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Review

Assessment of stormwater runoff management practices and governance under climate change and urbanization: An analysis of Bangkok, Hanoi and Tokyo

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ABSTRACT

As human history is changing on many fronts, it is appropriate for us to understand the different perspectives of major global challenges, of which, water is a major priority. The water resources in urban areas are either approaching or exceeding the limits of sustainable use at alarming rates. Groundwater table depletion and increasing flood events can be easily realized in rapidly developing urban areas. It is necessary to improve existing water management systems for high-quality water and reduced hydro-meteorological disasters, while preserving our natural/pristine environment in a sustainable manner. This can be achieved through optimal collection, infiltration and storage of stormwater. Stormwater runoff is rainfall that flows over the ground surface; large volumes of water are swiftly transported to local water bodies and can cause flooding, coastal erosion, and can carry many different pollutants that are found on paved surfaces. Sustainable stormwater management is desired, and the optimal capture measure is explored in the paper. This study provides commentary to assist policy makers and researchers in the field of stormwater management planning to understand the significance and role of remote sensing and GIS in designing optimal capture measures under the threat of future extreme events and climate change. Community attitudes, which are influenced by a range of factors, including knowledge of urban water problem, are also considered. In this paper, we present an assessment of stormwater runoff management practices to achieve urban water security. For this purpose, we explored different characteristics of stormwater runoff management policies and strategies adopted by Japan, Vietnam and Thailand. This study analyses the abilities of Japanese, Vietnamese and Thai stormwater runoff management policies and measures to manage water scarcity and achieve water resiliency. This paper presents an overview of stormwater runoff management to guide future optimal stormwater runoff measures and management policies within the governance structure. Additionally, the effects of different onsite facilities, including those for water harvesting, reuse, ponds and infiltration, are explored to establish adaptation strategies that restore water cycle and reduce climate change-induced flood and water scarcity on a catchment scale.

1. Background

The world's population has reached 7.2 billion, and more people live in cities than in rural areas (UNDESA, 2014). Water is a very critical natural resource for the world's fastest growing urban areas. Commercial, residential, and industrial users already place considerable demands on cities' water resources and supply, which often require water treatment (Bahri, 2012). The demand of water resources in urban areas is approaching the capacity of the water supply and, in many cases, the limits of sustainable water use are being exceeding (Hatt et al., 2004; Mitchell et al., 2003). In some cases, water scarcity is leading to conflict over water rights. In urban watersheds, competition with agriculture and industry is intensifying as cities expand in size and political influence (Bahri, 2012). With industrial and domestic water demand expected to double by 2050 (UNDP, 2006), competition among urban, peri-urban, and rural areas will likely worsen. A critical challenge to newly developed urban cities is design for resilience to the impact of climate change with regards to sustainable management of water resources. It is currently well accepted that the conventional urban water management approach is highly unsuited to addressing current and future sustainability issues (Ashley et al.,

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2005; Wong and Brown, 2008). The conventional approach to urban water systems around the world involves the use of a similar series of systems for drainage of stormwater, potable water and sewerage. As explained by Bahri (2012), the unsustainable nature of this approach is highlighted by the current ecosystem-related problems and degraded environment in urban areas due to changes in the hydrology of catchments and quality of runoff, leading to modified riparian ecosystems (Bahri, 2012). United Nations Agenda 21 (1992) stated that achieving sustainable urban water systems and protecting the quality and quantity of freshwater resources are key components of ecologically sustainable development. Because of climate change and the spread of urbanization, the negative impacts are intensifying, resulting in increasing runoff, pollutant loads and pressure on existing systems, with a significant economic cost required to augment conventional systems. Alternative approaches are required to develop sustainable water systems in urban environments, and Integrated Urban Water Management (IUWM) is one such approach, which views the water supply, drainage and sanitation as components of an integrated physical system within an organizational and natural landscape (Mitchell et al., 2007a, 2007b). It is an integrated system that seeks to reduce the inputs and outputs to decrease the inefficiencies of water resources that are associated with the traditional practices of urbanization (Hardy et al., 2005). Although this incorporation and diversification of urban water systems increase the complexity of urban water systems, they also provide more opportunities to attain sustainable water use and increase the overall water system resilience (Mitchell and Diaper, 2005; Mitchell et al., 2007b). The identified key components of the IUWM system are the methods and measures to capture and utilize urban stormwater. Fig. 1 defines stormwater as precipitation, such as rain or melting snow. In a natural environment, a small percentage of precipitation becomes surface runoff; however, as urbanization increases, the amount of surface runoff drastically increases. Surface runoff is created when pervious or impervious surfaces are saturated from precipitation or snow melt (Durrans, 2003). Pervious surface areas naturally absorb water to the saturation point, after which, rainwater becomes runoff and travels via gravity to the nearest stream. This point of saturation is dependent on the landscape, soil type, evapotranspiration and biodiversity of the area (Pierpont, 2008).

In the urban environment, due to the impervious surfaces that cover the natural environment, the hydrological processes of surface water runoff become more unnatural, causing damage to infrastructure and contamination of water by pollutants (Ragab et al., 2003). The need for stormwater runoff management capture and transportation systems developed as a result of human experiences with various challenges due to destructive floods.

The sustainable stormwater runoff management target is to understand the changes in the urban landscape, in which the addition of vegetation is not widely observed, with the aim of devising approaches to limit certain undesirable effects and to take advantage of the new opportunities (Huang et al., 2007). A sustainable stormwater system is not a system to address runoff problems and avoid unwanted contaminants in the water, but rather, it is a system to increase the potential usability of water resources in society (Sundberg et al., 2004). Stormwater capture and drainage may be considered not only as systems to divert undesired water from urban areas but also as valuable elements for landscaping the surroundings of buildings and roads (Boller, 2004). In general, to control surface runoff, flood control agencies have constructed large centralized facilities, such as culverts, detention basins and sometimes re-engineered natural hydrologic features, including the paving of city river channels to quickly convey runoff to receiving water bodies. These large-scale facilities are required to handle the massive amounts of runoff generated by the largest storm events, as it would be impractical to handle this runoff on a decentralized parcel-by-parcel basis with small-scale infiltration devices. The current trend is toward a more overall integrated approach to manage stormwater runoff as an integrated system of preventive and control practices to accomplish stormwater management goals. The first principle is to minimize the generation of runoff and pollutants through a variety of techniques, and the second principle is to manage runoff and its pollutants to minimize their impacts on humans and the environment in a cost effective manner (EPA, 2007). The utilization of remote sensing and GIS technology in stormwater management is constantly evolving, and commonly used GIS technologies are utilized to help decision-makers to determine the most efficient ways to manage stormwater, including the selection of capture measures based on criteria, and the evaluation of methods to capture urban runoff (Wilson et al., 2000). However, as explained by Wang et al. (2004), even in the most technically complex analysis, it is always necessary for the human element to select appropriate criteria and make other subjective decisions. There will frequently be decisions made in stormwater management that reflect the economic, political, social, and aesthetic components that may not always be easily incorporated into a GIS analyses and modelling system. Important aspects of community attitudes are also considered in this study, as these attitudes are influenced by a

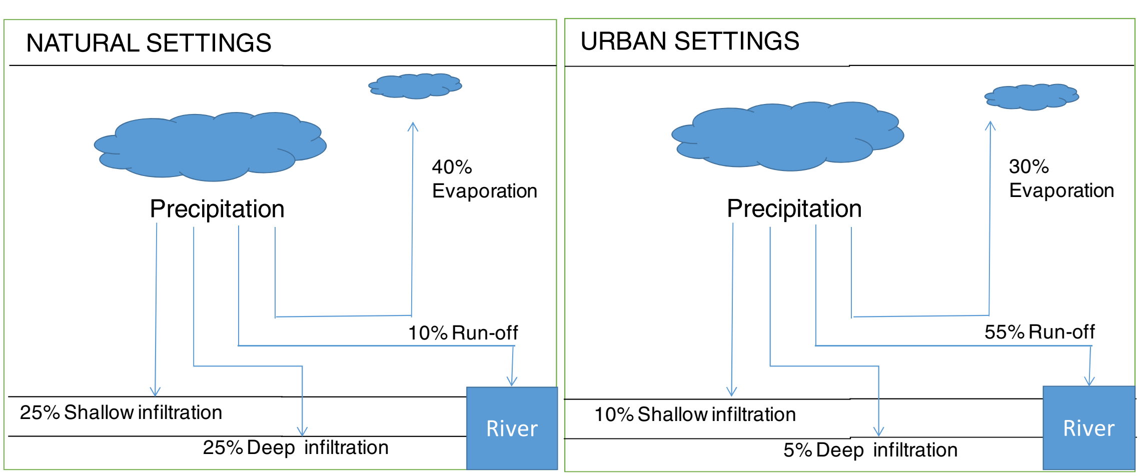

Fig. 1. Comparison of absorption and surface runoff between a natural and an urban environment.

range of factors, including knowledge of urban water problems, frequency and water restrictions, familiarity with use of alternative water sources, and either positive or negative support from water authorities, government agencies and researchers (Mitchell et al., 2007a; Dolnicar and Hurlimann, 2009). Stormwater management in Japan and Thailand has always aimed to control stream flow for municipal and commercial use while preventing water-related disasters in cities. City stormwater management policies were based on flood control and, in recent years, shifted from the exclusive use of structural approaches to using a combination of structural and non-structural approaches. Japanese flood management began with the policies implemented in 300BC in the Yayoi period. In 1960, there was an effort to move away from concrete dams and focus instead on the hydrologic function of green dams, which rely on the flow retarding the capacity of forests to reduce flood risk (Luo et al., 2015; Takara et al., 2004; Calder, 2007). Thailand has focused more on structural measures in addressing stormwater issues, including aggressive implementation of measures involving the general public and the private sector (Chiplunkar et al., 2012). In Vietnam, an integrated design of surface runoff infiltration, storage and transportation of stormwater was applied. The country has focused on increasing the groundwater levels by increasing the stormwater percolation rates through enhanced infiltration (Werner et al., 2011).

