40 m³/s and increase the time to peak flow by 40 min for the 50-year ARI. For the 100-year ARI, the detention pond could attenuate the flow at 42 m³/s and increase the time to peak flow by 45 min. Comparison between the existing detention pond and the simulation data strengthened the claim that the urban drainage model provides reliable predictions for the model design, and complied with the requirement for major urban storm water systems.

**URBAN WATER QUALITY MONITORING AND INTEGRATION OF EXPERT ANALYSIS**

Water quality monitoring is the determination of physico-chemical parameters, to provide the representative status of surface water quality, baseline data, standard levels, and assurance of compliance with regulatory requirements (Roig et al. 2014). Urban water contaminants can be broadly categorized into PS and NPS pollutants. NPS pollutants, derived mainly from precipitation, soil erosion, accumulation, atmospheric dust, fertilizers, pesticides, and direct discharge of pollutants, are more difficult to be controlled, planned and measured (Terekhanova et al. 2014). Storm event samplings and runoff quality analysis are the fundamental tools for estimating the pollutant mass loads in both natural and disturbed ecosystems (Simão et al. 2013).

In this context, Nazahiyyah et al. (2007) have conducted an evaluation to examine pollutant behavior in response to rainfall volume and intensity, and to quantify the pollutant loadings in a residential catchment, located in Skudai, Johor. The catchment is typically a high density low-cost residential area, with a total area of 3.34 ha. Approximately 15% of the catchment is still pervious, while the rest is roofs, pavements, and road surfaces. The rainfall was monitored continuously using a tipping bucket raingauge, while the stream flow was determined by the velocity-area method. One hundred and seventeen runoff samples from 10 storm events were collected on both rising and falling limbs of the hydrograph, between November 2003 and September 2004. The water samples were analyzed for BOD₅, COD, suspended solids (SS), nutrients (NO₃-N, NO₂-N, NH₃-N, ...
and phosphorus) and lead content, according to Standard Methods for the Examination of Water and Wastewater (APHA 1995).

The values of BOD$_5$, COD, SS, NO$_2$-N, NO$_3$-N, NH$_3$-N, and phosphorus were identified to be 72, 325, 286, 2.5, 0.58, 6.8, and 3.4 mg/L, respectively, which was likely due to sediment sources located close to the catchment outlet. Based on the Interim National Water Quality Standards for Malaysia, the storm water quality from the urban residential catchment was severely polluted, and fell into class V water. Meanwhile, the antecedent dry days and the rainfall of the studied area ranged from 21 to 120 h, and from 1.52 to 65 mm, respectively. These pollutographs and hydrographs were different from one storm event to another, with the variations in rainfall intensity, antecedent dry weather period, condition of the sewer system, dry deposits and the accumulation of pollutants. The study encouraged the establishment of a sewer system, dry deposits and the accumulation of pollutants.

Similarly, Ismail et al. (2011) have reported on government efforts to strive for a healthier urban river environment, through the monitoring of Gombak River, a tributary of the Klang River that passes through the populous and important city of Kuala Lumpur, over a period of 9 years from 1997 to 2005. Special attention was given to assessing the state of metal contamination of the river. The water quality data were used to determine the water quality status, whether it is in the clean, slightly polluted or polluted category, as indicated by Class I, II, III, IV or V (Table 1 and Table 2).

Table 2) based on the water quality index (WQI) and Interim National Water Standard for Malaysia (INWQS) on an annual basis (Environmental Impact Assessment (EIA) 2007). Results showed that the pollution status in relation to the concentrations of metals in the river water had essentially remained at the same levels over the study period for all metals investigated. In 1997, the river was classified as Class III based on the water quality parameters, however, in 2005, the river had fallen gradually to Class IV. The study highlighted site monitoring as providing valuable baseline data for identification of status, detectable changes, and control of water pollution.

Since 1978, the Department of Environment (DOE) in Malaysia has initiated the monitoring action on all river basins in Malaysia, involving mainly manual samplings and in-situ measurements. According to the DOE’s 2007 Environmental Quality Report, 158 river basins in Malaysia were involved in this program on a continuous basis (Department of Environment (DOE) 1997). Although a regular monitoring program to provide a complete environmental data set has been established, the calls of appropriate multivariate statistical techniques and exploratory data analysis for data reduction, and interpretation of chemical and physical measurements are highly stressed. Based on the water quality data, the WQI, formed by six selected water quality variables, namely DO, BOD$_5$, COD, SS, ammonial-nitrogen, and pH was developed to evaluate the water quality status and river classification in Malaysia. The values between 81 and 100 are considered as clean, while the values ranging from 60 to 80, and 0–59 are classified as slightly polluted and polluted areas, respectively.

