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Advancing stormwater management practice in Iran using water sensitive urban design approach

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More than 350 cities of Iran are subject to floods every year and flood phenomena cause annual 1,500,000,000,000 Rials loss to Iran. The reason for floods lie with lack of appropriate water management systems in terms of stormwater management. Current status of Iran water management calls for imitating the successful experience of other countries. The aim of this paper is to review better management frameworks for urban water management in regard to stormwater management in outstanding countries. In this paper, the concept of Water Sensitive Urban Design (WSUD) is initially reviewed, then the proposed frameworks of stormwater management in the world are reviewed and the initiatives associated with stormwater management are offered. Finally, an implemented case of Malaysia is studied to verify the use of initiatives in real similar scales. Among several variables in regard with stormwater management, three types of objectives are highlighted and two evaluation criteria are propsed. Analysis of the results is conducted based on proposed evaluation criteria. Result of the Analysis of the Putrajaya Stormwater Management System shows a remarkable contribution of WASUD initiatives in mitigating the stormwater in this city. Due to geometrical similarities of this city with Iranian ones, results show a great potential of employing WSUD initiatives in Iran.

Key words: Resource water management, Water Sensitive Urban Design (WSUD), sustainable management, Putrajaya stormwater management, water management criteria.

INTRODUCTION

In every year, more than 350 cities of Iran are subject to floods. The flood phenomena cause 1,500,000,000,000 Rials loss to Iran every year and in the recent years 70% of the annual credit of mitigation of natural disasters is devoted to combat the losses of floods (Organization of Geology and Mining Explorations, 2011; Iran Ministry of Energy, 2011). Likewise, Malaysia suffered from a loss of 300 Billion Dollars annually (Eighth Malaysian Plan, 2008). Many reasons account for the causes of floods, such as area's geographical location, old, poor, inadequate or insufficient drainage systems, and in particular surface drainages. Following the widespread realisation of the significance of climate change, urban communities are increasingly seeking to ensure resilience to future uncertainties in urban water supplies (Rutger, 2009; Iran Ministry of energy. 2011; Eighth Malaysian Plan, 2008). Both Iranian and Malaysian governments suffer from similar flood causes, despite insurmountable differences between their geographical aspects. Despite the efforts of Iran government to improve the reliability of water supply systems, enhancement is still unsatisfactory which arises from lack of a comprehensive guidelines nor practical samples of other countries for this purpose. Studying the course of action that Malaysia took

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in an effort to meet this problem is a good help to Iran floods problem.

WATER SENSITIVE URBAN DESIGN (WSUD)

Tony (2007) declares that the words ‘water sensitive’ define a new paradigm in integrated urban water cycle management that combined the various disciplines of engineering and environmental sciences associated with the provision of water services, including the protection of aquatic environments in urban areas. Water Sensitive Urban Design (WSUD) integrates the social and physical sciences. The inter-government agreement on a National Water Initiative defines WSUD as “the integration of urban planning with the management, protection and conservation of the urban water cycle that ensures that urban water management is sensitive to natural hydrological and ecological processes”. Andrew and Grace (2000) asserted that sustainable water management leads to WSUD and it encompasses the integration of a number of levels in many different measures that have a range of suitable applications, resulting in many different realisations of this concept, depending on the site-specific conditions of the location. Mohamed et al. (2010) determined the environmental impacts of traditional urban water systems which are shown in Table 1. Table 2 indicates the differences between elements of conventional and sustainable water management and WSUD. Effective management of stormwater is being the principal focus of WSUD (Wong, 2006). WSUD espouses the need to integrate stormwater management into the planning and design of urban areas and applies across the entire spatial scale from a catchment-wide regional level to the precinct level to the local, building level (Wong, 2006; Thomas et al., 1997; Ecological Engineering, 2003; Australian Runoff Quality, Australia). Benefits of implementation of stormwater management initiatives are shown in Table 3.

