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Using Green Roofs to Reduce Stormwater Runoff:

A Case Study of Alexandria, Egypt.

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Abstract

Stormwater runoff has become a major area of concern for developing communities due to water supply pollution, peak flow events that create severe flooding and threaten lives, and disruption of municipal services. Green roofs are becoming increasingly popular as a sustainable design strategy because of the numerous environmental, economic, and social benefits that they provide. They are considered one type of the Best Management Practices (BMPs) to help manage stormwater in urban areas.

The main goal of this research is to understand and elaborate the environmental impact of green roof by analyzing the variability of its stormwater responsibility. In addition, this research highlights existing stormwater runoff problems and solutions in Alexandria. Therefore, rainfall and peak runoff rates were calculated. The study clearly reveals that rainfall rate in Alexandria is not that much and its potential is not promising to promote cost effective sophisticated management practices. Therefore, it is useful to install green roofs as a simple practice. Through analysis, field observation, meetings and a questionnaire, a SWOT analysis was developed. The study identifies opportunities of installing green roofs, which will support sustainable development in the city.

Keywords: green roof, stormwater, environment, Alexandria

الملخص

أصبح جريان مياه العواصف المطرية مصدراً رئيسيًا للمخاطر التي تتعرض لها المجتمعات الحضرية النامية لما ينتج عنه من تلوث لإمدادات مياه الشرب وتعطيل الخدمات البلدية وصولاً إلى الفيضانات الشديدة وتهديد الأرواح، ومن هنا تأتي أهمية استخدام الأسطح الخضراء كاستراتيجية للتصميم المستدام، لما توفره من العديد من الفوائد البيئية والاقتصادية والاجتماعية، حيث تعتبر نوعًا من أفضل الممارسات للمساعدة في إدارة مياه العواصف في المناطق الحضرية.

إن الهدف الرئيسي من هذا البحث هو فهم وتوضيح التأثير البيئي للأسقف الخضراء من خلال تحليل مسؤوليته عن جريان مياه العواصف المطرية، كما يسلط البحث الضوء على مشاكل جريان مياه الأمطار القائمة وحلولها في مدينة الإسكندرية بمصر، لذلك فقد تم حساب معدلات هطول الأمطار وذروة الجريان السطحي بالمدينة، وتكشف نتائج الدراسة أن معدل هطول الأمطار في الإسكندرية ليس كثيرًا وأن إمكاناته ليست واعدة لتعزيز ممارسات إدارة متطورة وفعالة من حيث التكلفة، لذلك فقد اقترحت الدراسة تعميم الأسطح الخضراء، ومن ثم فقد تم استخدام أداة التحليل الرباعي بناءاً على المراقبة الميدانية والاجتماعات والاستبيان لتحدد فرص استخدام الأسطح الخضراء، والتي ستدعم التنمية المستدامة في المدينة.

الكلمات المفتاحية: الأسقف الخضراء، جريان مياه العواصف المطرية، البيئة، مدينة الإسكندرية

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1. Introduction: Stormwater Runoff

Urbanization is proceeding at an unprecedented pace all over the world. 68% of the world population projected to live in urban areas by 2050 (United Nations, 2018). Forests, lawns and cultivated land are displaced by the impervious surfaces of streets, driveways and rooftops greatly intensifying stormwater runoff and diminishing groundwater recharge (Stone, 2004), (Scholz-Barth & Weiler, 2013) (Fig.1). The loss of the water-retaining functions of soil and vegetation causes stormwater to reach streams in short concentrated bursts. In addition, roads, parking lots, and other impervious surfaces channel and speed the flow of water to streams (Table 1).

