Sustainable urban drainage as a viable measure of coping with heat and floods due to climate change

N W Chan, M L Tan, A A Ghani and N A Zakaria

1 School of Humanities, Universiti Sains Malaysia, 11800 Penang, Malaysia
2 River Engineering & Urban Drainage Research Centre, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia
E-mail: nwchan1@gmail.com

Abstract. Climate change is pervasive, bringing about heat and floods. To address these hazards, better coping, adaptation and resilience are needed. Cities all over the world suffer from heat and flood disasters that account for significant losses. This paper examines the incidence of heat and flood occurrence in urban areas, and examines how sustainable urban drainage systems (SUDS) is used to combat them. The methodology is based on historical event analysis, literature review and secondary data. Results indicate that heat and flood hazards in cities can be effectively reduced by using SUD systems which incorporate vegetated surfaces that absorbs and retains rain water, purifies stormwater and transfers heat. Results show that SUD system reduces flood peaks and heat, thereby reducing the incidence of flash floods and heat islands. SUD system is recommended as a viable method of heat and flood control in cities as cities using SUDS were found to cope very well with heat and floods. Overall, technical measures of flood management such as SUDS are found to be effective, affordable, aesthetically pleasing and socially acceptable. A holistic strategy combing technical SUDS and non-technical human aspects of coping and resilience is the key towards effective management of floods in cities.

1. Introduction
Globally and nationally, climate change is considered the most pervasive environmental change currently affecting human society, especially in urban areas. In Malaysia, climate change has intensified two already deadly hazards, viz. urban heat islands (UHIs) and urban flooding. [1] The 21st century is witnessing increasing frequencies and magnitudes of these hazards as global climate change intensifies vis-à-vis rapid landuse change and urbanisation. More significantly, rapid urbanization has witnessed the unprecedented growth of cities. [2] Cities are now the preferred places of habitation, but are currently routinely affected by the impacts of heat and floods, but as climate change escalates, more severe heat and flood-related events are expected to occur. [3] [4] In order to reduce loss of lives and property damage, cities need to brace themselves by better coping and adaptation. More importantly, countries and cities need to increase their resilience to face climate-related disasters from the perspectives of water, land, energy, food and environmental sustainability. [5] As cities grow and encroach upon their hinterland, urban heat islands and flash floods are expected to intensify. For example, the larger the city, the larger is its heat island effect and the more devastating its floods. Almost every year, cities all over the world suffer from heat-related and flood-related disasters that account for a significant number of casualties, disease epidemics, property and crop damage and other intangible losses. [6]
The term Sustainable Urban Drainage (SUD) is used to describe a type of urban drainage that provides ecological, environmental and social benefits. SUD generally takes care of the rain water or stormwater water quantity and quality (runoff quality), and the amenity value of surface water in the urban environment. This is in contrast to other types of urban drainage such as open type monsoon drains and open canals which can cause flash floods, water pollution, soil erosion, and mudflows which are unsustainable. In Malaysia, SUD can be implemented to solve environmental problems related to flooding, water pollution and excessive heat. Historically, flooding is one of the central issues affecting people and economic growth in Malaysia. [7] [4]. In Malaysia, deforestation followed by rapid land use change from forests into agriculture and then later into urban landscapes and urban sprawl over the last half a century has resulted in increased stormwater flow into receiving waters. This has increased flood magnitudes and frequencies, as conventional urban open drainage systems such as concrete monsoon drains fail to address flash floods and also cause degradation of stormwater quality. [8] Large and open monsoon drains are also exposed to garbage disposal as they are grossly polluted leading to receiving rivers being polluted as well. Consequently, SUD is needed to address flash floods via detention of rainwater at source as well as effective drainage of cities into receiving water bodies further downstream. Chan et al. (2016) [9] documented that sustainable urban drainage system (SUDS) is an innovative and aesthetic approach in the management of stormwater for urban land developments that replicate the natural drainage regime and characteristics. Via SUDS the runoff from rainfall is collected and stored temporarily to avoid flash flooding. This type of drainage also allows natural treatments to the rainwater at source prior to infiltration and the treated rainwater then flows into receiving waters via a controlled release. SUDS blends into the landscape surrounding the development and carry out water treatment with the aim to prevent pollution, flood control, groundwater recharge and environmental enhancement. Runoff is treated using enhanced natural mechanism such as filtration, infiltration, biological uptake, and settlement. It is important to understand how these techniques work together to provide the aims of sustainability in the most practical, cost effective and beneficial way. [10]