In this paper, we present an assessment of stormwater runoff management and the latest practices in use to achieve urban water security. For this purpose, we explored the different characteristics of stormwater runoff management policies and strategies adopted by Japan, Vietnam and Thailand. In addition, this study provides case studies from Tokyo, Hanoi and Bangkok to evaluate the advantages and disadvantages of stormwater runoff practices and policies with respect to historical measures and hydrologic dimensions of city stormwater management systems. This paper provides a detailed assessment to assist future policy makers and researchers in the field of stormwater runoff management planning in understanding the significance and emerging role of remote sensing and GIS in designing optimal surface runoff measures under the threat of future extreme events and climate change.

2. Stormwater runoff in a changing context

In the changing context of urbanization, climate change and various shifting management policies, stormwater runoff is severely impacted. It is well known that urbanization alters watershed hydrology as land becomes increasingly more covered with surfaces impervious to rain, water is redirected from groundwater recharge, and climate change increases the evapotranspiration rate of stormwater runoff. As the area of impervious cover increases, so do the volume and runoff rate. Weak regulatory policies can worsen the situation (Schueler, 1994; Corbett et al., 1997). Pollutants accumulate on impervious surfaces, and the increased runoff with urbanization is a leading cause of nonpoint source pollution (USEPA, 2002). Sediment, chemicals, bacteria, viruses, and other pollutants are carried into receiving water bodies, resulting in degraded water quality (Holland et al., 2004; Sanger et al., 2008). Blair et al. (2011) tested and analysed more than thirteen watershed locations in coastal Carolina (USA), and developed a method to model the impacts of urbanization and climate change on stormwater runoff, which was based on the modelling methods of the Natural Resources Conservation Service (NRCS) and the United States Department of Agriculture (USDA), and generated hydrographs of rate and time. In Fig. 2, the hydrograph shows the impact of different levels of urbanization on rainfall percentage as well as climate change impacts on urban, suburban and forested watersheds.

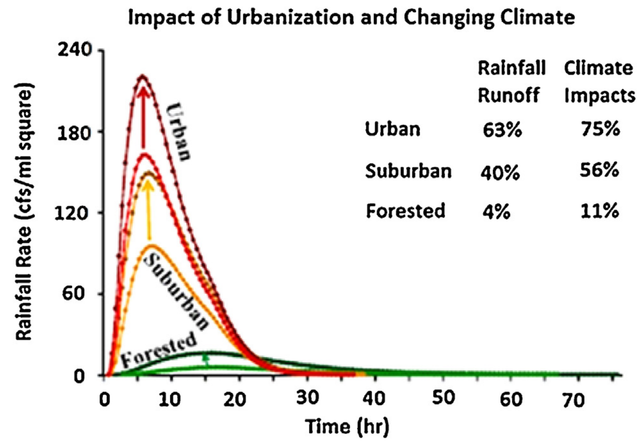

Fig. 2. Hydrographs showing runoff from 3 areas at different levels of development based on impervious cover.
Adapted from Blair et al. (2011).

In Fig. 2, the y-axis shows the runoff rate, and the x-axis shows time in hours. This hydrograph illustrates the impact of urbanization and climate change on runoff. Climate impact curves are based on a 24-h 5-inch rain with semi-saturated runoff conditions (Blair et al., 2011). Considering changes in urbanization, climate and management policies, stormwater discharge pollution is versatile and arises from stormwater volume quantity and quality. All of the above-mentioned factors affect stormwater, which is derived from precipitation, such as rain, sleet, or melting snow. In a natural setting, only a very small percentage of precipitation becomes surface runoff, but as urbanization increases, this percentage of stormwater drastically increases. This runoff normally flows into the nearest stream or river, increasing the percentage of water in the system and, if it is polluted, it can lead to disastrous situations and various forms of pollution.

2.1. Urbanization

In the context of urbanization, we can accurately define stormwater as the runoff from pervious and impervious surfaces in predominantly urban environments. Impervious surfaces can be defined as concrete charcoal roads, highways, roofs, pavements and footpaths. The land cover and precipitation relationship pathways have created a state in which the watersheds and their streams and channels are adversely impacted (Frazer, 2005). In Fig. 3, from the centre of watershed protection, we can see the relation between urbanized areas covered with impervious roads and streams. The figure demonstrates that increasing impervious surfaces alters the hydrologic cycle and creates conditions that no longer can support the diversity of life. The Centre for Watershed Protection has reported that in areas that exceed 10% impervious coverage, stream health begins to decline (Coffman and France, 2002). The problems that urbanized watersheds face include flooding, stream bank erosion and pollutant export. The receiving streams of these intensified storm flows alter hydraulic characteristics due to peak discharges several times higher than predevelopment or even rural land cover characteristics (LeRoy et al., 2006). Improving the water quality of runoff entering receiving waters and reducing pressure on existing water supply systems are thus major goals of urban water management.

We can clearly understand the impact of urbanization on stormwater runoff based on the analysis of Blair et al. (2011), in which a model was developed to understand the impact of urbanization on the surface runoff and tested in 13 locations in the USA. The presented hydrograph clearly demonstrates the impact of

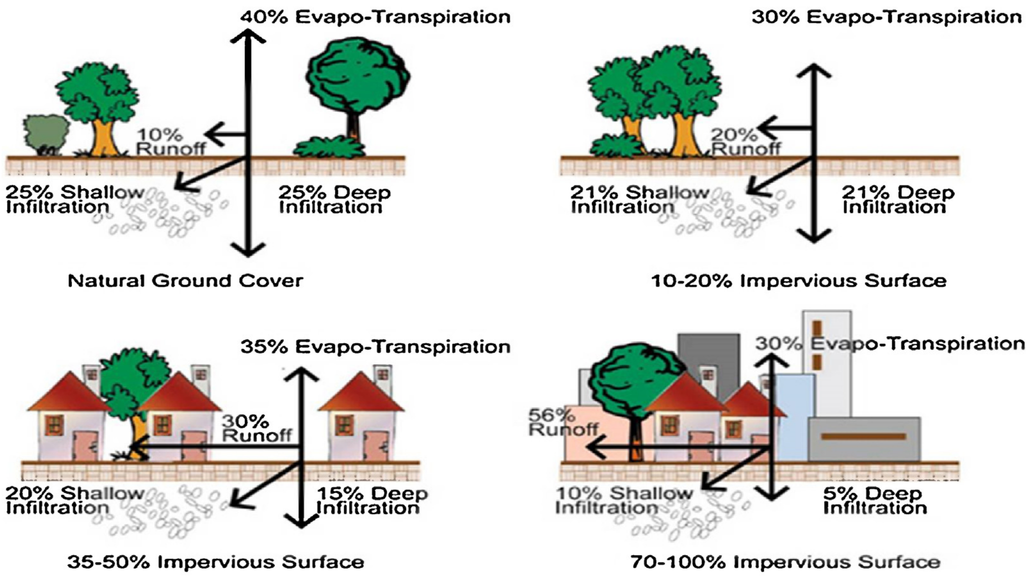

Fig. 3. The difference between the natural ground cover and various types of impervious surfaces in urbanized areas. The impervious surfaces are directly responsible for the reduction in deep infiltration of water, and increase surface water runoff by at least 50% (https://www3.epa.gov/caddis/ssr_urb_is1.html).

urbanization based on increasing impervious cover percentage and on the watershed or areas.

2.2. Climate change

In the context of climate change considered in concert with urbanization, stormwater runoff and its impacts are likely intensified, further increasing the quantity of polluted runoff. Numerous studies involving climate change predictions have indicated that heavy precipitation events will likely increase in frequency and intensity (Bates et al., 2008; Karl et al., 2008). Semadeni-Davies et al. (2008) showed that the correlation between the increased intensity of rainfall and increased impervious surfaces cover is directly proportional to more extreme events, such as flooding, flash floods and greater peak flows. Hence, within the context of climate change, a science-based system for evaluating the relative impacts of both urbanization and climate change on stormwater runoff at a local scale is very much needed for better management policies. Stormwater management is planned based on local weather and climate. However, climate changes, such as the amount, timing, and intensity of rain events, in combination with land development, can significantly affect the amount of stormwater runoff that needs to be managed. In some regions of the developing countries, the combination of climate and land use change may worsen existing stormwater-related flooding, whereas other regions in the world may be minimally affected. In the past, stormwater management was practiced in an anthropocentric, human-centric manner, and as a result, has had a profound effect on the environment. Fig. 4 describes the correlation between the climate change and rainfall, which is directly related to stormwater runoff.

Along with climate change, a suburban expansion has exploded over the last few years, thereby increasing impervious surface cover in place of forests, pastures, and cropland. This has affected local hydrological cycles by producing more surface runoff and decreasing the base flow, interflow and depression storage (Davis et al., 2006). The Fig. 5(a) shows the shift in climate and increase of global average temperature resulting in more hot extreme weather in future. The Fig. 5(b) is a time-series graph that compares the multi-model mean of the simulations of global surface air temperature and precipitation from January 1979 to November 2012. The models suggest that manmade greenhouse gases have caused global surface air temperatures to warm and global precipitation to increase. Studies have shown a direct correlation between stream water quality and impervious surface coverage; with more than 10% impervious surface coverage, streams in some watersheds become unstable due to increasing erosion or sedimentation damage (Vargas, 2009).

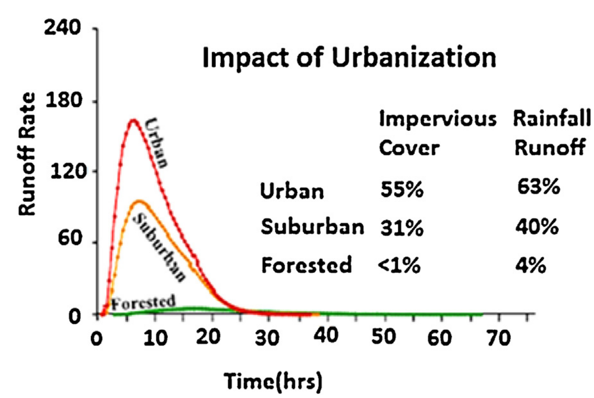

Fig. 4. Hydrographs showing runoff from 3 test areas at different levels of development (based on impervious cover). The hydrograph illustrates the impact of urbanization on runoff. Curves are based on a 24-h 4.5-inch storm, with average runoff conditions.
Adapted from Blair et al. (2011).

