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Sustainability Analysis and Quality Assessment of Rainwater Harvested from Green Roofs: A Review

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***Abstract*—**Most people today are aware that global climate change is not just a scientific theory but also a fact with worldwide consequences. Global climate change is due to rapid urbanization, industrialization, high population growth and current vulnerability of the climatic condition. Water is becoming scarce as a result of global climate change. To mitigate the problem arising due to global climate change and its drought effect, harvesting rainwater from green roofs, an environmentally-friendly and versatile technology, is becoming one of the best assessment criteria and gaining attention in Malaysia. This paper addresses the sustainability of green roofs and examines the quality of water harvested from green roofs in comparison to rainwater. The factors that affect the quality of such water, taking into account, for example, roofing materials, climatic conditions, the frequency of rainfall frequency and the first flush. A green roof was installed on the Humid Tropic Centre (HTC) is a place of the study on monitoring program for urban Stormwater Management Manual for Malaysia (MSMA), Eco-Hydrological Project in Kuala Lumpur, and the rainwater was harvested and evaluated on the basis of four parameters i.e., conductivity, dissolved oxygen (DO), pH and temperature. These parameters were found to fall between Class I and Class III of the Interim National Water Quality Standards (INWQS) and the Water Quality Index (WQI). Some preliminary treatment such as disinfection and filtration could likely to improve the value of these parameters to class I. This review paper clearly indicates that there is a need for more research to address other microbiological and chemical quality parameters to ensure that the harvested water is suitable for use potable water for domestic purposes. The change in all physical, chemical and microbiological parameters with respect to storage time will be a major focus of future studies in this field.

***Keywords*—**Green roofs, INWQS, MSMA-SME, Rainwater harvesting.

I. Introduction

A green roof or ‘living roof’ is a roof that is partially or completely covered with vegetation and a growing medium, planted over a water proof membrane. Also, it can include additional layers, such as a root barrier, a drainage system and an irrigation system.

A green roof is an existing roof structure that has active vegetation growing on the top of a waterproofing membrane covered with the growing medium of (soil). The soil must be placed on a water proofing membrane to prevent damage to the roof. Green roofs can support traditional vegetation without disrupting urban infrastructures in any way, and they produce useful products in areas that conventionally have been unused. There are two main types of green roofs, i.e., intensive and extensive. Intensive green roofs have a thicker growing medium (more than 150 mm), and they usually grow shrubs, perennial herbs, and grasses. Extensive green roofs have a thinner substrate layer(less than 150 mm) and generally have flowering plants and grass [1]-[3]. The scarcity of fresh drinking water has become the one of our most important problems [4]. Due to the high growth rate of the world’s population, rapid urbanization, industrialization and the destruction of green trees, the availability of drinking water has decreased worldwide. Among various proposed solutions for the scarcity of water, harvesting rainwater from roofs is one of the best solutions for urban areas. It could eliminate the current domestic water shortages and reduce the runoff of stormwater from urban areas, thereby protecting against urban flooding [5]. Harvesting rainwater is a sustainable solutions for the demand for potable water in urban developments, because it provides the cleanest water [6], [7]. The quality of harvested rainwater basically depends on the types of roofing materials, the climatic conditions of the local area and the levels of atmospheric pollutions [8], [9]. The peak discharge of stormwater can be reduced by as much as 47% by the extensive use of green roofs for design storms, specific design storm’s durations were 10, 30, and 60 minutes in 2 years, and 26% for actual random storm [10] in comparison with impervious brown roof. Harvesting rainwater has been practiced in past years as a philosophy and as well as a technology to manage the supply of water [11]. This system has been used in almost every part of the world and by all societies. The Earth’s most significant source of fresh water is rain and harvesting rainwater is a vitally important component of water resource management and watershed management. Due to rapid increase in population, rapid urbanization and global climate change, the demand for water increases day by day and water shortages are already occurring. Thus, the harvesting of rainwater has been identified as a way of mitigating the effects of drought, responding to the impact of saltwater encroachment related to global climate change and slowing the increase in the sea level and its effects on the coastal groundwater resources of small island states (Eastern Caribbean 2009).