Furthermore, a SUD system that encompasses green areas, vegetation and green roofs is also effective in its cooling effect, thereby controlling heat and UHIs. Malaysia, as a tropical climate country, is already hot and humid with daytime temperatures between 30-37 degrees Celcius. Illyani Ibrahim and Azizan Abu Samah (2011) [11] showed that urbanization creates a landscape modification that leads to urban heat island in the city of Kuala Lumpur, and qualitative and quantitative analysis indicated that the land cover conditions influence the urban temperature leading to the formation of urban heat island. Norlida Mohd Dom (2016) [12] also showed that urban heat islands are contributing to climate change in Malaysia, and vice versa. Elsayed (2012) [13] examined the UHI of the City of Kuala Lumpur, and found that the intensity of the UHI of the city of Kuala Lumpur varies from 3.9 to 5.5 °C. Comparing these values to that shown in a study by Sham (1987) [14] in 1985, the intensity was seen to have increased from 4 °C to 5.5 °C. In Penang, Nur Aili Hanifah Hanafiah and Chan (2013) [15] found that George Town city was about 2 to 3 degrees Celcius warmer that its surrounding green areas. The Department of Irrigation and Drainage, Malaysia (DID) had launched the Urban Stormwater Manual of Malaysia (MSMA) in 2001 and the second edition of MSMA in August 2012. This manual promotes the application of Sustainable Urban Drainage System (SUDS) facilities like bioretention, swale, wetland and etc. Green roof is one of the SUDS facilities. However, it is not included in the latest MSMA. There is no legislation or rule provided for the green roof construction. Green roof when used together with other SUDS or BMPs facilities will intercept rainwater that can reach to the ground and consequently control the volume of rainwater on the ground. Besides, rain water quality also can be improved. According to findings by Ayub et. al. (2010),[16] a SUD system involving green swales, ponds, wetlands and green roofs provide numerous benefits such as attenuating stormwater runoff which lowers risks of urban floods and improving the urban water balance, acting as noise buffer and reduce air pollution. Moreover, green roof also creates new habitat for wildlife and biodiversity enhancement and reduction of heat in the microclimate of the area. Implementation of green roofs in SUDS in stormwater management would help not only reduce heat but also prevent floods and help increase water availability.
SUDS is consistent with objectives of stormwater management approach, controlling rain water at source and managing stormwater quantity and quality via controlling the runoff. The application of SUDS is aimed at solving three major problems commonly encountered in Malaysia namely flash floods, river pollution and water scarcity during dry periods. SUDS is an innovative way of managing stormwater in a sustainable manner without compromising the overall project cost compared to conventional open drainage system. SUDS reduces infrastructure costs, as well as maintenance costs. It’s also beneficial to the environment due to its minimal impact on local ecology, and it preserves ecosystem values and functions, as well as provides benefits to society. SUDS is a viable way forward in managing water resources in the face of climate change. SUDS emphasizes a holistic approach to stormwater management, meeting the multi-objectives of runoff quantity, quality and public amenity aspects, rather than just quantity aspect of conventional approach (Figure 1). SUDS uses the concept of the stormwater management train, starting with prevention or good house-keeping measures for individual premises, and progresses through to local source control, larger downstream site and regional controls. Water could flow straight into a site control but as a general principle it is better to deal with runoff locally, returning the water to natural drainage system as near to the source as possible. Only if the water cannot be managed on site should it be conveyed elsewhere. This concept of treating and storing water locally is very beneficial for water conservation and has a huge potential on water reuse. Just as rainwater harvesting technique, SUDS can be successfully used to provide water source for non-potable use. The increased green area and enhance infiltration facilities are also important to soil moisture replenishment and ground water recharge at local level. [17] [8]

2. Methodology
The methodology is based on the following: (1) A literature review on Sustainable Urban Drainage; (2) A “Demonstration Project” on SUD in the Universiti Sains Malaysia (USM) Engineering campus whereby construction started in 2000 and the campus was completed in 2002. Data was collected on water quantity and quality after the construction of the campus was completed in 2002. Data from previous studies were documented and compared; and (3) A literature review on Urban Heat Islands and evaluation of SUD system on heat reduction, and the development of a physical model of green roof and rainfall simulator in the Universiti Sains Malaysia’s Engineering campus. Results were then collected from the model to provide important data to be referred in the guidelines for the related or relevant agencies in order to implement the green roof in their developing areas.

3. Results and discussion
According to Zakaria et al. (2016), [8] there was a need for a paradigm shift in the way stormwater is managed in Malaysia in the early 2000s. The Malaysian government subsequently launched the Urban Stormwater Management Manual for Malaysia (MSMA) in 2000.[18] This manual was later revised and improved into a new-look manual titled the 2nd Edition of Urban Stormwater Management Manual for Malaysia in 2011 [19] that incorporated the latest approaches in stormwater management. The introduction of MSMA marked a significant change in the approach of water engineers towards urban drainage and flood management, strategically transforming the stormwater management landscape in the country. The new approach gave rise to the increasing demands for green technologies to be incorporated into urban drainage and flood management that also addresses climate change issues. Engineers are now forced to consider urban drainage in a more holistic manner as they face multiple challenges to provide effective and sustainable drainage systems that can tackle multiple problems. The implementation of MSMA necessitated the need to blend new technologies or innovations into the design of drainage facilities which can provide multiple benefits rather than single benefit.