As shown in Fig. 6, climate change and urbanization alter the physical factors associated with stormwater runoff and the responses of receiving waters.

2.3. Regulatory policies

Sustainable stormwater management not only depends on the financial capability of any country but also on the policy priorities and institutional framework. Due to weak regulatory practices, many parts of the world are unable to sustainably use stormwater. Studies have shown that stormwater runoff impacts both water

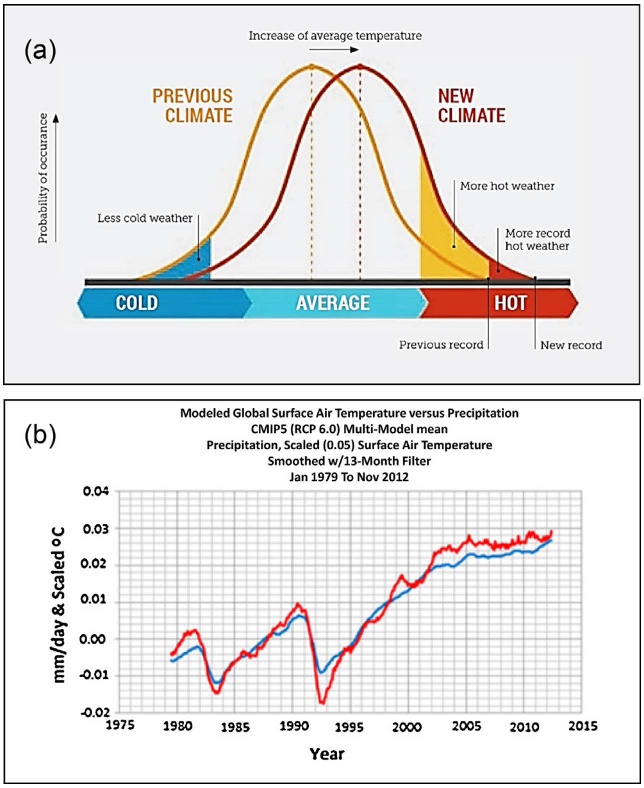

Fig. 5. (a) Shift in climate and increase in global average temperature. (b) Modelled global surface temperature with respect to precipitation.
Adapted from Steffen et al. (2013). Source: https://bobtisdale.wordpress.com/2012/12/27/model-data-precipitation-comparison-cmip5-ipcc-ar5-model-simulations-versus-satellite-era-observations/.

quantity and quality. Excessive stormwater may result in erosion of stream banks, thereby altering the stream bed morphology (Wynn, 2004). During the development stages, soils may become compacted, and thus have reduced infiltration capacity, which means that during construction, the amount of stormwater could possibly increase in quantity because less rainwater is evaporating and infiltrating; this may lead to erosion, sedimentation, flooding, dissolved oxygen depletion, nutrient enrichment, reduced biodiversity, toxicity and other associated impacts on water use (Wagner et al., 2007). Water quality concerns vary from region to region, depending on factors such as population density, land use degradation and pollution in the area (Fletcher and Deletic, 2007). The major pollutants recognized in conventional stormwater management practices are suspended solids, oxygen-demanding matter, bacteria, and nutrients, such as nitrogen and phosphorus, and heavy metals. Suspended solids cause an increase of turbidity, which directly affects ecosystems by lowering the amount of dissolved oxygen (DO) in the water (Bilotta and Brazier, 2008). It is critical to maintain high DO levels in water to sustain aquatic life. The organic matter from animal faeces and sewer overflows typically lowers DO levels in the receiving surface waters. Pathogenic bacteria in overflow have caused detrimental human health effects and have caused beaches to be off limits because of health safety issues, including many diseases associated with waterborne infections, such as gastroenteritis and hepatitis (EPA, 2001). Nitrogen and phosphorous mainly originate from agricultural fields, but they can also originate from the usage of fertilizers and pesticides in any area (Adams and Papa, 2000). The phenomenon which destructively affect water bodies with cold aquatic life with sensitivity to higher temperatures and reduce the dissolved oxygen concentration is known as thermal enrichment. Which is another type of water pollution, where surface water is heated and discharged to receiving water bodies with lower temperature which can impact the entire aquatic ecosystem.

3. Methodology of the assessment of optimal stormwater management

This study provides an overview of the environmental impacts of surface water runoff and the need of strong surface runoff management measures to achieve sustainable use of water resources in urban environments. Fig. 7 provides an overall methodology for the assessment of optimal stormwater management. The impacts of stormwater runoff in changing environments

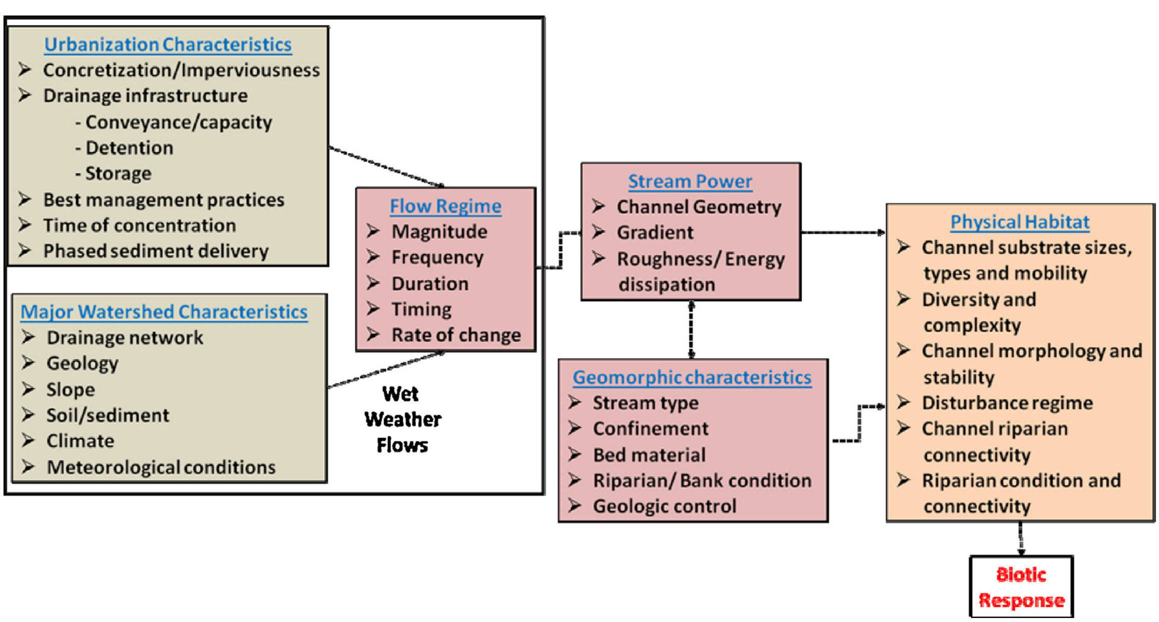

Fig. 6. Physical effects of urbanization on streams and habitats.

Adapted from Roesner and Bledsoe (2003).

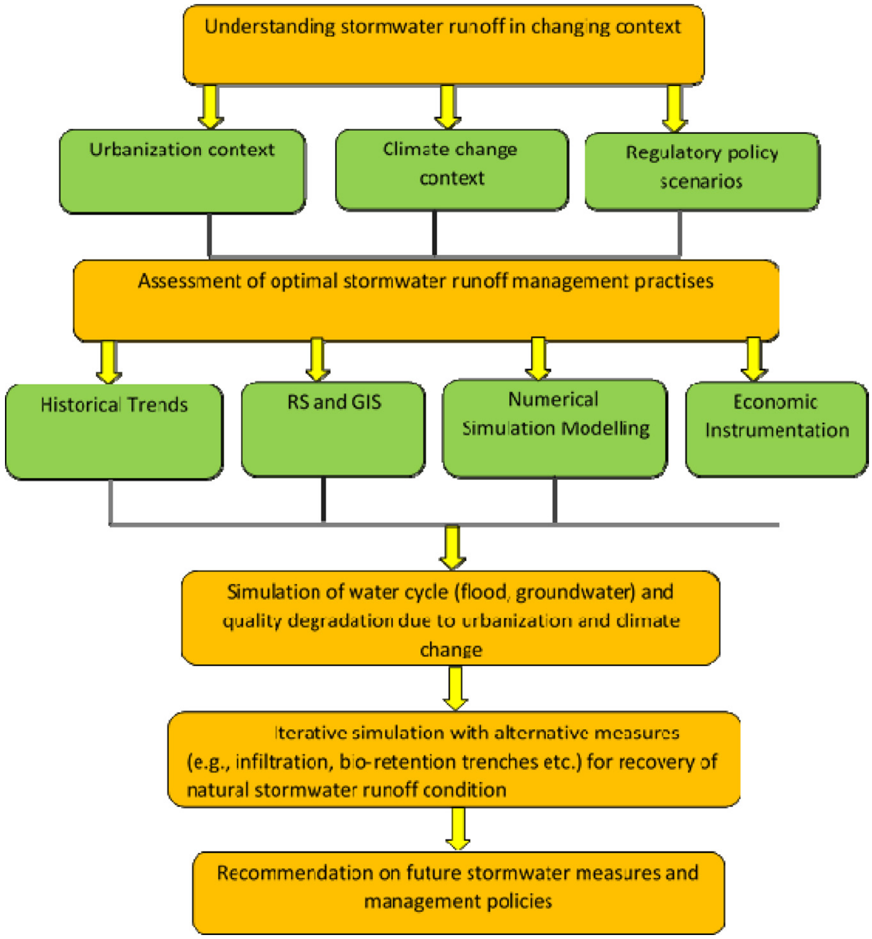

Fig. 7. Methodology for the assessment of stormwater runoff management measures to attain urban water security.

is analysed by comparing and evaluating findings under context of climate change, urbanization and the regulation of stormwater management. Using hydrographs, it is easy to understand the major negative impacts on surface runoff and nearby water bodies. Analysis of stormwater runoff impacts under various contexts largely employs historical trends analysis, and remote sensing, GIS, numerical hydrodynamic and economic models. Trends analysis based on historical observations is popular technique to predict future outcome. Information about past changes in flood peaks and groundwater table can be important to determine trend and response tendencies in the urban area as a reference for future floods and groundwater prediction. Based on numerical simulation modelling and economic aspects of stormwater runoff management measures, we assess current scenarios and optimal future strategies. Water cycle under different scenarios is analysed using high-resolution distributed hydrological model coupled to onsite facility performance at grid level, analyse the resulting water cycle. Iterative simulations require to be carried out for different policies for onsite facility installations until water cycle is close to pre-development stage. Local people's perception on alternative infiltration and storage facilities are also highly important in reducing urban flood risk and improving urban water cycle. Physical/environmental constraints with local acceptance and engagement in urban stormwater runoff management are done by combining, simulation based on natural science approach and field survey based on social science approaches. Finally, recommendations are suggested for policy makers to design optimal stormwater runoff measures.