PROPOSED FRAMEWORKS AND INITIATIVES OF STORMWATER MANAGEMENT

Andrew and Grace (2000) in their research, proposed new concept of stormwater management throughout a new water management approach. This concept, which is known as integrated urban water cycle, proposes the treatment of the development water in three steps of blackwater, greywater and stormwater before releasing the wastewater into the sewage system. In their method, balckwater, greywater and stormwater are stored in a pond and will receive treatment in order to recycle and reusing purpose. The remaining of each stage is released into the next stage and eventually sewage. This proposed model is very rudimentary one and therefore suffers from lack of detailed techniques and variety of initiatives. In 2002, Australia announced its guideline of water sensitive urban design and through the guideline; they proposed the scheme of WSUD to be implemented in the city of Australia. The guideline proposed to integrate three types urban water cycle including potable water, stormwater and wastewater and conservating, managing and minimising them respectively throughout recycling, reusing and recovering techniques. Despite sound solutions, the implementation required more advances in terms of administrative measures rather than only technical means (Australian Environmental Water Management, 2012). Gardner (2003) proposed healthy home initiative. In this framework, the focus is to manage water at consumer point as far as possible. The precipitation entered to the home will receive several treatments from the very first point. Rainwater is initially collected from the roofs and is sent to a tank located at the basement of the home and after undergoing disinfection by radiation of UV, it will be sent to home for use. The return water of this water is then stored in the greywater treatment tank and subsequently, this greywater is used for irrigation purposes and finally it is discharged to the sewer. In this method, focus is using the rainwater as the main source of water use and the urban water is assumed to be a supplementary for special circumstances. Despite its high efficiency in controlling stormwater management, this framework has several drawbacks. It takes a long time for implementation and also it is a costly method which is unjustified in small scales. Moreover, it can be implemented in those areas with high rate of precipitation and other areas with less rain amount cannot use this method expecting high efficiency. Brown et al. (2009) proposed a framework for stormwater management towards achieving water sensitive city. Their proposed model is based on providing water supply security, public health and flood protection, social amenity, considering natural resources and climate changes by by separating sewerage schemes, providing drainage channelisation, point and diffuse source pollution management, waterway protection and fit-for-purpose source scheme, multi-functional infrastructure and public awareness. Although their framework was comprehensive and covered the shortcomings of the previous proposed frameworks, it did not vividly point out the appropriate measure for every single step of water management. Singapore has proved itself as a premier country in sustainable stormwater management recently. Singapore’s framework, which is called ABS water framework, consists of three major categories: regulatory and administrative framework, technology development and industry capacity. According to this framework, a water management initiative is not implemented unless the requirements of these three categories are met consecutively. The first category comprises policies in regard with using reservoir, catchments precinct and regional stormwater management and compliance validation. The second category involves R&E activities and at the third category

Table 1. Environmental impacts of conventional urban water systems.

Impact	Description	Urban water relation
Carcinogens	Damaging human health	Heavy metals in effluents
Climate change	Temperature variation, sea level changes	Waste water emissions (Greenhouse Gas)
Eco toxicity	Eco toxic substances damage air, water and soil	Eco toxics exist in wastewater
Minerals and fossil fuels	Gradual depletion of minerals	Water treatment requires consumption of minerals
Respiratory organics	Pollutants cause respiratory disease	Water treatment substances include respiratory organics
Eutrophication and acidification	Deposition of inorganic substances will damage environment	Substances in water or waste water treatment are subjected to acidification
Ozone layer	Ozone layer depletion	Water and waste water treatment substances affect ozone
Land use	Land cover changes affects ecosystem	The urban water infrastructures change landuse

Table 2. Differences between elements of conventional and sustainable WSUD water management (Peter et al., 1996).

Comparison of conventional and sustainable water management practices in different categories		WSUD
Water supply		
Conventional	Scheme water in standard fashion and groundwater bores for POS	The integrated management of the three urban water streams of potable water, wastewater and stormwater.
Sustainable	Supplemented by community groundwater schemes as a secondary supply for all outdoor use in households and for POS	
Water conservation		The integration of the scale of urban water management from individual allotments and buildings, to precincts and regions.
Conventional	Neither interior nor exterior water conservation devices	
Sustainable	Application of low water use applications and technologies	
POS		The integration of sustainable urban water management into the built form, incorporating building architecture, landscape architecture and public art.
Conventional	Design dominated by high water use plants	
Sustainable	Design based on WSUD techniques	
Sewerage		The integration of structural and non-structural sustainable urban water management initiatives.
Conventional	Standard reticulation systems	
Sustainable	Full recovery of water used in POS rather than direct linkage to main	
Stormwater		
Conventional	Large sums and piped systems	
Sustainable	Application of WSUD and BMP concepts	