The USM Engineering Campus (Figure 1) was constructed in 2002 based on DID’s MSMA approach in using the SUD system. This green and sustainable urban stormwater management system is better known as Bio-Ecological Drainage Systems (BIOECODS). It was designed by the USM’s River Engineering and Urban Drainage Research Centre (REDAC), a research centre. This was the first large-scale construction using SUD system as the campus was a demonstration project to show-case the MSMA concept. BIOECODS attempt is aimed at addressing three major problems commonly
encountered in Malaysia namely flash floods, river pollution and water scarcity. [8] The Design Concept of BIOECODS is based on the concept of SUDS, that fully complies with the MSMA requirements. The USM BIOECODS model comprises several important components that combine to form an effective stormwater treatment train that controls runoff quantity, preserves runoff quality, ensures safety, beautifies the landscape and reduces heat. Significantly, BIOECODS is designed to provide time for natural processes of sedimentation, filtration and biodegradation to occur, all of which reduce the pollutant loads in stormwater runoff. In addition, BIOECODS blends easily into its surrounding, adding considerably to the local amenity and/or local biodiversity. [17]

Figure 1. Typical Example of Constructed Swale in USM Engineering Campus.

In the experimental project of the USM Engineering Campus, the design of the SUD system is aimed at reducing the drainage footprint of the BIOECODS, to provide water treatment function, and to achieve aesthetic appeal. A dual layer conveyance system was introduced with a design where the surface of the swale is similar to a conventional open drain, but with water storage and treatment function that the conventional open drainage system does not possess. Typically, the surface layer resembles a grassed channel or a swale. The typical swale design has a gentle side slope, low gradient and shallow depth. Beneath the surface, the underground layer consists of a geosynthetic module enclosed in geotextile. The module is connected to the surface layer via a layer of river sand or infiltration media. Figure 1 (above) presents a cross-sectional view of the said ecological swale. During heavy rain events, runoffs initially build up on the swale surface and infiltrates into the underground module. This infiltration process provides both quantity and quality treatments to the runoff. First, the infiltration detains some of the rain water and delays flow. Then the infiltrated water is stored in subsurface module. Only after the pool of water generates enough energy will it flow downstream within the module. In the module, water is loss to adjacent ground through exfiltration of water from the side or bottom of the module. This water will percolate through the ground and are either retained as soil moisture or contribute to groundwater recharge. On the surface, swale attenuates flow by providing larger surface friction than concrete channel. [17]

In terms of water quality, the infiltration also filters the stormwater. Hence, the stormwater undergoes water quality treatment that involves three important processes. First, as water flows into the swale from impervious surfaces, grass on swale surface acts as filter media to trap out particulate pollutants. The aerobic condition of the soil promotes hydrocarbon breakdown. The second treatment involved is the infiltration of water through sand layer and into the module. Infiltration filters out particulates and some smaller solid nutrients that are attached to the runoff. The geosynthetic module is manufactured in such a way that the internal structure of the module helps to break up water flow, creating turbulence and therefore increase dissolves oxygen. Finally, both the surface and subsurface flows will combine again by both discharging into the ponds and wetlands system before discharging back into receiving waters of the Kerian River. There are also other components in the SUD system in the USM
Engineering Campus drainage design. These include “Dry Ponds”, “Detention Ponds”, and “Wetlands”. During rain events, excess stormwater is also stored in the dry ponds which are constructed with a storage function. The dry pond is essentially a detention pond, which has been integrated with the ecological swale to temporarily store stormwater runoff. A module storage tank is placed beneath the detention pond. The outflow path of the storage module is connected to the ecological swale at the lowest point, in order to drain the dry pond system in less than 24 hours. Dry ponds diffuse flow conveyed by swales and the reduced stormwater velocities enable more effective sedimentation, filtration and infiltration water treatments. The grassed surfaces of dry ponds are able to infiltrate a substantial portion of the annual surface runoff volume due to the increased soil permeability that is created by the deep and fibrous root systems of the landscape vegetation (Figure 2). [17] Another component of the SUD system in the experimental project is the “Detention pond”, which is the first community facility of the BIOECODS. The pond is primarily designed for attenuating runoff from developed areas through regulated outlet structures. The facility is typically designed to limit discharge to the pre-development stage, while storing water temporarily. On top of that, the detention pond also facilitates water quality treatment and ecological functions. With aquatic and wetland plants planted along the water fringes, the pond provides some water quality treatment and habitat for urban wildlife. Extended exposure to sunlight in a pond will also help to breakdown certain pollutants. Figure 3 shows the detention pond in USM Engineering Campus.

![Figure 2. Typical Example of Constructed Dry Pond (Source: [17]).](image1)

![Figure 3. Typical Example of Constructed Detention Pond (Source: [17]).](image2)