### Table 1 | Water classes based on the WQI and INWQS (Environmental Impact Assessment (EIA) 2007)

<table>
<thead>
<tr>
<th>Class</th>
<th>Uses</th>
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<tbody>
<tr>
<td>Class I</td>
<td>Water supply – practically no treatment necessary. Fishery – very sensitive aquatic species</td>
</tr>
<tr>
<td>Class IIA</td>
<td>Water supply – conventional treatment required. Fishery – sensitive aquatic species</td>
</tr>
<tr>
<td>Class IIB</td>
<td>Recreational use with body contact</td>
</tr>
<tr>
<td>Class III</td>
<td>Water supply – extensive treatment required. Fishery – common, of economic value and tolerant species; livestock drinking</td>
</tr>
<tr>
<td>Class IV</td>
<td>Irrigation</td>
</tr>
<tr>
<td>Class V</td>
<td>None of the above</td>
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</table>
A collective set of data deduced from the monitoring program by the DOE in Malaysia has been reported by Nasir et al. (2011) to assess the contributions of external sources in affecting the water quality in Klang River, Selangor. A precise technique of multiple linear regressions was prepared as an advance tool for surface water modeling and forecasting. Likewise, principal component analysis (PCA) was adopted to simplify the complex relationship between the water quality parameters. In total, 1,105 observations were used for source apportionment and modeling techniques. The 30 water quality parameters consisted of DO, BOD5, COD, SS, pH, NH3-N, dissolved solids, total solids, nitrate, chloride, phosphate, Escherichia coli, coliforms and several heavy metals.

Results showed that the model was accurate for WQI forecasting, with \( R^2 = 0.75 \), indicating that 75% of the variability of the WQI was well explained by the five independent variables used in the model. Urban domestic pollution was the source of most pollution of the Klang River, followed by anthropogenic inputs from the area around the Klang River. The applications of PCA in the model are better than using the original data, because PCA could reduce the number of inputs, and decrease the model complexity. This assessment presented the importance and advantages of using multivariate statistical analysis to improve the large and complex databases, reduce the sampling campaigns, and reduce the cost of reagent used in the analyses.

Water quality monitoring is conventionally conducted by shipboard and laboratory analysis, which is time-consuming, and unable to represent the detail of the distribution patterns of a larger area of river or ocean (Lopez-Roldan et al. 2013). Remote sensing has been proposed as an alternative strategy for water quality assessment, in which the pollution discharged from pipes or open channels could be easily identified. In addition, remote sensing imagery could be carried out to provide a synoptic view for water quality mapping, that can be related to the collected water samples based on the proposed water quality algorithm (Trescott et al. 2013). Accordingly, Yusop et al. (2011) have attempted to determine the water quality in the Penang strait, within the longitudes 100° 15’E to 100° 25’E, and latitudes 5° 15’N to 5° 30’N, using the remote sensing imagery data. The water samples were collected from February 1999 to July 2000. The algorithm for the TSS mapping was examined by Landsat TM imagery, and tested around the water environment of Penang Island. The applied algorithm produced high correlation coefficient, \( R \) and low root mean square, RMS, values, that hinted at its wide applicability to multi-date and other satellite data.

Establishing a water quality monitoring plan is an essential and time-consuming task encompassing various information, data, domain law, expert knowledge and experience to inform project owners, consultants and decision-makers to enable them to make rapid, timely and accurate decisions. The reliability of the monitoring plans could be strengthened by the introduction of supporting expert systems, a computer based system that manages data, information, and the required expertise suited to various tasks associated with water resources management. An expert system control measure, CWQM, developed with Microsoft Visual Basic software to provide educational and decision support has been proposed by Ooshaksaraie & Basri (2011).