3.1. Historical trends

In the ancient history of water management, which began thousands of years ago, the quality of life was directly correlated to flood control measures because floods had severe consequences in terms of human lives and crops. Even in ancient societies, the practices, techniques and strategies to control and manage stormwater can be studied (Koutsoyiannis et al., 2008). Approximately 3000 years ago, the ancient civilizations of Babylonia and Assyria were able to combine wastewater and stormwater sewage systems (Durrans, 2003). In ancient times, water management was utmost priority because of basic human needs of sanitation, clean drinking water, and flood prevention, and gradually evolved into conventional stormwater management. The conventional approach requires the construction of a massive and costly centralized infrastructure system to function efficiently. Many ancient stormwater drainage systems, such as the *Cloaca maxima* in Rome, which was built in approximately 600 BCEE, still exist today (Fardin et al., 2014). Underground stormwater drainage was common in Europe and many places in the Americas in the 19th century following rapid urbanization (Burian and Edwards, 2002) due to the industrial revolution. In particular, combined sewers can be observed in many cities, and the water carried in combined sewers has historically been transported directly to receiving waters bodies. These approaches helped prevent flood damage and also pollution in ancient times, which often resulted in financial and environmental benefits. In the beginning of the 1920s, flood prevention and stormwater management implementation was improved in linear fashion. It was assumed that stormwater was wastewater that needed to be transported outside of cities, and it was never considered as a resource (Durrans, 2003). With the help of gravity, the stormwater was easily disposed through sewerages to nearby water bodies. This inspired the urban drainage systems in development and the control of damage from infrequent flooding events. It was followed by designs that became common in every urban setting, which can be divided in two types of drainage systems: major systems, designed to manage 100-year storm events, and minor systems, designed to manage 2–25 year storm events (Grigg, 2012). Next was the development of detention ponds, a conventional, yet inexpensive method to reduce peak flows and total volumes, up until recent years. However, detention ponds are limited in that they have a negative effect on the environment because they disrupt the drainage paths of streams and are unable to improve the quality of stormwater due to non-point pollution (Durrans, 2003). In recent years, the development of new technology and infiltration facilities changed the scenarios from ancient technologies with the one-dimensional view that stormwater is not useful and its management is only to reduce flood damage; as a result, an environmental insight that rainwater can be utilized as a valuable resource was developed.

3.2. Role of remote sensing and geographic information system (GIS) technology

Remote sensing and Geographic Information System (GIS) technology have been widely applied, and the integration of both is recognized as a powerful and effective tool to design and formulate strategies for stormwater management. Remote sensing effectively collects multi-temporal, multi-spectral and multi-location data and helps in observing land use changes, whereas GIS provides a platform for analysing and displaying digital data and acts as a decision support system (Weng, 2001). In urban environments, the first and foremost important selection is to identify suitable stormwater harvesting sites for urban water management. GIS has been recommended as a DSS (decision support system) to facilitate the identification of potential stormwater harvesting sites during the decision making process (Mbilinyi et al., 2005). GIS also can serve as a screening tool for the selection of preliminary sites as it has a unique capability for spatial analysis of multi-source datasets, allowing for integration (Malczewski, 2004). There is widespread literature available on the use of GIS for the assessment of site suitability in areas in terms of stormwater harvesting across the world. For example, the potential site selection for the harvesting of water in India was identified using the International Mission for Sustainability Development (IMSD) guideline in a GIS environment (Kumar et al., 2008). Various studies have explained the development of GIS-based DSSs (decision support systems), developed for locating suitable sites for water harvesting (De Winnaar et al., 2007; Mbilinyi et al., 2007). Using a biophysical approach, criteria can be assessed to formulate a strategy to identify surface runoff harvesting sites to understand the catchment hydrological information derived from the catchments characteristics (De Winnaar et al., 2007). Various studies have shown that areas with less spatial constraints for various water storages are considered suitable for criteria such as precipitation, runoff, soil type, topography and distance to storage for stormwater harvesting (Mbilinyi et al., 2005; Kahinda et al., 2008). However, in an urban context, the spatial constraints are greater due to the overall lower storage space and an already exhausted drainage network; this places constraints on social, institutional and economic factors needed to locate suitable stormwater harvesting sites. For example, in Australia, Shipton and Somenahalli (2010) applied GIS for the identification of suitable stormwater runoff collection sites in the Central Business District of Adelaide. However, the study was limited because it did not account for the demands of stormwater, and it only considered the drainage pattern in the region. The major finding is that GIS is a valuable tool to identify sites to build facilities related to stormwater management and handling of the surface runoff, as using remote sensing provides the capability to design from a greater perspective rather than a narrow one. For effective stormwater runoff management, the use of specialized computer-based model in concert with GIS can produce better results (Rusko et al., 2010). Furthermore, Rusko et al. (2010) explained that the integration of simulations with sustainability objectives of social, environmental and socioeconomic factors into stormwater management policies could prove useful. For effective stormwater management at the local level, this approach would be useful along with the use of GIS and remote sensing. It is easier for a policy maker to implement policies using different areas in the watershed rather than different locally adaptable strategies to solve locally variable problems, such as erosion, sedimentation, flooding or pollution, and in this respect, GIS and remote sensing is of great usability. This allows for a complete stormwater plan across the watershed to prevent the negative effects of stormwater at specific sites and anywhere downstream where there is potential for harm, which can be identified easily by monitoring the sites using a remote sensing map and processing data through GIS. Another use of GIS and remote sensing is to collect and manage spatial data, which is an important requirement as such data are used as input for computer stormwater models, such as MOUSE, MIKE II, Hydroworks, SWMM and STORM (Elliott and Trowsdale, 2007). GIS can then be used to present the user-friendly processed result of output from the models (Heaney et al., 2001). Modelling with the use of GIS to handle data from computer-based tools to make a user-friendly decision support can improve communication to stakeholders involved in modern world stormwater planning. GIS and remote sensing for stormwater runoff management are used for flood mapping, flood hazard mapping, hydrologic modelling, catchment level stormwater management and designing storm sewer systems, including determining the slope and surface elevation from digital elevation model (DEM) data. Moreover, they can be used for planning in stormwater practices, such as Best management practices, Low Impact Development and assessment of the feasibility system (Rusko et al., 2010).

The use of GIS and remote sensing in estimating stormwater runoff from the land use, slope, impervious surface coverage and soil characteristics is common and evolving in nature. It is useful to aid decision-makers in deciding the optimal way to manage stormwater planning decisions. However, it is important to note here that for any complex situation or analysis, it is still necessary to have human element to select appropriate criteria and make subjective decisions because of the requirement of frequent decisions in stormwater management. Another widely applicable use of remote sensing is in controlling the non-point source pollution by analysing impervious surfaces inside of watersheds (Slonecker et al., 2001). It is also useful in estimating the stormwater pollutant mass loading (Ackerman and Schiff, 2003).

3.3. Numerical simulation modelling of stormwater

With rapid urbanization and climate change, stormwater managers face increasingly complex issues regarding the design, construction, operation and maintenance of different stormwater infrastructures. Recent stormwater management systems have largely focused on ecosystem-based approaches (instead of traditional approaches of moving the stormwater out of the affected area), which require groundwater recharge, maintenance of the natural flow regime, downstream impacts and water quality. With the advent of computer systems and tools such as GIS and remote sensing, numerical models are more widely used to simulate the hydrologic-hydraulic processes by mathematically representing the stormwater movement systems. Numerical models enable testing the effectiveness of different alternative stormwater management measures by simulating water quantity and quality values at different locations. Numerical models are principally based on a set of differential equations representing the physical stormwater management systems. They describe rates of change of various parameters with respect to time and space. Running a numerical model implies solving these equations with boundary conditions and spatial/temporal changes within the systems. Model results represent the responses to global changes (climatic, land use, population, etc.) and alternative management measures. Examples include graphs of depth or flow at specific locations in the network.

The section discusses about the collection of urban stormwater models used for stormwater simulation and management; Showed in Fig. 8(a), the list of potential uses of the listed urban stormwater models are shown, e.g., the model MOUSE is applicable in developing sizing rules for devices, planning and land use in catchments, and detailing in designing and site layouts. Fig. 8(b) shows the various urban stormwater models analysed on the basis of spatial and temporal resolution, and Fig. 8(c) shows the model capability of simulating runoff generation with different routing methods.