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II. Contributing Factors on the Quality of Harvested Rainwater

A. Roofing Material

The quality of roof-harvested rainwater depends significantly on the roofing materials. Reference [12] made a comparison among six types of roofing material, i.e., asphalt shingles, metal, cedar shake, two types of treated wood and green roofs. The acidic parameter of rainwater may be neutralized by metal, shingle and green roofs. Among the types of roofs, treated wood contains the highest copper concentration, and galvanized metal contains highest zinc concentration. Turbidity, total organic carbon and color concentration were less amount for steel roofs than the other types [13].

The rainwater collected from shingle, metal, concrete tile and green roofs after first flush of water would require treatment for total coliform (TC), fecal coliform (FC), aluminum, turbidity and iron to reach the drinking water quality standard and treatment for TC, FC, turbidity and aluminum would require for green-roof harvested rainwater [14]. Thus, in this paper we have suggested diverting the first-flush, filtration and disinfection to meet the water quality standards. The quality of water harvested from roofs will vary with different locations and for different weather conditions and the extent to which this occurs should be examined.

The dissolved organic carbon (DOC) concentrations were very high for shingle and green roof harvested rainwater after the first flush of water, and the green roof had significantly higher DOC concentration than the other types of roofs [14], also it was found that water harvested from metal roofs had the lowest concentration of fecal bacteria because of the higher surface temperature of the roof. The concentrations of heavy metals such as zinc and copper were lower than that of arsenic, which was found to have a very high concentration even after the first flush for a green roof. The possible reason for the higher concentrations of arsenic may be due to the quality of growing medium (soil) used, and such media should be analyzed thoroughly to the quality of harvested rainwater from green roofs, also the variation of arsenic concentration should be determined with respect to the amount of rainfall, the duration of the rainfall and storage time of the water domestic use.

The rainwater harvested from green roofs in humid tropic center (HTC) has an average quality compared to INWQS (Interim National Water Quality Standards) and WQI (Water Quality Index) [15]. The electrical conductivity parameter always has an excellent Class I value. Some preliminary treatments, such as filtration and disinfection, may have to be used to reach the standard's requirements for dissolved oxygen (DO) and p^H for water that has Class II values [15]. Untreated rainwater from green roofs can be used for flushing toilets and watering gardens. Green roofs can control the indoor temperature because they absorb heat, which helps keep the internal temperature in a comfortable range.

B. Rainfall Frequency

The intensity of rainfall varies with changes in the seasons. The treatment and utilization of water runoff from roofs are related to the seasonal trends in the parameters of water quality. Due to the high rainfall intensity during the summer and autumn, the average concentrations of water contaminants are lower during those months than in winter and spring. The time required for the dilution of pollutants with rainwater in the atmosphere and on the roof is lesser in summer and autumn [16], it was found that a larger volume of rainfall contains lesser amount of pollutants due to increased volume of rainwater. Thus the water collected during the rainy season would be cleaner than other season. Therefore, it will be cost-effective to harvest rainwater during the rainy season (summer and autumn) and store it for longer periods for use during the dry season (winter and spring). So, more treatment would be required to remove pollutants from roof runoff in spring and winter [17].

B. Climate Change

Several impacts of environments including production of huge surface runoff, occurrence of floods, soil erosion, and the unseen cumulative effect is declining of groundwater level recharge. It may expressed as the "urban stream syndrome" which describes the consistently observed ecological degradations of streams draining urban land [18]. Except for hydrological effects, the replacement of impervious surfaces in a vegetated green area also enhances the urban heat island effect [19]. This occurs because evapo-transpiration is decreased, which causes an increase in the absorption of heat energy [20]. Fifty percent of total impermeable surface can be replaced by the huge amount of unused roof area in an urban area [21]. Green roofs are the best option for dealing with such environmental problems.

In [22], the authors studied the sustainability of different green roofs for different climate change scenarios, focusing on the reduction of stormwater runoff and the effect of drought. They found that, in summer, sedum mosses and grass-herbs green roofs decreased stormwater runoff by 61% and 75% respectively, whereas, in the winter the decreases were 6% and 18% respectively. Grass and herbs are more efficacious for reducing runoff, but they are less effective in droughts and hot climates. Though sedum mosses are less efficient in retaining runoff, they survive better in temperate weather and can tolerate the stress associated with drought. Future study should be focused on examining the quality parameters of runoff water from roof after retention in the soil in order to improve parameters sufficiently to meet water quality standards.