CWQM was designed with the objective to minimize river pollution through: identification of selected pollutants with probable adverse impacts, diagnosis of pollution sources, planning action to cope with an indicated problem, and providing advice to reduce pollution (Table 3). This framework simulates the learning, communication and action of a human expert in a given area of science, based

<table>
<thead>
<tr>
<th>Items</th>
<th>Characteristics</th>
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<tbody>
<tr>
<td>Domain</td>
<td>River pollution prevention during construction activities</td>
</tr>
<tr>
<td>Knowledge resources</td>
<td>Textbooks, manuals, research publications, guidelines, expertise</td>
</tr>
<tr>
<td>Knowledge acquisition technique</td>
<td>Interviews with experts, certainty factor</td>
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<td>Knowledge representation technique</td>
<td>Rules</td>
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<tr>
<td>Inference engine</td>
<td>Forward chaining</td>
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<td>Explanation facility</td>
<td>Relation between regulations and expertise analysis</td>
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<td>Development method</td>
<td>Prototype</td>
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<td>Development tool</td>
<td>Visual basic</td>
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<tr>
<td>User interface</td>
<td>Visual basic</td>
</tr>
<tr>
<td>Objectives</td>
<td>To help in preventing river pollution from construction sites</td>
</tr>
</tbody>
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on expert knowledge, lowest cost, highest efficiency, durability, and availability of technical expertise. In developing CWQM, a few meetings were organized to consult experts from universities, DOE and consultants. The diagnosed critical factors including experience and associated regulations, law and evaluation processes were considered to construct the decision model, and subsequently to develop the inference engine. The interface utilizes geographic information system functions as a supportive component to display spatial maps for visualization of water quality monitoring stations, and it enables users to enter information for the inference mechanism and results. The developed CWQM was tested and evaluated in a variety of scenarios, and the test outputs at each stage were checked, validated and revised. The feasible use of CWQM is likely to offer beneficial mitigations in decision-making and reduction of storm water pollution.

ENVIRONMENTAL BENEFITS, MULTI-DISCIPLINARY FRAMEWORKS AND INSTITUTIONAL ETHICS OF WATER RESOURCES MANAGEMENT

The potential benefits of urban rivers quality improvement have been previously described by Bradley (2010). The quantifying benefits in developing countries were discussed with particular reference to the Klang River as a case study. The Klang River drains an area of 1,288 km² from its headwaters in the rain forests of the main Central Range along Peninsular Malaysia to the river mouth in Port Klang. The river basin is the most densely populated area of Malaysia, with a population approaching 4 million people, about 20% of the nation’s population. The average BOD₃ levels of the capital are typically 5.0–7.0 mg/L, with TSS varying over a wide range of 40–80 mg/L, from erosion during heavy rain.

Following the implementation of clean-up projects and upgrading strategies that established a number of discrete sub-regional wastewater treatment plants, the polluted Klang River has been improved gradually to support different fish and fresh water prawn species, and it enables the river to be used as a renewable resource for direct abstraction for municipal, industrial or agricultural water supply. In addition, a clean environment could reduce the exposure to illness and disease, and make Malaysians and tourists aware of the attractions of waterways for recreations such as sport fishing, walking and jogging along the riverside paths. The impact of water quality was also measured as an effect on investment land and property values, which is a common parameter of indirect use benefits. The use and non-use benefits of urban water quality improvement are listed in Figure 3.

Water shortage in Selangor state and the federal territory of Kuala Lumpur is not a recent issue in Malaysia. In 1998, a serious water crisis occurred in the Klang Valley, Malaysia when the three reservoirs, Klang Gates Dam, Batu Dam, and Semenyih Dam suffered a substantial drop in water level. According to the government of Malaysia, the water consumption of the domestic, industrial and agriculture sector was 53 million liters per day in 2000. By 2050, the total water demand is expected to reach 4,160 million liters per day (Economic Planning Unit (EPU) 2006). Therefore, an effective management of water resources requires an appropriate institutional framework, clear policies, effective plans, and full participation from various stakeholders. Meanwhile, the current institutional framework for urban water development has been outlined by Tan & Mokhtar (2009).

Pahang River Basin, made up of a catchment area of 27,000 km², with longitude of 101° 30'E-105° 30'E, latitude 3° 00'N-4° 45'N, has been chosen as the study area. The river consists of five sub-basins, Pahang River Basin, Bertam River Basin, Bekapor River Basin, Mentiga River Basin, and Bera River Basin. With a population of 935,750 in 2000 (Statistic Department Malaysia 2004), the state has been experiencing heavy immigration due to the pull factors of economic development and, particularly, the launching of new land schemes by the Federal Land Development Authority Malaysia. This socio-economic change has brought forward pressure on water and land resources.