The USM BIOECODS has a wetlands component. These are considered as constructed wetlands. In terms of water quality improvements, the constructed wetland is designed as a community treatment facility. [20] Data collected showed that about 90% of the total volume of annual stormwater runoff will flow through an area supporting a healthy population of wetland plants. Water pollutants and other contaminants are shown to be removed either by direct absorption into plant tissues (soluble nutrients) or by physical entrapment and subsequent settlement on the bed of the wetlands. Apart from water quality, the wetland is also designed as a habitat area for biodiversity conservation within a development, supporting species such as small mammals, birds, fish, reptiles and plants. The end
product is expected to improve the aesthetic value for surrounding areas at the most downstream end of the drainage system. [17][8]
The performance of BIOECODS based on research data collected in the USM Engineering Campus experimental site is remarkable. Since its establishment, BIOECODS has been closely monitored for its hydrological and hydraulic performances. The first BIOECODS system in USM engineering campus has been monitored with sophisticated water quantity and quality equipment to record its performance during rainfall events continuously for almost a decade. The most significant benefit of BIOECODS is its ability to reduce flow peak and flow volume. The retardation in ecological swale and detention in dry pond, wet pond and wetlands have enable BIOECODS to successfully create a stormwater system that mimics natural condition, hence reducing flood risks. Figure 4 shows an example of flow attenuation in a stretch of ecological swale while Figure 5 shows flow attenuation with detention pond during a rainfall event. Table 1 and 2 provide further examples of flow attenuation in swale and pond respectively.

![Figure 4. Example of Flow Attenuation of Ecological Swale (Source: [17]).](image1)

![Figure 5. Example of Flow Attenuation by Detention Pond (Source: [17]).](image2)

**Table 1. Example of Ecological Swale Performances for Frequent Rainfall Events**

| Precipitation Event | Average Rainfall Intensity (mm/hr) | Estimated (ARI) | Peak Flow (l/s) | Total Runoff Volume (m³) | Percentage of Reduction (%) |
|---------------------|-----------------------------------|-----------------|-----------------|--------------------------|-----------------------------|
|                     | Inlet | outlet | Inlet | outlet | Peak Flow | Runoff Volume |
| 24/6/2003           | 11    | 3 months | 128   | 91     | 418.5 | 246.6 | 28.9 | 41.1 |
| 30/8/2003           | 14.5  | 3 months | 59    | 26     | 388.8 | 123.6 | 55.9 | 66.6 |
| 8/9/2003            | 13.8  | 5 years   | 195   | 176   | 4043.1 | 3043.2 | 10.0 | 24.1 |

(Source: [17]).
More detailed observations regarding the USM’s SUDS are recorded in Ainan et al. (2004). [21] The performance of ecological swale was also verified using computer model by Abdullah et al. (2004) [22] using XP-SWMM. In both cases, the authors found that the system performed admirably to attenuate flow from the catchment. Recently, a water balance analysis by Ayub et al. (2010) [16] confirmed that the BIOECODS system actually increases groundwater recharge through infiltration. During drier days, percolated surface water eventually ‘resurface’ to supply much needed base flow to sustain plants and ecology within the constructed wetland. The data collected also showed substantial Water Quality Improvements. Apart from controlling the quantity of rain water flow (runoff), rain water and stormwater quality were also under control via the BIOECODS system. Regular and constant monitoring through in-situ test as well as laboratory testing for the common water quality parameters showed that the water quality is of a good class after flowing through the SUD system. The final discharge from the system is found to conform to Class IIB of National Water Quality Standard published by Department of Environment. Table 3 shows the results from a quick sample test for a 3-month ARI event on 19 April 2006. [17]

Results from this study showed that the use of this SUD system significantly reduces the pollutant loads especially particulate pollutants, i.e. sediment. For the entire system, TSS was non-detectable, indicating that even if sediments were washed into the system, they are trapped very early on by the ecological swale networks. With the use of detention ponds and wetlands, most biological activities are concentrated in this area, the biological load is rather higher, but still in Class IIB limit. However, the discharge from wetlands is significantly of better quality, indicating the success of biological treatment occurring within the ponds and wetlands. Similar testing in research by Mohd Sidek et al. (2004) [23] and Ayub et al. (2005) [24] confirmed the improvement in water quality as a result of BIOECODS.

Table 2. Example of Detention Pond Performances for Frequent Rainfall Events

| Rain Event | Total Time (min) | Rainfall Depth (mm) | Rainfall Intensity (mm/hr) | Peak Flow (m³/s) | Volume (m³) | Percent Reduction (%) |
|------------|------------------|---------------------|---------------------------|-----------------|-------------|----------------------|
|            |                  |                     |                           | Inlet           | Outlet      | Inlet               | Outlet               | |
| 14/4/2007  | 40               | 23.5                | 35.3                      | 0.041           | 0.032       | 2.214              | 1.777               | 21.95               | 19.74               |
| 16/4/2007  | 70               | 23.2                | 19.9                      | 0.034           | 0.026       | 1.545              | 1.200               | 23.53               | 22.33               |
| 18/10/2009 | 65               | 84.6                | 78.1                      | 0.335           | 0.235       | 23.919             | 18.36               | 29.85               | 23.22               |
| 11/11/2009 | 155              | 171.5               | 66.4                      | 0.689           | 0.289       | 38.859             | 18.87               | 50.65               | 51.44               |

(Source: [17]).