3.4. Economic assessment

Economic assessment of stormwater runoff management is important in improving the environmental quality; the basic concept is to have an incentive-based market to understand stormwater as a resource rather than waste. In this section, the cost-effective measures are explored to control stormwater runoff by providing incentives for small-scale BMPs (Best Management Practices) throughout urban watersheds (Parikh et al., 2005). The solution to reduce stormwater runoff and other impacts is a market mechanism within the incentive-based market, such as stormwater runoff user fees, charges, cap and trade, and voluntary offset programs (Parikh et al., 2005). There are many other proposed solutions, one of which is to pay for pollution, which is a basic strategy that can be achieved by measuring the pollutant in an environment and charging the culprits of its source (Dales, 2002); another strategy is the promotion of technological advancement to increase stormwater conservation and prevent pollution. The stormwater controls can be created using fee structure that is directly related to the degree of water degradation, i.e., "pay for your pollution," which forces polluters to provide compensation for damage to the environment in any form, with the goal of preventing pollution as the first priority. However, some studies have shown that existing fees do not have the impact required to lead to onsite reductions, and in a few cases, they are not even able to stop polluters from polluting (Doll et al., 1999). These studies

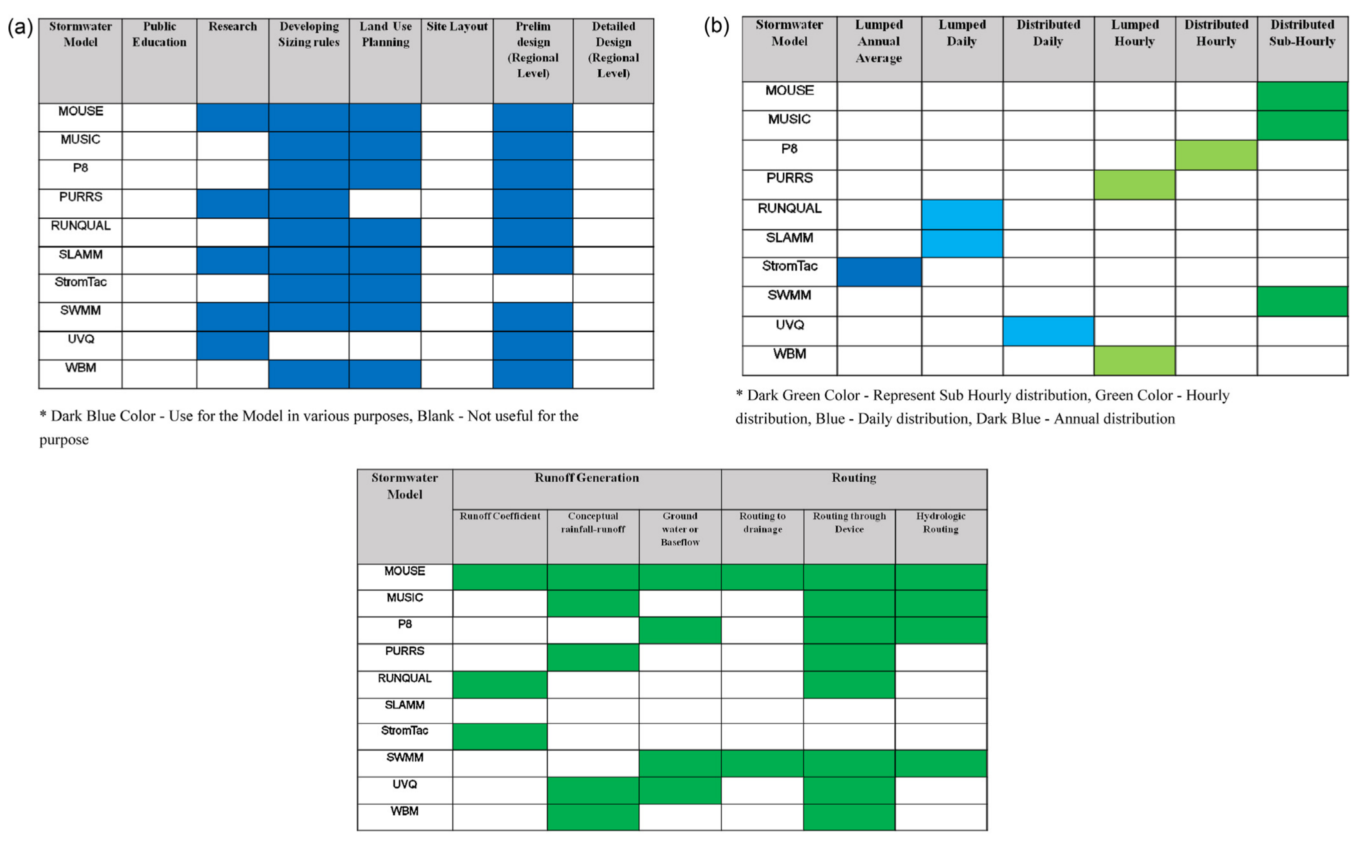

Fig. 8. (a): Potential uses of the selected models.. *Dark Blue Color – Use for the Model in various purposes, Blank – Not useful for the purpose. (b): Temporal and Spatial resolution of the urban stormwater models. * Dark Green Color – Represent Sub Hourly distribution, Green Color – Hourly distribution, Blue – Daily distribution, Dark Blue – Annual distribution. (c): Runoff generation and routing method for the urban stormwater model. *Dark Green Color – Represents the Models usefulness in the methods. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Adapted from Elliott and Trowsdale (2007).

indicated that the fees were too low to have an impact on stormwater runoff control. Another method is to utilize stormwater to generate revenue to combat stormwater degradation in relation to percentage of impervious surface coverage at any level (Cyre, 2000). Generally, non-point source constituents are not regulated by any mechanism because of their unobservable nature. A popular method used for stormwater runoff control is a stormwater trading mechanism (Thurston, 2006). Some communities have implemented this by calculating a flat rate based on the imperviousness, and the generated money is used to develop infrastructure for stormwater control, which requires local and regional partner involvement in investing in groundwater infiltration facilities and stormwater technologies, such as LID and BMPs (Doll et al., 1999). Trading mechanisms provide credit trading incentives to manage sustainable stormwater use, and allow developers and designers to protect the overall quality of water bodies (Woodward and Kaiser, 2002). The total stormwater produced in an urban area and its sustainability values (i.e., economic, environmental and social) are important considerations for trading schemes in addition to water temperature and nutrient loading. Using a market-based strategy to control stormwater and improve water quality, large polluters are allowed to purchase water quality improvements from smaller producers, as a voluntary offset of runoff, to optimize economic metrics.

To control and manage stormwater runoff, BMPs are considered less expensive than conventional centralized systems, and efficient in improving water quality, however, they require considerable investment. Analysing their cost effectiveness is a complicated process. Cost-effectiveness analysis identifies the least expensive way of achieving environmental targets (Ecosystem Valuation, 2007). The five techniques used for measuring the value of BMPs are replacement cost methods, lifecycle cost analysis, cost-benefit analysis, the productivity method and the hedonic pricing method. In the replacement cost method, estimation of ecosystem services is performed based on the cost of avoiding damage or lost services. For example, in 2006, at the University of California, Davis, researchers estimated that for every 1000 trees in the central valley, stormwater runoff was reduced by nearly 1 million gallons, equivalent to 7000 USD (Viers et al., 2012). When those trees are cut down, and their required function is lost due to deforestation, the costs are passed to the local government (NRDC, 2006). The life-cycle approach is useful in estimating the BMP costs because, most of the time, the maintenance costs are far less than the cost involved in maintaining and operating conventional approaches (Powell et al., 2005). In cost-benefit analysis, the lack of information of economic benefits provided by the BMPs can ultimately obstruct the adoption and implementation (MacMullen, 2007). The method of productivity valuation, which is also known as the net factor income, can be used to estimate the economic value of ecosystem products that contribute towards the production of marketed goods. Lastly, the hedonic pricing method estimates the economic values for environmental services that directly affect the market price, and it is widely used to determine the variations in housing prices, while reflecting the values of local environmental attributes (Ecosystem Valuation, 2007).

4. Case studies

Cities in Japan, Vietnam and Thailand are eagerly applying stormwater infiltration as a stormwater runoff management measure, but still, many of the local governments are hesitating to ask residents to install soakaways and small detention basins on private properties. Based on the above discussion of stormwater runoff control management, lets discuss the case studies of three megacities in Asia; it appears that stormwater infiltration is widely accepted and implemented all over Japan, but in other countries, such as Thailand and Vietnam, it remains unpopular. Along with building stormwater infiltration measures, governments have also focused on building massive sewerages to capture and transport stormwater out of the city in case of flooding or emergencies. For our case studies, we chose Tokyo, Bangkok and Hanoi to analyse the stormwater runoff management practices and compare with each other to understand the optimal strategies for recommendations.

4.1. Tokyo

Tokyo is capital city of Japan, with a total area of 2188 km^2, situated at 35° North and 139° East. The annual precipitation in Tokyo is approximately 1530 mm, and it has the largest population of any city in the world. The city also suffers from serious flood problems and stormwater runoff has always been serious concern for the local government. As shown in Tokyo land use and land cover map in Fig. 9, Tokyo has undergone substantial urbanization. Tokyo is focused on structural and non-structural measures for stormwater runoff control. For example, Tokyo has been investing in and building huge tunnels, such as G-cans, and simultaneously, the local government has been encouraging residents to use BMPs and ground water infiltration systems.

To address flooding concerns and the exacerbating effect of stormwater runoff and torrential rains, Tokyo has invested in underground infrastructure, using five silos and through-tunnel channels to transport water out of the city; this is referred to as the Metropolitan Area Outer Underground Discharge Channel or G-Cans project, and it is the largest underground flood water diversion facility in the world (Bobylev, 2007). It is located in the outskirts of the city between Showa in Tokyo and Kasukabe in Saitama prefecture and is an example of a critical underground infrastructure of flood and stormwater control management system. The figure shows the wide network of the tunnel used to manage the stormwater by draining surface runoff out of the city (Fig. 10).