The study was conducted by background literature research, mainly national development policies, local development plans and water related provincial laws, and field surveys with 20 officers from water related technical government agencies, and 150 local individuals. Generally, the assessment is addressed by sectoral policies such as the National Policy on Urbanisation 2005, National Policy on the Environment 2002, National Policy for Biodiversity 1998, and National Policy for Forestry 1987. The concept of conservation has been further integrated in the Environmental Quality Act (EQA) 1974,
and enactments of federal laws (Table 4). The survey revealed that although there is comprehensive legislation and guidance related to water resources, the provision of integrated action plans is necessary.

The National Development Planning Committee, National Physical Planning Council, and National Action Council should be formulated as a monitoring body for any water related projects at federal level. Aligned with national development, the private sector, non-governmental organizations (NGOs), and community based organizations were encouraged to participate in consultations for water sector development. This will provide collaborative

Table 4 | Statutes established to address water management and other resource issues in Malaysia (Tan & Mokhtar 2009)

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<th>Management Issue</th>
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<td>Water and river protection</td>
<td>Water Act (1920); F.M.S. Silt (Control) Enactment (1922); Drainage Works Act (1954); Street, Drainage and Building Act (1974); EQA (1974), Local Government Act (1976); National Parks Enactment (1939); National Forestry Act (1984); Forestry Enactment (1985); Mining Enactment (1926)</td>
<td>Water Supply Department, DOE, Department of Irrigation and Drainage, Local Authority, Town, and Country Planning Department, Forestry Department</td>
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<td>Land and soil</td>
<td>Mining Enactment (1929); Land Conservation Act (1960); National Land Code (1965); Street, Drainage and Building Act (1974); Town and Country Planning Act (1976)</td>
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<td>Water services</td>
<td>Water Act (1920); National Water Services Industry Commission Act (2007); Water Services Industry Act (2007)</td>
<td>Sewerage Services Department, Water Supply Department</td>
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decision-making in preliminary water resource planning within the national development plan. These committees and institutional frameworks need to be established permanently to translate the federal policy into the state and local plans. Ultimately, an integrated approach in water resources management, which requires full participation and commitment from consultations to involvement, was strengthened through a joint management concept.

The development of ‘water ethics’ in the management of water resources has been an emerging topic, initiated by the World Commission on the Ethics of Science and Technology and the International Hydrology Program. This core principle identifies the aspects of solidarity, equality, common good, stewardship, transparency and universal access to information, inclusiveness and empowerment as immediate mitigation initiatives to the problem of river pollution (Liu et al. 2011). Accordingly, the environmental ethics in the management of urban rivers has been outlined by Moorthy & Jeyabalan (2011).

The research employed the case study of Malaysia’s Gombak River, one of the most polluted urban rivers which flows through several urban centers in the locality of the capital Kuala Lumpur. The water quality along the river was assessed by a series of scientific tests taken from five points on 5 consecutive days from 26–30th January 2009. A qualitative approach was gathered through expert interviews with several key informants from the Drainage and Irrigation Department (DID), DOE, and Selayang Municipal Council, who were involved in environmental protection. The interviews solicited respondents’ impressions, interpretations and opinions regarding agencies’ roles in river management, and the issues pertaining to inter-agency coordination. Feedback from the interviews suggested lack of awareness and sluggishness in the enforcement of legislation and mitigation efforts against river water management. Inter-agency communication and coordination has been cited as a holistic approach to water resources management. The study embarked on cohesive measures to inculcate an ethical grounding on river water management, by considering the elements of human dignity and society participation, that will assist in the preservation of rivers and their ecosystems for the continual use of future generations.

A similar opinion has been expressed by Jahi et al. (2009), who suggested the inclusion of non-legislative measures for the management of water resources. An example of the multi-disciplinary framework in environmental management (Figure 4) has been proposed, as
depicted by the conservation of habitat and species diversity (biosphere), air pollution (atmosphere), water pollution (hydrosphere), and land pollution (lithosphere). This management requires knowledge of culture, socio-economics, environmental education and ethics to control human actions, a concrete relationship between the federal and state authorities, the support of NGOs, funding for research and development, mass media involvement, and public participation. The authors suggested the formulation of an environmental master plan, with agreement between federal and state governments, under the purview of policies, laws and planning toward creating an integrated environmental management system.