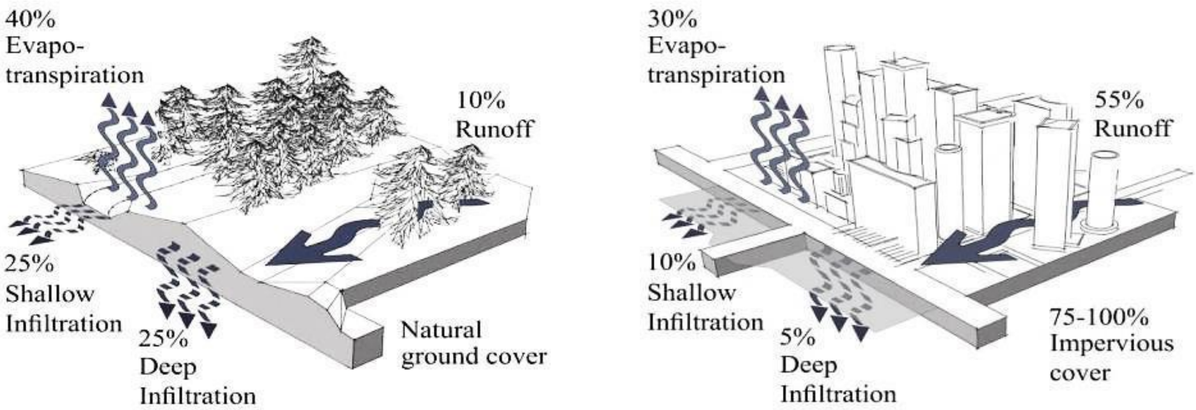

Fig.1. land use change and its effects on stormwater (The authors)

Ground Cover or Land Use	Runoff Coefficient (C)*
Forests	0.05–0.25
Lawns	0.10–0.35
Cultivated land	0.08–0.41
Asphalt or concrete streets	0.70–0.95
Brick streets	0.70–0.85
Roofs	0.75–0.95

*C = Runoff coefficient, a dimensionless coefficient between 1 and 0, where 0 is completely pervious and allows no runoff and 1 is completely impervious.

Table 1. Runoff Coefficient in various ground covers

(Scholz-Barth & Weiler, 2013)

Modified by the authors.

On the other hand, climate change may further increase those fluctuations including more frequent and intense storms and more extreme flooding events which can increase stormwater runoff (Villarreal, Semadeni-Davies & Bengtsson, 2004). Some evidence exists that precipitation regimes are shifting systematically toward an increase in more intense rainfall events. Any small change in rainfall (10–20% for example) leads to a large change (up to 75%) in perennial stream flow (Muller, 2007).

This increase in stormwater runoff can cause severe accidents and exacerbate existing, or introduce new, pollution problems. It can wash sediment, nutrients or other pollutants into water sources. Increased sediment, nutrients and other pollutants can diminish water quality, threaten drinking water sources, and complicate water treatment processes.

More frequent and intense downpours can overwhelm the design capacity of municipal stormwater management systems. This can lead to backups that cause localized flooding or lead to greater runoff of contaminants such as trash, nutrients, sediment or bacteria into local waterways.

More frequent and intense downpours can also challenge cities with combined stormwater and wastewater drainage systems. These systems can be overwhelmed by large amounts of rainfall and lead to more combined sewer overflows into waterways. This can reduce water quality and make meeting water quality standards more difficult. (Climate Adaptation and Stormwater Runoff | US EPA, 2021).

2. Stormwater Management

One of the problems in managing stormwater discharge is that it is being addressed so late in the development of urban areas. Historically, traditional stormwater management moved water offsite into underground infrastructure as quickly as possible (Scholz-Barth & Weiler, 2013). Ideally, stormwater discharges would be regulated through direct controls on land use, strict limits on both the quantity and quality of stormwater runoff into surface waters, and rigorous monitoring of adjacent water bodies to ensure that they are not degraded by stormwater discharges. Future land use development would be controlled to minimize stormwater discharges.

Stormwater best management practices (BMPs) use a decentralized system where rainwater is kept on site, reused, and recycled wherever possible. When designed, constructed, and maintained correctly, BMPs reduce peak flow rates and increase infiltration, thereby decreasing the total volume of stormwater to be conveyed so that existing sewer capacities need not be upgraded, saving both capital and operating costs (Scholz-Barth & Weiler, 2013).

BMPs are grouped in two categories: nonstructural and structural. Nonstructural BMPs include a wide range of actions that can reduce the volume of runoff and pollutants. Examples include improved land use planning; enhanced urban design of new developments that have fewer hard surfaces; the conservation of natural areas; the use of products that contain fewer pollutants; and the disconnection of downspouts from hard surfaces to instead connect with porous surfaces.