The project includes a 6.5 km long connecting tunnel and a storage tank with 78 pumps and five massive silos. There are five concrete containment silos, which act as a regulator, with dimensions of 65 m in depth by 32 m in diameter and are located at the limits of the rivers to connect to tunnel. The tunnel was constructed underground, at approximately 50 m depth, to send the water to the storage tank after overflow conditions. The storage tank, also known as the underground temple, is 177 m long and

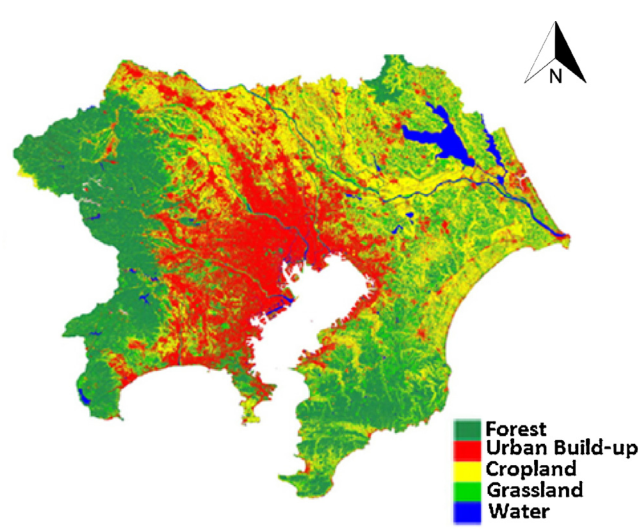

Fig. 9. Tokyo land use and land cover map.

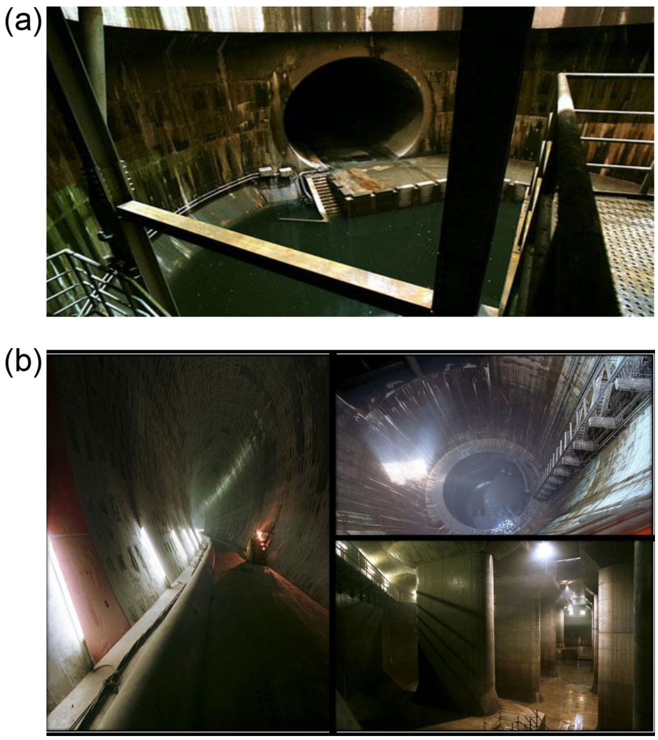

Fig. 10. (a) and (b): G-Cans, Tokyo is an underground infrastructure for flooding prevention during the rainy season.
Source: G-Cans project, Tokyo; http://www.water-technology.net/projects/g-cans-project-tokyo-japan/.

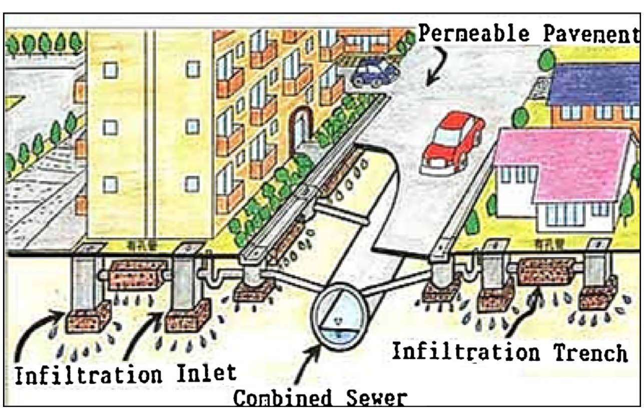

Fig. 11. Infiltration trench and sewerage system in Tokyo.
Source: http://www.recwet.t.u-tokyo.ac.jp/furumailab/crest/workshop05/june9pm_2.pdf.

25 m high, and supported by 59 pillars that are 20 m tall. The tank has approximately 14000 turbines. This facility is also open to tourists in the dry season (G-Cans project, Tokyo).

Another very popular and highly focused stormwater control measure is the artificial infiltration stormwater system in the city. Fig. 11 shows the structure, in which permeable pavement leads to a facility with an artificial infiltration trench, which is connected to the combined sewer in the case of over flow. In addition of flood prevention, this provides clean water to the environment and a functional water cycle with a recharging groundwater table that can restore the spring water, and allow for disaster prevention and local ecosystem preservation. Many cities in Japan are applying stormwater infiltration (Fujita, 2005). The Setagaya, Tokyo government initiated the Setagaya Reservoir framework in 2009, and started to raise public awareness of rainwater harvesting systems in the household in order to decrease the possible inundation of the river. Non-profit organization (NPO) joined the Setagaya Reservoir Framework by proposing a collaborative project on infiltration measures aiming to contribute to water management measures for Nagowa River in the jurisdiction of Setagaya and avoid the depletions of ground water. In the Setagaya, 5000 soakways are being installed annually. In the city of Koganei, a Tokyo suburb with a population of 110,000 and an area of 1133 ha, there are as of March 31, 2005, as many as 48,935 soakways and infiltration trenches as long as 38 km, which may be the highest installation density in the world. In the case of the experimental sewer system in the western part of Tokyo, the Nerima ward, where such as system was installed is 1434 ha. More than 34,000 soakways, 220 km infiltration in trenches, 70 km of infiltration curbs, and so much of 500,000 m2 of permeable pavement were provided in the urban area in the 13 years from 1982 and 1994. The stormwater runoff control management practices in Tokyo are overall very effective.

4.2. Bangkok

Bangkok is the capital of Thailand. The total area of the city is 1569 km^2, and it is located at a latitude of 13.45° North and longitude of 100.28° East. The mean elevation is 2.31 m above mean sea level (BMA and UNEP, 2004). In total, 60% of the city land area is built up, and approximately 30% is utilized for agriculture (Fig. 12). In 2015, the total population of city was approximately 8,500,000, with a growth rate of less than 2% annually (United Nations, Department of Economic and Social Affairs, Population Division, 2014). The important seasons in Bangkok include the rainy season from May to October, winter from November to January, and summer from February to April. The average annual precipitation is approximately 1500 mm (Shrestha et al., 2015).

Bangkok is facing severe challenges in terms of stormwater runoff management, mostly inter-related with the impact urbanization and changes in hydrology associated with global climate change (IPCC, 2007). To address such stormwater issues, the Bangkok Metropolitan Administration (BMA) has been focused on structural measures, and has been aggressively implementing measures involving the general Bangkok populace, focusing on strong drainage provisions, such as retention ponds and large-scale rainwater harvesting, especially in public and private establishments, to alleviate stormwater runoff. Another focus, which is slowly building its momentum, is recharging the groundwater bodies via infiltration of stormwater using infiltration techniques (Chiplunkar et al., 2012).

BMAs focusing on flood mitigation of stormwater runoff help combat flash flooding in urban areas; groundwater infiltration and the use of various BMPs from vegetation swale, bioretention BMPs, vegetative strips along roads, ponds, and permeable pavements are quite popular. Critical underground infrastructure is gaining popularity in Bangkok as previous flood effects were disastrous. Bangkok is currently building comprehensive surface runoff and flood control systems. Additionally, on a governance level, the use of multipurpose critical underground drainage facilities has been gaining support for stormwater management (Thewes et al., 2012). The plan is to build a double deck cut and also cover the infrastructure beneath the existing eight lane eastern outer ring road, which is approximately 100 km from a northern suburb, and runs parallel to the river to drain the extra water to the gulf of Thailand (Tunnel Talk, 2011). In Fig. 13, we can see the plan to build the underground infrastructure in a schematic diagram.

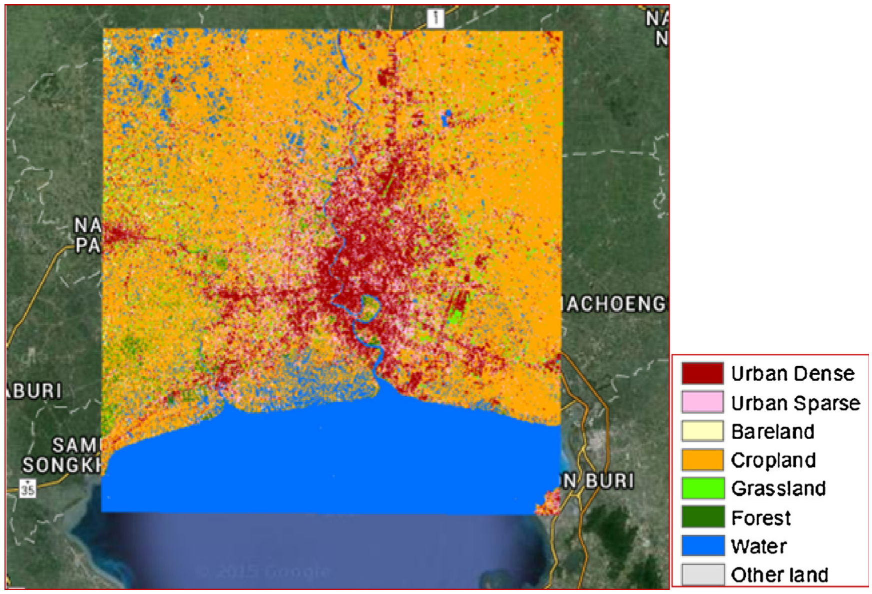

Fig. 12. Land use and land cover map of Bangkok in 2001.
Source: http://giswin.geo.tsukuba.ac.jp/capital-cities/.