Public-public partnerships, developed between the public water operators, communities, trade unions, and other key players, are an important tool to ensure the good governance of water management systems (Voleta 2002). Public participation is the process by which public concerns, needs, and values are incorporated into governmental and corporate decision-making (Creighton 2005). It is a two-way communication and interaction, with the overall aim of better decisions that are supported by the public. Public participation can be seen as a process for dividing or sharing the power, particularly in the decision-making process to fulfill unique needs from different groups, to target resources more effectively and efficiently, to develop skills and build competency and capacities within communities, and offer new opportunities for creative and innovative planning and development (Dulc et al. 2013). Therefore, the public participation program should be accentuated by the practitioners, at different levels, from manipulation to therapy of community, consultation, and full participation. Public participation is effective when it is both functional for planning and meaningful to the stakeholders. Functional for planning indicates a better decision through community plans, while meaningful participation could be achieved when the public is given opportunities to influence the ultimate decisions (Kamariah 2006). The public referred to here is not only private citizens, but also representatives of consumers, environmental departments, trade, industrial, agricultural and labor organizations, professional societies, civic associations, public officials, and educational institutions. In Malaysia, the degree of public involvement is disappointing, a reflection of low awareness and ineffective public participation in the planning process (US Environmental Protection Agency 2002).

Meanwhile, the preservation of water quantity has evolved to be a major component of the sustainable management of urban stormwater, water catchments and runoff (Bai et al. 2013). In Malaysia, streams and rivers contribute approximately 98% of the total water use over the country. There are 47 single purpose and 16 multipurpose dams, and more than 150 river systems, with total water storage of 25 billion m³. The annual rainfall amounts to 990 billion m³/yr, with 566 billion m³/yr appearing to be surface runoff and 64 billion m³/yr as groundwater recharge (Lee 2007; Water Resources Management & Hydrology Division, Department of Irrigation & Drainage, Ministry of Natural Resources & Environment Malaysia (DID) 2009). Therefore, universal water access has almost been achieved in most urban and rural areas all over the country. The planning, development, and management of water resources comes primarily from the state governments and their agencies. These institutions are responsible for the specific implementation of water resources management plans (Azhar 2000). A summary of the unique functions of the major departments and agencies is given in Table 5.

Within the framework, much of the responsibility for water resources assessment falls on the shoulders of the DID, which provides a wealth of hydrological information, including rainfall, river levels, stream flow, evaporation, and water quality. The efforts of DID in water data collection and water resources management have earned recognition from international agencies such as the United Nations Organization for Education, Science and Culture, the World Meteorological Organization, and the Economic, and Social Commission for Asia and the Pacific (Chan 2004). At the national level, the federal government is moving toward greater involvement in the management of water resources and water supply services. The National Water Resources Council (NWRC) was set up in 1998 to pursue more effective water management, including the implementation of interstate water transfers (Sukereman et al. 2013).

In 1999, a guideline entitled ‘Guidelines for installing a rainwater collection and utilization system’ was circulated to developers and relevant agencies. This guideline documents some of the ways in which rainwater can be
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<th>Water supply</th>
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collected from roofs of buildings, and the practical utilization of rainwater. In June 2002, the government imposed a condition for the installation of 6-liter toilet flushing systems in new buildings. The program of reducing non-revenue water (NRW) and rehabilitation of water treatment plants and distribution pipes is an on-going program in every 5-year development plan (Zaharaton 2004). The first step toward Integrated Water Resource Management (IWRM) in Malaysia was realized with the formation of Selangor Water Management Authority, commonly known as LUAS, with the aim of adopting IWRM at the river basin level within the State of Selangor. LUAS is a one-stop agency set up for the regulation, monitoring, planning, and conservation of river resources in an integrated manner (Chan 2000).

Another good example is the Sarawak Rivers Board (SRB), with the main objective of formulating a master plan for the integrated development of Sarawak water supply. SRB is not only concerned with water resources, but also with irrigation, transport, power, recreation, tourism, and environmental conservation. In addition, the programs on river rehabilitation were undertaken on selected rivers for pollution abatement and water quality improvement (Keiz run 2002). The Klang River Clean-Up Program is a key feature which involves construction, maintenance and desilting activities, education and beautification program, relocation of squatters, rehabilitation of aquatic life, treatment of animal waste, and water pollution control (Chan 2005). Increasingly, the government is encouraging a more comprehensive approach balancing both supply and demand management, where civil society, NGOs and local communities are allowed to play greater roles in the water industry, for better economic development, poverty eradication, and improvement of quality of life (Chan 2004).