Structural stormwater BMPs are designed to reduce the volume and pollutants of small storms by the capture and reuse of stormwater, the infiltration of stormwater into porous surfaces, and the evaporation of stormwater. Examples include the planting of “swales” along the roadside and “bioswales” that capture and treat stormwater; rainwater harvesting systems that capture runoff from roofs in rain barrels, tanks, or cisterns; the use of permeable pavement; the creation of “infiltration trenches”, into which stormwater can seep or is piped; the planting of rain gardens on both public and private lands; and the installation of green roofs (Johansen, 2009).

a. Bioswale **b. Rainwater harvesting system** **c.** Permeable pavement

Fig.2. Examples of structural stormwater BMPs (Langmead, 2009)

3. Stormwater Runoff Management through Green Roofs

One way of creating more natural and hospitable environment within cities and helping to mitigate climate change, remove air pollution, and reduce stormwater is to use the green roofs (Poórová & Vranayová, 2020). Green roofs - also known as rooftop gardens, vegetative roofs or even ecoroofs - have been long established in Europe, and were more recently introduced to North America and Asian countries (Hopkins & Goodwin, 2011).

Research on green roofs in general began in the 1950s in Germany “as part of a wider movement that recognized the ecological and environmental value of urban habitats” (Dunnett & Kingsbury, 2010). It wasn’t until the late 1970s and on that research began to make clear that some of the rewards of green roofs consisted of energy conservation. Other advantages now known include the reduction of the Urban Heat Island Effect, the increase of a roof life span, other potential economic savings to the building owners, and social advantages to the building users. It is widely recognized that one of the greatest benefit green roofs offer is mitigating increased runoff volumes in urban areas. (VanWoert et al., 2005; Berndtsson, 2010; Ferrans, Rey, Pérez, Rodríguez & Díaz-Granados, 2018; Todorov, Driscoll, Todorova & Montesdeoca, 2018).

Green roofs have the capability to aide with stormwater retention, particularly reducing peak storm flow runoff, which reduces pollutant flow into rivers and other water bodies. They are designed to capture the first portion of a rainfall event. They collect airborne deposition and acid rain and may export nutrients when they overflow. However, this must be tempered by the fact that in larger storms, most natural lands would produce nutrients (Urban stormwater management in the United States, 2009).

A previous research found that green roofs did reduce stormwater flow volume and rate. In this study, a green roof and a conventional roofing assembly were evaluated. The research showed that a green roof containing 150mm depth growth medium, in a 19mm rain event over a 6.5-hour period reduced the stormwater volume by 2.9mm, delayed the runoff about 1.5 hours, and reduced the flow rate from 2.8mm/h to 0.5mm/h (Liu, 2004). A recent research showed that the peak discharge of stormwater run-off was reduced up to 26% in relation to concrete tile roof (Kok et al., 2015).

Green roofs are more likely to succeed in areas having smaller, more frequent storms compared to areas subjected to less frequent, more intense storms. The reason is that during larger events, a green roof may export pollutants. (Urban stormwater management in the United States, 2009).

3.1. Stormwater Retention

Stormwater performance can be documented in terms of runoff or retention. Retention is taken as the difference between the measured precipitation depth and the runoff depth once the precipitation event has stopped. Unlike conventional roofing, green roofs promote retention (DeNardo et al.; 2005; Mentens, Raes & Hermy, 2006) and evapotranspiration of precipitation. This stormwater management technique is very effective in reducing the volume and velocity of stormwater runoff from roofs. Green roofs have been reported to retain 39 to 100 % of rainfall, with an average retention just under 78 % (Carter & Rasmussen, 2007). The magnitude of the retention depends on the climatic conditions, the amount of precipitation and the structure of the green roof (the amount of layers and their corresponding depths).