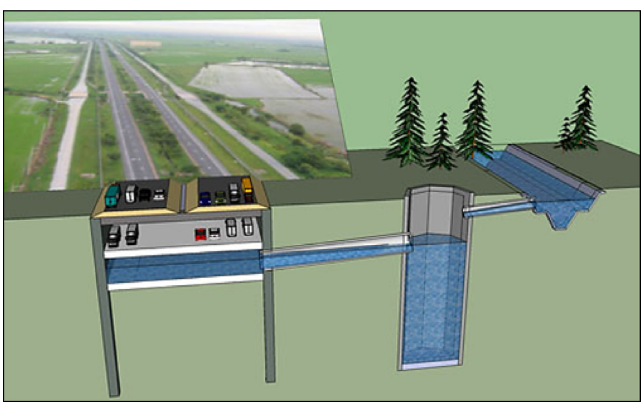

Fig. 13. Plan to build underground infrastructure to mitigate floods and stormwater surface runoff.
Adapted from Tunnel Talk (2011).

4.3. Hanoi

Hanoi is the capital city of Vietnam and is surrounded by the Red river, the Nhue river and the Lich river, with an area of approximately 925 km^2 (Duan and Shibayama, 2009). It is estimated that the population of the city has exceeded 4 million inhabitants. The four main precincts have each exceeded 1 million. According to the Hanoi Master Plan for the year 2020, calculations show an increase in population of the urban core to nearly 4.5 million inhabitants by the year 2020 (Duan and Shibayama, 2009). This forecast is more than just an estimate, and with the current rate of urbanization, this is a very realistic scenario. In Fig. 14, we see the land use and land cover of Hanoi; the effect of urbanization on the land use of the city is easily observed.

According to a study by the World Bank, the country ranked among the top five countries that are going to be severely impacted by climate change, especially in terms of sea level rise and flooding (Dasgupta et al., 2007). The common practices for stormwater management in Hanoi are surface runoff drainage, rainwater harvesting, subsurface rainwater infiltration and storage and urban aquaculture (Hoan and Edwards, 2005). In general, decentralized stormwater management measures are incorporated into the design of the urban landscape to tackle the problem at the source, and drainage systems are designed to drain the runoff to the nearest stream. The urban aquaculture system in Hanoi is very useful in addressing excess stormwater runoff (UNEP International Environmental Technology Centre, 2008). As shown in Fig. 15, a good practice is to avoid stormwater runoff and mitigate its negative effects. Another approach for Hanoi to reduce its stormwater runoff is urban forestry within the city, as urban plantations can mitigate the stormwater runoff management problems caused by impervious surfaces. It is estimated that trees slow down the flow of stormwater runoff by absorbing the first 30% of precipitation through their leaf system, and another 30% through their root systems (Burden, 2006); in addition, trees help in filtering the pollutants out of the water before it drains to the nearby streams. An important measure in Hanoi is rainwater harvesting, as can be observed in Fig. 16. The design is adopted from Nguyen et al. (2013). Rainwater harvesting is effective in reducing stormwater runoff and useful for Hanoi due to its high precipitation. Nguyen et al. (2013) installed ten rainwater harvesting machines at low cost using a canvas catchment, a plastic tank and a stainless steel tank. Fig. 16 shows the stainless steel tank, which is very useful in reducing and controlling stormwater (Nguyen et al., 2013).

5. Discussion

Stormwater runoff management practices can be broadly classified into two categories. The first is the reduction of surface water runoff quantity, and the second is the improvement of stormwater quality, before draining out in nearby water bodies or infiltrating into the ground. The stormwater runoff management practices evolved with time, and new strategies have been developed to minimize the negative stormwater runoff impacts. These strategies are known as LID or Low Impact Development. LID involves a combination of sound site planning, structural techniques and non-structural techniques (Dietz, 2007). LID techniques promote nature-based designs, and interact with the

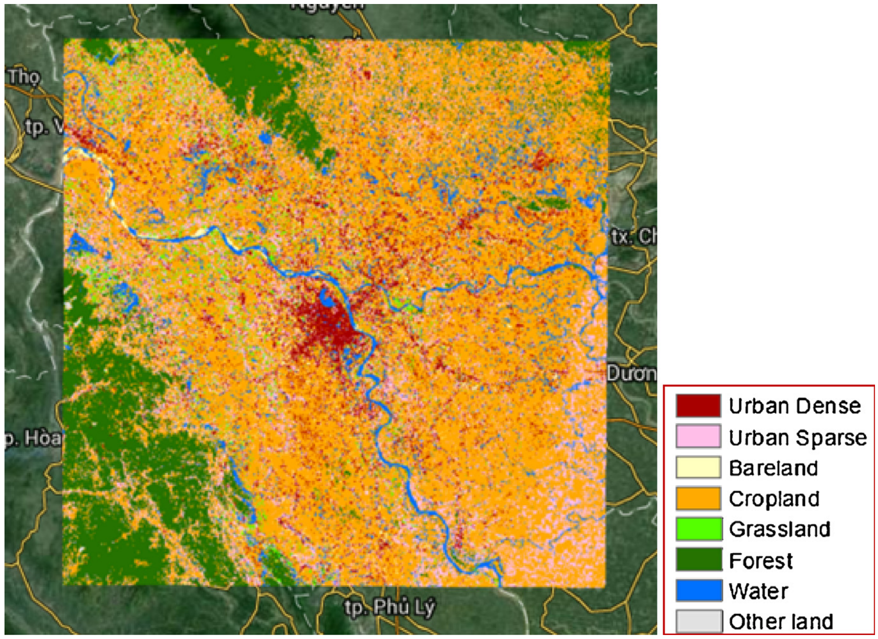

Fig. 14. Land Use and land cover map of Hanoi in 2014.
Source: http://giswin.geo.tsukuba.ac.jp/capital-cities/.

Fig. 15. Raw wastewater- and stormwater-based fed fish ponds in Hanoi, Vietnam. Source: http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-15/2-9/9-3-1.asp.

processes that control stormwater runoff, thereby reducing the negative impact of surface water runoff (Davis and Richard, 2005). Typical elements of conveyance are pavements, roofs, pipes and lawn area. Studies have revealed an increasing trend toward more sustainable practices, and it is clear that conventional practices are not sustainable and cause environmental degradation (Villarreal 2004); thus a shift to LID or Best Management Practices to mitigate effects of stormwater is warranted. Effective LIDs include runoff mitigation measures that are part of larger group of strategies and practices in stormwater management known as Best Management Practices or BMPs (Perez-Pedini et al., 2005), and the combination of both is known as LID-BMPs, which use low-impact development-based BMPs. Table 1 shows the list of BMPs to demonstrate the effectiveness of different strategies in terms of managing stormwater runoff.

Non-structural BMPs include practices such as reducing the disturbance at a given site, preserving the important features, reducing impervious cover, incorporating vegetation options, and also focusing on natural drainage. Non-structural BMPs are generally classified in four categories, including landscaping and vegetation swales, minimizing the disturbance at a given site, management of impervious areas, and modification of stormwater concentrations. Alternatively, structural BMPs operate very close to the runoff sources and are used to control and treat runoff. Typical structural BMPs include filters and surface devices located on individual lots in a residential commercial or industrial development area (Horner et al., 2001). Fig. 17 shows all the types of structural BMPs, including cisterns, rain barrels, and vertical storage devices, which are used to capture rainwater. Cisterns are used for holding larger volumes of water, i.e., approximately 500 gallons or more; rain barrels normally collect drainage from roofs using pipe networks and are particularly useful in small irrigation units. Vertical storage involves standing towers against a building to capture and store water. Another interesting form involves storage beneath the structure, in which the stormwater is stored inside the structure (Guo and Baetz, 2007). Another type of stormwater management policy is the drainage system to take the stormwater out of the city to the of the nearest water bodies; e.g., Japan built a massive drainage structure. The above-mentioned LID and BMP techniques integrated with bioretention basins and structural BMPs are applied in stormwater management to improve the quality of stormwater. A new paradigm of infiltration systems, bioretention basins, and surface and subsurface detention basins is developed to address stormwater runoff close to its source.

Green infrastructure is also an important part of the management, as it is comprised of interconnected networks of natural areas, such as forests and wetlands, which help in improving water quality and provide ecosystem services in the form of recreational activities, wildlife, and good air quality.

The important aspect of discussion here is that community acceptance and governance of stormwater runoff management are equally important in this respect. As shown in Table 2, on various governance levels, different entities become responsible for governance. At the international level, policies are formed based

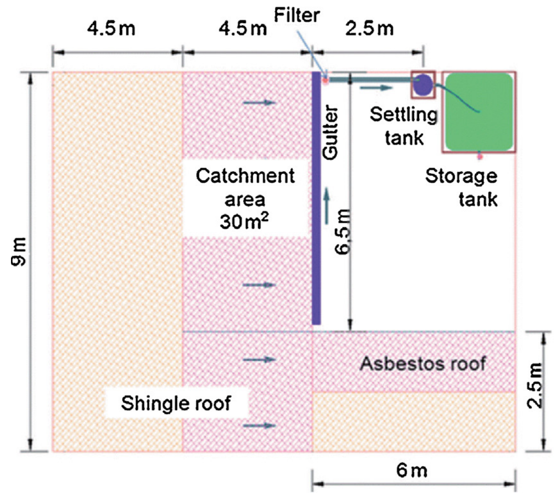

Fig. 16. Rainwater harvesting practices in Hanoi.

Adapted from Nguyen et al. (2013).

on agencies such as the UN and other NGOs, and on the national level, the governance structure and policies are formed by environmental agencies and legislative bodies. Proper maintenance of stormwater facilities can lead to reduced costs for stream channel restoration and pollution mitigation in the future. Ferguson (2005) described the conventional engineering methods used to mitigate the effects of stormwater by quoting the oldest method, i.e., reduce the nuisance of water by providing a smooth surface. Fig. 18 shows how a hybrid governance structure manages stormwater. As infiltration-based approaches increase, cities have to share the responsibility by building and maintaining green roofs, rain gardens, and swales on private properties. Local municipalities can oversee public communication, incentive programs and monitoring (Porse, 2013). This system is reviewed as better in many respects than federal regulation in regards to the centralized system to mitigate stormwater runoff because, in hybridization

Table 1
BMP Table – type and Effectiveness of different types of BMPs (Best management Practices), including infiltration BMPs.