Table 3. Water Quality Condition for Various Sampling Location of BIOECODS on 19 April 2006

(Source: Ab Ghani et al., 2004).

| BIOECODS Components | Location | pH   | DO (mg/l) | Temp (°C) | Turbidity (NTU) | BOD5 (mg/l) | TSS (mg/l) | TP (mg/l) | COD (mg/l) | NH3-N (mg/l) |
|---------------------|----------|------|-----------|-----------|----------------|-------------|------------|-----------|------------|--------------|
| Ecological Swale    | Upstream | 8.3  | 6         | 28        | 14             | 2           | ND         | 0.1       | 34         | 0.1          |
|                     | Downstream | 7    | 6         | 25        | 23             | 2           | ND         | 0.2       | 13         | 0.1          |
| Wet Pond            | Inlet    | 6.9  | 6         | 24        | 48             | 2           | ND         | 0.2       | 7          | 0.1          |
|                     | Outlet   | 6.5  | 7         | 26        | 74             | 2           | ND         | 0.3       | 6          | 0.2          |
| Detention Pond      | Inlet    | 6.9  | 8         | 24        | 80             | 1           | ND         | 0.5       | 22         | 0.4          |
|                     | Outlet   | 6.8  | 8         | 25        | 10             | 1           | ND         | 0.3       | 20         | 0.1          |
| Wetland             | Inlet    | 7    | 6         | 29        | 18             | 1           | ND         | 0.1       | 13         | 0.1          |
|                     | High Marsh | 7.1  | 8         | 24        | 26             | 1           | ND         | 0.2       | 16         | 0.1          |
|                     | Micropool | 7.1  | 7         | 23        | 15             | 1           | ND         | 0.3       | 26         | 0.1          |
|                     | Outlet   | 7.3  | 6         | 28        | 13             | 1           | ND         | 0.3       | 19         | 0.1          |

**note: ND denotes non-detectable**

Class IIB, NWQS 6 – 9 5 - 7 - 50 3 50 - 25 0.3
Ayub et al. (2010) [16] documented the monitoring of water balance within the constructed wetland of BIOECODS system for 2007 and 2009. It was found that the constructed wetland received considerable amount of direct precipitation as well as runoff inflow. Outflow records from the wetland however, showed significant reduction in volume, as compared to the combined inflow. Hence, water conservation and water reuse are significant benefits in BIOECODS. As evapotranspiration rate are almost constant (tropical climate) year round, the balance of water volume are translated into active storage and soil moisture or groundwater recharge. Since early 2010, a series of trials were conducted to investigate the potential water reuse in the BIOECODS system. In the first stage, the potential for non-potable use was explored. The trial involved withdrawal of water from BIOECODS recreational pond to support laboratory use in REDAC's Physical Modelling Laboratory. A simple water usage budget calculation revealed that the recreational pond was capable of supplying sufficient water demand for the physical laboratory. The laboratory requires replacement and replenishment of freshwater every week to support mainly sediment transport and scour modelling.

In terms of heat reduction, the SUD system in the USM Engineering Campus showed great potentials. A literature review on Urban Heat Islands was conducted. The review showed that cities are “hot spots” generating urban heat islands (UHIs). Green lungs such as trees and vegetation reflect solar radiation and possess lower surface and air temperatures by providing shade and transfer of heat upwards via evapotranspiration. Every 1 gram of water evapotranspirated takes away roughly 600 calories of heat. Hence, shaded surfaces, for example, experience temperatures between 1–5°C cooler than the peak temperatures of unshaded materials. The process of evapotranspiration in combination with shading and reflection, can help reduce peak summer temperatures by 1–5°C. Energy absorbed from the sun is transferred from the urban surface to the atmosphere through evapotranspiration, thereby linking the urban energy balance to the hydrological cycle. Significantly, the process of evapotranspiration is influenced by the availability of moisture which is found in vegetation cover, precipitation, irrigation, humidity, water surfaces and wind flow. It is estimated that annual global evapotranspiration consumes about 22% of the total available insolation at the top of the Earth’s atmosphere. [25] When vegetation is replaced by concrete, evapotranspiration is greatly reduced and this alters the partitioning of the urban energy balance, as heat that would have otherwise been transferred upwards, stays in the concrete jungle and then contributes to the formation of the UHI. Urban planners now plan green structures to increase evapotranspiration (e.g. by planting trees, increasing vegetation cover and waterbodies) to a city, thereby replacing ‘sensible heating’ ($Q_s$) with ‘latent heating’ ($Q_e$), which in turn reduces the ‘Bowen ratio’ (of sensible to latent heat flux) leading to evaporative cooling ($B=Q_s/Q_e<1$). [26]

Results of the USM BIOECODS study show that water bodies (ponds, wetlands, streams) and green areas have a significant cooling effect on the micro-climate, especially at higher ambient air temperatures. Such green areas experience an average reduction of 1°C during temperatures higher than 20°C. Cooling occurred significantly during the daytime and ranged from 0.5 to 2.0°C. The cooling effect was found to be greater when temperatures are higher. It was also found that the cooling effect did not extend beyond 50 metres from the water body/green area. Cooling was significantly affected by landuse type, with road temperatures 43-50 °C compared to temperatures of surrounding trees between 28-30 °C. The average mid-day outdoor temperatures beside buildings in the USM Engineering campus was between 33-40 °C but in the BIOECODS areas with green vegetation and trees, temperatures were much lower between 28-30 °C. Road surfaces inside the campus recorded the highest temperatures of between 43-50 °C but the BIOECODS experimental area with greenery, open fields, lakes, ponds, rivers/streams, and grass, i.e. areas with reflective and evaporative surfaces, experienced effective cooling with temperatures between 28-30 °C. Hence, this study showed that SUDS with water bodies and green vegetated areas have cooling effects on their surroundings reducing high temperatures which can have a negative effect on health and wellbeing. Hence, a city that incorporates SUDS will benefit with cooling effects greatly enhanced. This can be done by careful consideration of urban design incorporating Sustainable Stormwater Management Systems.