technical requirements as well as training requirements are encompassed. Framework of stormwater management in city of Oslo in Norway encompasses a series of conditions and procedures in which treat water from the source to sewage. In this framework, water treatment is initially checked in order to comply with the elements of boundary conditions (Economic, social and environmental considerations) and control the performance within the boundary condition. In simpler terms, all management initiatives must be economic, social and environmental friendly so that they can yield a number of positive results. At the first stage of this framework, water is treated through the water supply and source point. Then water pipes and distributors are monitored and improved. Then wastewater of the consumer is managed and subsequently drainage systems are managed for reusing or recycling purposes in following stages. This framework however, is based on implementation of technologies in every stage for water management (Venkatesh and Helge, 2011).

EVALUATION CRITERIA

Basically, among several variables in regard with stormwater management, three types of objectives are highlighted: common good interests, sectoral interests and operational interests. Table 4 shows these interests and the associated objectives. As indicated in this table, objectives are of varying importance and each variable has its own weight. The objectives are ranked in order of importance. The highest achievable weight is absolute.

Table 3. Benefits of implementation of WSUD and its initiatives in outstanding countries.

Benefit	Amount (Or Rate)	Reference	Benefit	Amount (or Rate)	Reference
Wastewater amount reduction	50%	Andrew and Grace (2000)	Urban water management	40% Optimization	Seong-Rin et al. (2010)
Stormwater management	Twice faster				
Water consumption reduction	25% Reduction per capita	Gardner (2003)	Rainfall effects and mitigation	80% Mitigation	Burns et al. (2011)
Total suspended solids	80% Reduction	City of Melbourne WSUD guideline (2008)	Source control practices	More attractive than traditional water supply and stormwater infrastructure	Coombes et al. (2000)
Total nitrogen	45% Reduction				
Phosphorous amount	45% Reduction				
Litters of urban water	75% Reduction				
Green-house emission	2 To 4 times less than conventional ones				
Life cycle environmental impacts	40% Reduction	Fagan et al. (2010)			
Ecological footprint	Negligible impact				

Therefore the traditional water management system will convert from an ordinary system to a resilient system which is interpreted as Tony (2007):

i) The amount of disturbance the system can absorb and still remain within the same state;
ii) The degree to which the system is capable of self-organisation (versus lack of organisation, or organisation forced by external factors); and,
iii) The degree to which the system can build and increase the capacity for learning and adaptation.

Resilient system leads to a water sensitive city with following characters: (Tony and Rebekah, 2000):

(i) access to a diversity of water sources underpinned by a diversity of centralised and decentralised infrastructure;
(ii) provision of ecosystem services for the built and natural environment; and
(iii) A socio-political capital for sustainability.

The use of weights allows determining the PI on the basis of satisfying the objectives set. Equation (1) presents the overall structure for determining the PI during dry weather and storm events.

$$\mathrm{PI}_c = \sum_n O w_o, \quad \sum_n w_o = 1, \tag{1}$$

in which, PI: dimensionless performance index; c: system loading condition (dry weather or storm event); n: number of objectives; O: objective; W_o: weight of objective O. Satisfying objectives can be determined on the basis of meeting requirements, expressed in terms of water-system variables. Again, weighting is possible at this level. Subsequently, meeting the objectives O can be determined, using Equation (2):

$$O = \sum_m I w_I, \quad \sum_m w_I = 1, \tag{2}$$

in which, O: ratio of meeting objective; m: number of performance indicators; I: performance indicator; WI: weight of indicator, I.

CASE STUDY

City of Putrajaya is located at about 25 km south of Kuala Lumpur, the capital of Malaysia, and is anticipated to accommodate a population of 330,000. The centre-piece of the city is an artificial lake surrounded by 20 planning precincts. The primary goal of the stormwater management plan is to facilitate coordinated management of stormwater within each development precinct of Putrajaya to maximise

Table 4. interests of objectives and associated priority.