German designers in the 1970s came up with the green roof model commonly used today. They basically consist of a vegetation layer, a substrate layer (where water is retained and in which the vegetation is anchored) and a drainage layer (to evacuate excess water) (Brebbia, 2003). There are three types of this modern green roof. The simplest type of all is the extensive green roof. Extensive green roofs are shallow with less than 150 mm of growing medium (Sutton, 2016), typical for the drought-resistant succulents and grasses used (McDonough, 2005). Drought-tolerant plants are used so an irrigation system is not needed, making this type of roof low-maintenance. Typically, an extensive green roof is inaccessible to building users (Dunnett & Kingsbury, 2010). Its main purposes are focusing on environmental issues, adding thermal mass, and improving views from neighboring buildings (Osmundson, 1999). Water retention capacity of the flat model of this green roof type is about 15-25 L/m2.

The second type is semi-intensive roof. It contains a depth of growth medium 25% above or below 150 mm (>100 and <200 mm) (Sutton, 2016) and portions of the roof may be accessible. A greater variety of plant diversity is allowed and this will typically increase the cost and maintenance requirements. Water retention capacity of this type is about 45-65 L/m2.

The third type of green roofs is the intensive green roof. As the name implies, this type of roof needs more attention and is more labor intensive. An intensive green roof has a larger substrate depth and, therefore more serious weight and structural implications than an

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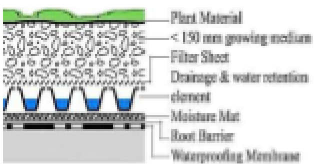
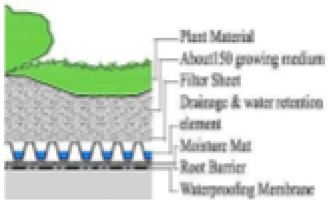
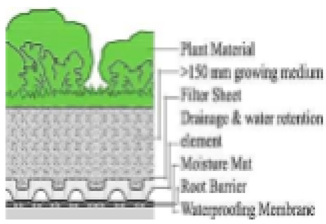
extensive roof (Dunnett & Kingsbury, 2010). Because of the deeper growing medium, intensive roofs are able to support a wider range of plants including trees (McDonough, 2005). The deeper roots require an irrigation system to be used (Snodgrass & Snodgrass, 2010). Therefore, more maintenance is involved for this roof than the other types. If the substrate reaches 600 mm or greater, it creates elevated landscape as a new ground plane. It has the same insulation and stormwater management potential as the existing ground surface.

There is enough substrate depth for moisture retention, which can significantly contain stormwater runoff within the roof system (Hopkins & Goodwin, 2011). Therefore, water retention capacity of this type is more than 75 L/m2 (Table 2). A general rule is that the deeper the substrate is, the greater rainwater absorption or retention the system has, and the better its stormwater management potential.

Specifications	Extensive green roofs	Semi-intensive roof	Intensive green roof
Accessibility	Could be inaccessible	Partially accessible	Accessible roof
Growing medium	<150 mm	Around 150mm	>150 mm
Irrigation system	not needed	not needed	needed
Maintenance	low-maintenance	low-maintenance	More maintenance
Saturated weight	70-170 kg/m2	170-290 kg/m2	290-970 kg/m2
Retention capacity	15-25 L/m2	45-65 L/m2	>75 L/m2
Roof Detail			
Example			

	Multiple extensive green roofs (Dunnett & Kingsbury, 2010)	**The Waitakere Center, NZ** (Hopkins & Goodwin, 2011)	**Grove Inn in Asheville, North Carolina** (Snodgrass, 2010)

Table 2. Comparison between deferent types of green roofs

Although the water retention within green roofs primarily depends on the water loss due to evapotranspiration between storm events, few studies have examined that loss.

3.2. Reducing the Runoff Peak

Peak runoff during a rainstorm event is defined as the amount of runoff during the last 5 minutes of the rainfall. Green roofs may significantly reduce the runoff peak of the most rainfall events. The reduction consists in: (a) delaying the initial time of runoff due to the absorption of water in the green roof system; (b) reducing the total runoff by retaining part of the rainfall and (c) distributing the runoff over a long time period through a relative slow release of the excess water that is temporary stored in the pores of the substrate.