Elsewhere, many cities adopting SUDS have benefited from the cooling effect. In Seoul, the Seoul Metropolitan Government undertook a major urban renewal project in restoring the Cheonggyecheon River via dismantling the highways which have covered the river. Despite initial criticism and
skepticism, the project is now recognised as highly successful, strengthening the resilience of the ecosystem and providing a useful green space for the citizens. Results of this project showed that a river as well as wind corridor was created, thereby reducing the heat island effect, improving air quality, and restoration of the natural environment. After the dismantling of the highways, the reduced traffic volume in the Cheonggyecheon area significantly reduced the concentration of fine dust (PM-10), NO₂, volatile organic compound (VOC) and other air pollutants. The heat island effect in the downtown area also declined. The temperature of the Cheonggyecheon area before the restoration was 2.2°C higher than the average of Seoul, but it declined to 1.3°C after the restoration, dropping by 8 to 18 %.

The temperature of green point within the stream was 0.9°C lower than the neighbouring area. As the air-blocking elevated highway disappeared, a wind corridor was established and the creation of a stream affected the neighbouring environment. The ecosystem was also restored as wildlife fish species, birds, insects and plants increased. [27]

In Bangkok, the Chulalongkorn Centenary Park [28] was designed to hold excess rain water in large underground tanks to prevent flooding, and control heating. The park is intended not only as a welcome green space in the middle of one of the most congested cities in the world with 10 million people, but also as a place that could also retain large amounts of water, reducing monsoon flooding around Chulalongkorn University. Parks and "green roofs" planted with vegetation soak up rain during the annual monsoon and help dense urban centres like Bangkok adapt to climate change. Green architects are thinking about everything they build in the context of mitigating climate-change impact. Buildings and parks must be multi-functional and not be just about one or two aspects such as aesthetics or economics, but also about other functions such as flood control, heat management and recreational. This is Bangkok's first park in many years, a kind of "metro forest" project in a Bangkok suburb that has converted 0.8 hectares of abandoned land into a local forest with native trees, to make a start on reversing urban sprawl. The city's 11-acre Chulalongkorn Centenary Park is designed at an inclination of a three-degree angle, so that rain and floodwater flow to its lowest point, into a retention pond. At the park's highest end, a museum is topped by a green roof covered with native plants, which filter rainwater before it is stored in large tanks underground. Rainwater also flows through the park's lawn and wetlands where native vegetation filters the water, while its walkways are made of porous concrete. The park can hold up to 1 million gallons of water that can be discharged later or used in the dry season. The park also highlights the important role that green roofs and permeability of driveways and yards can play in reducing surface (water) runoff, with added benefits in reducing urban heat island effects.

Globally, the hundreds of megacities combined have become awesome in their sizes, and contribute significantly to greenhouse gas emissions and global warming. Large megacities have a ravenous appetite for energy, consuming ⅔ of the world's energy and creating over 70% of global CO₂ emissions. The implementation of SUD system in cities with green lungs and parks can have significant heat reduction effect. For example, the vegetation and greenery produced by SUD systems reduces concrete jungle, replacing dark absorbant surfaces of concrete jungle with reflective surfaces, and the increase in vegetation (especially trees) in SUD system increases the rates of evapotranspiration which transfer the heat from absorbed sunlight upwards into the atmosphere. Furthermore, the development of a physical model of green roof and rainfall simulator in the Universiti Sains Malaysia’s Engineering campus depict results of heat reduction. This reduction in heat and UHIs from the model provides important data to be referred in the guidelines for the related or relevant agencies in order to implement the green roof in their developing areas. Significantly, the green areas under SUD systems are typically shown to be between 2 to 5 degrees Celsius lower than non-green areas of the city.