Best Management Practices	Volume	Peak Discharge	Water Quality	Unit Operation/Process
Low Impact Development Techniques				
Bioremediation	†	‡	‡	Volume reduction; microbially mediated transformation; uptake and storage; size separation; sorption
Bioslope	†	†	‡	Volume reduction; microbially mediated transformation; uptake and storage; size separation; sorption
Catch Basin Controls	**0**	**0**	•	Size separation and exclusion; density, gravity, inertial separation
Gutter Filter	**0**	•	†	Size separation and exclusion; physical sorption
Infiltration Trenches/Strips	†	†	†	Volume reduction; size separation and exclusion; chemical sorption processes
Permeable Pavement	‡	‡	†	Volume reduction; size separation and exclusion
Pollution Prevention/Street Sweeping	**0**	**0**	•/†	N/A
Surface Sand Filter	•	•	†	Size separation and exclusion; microbially mediated transformation; sorption
Soil Amendments	†	†	†	Volume reduction; size separation and exclusion; microbially mediated transformation; uptake and storage; sorption
Swales	†	†	‡	Volume reduction; density, gravity, inertial separation; microbially mediated transformation; sorption
Vegetation/Landscaping	‡	‡	‡	Volume reduction; microbially mediated transformation; uptake and storage
Conventional and Innovative techniques				
Advanced Biological Systems	†	†	‡	Microbially mediated transformation; uptake and storage
Detention and Retention Ponds	**0**	‡	•	Flow and volume attenuation; density, gravity, inertial separation; coagulation/flocculation
Disinfection Systems	0	0	†	Chemical disinfection
Flocculent/Precipitant Injection	0	0	†	Coagulation/flocculation
Sedimentation Ponds and Forebays	0	†	•	Flow and volume attenuation; density, gravity, inertial separation
Surface Filters (Filter Fabrics)	0	0	•	Size separation and exclusion
Disturbed Soil Restoration	†	•	†	Size separation and exclusion; density, gravity, inertial separation; microbially mediated transformation
Rain garden	•	•	†	Flow and volume attenuation; density, gravity, inertial separation
Pocket wetland	0	‡	†	Flow and volume attenuation; density, gravity, inertial separation; microbially mediated transformation; coagulation/flocculation

0–No impact, •– Less effective, † – Moderately effective, ‡ – Highly effective.Source: http://www.coralreef.gov/transportation/evalbmp.pdf.

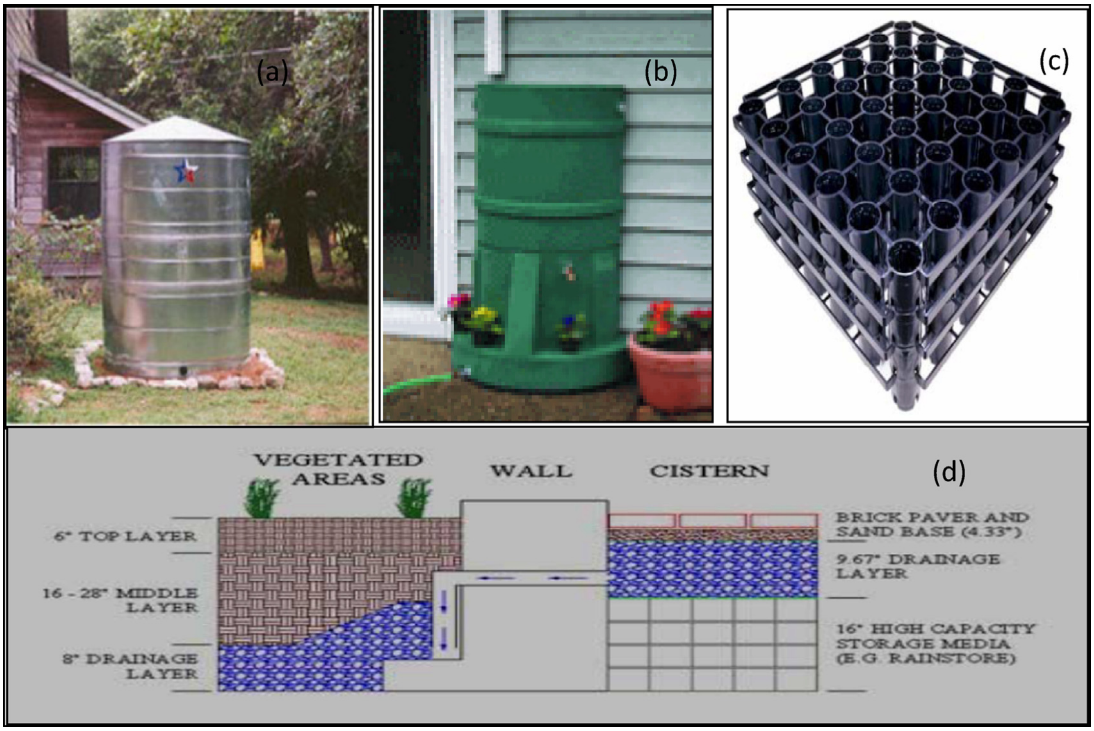

Fig. 17. Structural Best Management Practices for stormwater runoff management: (a) Cisterns, (b) Rain Barrel, (c) Vertical Storage structures and (d) Storage beneath a structure. (http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-68001/6.5.2%20BMP%20Runoff%20Capture%20and%20Reuse.pdf).

Table 2
Structural governance level and the responsible entities for stormwater management.

	Governance Level	Entities Responsible
1.	International	UN Agencies Non-governmental organizations
2.	National	Environmental agencies Flood management agencies Legislative bodies
3.	State/Territorial	Water Management agencies Environmental agencies
4.	Regional	Regional governmental councils Issue-focused, multi-agency entities

Adapted from Porse (2013).

management, the citizens of the cities have the opportunity to decide the governance, economic and social aspects of stormwater management.

6. Conclusions and recommendations

Stormwater runoff management practices have evolved through time, from conventional centralized systems in the past to low-impact development and best management practices. More innovative technologies, such as stormwater artificial infiltration to the ground, the combination of LID and BMPs, structural and non-structural techniques, massive underground tunnels, and the use of nature-based techniques, are now commonly used around the world. The case studies from Tokyo, Bangkok and Hanoi showed the effectiveness and efficiency of these practices. In the context of climate change, it is necessary to manage stormwater

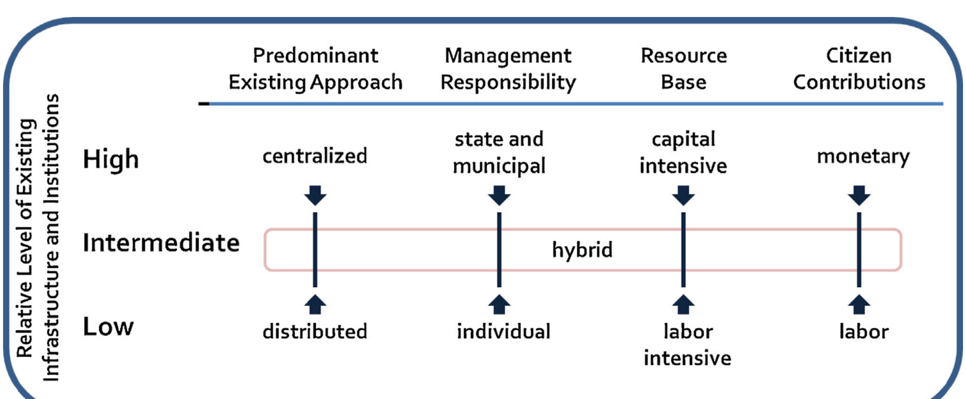

Fig. 18. Governance structure for stormwater management in cities.

Adapted from Porse (2013).

runoff in an efficient way, and for this purpose, numerical computer model simulations are very helpful to compare the advantages and disadvantages. To understand the impact of climate change on the hydrological cycle, the assessment of local areas and representation of the result in a digital or presentable format are more easily performed with the advancement of GIS and remote sensing technology. In this paper, we also discuss methods to assess the cost effectiveness of various stormwater runoff management practices, and explain the important factors behind the success, i.e., community acceptance. In the discussion in this paper, stormwater governance structure is also analysed.

The important recommendations of the study are to understand the topographical and lithological features, identify appropriate drainage areas, and conduct land use/land cover analysis of flood prone areas to determine the runoff coefficient (Ouma and Tateishi, 2014). Also rainfall data, runoff coefficient and runoff data for at least the last three decades will give a sound idea about the trend in the area of interest so that proper structural and non-structural mitigation can be taken for stormwater management. The estimation of carrying capacity and its structural stability using different methodologies for the existing stormwater drainage system and proper judgment of disposal location of stormwater will be other useful tools for decision makers engaged in stormwater management. Economic assessment for stormwater management and its related damage reduction need to be judicially evaluated for their relative effectiveness in addressing the most critical problems. Regular monitoring before, during, and after project implementation can provide information to assess and improve project outcomes. More attention should be paid for minimizing the adverse effects of stormwater on the ecological disturbance, estuarine damage, water quality degradation and the loss of natural resources rather than flooding and drainage problems, which are often given more consideration. However, this broader range of action warrants more legislative and community awareness supported by scientific studies (Bernadette et al., 2009). Through an integrated cost-benefit analysis in a socioeconomic context, the willingness to pay to avoid pollution was assessed. The results vary greatly (Feng and Wang, 2007).

There is also discussion of the preventative measures that are less expensive than restoration after stormwater damage or treatment in urban areas; in addition, the natural drainage in local regions is beneficial as an open space for citizens to enjoy nature (Karr and Rossano, 2001). The restoration of healthy nature-based areas is important for community acceptance; the success of stormwater programs requires a detailed understanding of local environments. The integral part of any stormwater management practice is community acceptance, and various studies have shown that if a community is more aware of the advantages, maintenance and operation problems, they are more willing to contribute in any form, so it is vital to involve the community as an integral part of any new stormwater management policy (Sohail et al., 2005).

Acknowledgments

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