3.3. Improving Water Quality

By reducing both the volume and the rate of stormwater runoff, green roofs benefit cities with combined sewer overflow impacts. In cities with combined storm and wastewater sewer systems, stormwater dilutes the sanitary wastewater, rendering treatment less efficient. During heavy rainfalls these systems also overflow, discharging raw sewage mixed with runoff into the receiving streams-resulting in ecological damage and human health hazards. Therefore, important water quality benefits are achieved by controlling runoff. In addition, in urban areas, up to 30% of total nitrogen and total phosphorus released into receiving streams is derived from airborne pollutants that accumulate on rooftops. Acting as natural bio-filtration devices, green roofs reduce the pollutant load transported back to natural bodies of water and the underground water table (McDonough, 2005).

Recent studies have indicated that the effect that green roofs have on the quality of runoff is most highly dependent on factors such as soil media composition and fertilizer applications

(Hathaway, Jennings, and Hunt 2008). Furthermore, it may also be affected by soil depth and climate (Berghage, 2009).

4. Study Area

Alexandria (30° 00' 00" and 29° 25' 00" E, and 30° 10' 00" and 31° 15' 00" N), the famed Egyptian coastal city, was founded by Alexander the Great in 331 BC. It is one of the major cities on the Mediterranean Sea and Egypt's second largest metropolitan spanning over 2,300 km² (Fig.3). The city has a waterfront that extends for 90 km, from Abu-Qir bay in the east to Sidi-Krier in the west. The area is characterized by the irregular hills in the southern parts with an elevation from 0 to 40 m above mean sea level and slopes towards the Sea. Zevenbergen et al. (2016) reported urban areas of the city have grown almost 40% (from semi-bare) during the past 15 years suggesting a significant reduction in open permeable areas. Of 5.4 million inhabitants in 2021; 98.2% live in urban areas (*Egypt in Figures - Population 2021*, 2021)

4.1. Analysis of Stormwater in Alexandria

Alexandria is one of the wettest areas of Egypt, with an average annual precipitation of about 200 mm, compared with the nation's annual average rate of 80 mm. Winter storms are locally referred to as "Nawas or Nawats"; a storm accompanied with strong winds and rains (Young, Bhattacharya & Zevenbergen, 2021). Most rain falls along the coastal area and it decreases suddenly moving southwards (El Shafie et al., 2012).

Fig.3. City of Alexandria (Google Earth, 2021)

There are several rainfall stations in Alexandria. Rainfall data for Nouzha Station, which is located in the center of the city, for the period from 1958 to 2020, was obtained. The data covers series for daily, monthly and annual rainfall depths. The analysis of annual rainfall reveals that the maximum annual rainfall was 516 mm for year 2018, while the minimum value of 67 mm was recorded in year 2010. Fig. 4 shows a plot for the annual rainfall for the available data. This figure shows an increasing trendline for the annual rainfall series. Furthermore, data for Nouzha Station shows that the rainy months are from October to March. However, in many years October is a dry month. Furthermore, the rainiest months are December (52mm) and January (51mm). In addition, there are always dry days between successive rainy days. Alexandria also tends to get the majority of its rain in a few major storms each winter; some storms can bring up to 54 mm in a single day.