4. Conclusion
Sustainable Urban Drainage has been shown to be effective in performing a wide range of functions. SUD is proven to be a viable method of heat and flood control in cities. Cities using SUDS were found to cope very well with heat and floods. Overall, technical measures of flood management such as SUDS are found to be effective, affordable, aesthetically pleasing and socially acceptable. A holistic strategy combing technical SUDSs and non-technical human aspects of coping and resilience is the
key towards effective management of floods in cities. The Urban Stormwater Management Manual for Malaysia, or MSMA, has been found to be an effective tool in controlling not only water quantity but also water quality. The Bio-ecological Drainage System or BIOECODS introduced in 2001 is adapted from the MSMA. Adopting the concepts of integration, control-at-source and sustainability, BIOECODS showed the way forward in USM’s Engineering Campus’s SUD design. The BIOECODS has innovation in design, with ecological swale, a dual layer conveyance system that minimize drainage footprint but provide additional water quantity and quality treatment. Other components such as dry ponds, wet ponds and wetlands are further evidences of the integration of stormwater facilities into surrounding landscape, adding significant values to otherwise passive open spaces. The results also showed that water bodies (ponds, wetlands, streams) and green areas have a significant cooling effect on the micro-climate, especially at higher ambient air temperatures. Cooling occurred significantly during the daytime and ranged from 0.5 to 2.0°C. It was also found that the cooling effect did not extend beyond 50 metres from the water body/green area. Cooling was significantly affected by landuse type, with road temperatures 43-50 °C compared to temperatures of surrounding trees between 28-30 °C. The average mid-day outdoor temperatures beside buildings in the USM Engineering campus was between 33-40 °C but in the BIOECODS areas with green vegetation and trees, temperatures were much lower between 28-30 °C. Road surfaces inside the campus recorded the highest temperatures of between 43-50 °C but the BIOECODS experimental area with greenery, open fields, lakes, ponds, rivers/streams, and grass, i.e. areas with reflective and evaporative surfaces, experienced effective cooling with temperatures between 28-30 °C. Hence, this study showed that SUDS with water bodies and green vegetated areas have cooling effects on their surroundings reducing high temperatures which can have a negative effect on health and wellbeing. Hence, a city that incorporates SUDS will benefit with cooling effects greatly enhanced. This can be done by careful consideration of urban design incorporating Sustainable Stormwater Management Systems. BIOECODS is currently being put on trial for water reuse by supplying non-potable water from its recreational ponds for landscape watering and laboratory use. There is a huge potential of this trial to be expanded to include other non-potable in the campus. The system is a living proof for feasibility and multi-benefits of MSMA implementation. BIOECODS also testified that the current stormwater management concept is ready to face the challenges and meet the demand for the nation, and most importantly, to secure a new source of water for the future generations.

5. References

[1] Intergovernmental Panel on Climate Change (2018) Global warming of 1.5°C. Switzerland: Intergovernmental Panel on Climate Change. ISBN 978-92-9169-151-7.
[2] United Nations, Department of Economic and Social Affairs, Population Division (2018) World Urbanization Prospects: The 2018 Revision, New York: United Nations. (Online Edition: Available from https://esa.un.org/unpd/wup/Publications Accessed 23 January 2019).
[3] Chan, N.W. (2015) Chapter II: 20 Urbanization and the Generation of Urban Heat islands in Selected Cities in Malaysia. In Urban Sustainable Development Opportunities – Challenges. Ho Chi Minh City: University of Social Sciences & Humanities, Vietnam National University, 218-232 (ISBN 978-604-73-3272-4).
[4] Chan, N.W. (2018) Building a Collaborative Flood Disaster Management Model for Malaysia. Paper presented at the ISEAS-Yusof Ishak Institute Singapore Workshop, 12 November 2018.
[5] Tan, M.L., Ab Latif Ibrahim, Zulkifli Yusop, Chua, V.P. and Chan, N.W. (2017) Climate change impacts under CMIP5 RCP scenarios on water resources of the Kelantan River Basin, Malaysia. Atmospheric Research Volume 189, 1 June 2017, Pages 1–10 (Online) © 2017 Elsevier B.V., IF 3.377).
[6] Kerle, N. and Müller, A. (2013) Megacities and Natural Hazards. In: Bobrowsky P.T. (eds) Encyclopedia of Natural Hazards. Encyclopedia of Earth Sciences Series. Springer, Dordrecht.
[7] Chan, N.W. (1995) A Contextual Analysis of Flood Hazard Management in Peninsular Malaysia, Unpublished Ph.D. thesis, Middlesex University (UK).
[8] Zakaria, N.A., Aminuddin Ab Ghani, Ngai Weng Chan and Chun Kiat Chang (2016) Chapter 39: Sustainable Urban Drainage and Cities. In Chan, N.W., Hidefumi Imura, Akihiro Nakamura and Masazumi Ao (Editors) Sustainable Urban Development Textbook. Penang: Water Watch Penang & Global Cooperation Institute for Sustainable Cities, 259-270.

[9] Chan, N.W., Masazumi Ao, Nor Azazi Zakaria and Aminuddin Ab Ghani and Zullyadini A Rahaman (2016) Chapter 38: Rivers and Cities. In Chan, N.W., Hidefumi Imura, Akihiro Nakamura and Masazumi Ao (Editors) Sustainable Urban Development Textbook. Penang: Water Watch Penang & Global Cooperation Institute for Sustainable Cities, 248-258.

[10] Construction Industry Research and Information Association or CIRIA (2007). The SUDS Manual. CIRIA, London, UK.

[11] Illyani Ibrahim and Azizan Abu Samah (2011) Preliminary Study of Urban Heat Island: Measurement of Ambient Temperature and Relative Humidity in Relation to Landcover in Kuala Lumpur. June 2011, IEEE Geoscience and Remote Sensing Letters, DOI: 10.1109/GeoInformatics.2011.5981068.