Despite such encouraging figures, water stress, and water cuts continue to plague many parts of the country, specifically in the high-density cities where water consumption is high. Changing weather patterns, high-NRW, wastage, pollution, sedimentation, public apathy, and a lot of poor governance have seriously depleted the water resources, notably during the El Nino in 1997/98 and in early 2002. This has manifested itself in an ugly way to exert a heavy toll on the environment and human populations. Traditionally, the management of water resources in Malaysia is largely fragmented and placed under the responsibility of a large number of departments and agencies, each managing a distinct component with little interaction or coordination. This fragmentation has been recognized as a major obstacle for the effective management of water resources. One answer to the above dilemma is the integration of departments encompassing the relevant disciplines throughout the whole development cycle, from planning, design, to implementation, operation, and management (Chan 2002).

In general, water governance is not merely a case of managing water resources, either by government, the private sector or any other institutions. It refers to the range of political, social, economic, and administrative systems that are in place to deliver water services at different levels of society (Chan 2009). Water governance comprises the mechanisms, processes and institutions, to articulate the priorities, exercise the legal rights, meet the obligations and mediate differences in relation to water. Good governance is epitomized by predictable, open and enlightened policy-making, a bureaucracy imbued with professional ethos acting in furtherance of the public good, the rule of law, transparent processes, and strong public participation (Santiago 2005). Water governance in Malaysia is largely based on a top-down approach. This top-down approach has been proven to be ineffective, with the absence of a clear-cut National Water Resources Policy for the sustainable development of water management strategies. Another area to ensure better governance is the active engagement of stakeholders, committed to professional training, public service, and excellent integrity in the water sector (Karamouz et al. 2004).

In terms of legislation, there are sufficient laws for the protection and conservation of freshwater supply; unfortunately, loose enforcement is a major obstacle leading to poor implementation. In addition, the social principles of water management, the rights and responsibilities of states, the private sector and individuals have not been thoroughly outlined. The ‘Privatization Policy’ was mooted by the fourth Prime Minister, Dr Mahathir Mohamad in 1983. This introduction has saved RM132.16 billion and RM7 billion in capital and operating expenditure, respectively. Privatization, according to the principles of the national privatization policy, should be a catalyst in kick-starting the economy, and organized in a transparent, accountable,
and sustainable manner. Arguably, the majority of these water works departments, water corporations and departments involved with managing water are not as effective as they ought to be, as testified by their susceptibility to water stress (Chan 2009).

Another problem is the high domestic water usage per capita. In the 1970s, Malaysians used less than 200 liters of water per capita per day (LPD). During the 1980s, the figure rose to 250 LPD, and later to more than 300 LPD. In urban areas, the LPD value has exceeded 500 (Renganathan 2000). The general consensus to explain this phenomenon is the low water tariffs in Malaysia, which inadvertently encourage water abuse and wastage. Water conservation through improved water-use efficiency and wastage minimization schemes for all users, including the development of water-saving devices, is a significant sector that needs greater focus and emphasis. Furthermore, the establishment ISO14000 certification is not mandatory for large water users, such as industries and hotels. Consequently, there are huge gaps between integration and cooperation at all levels: government, the public sector, NGOs, industry, and the general public (Chan 2004).

CONCLUSION

The commencement of the 21st century represents a global pressure brought about by the tremendous impacts of climate change, rapid urbanization, population growth, depleting water supplies, and the natural environment. A couple of policy recommendations, regulatory and institutional arrangements, and appropriate water saving and wastewater reuse technologies have been addressed in respect to the resurgent need for sustainable water resources management. In Malaysia, specific focus has been emphasized on the establishment of waterfronts, urban water recycling, and incorporation of swales, bio-retention systems and constructed wetlands for the treatment of storm water prior to discharge to the receiving streams. This strategy promotes the implementation of expert analysis and water quality monitoring systems as a potential solution to these urban water challenges. Although it is in its infancy, more integrated actions should be pursued systematically to underpin inter-agency collaboration, public engagement and innovation, which are paramount toward building a sustainable future.

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REFERENCES


Bunce, S. & Desfor, G. 2007 Introduction to political ecologies of urban waterfront transformations. Cities 24, 251–258.