Interest	Priority	Description	Weight
Flood prevention (Common good)	1	Secure health and safety of people	Absolute
	2	Reduction of flooding material loss	Absolute
Ecology/nature/water recreation (Sectoral)	3	Reduction of pollution of surface water, canals, ponds and main rivers pollution, discharge of WWTPs	10 to 30
Water management (Operational	4	Reduction of operation cost	1
	5	Reduction of sedimentation	
	6	Reduction of odour problems	

ecological sustainability, mitigate development impacts, minimise the potential for future impacts, enhance water sensitive urban design principles, maximise social and economic benefits using sound stormwater, Enhance aesthetic and ecological values into stormwater management infrastructure and provide opportunity for the community to gain an appreciation of water as essential element of the urban environment (Angkasa, 1996). Principal features of Stormwater Management System for City of Putrajaya is based on Integrated strategy, meaning that, the stormwater management strategy is based on the philosophy of Avoiding pollution whenever possible through source control measures, Controlling and minimizing pollution by means of in-transit and end-of-pipe control methods where pollutant generation cannot be feasibly avoided, Managing the impacts of stormwater pollution by managing receiving waters and their appropriate utilization as a last resort (Angkasa, 1999). Structural measure include four major steps: 58 km of trunk main for drainage conveyance system, planting of macrophytes in wetlands and riparian parks for aesthetic perspective, 300 gross pollutant traps for water quality control system, and integration of 400 ha lake and 7 detention basins for stormwater detention system. Non-structural measure also comprise of Source controls, In-transit controls, and end-of-pipe controls. Seven measures taken into account of source control are: Community awareness, Landuse planning and regulation, construction sites management, Isolation of high pollutant source areas, Permissible discharge, Street cleaning and Sewerage management. In the second level (In-transit controls) measure consist of: detention basins, swale drains and GPTs. Two types of GPT initiatives are used including Closed GPTs: enclosed units used for underground drains and Open GPTs: open systems used for open channels. End of pipe measure include Reparian parks, lake and wetlands, submerge outlets (Angkasa, 1996; Angkasa, 1999). The result of implementation of the initiatives are evaluated by the method porposed by Johannes and Arnold (2002). Their proposed method was used to evaluate the urban water drainage system of Rotterdam city, Holand (Johannes and Arnold, 2002). The results for City of Putrajaya show a great conformity with expected results of a stormwater management system, with negligible discrepancies. Other countries enjoyed similar results of implementation of stormwater management initiatives as malaysia enjoyed, as shown in Table 5. Results of the case study of Malaysia have shown a great potential of desirable effect on the water management system (Putrajaya Wetlands Book, 1999).

RESULTS AND DISCUSSION

In this study the environmental impacts of conventional urban water systems were pinpointed which necessitates the need for new water practices. Followingly, the concept of WSUD was discussed and the differences between the WSUD and conventional systems were highlighted. Proposed Frameworks and initiatives of WSUD in regard to stormwater initiatives, which were implemented in different countries shows a wide range of benefits in terms of water management practice. The case study of city of Putrajaya in Malaysia, using the most important criteria in this study, showed a remarkable contribution in mitigation of stormwater and towards a sustainable water resource management practice by more than 60% runoff and pollutant mitigation as well as flood occurrence likelihood. However, the country of Iran has several similarities with Malaysia in terms of flood threats. Although there are major differences in location and topography features of these two countries, imitating general features of Malaysian management scheme will yield similar positive results in Iran as well. Critical issues in regard with water management practices and also critical issues on selecting the practices are similar in both countries and therefore using the exerience of Malaysia in the same field is a sound and wise decision. However, it must be considered that the essential prerequisites of WSUD, such as Regulatory Framework; Assessment and Costing; Technology and Design; and Community Acceptance and Governance must be taken into account first. Meanwhile, implementation of WSUD initiatives require integration with construction practices where many constructed projects have faced problems caused by a combination of poor engineering water design and

Table 5. Result of the analysis of the Putrajaya Stormwater Management System.

Objective	Description	Priority	Achievement		
Flood prevention	Secure health and safety of people	1	Absolute	Runoff water detention	60% of runoff is intercepted by Wetlands
	Secure safety of asset	2		Flood occurrence likelihood	70% enhance
Ecology and water recreation	Surface water pollution reduction	3	Satisfactory	Acceptable quality of water runoff entered to lake	Enhancement from ordinary <7% to 40% of total runoff
	Canals and ponds			Total area drainage	51.9 Km^2
	Rivers			Pollutants controls including: rubbish, debris, suspended sediment	
Water management	Reduction of cost of operation	4	Satisfactory	Nitrogen	60% reduce in the pollutants
	Sedimentation reduction in sewers	5		Oil, grease and oil derivatives	

construction practices.

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