[12] Norlida Mohd Dom (2016) Urban heat islands and the climate change in Malaysia. Paper presented in the Workshop for Capacity Building on Climate Change Impact Assessments and Adaptation Planning in the Asia-Pacific Region: Needs and Challenges for Designing and Implementing Climate Actions ; 27-28 January 2016, Manila, The Philippines.

[13] Elsayed I.S.M. (2012) A Study on the Urban Heat Island of the City of Kuala Lumpur, Malaysia. *JKAU: Met., Env. & Arid Land Agric. Sci.*, Vol. 23, No. 2, pp: 121-134 (2012 A.D./1433 A.H.) DOI: 10.4197/Met.23-2-8.

[14] Sham, S. (1987) Urbanization and the Atmospheric Environment in the Low Tropics: Experiences from the Klang Valley Region, Malaysia. Bangi: Penerbit Universit Kebangsaan Malaysia.

[15] Nur Aili Hanim Hanafiah and Chan, N.W. (2013) Kajian Keprihatinan Awam Terhadap Pulau Haba Bandar dan Amalan Mereka Terhadap Pengurusan Tekanan Haba di Pulau Pinang. In Jamaluddin Md. Jahi, Muhammad Rizal Razman, Kadir Arifin, Zuliskandar Ramli, Abdullah Sulaiman and Emrizal (Editors) Prosiding Seminar Serantau Ke-2 Pengurusan Persekitaran di Alam Melayu, Pekanbaru, Provinsi Riau, 6-7 Mei 2013. Bangi: Institut Alam dan Tamadun Melayu (ATMa), Universitas Islam Riau dan Persatuan Pengurusan Persekitaran Malaysia, 204-208 (ISBN 978-983-2457-63-3).

[16] Ayub, K.R., Zakaria, N.A., Abdullah, R. & Ramli, R. (2010). Water Balance: Case Study of A Constructed Wetland As Part of the Bio-Ecological Drainage System (BIOECODS). *Water Science & Technology*, Vol. 62, No. 3, pp. 1931-1936.

[17] Ab. Ghani, A., Zakaria, N.A., Abdullah, R., Yusof, M. F., Mohd Sidek, L., A.H. Kassim & A. Ainan. (2004). BIO-Ecological Drainage System (BIOECODS): Concept, Design and Construction. The 6th International Conference on Hydroscience and Engineering (ICHE-2004), May 30th -June 3rd, Brisbane, Australia.

[18] Mansor, M., Lim, P. and Shutes, R. (2002). *Constructed wetlands : Design, management and education*. Penang: Penerbit Universiti Sains Malaysia.

[19] Mansor, M., Lim, P. and Shutes, R. (2002). *Constructed wetlands : Design, management and education*. Penang: Penerbit Universiti Sains Malaysia.

[20] Mansor, M., Lim, P. and Shutes, R. (2002). *Constructed wetlands : Design, management and education*. Penang: Penerbit Universiti Sains Malaysia.

[21] Mansor, M., Lim, P. and Shutes, R. (2002). *Constructed wetlands : Design, management and education*. Penang: Penerbit Universiti Sains Malaysia.

[22] Mansor, M., Lim, P. and Shutes, R. (2002). *Constructed wetlands : Design, management and education*. Penang: Penerbit Universiti Sains Malaysia.
Mohd Sidek, L., Ainan, A., Zakaria, N.A., Ab. Ghani, A., Abdullah, R. & Ayub, K.R. (2004). Stormwater Purification Capability of BIOECODS. The 6th International Conference on Hydroscience and Engineering (ICHE-2004), May 30th -June 3rd, Brisbane, Australia.

Ayub, K. R., Mohd Sidek, L., Ainan, A., Zakaria, N. A., Ab. Ghani, A. & Abdullah, R. (2005). Storm Water Treatment using Bio-Ecological Drainage System. International Journal River Basin Management, Special Issue Rivers’04, IAHR & INBO, Vol. 3, No. 3, pp. 215-221.

Qiu, G.Y., Li, H.Y., Zhang, Q.T., Chen,W., Liang, X.J. and Li, X.Z. (2013) Effects of evapotranspiration on mitigation of urban temperature by vegetation and urban agriculture. J. Integr. Agric.,12 (2013), 1307-1315.

Gunawardena, K R, Wells, M.J. and Kershaw, T. (2017) Utilising green and bluespace to mitigate urban heat island intensity. Science of the Total Environment Vol. 584-585, 15 April 2017, 1040-1055.

https://policytransfer.metropolis.org/case-studies/seoul-urban-renewal-cheonggyecheon-stream-restoration (Accessed 24 Jan 2019).

https://www.chula.ac.th/en/cu-services/creative-space/cu-centenary-park/ (Accessed 24 Jan 2019)

Acknowledgements
The author graciously acknowledges the data and secondary publications related to SUD system, particularly those produced by the River Engineering and Urban Drainage Research Centre (REDAc) in USM. The Grant under the USM Account Number 304/PHUMANITI/650906/W109 is also acknowledged.