C. First Flush

After a long dry period, initial runoff from impermeable surfaces obviously will be more contaminated than subsequent runoff. In drought periods, the surfaces of roofs are contaminated by dust, leaves, bird droppings, and by the other debris. These contaminants are washed off in the first rain that occurs, so it is to be expected that the first flush of runoff has lower quality. Thus, various contaminants in the first runoff, e.g., total phosphorus, ammonium nitrogen, nitrate nitrogen, zinc, and copper, will be present in higher concentrations in first runoff than in the samples taken later [23].

III. Scope and Overview of Rainwater Harvesting in Malaysia

Due to increasing water requirements for industrialization, urbanization and household uses, the existing infrastructure for supplying water in Malaysia is inadequate to meet present and future needs. In order to resolve the water crisis, the Malaysian government has suggested that harvesting rainwater can be the best solution. Thus, this approach would benefit the people of Malaysia, the government and the environment [24].

Rainwater is slightly acidic and contains carbon dioxide and nitrogen compounds [29]. The quality of rainwater is always better than the quality of surface water, it is very soft, clean, and very suitable for use as potable and non-potable water. The factors that affect the quality of rainwater include geographical location, characteristics of the area, storage and collection systems. But some impurities enter into the water during collection and storage systems, different level of treatments are required to meet the water quality standard. Given the increasing demand for water as the global temperature increases, harvesting rainwater from green roof areas may be very effective in meeting the demand for water in reducing environmental pollution.

After drought of 1998, the Ministry of Housing and the government of Malaysia proposed guidelines for harvesting rainwater and its utilization for domestic use. The guideline also included the constructions of "mini dams" in urban localities instead of larger dams at the upstream points [25] But the general population did not enthusiastically endorse or support these proposals. In recent years, extreme natural catastrophes have been occurring very frequently because of global climate change. As a result, many countries that are experiencing extreme water shortage have begun to use the harvesting rainwater as an alternative, reliable source of water for landscaping and irrigation purposes [26].The average rainfall in Malaysia is 3000mm per year, which is a comparatively large amount and there are no significant dry regions in the country [27]. However, the dry period is being extended due to global climatic change, so the present water supply system must be updated to cope up with the increasing demand for water; thus there is a pressing need to store rainwater for long period of time for use during the dry season. When rainwater is being collected in this way, different type of contaminants, such as dust, fecal matters from animals, leaves and other debris can get into the rainwater. The level of treatment required depends on the levels of these and other impurities. The simple treatment of filtration followed by disinfection can provide water that is suitable for domestic use, such as bathing, washing clothes, cooking, and washing dishes. More treatment may be required for drinking water and if the water will be stored for long period of time.

A monitoring program for MSMA (Stormwater Management Manual for Malaysia) Eco-Hydrology project is performing at humid tropic Centre, Kuala Lumpur, Malaysia. The rainfall intensity is very high in Malaysia, as is the intensity of urbanization and industrialization. As a result, the management of urban stormwater is very challenging for urban planners and engineers. They are trying to establish the MSMA SME's guidelines as the best alternatives for providing sustainable management through improving water quality by the use of stormwater and harvesting grey water to meet the increasing demand for domestic potable water [27]. The quality of outflow from green roofs depends mostly on the proper installation of geotextile materials. Yellow or brown colored outflows are generated when appropriate geotextile materials are not placed underneath the soil layer. However, the outflow produced from roofs are relatively clean when the appropriate geotextile materials are installed properly underneath the soil layer, with the edge joints of the sheets overlapping by at least 30 cm to prevent leakages along the connection points [28].

Fig. 1 Layer of geotextile materials (white sheets) placed underneath the soil layer and vegetation in a green roof system

IV. Scope of Future Study

The effect of seasonal variations with respect to the summer and rainy seasons also analyzed in [18], and they suggested that rainy seasons are more suitable for harvesting rainwater than summer. But they didn't examine the effect of microbial pathogens and pesticides or the effect of first flush on the quality of the rainwater. Those two parameters may have a significant effect on the quality of rainwater and its potential use for domestic purposes, and these issues must be studied further. At the Humid Tropic Centre (HTC), Stormwater Management Eco-Hydrology Project in Kuala Lumpur, other water quality parameters should be considered for further study, e.g., biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solid (TSS), turbidity, ammonia nitrogen (NH_3-N), and Phosphate (PO_4). Another analysis should be conducted on the treatment required for green roof harvested rainwater to attain the drinking water quality standards. Also the change in the quality of the water should be investigated with respect to storage time.

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