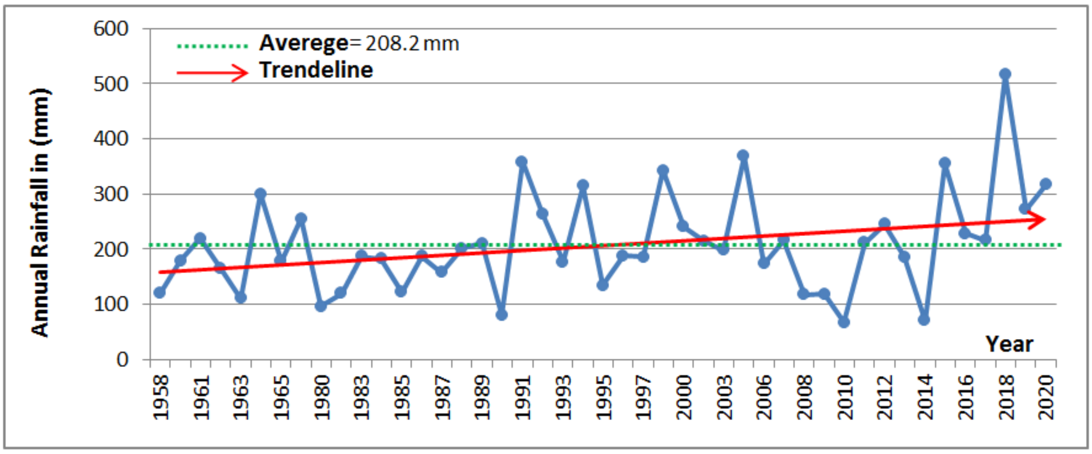


Fig.4. Annual rainfall precipitation in Alexandria, Egypt (1958- 2020)

(Source: The authors based on Nouzha weather station data, Alexandria)

Although the city receives rainfall of about 208 mm/year, this stormwater finds its way into sewage systems, drains into the Mediterranean Sea without use, or seeps into the coastal groundwater aquifer through the little-left infiltration areas of the city. Localized flooding occurs in Alexandria where the combined sewer network does not cover the whole city. The "old city" section of Alexandria is the only area to have a combined sewer system. Many peri-urban and informal settlements lack storm sewage and sanitation coverage. In addition, this network has limited capacity to deal with heavy precipitation. Furthermore, solid waste and sediments can block stormwater drains, impeding the flow of water from the impacted area and increasing area pollution.

Anyone lives in Alexandria knows the problems a heavy rainfall can create. Roads become flooded and standing water remains long after the storm passes. Although destructive flooding is rare, less severe storms can result in public safety hazards, health risks, and environmental threats. Street flooding, like that in Fig.5-(a) & (b), happens every so often – severely damaging the roadways, people's vehicles, and ground floor businesses and residences. Minor flooding, or ponding, as in Fig.5-(c), leads to potholes. Ponding and flooding represent an urgent public health hazard because these stagnant pools are breading grounds for odors, insects and bacteria. Recent heavy rainfall events in the densely populated regions of Alexandria have forced authorities to close schools, offices, and highways connecting Alexandria to other provinces, producing electricity disruption and floods in large areas of the city. These floods have also caused deaths and trapped people in their cars for several hours, as happened during the recent years.

Conclusively from the foregoing we can deduce that the city is always at risk of flooding due to heavy rainfall, insufficient drainage capacity and the lack of preparedness (Young, Bhattacharya & Zevenbergen, 2021). These trends suggest that the need for stormwater management is increasing, but Alexandria lacks appropriate stormwater BMPs. The previous data analysis clearly reveals that rainfall in Alexandria is limited and its potential is not promising to promote cost effective sophisticated BMPs. However, it may be useful to apply some simple BMPs like green roofs.

(a) (b) (c)

Fig.5. a &b. Street flooding in Alexandria, b. Ponding that leads to potholes

4.2. The Effect of Urban Aspects of Alexandria on Stormwater Runoff

Urban area which represents about 12% of the governorate area including housing buildings of about 46%, industrial and military buildings of about 22%, Public and recreation areas of about 3%, as well as roads, railway, and marine uses of about 29%. These huge impervious surfaces of the city intensify stormwater runoff.

Annual runoff of the various land cover types varies widely from 0% for water surfaces, forests and public parks, 10% for agriculture and other green zones, 15% for privately owned green, 25% for recreational zones and 90% for roads, parking areas and buildings (Dunnett & Kingsbury, 2010). Using the percentages of runoff for the several land cover types mentioned in (Table 1) and the area of the different land cover classes in Alexandria, the total annual stormwater runoff was estimated at 88%.

4.3. Stormwater management plans in Alexandria

Across the region, intense seasonal rains, which used to occur once every 20–30 years, are now occurring on a nearly annual basis. Despite this, the current regulatory scheme is control flood by moving water away from streets. Alexandria governorate does not invest in innovative solutions to accommodate the changing climate and intense stormwater disasters. The use of BMPs in Alexandria remains a relatively new area of research, where initial studies have suggested that the transfer of this technology is not necessarily a straightforward process, particularly with regard to the environmental impact and operation of these systems under different climatic and socio-economic conditions.

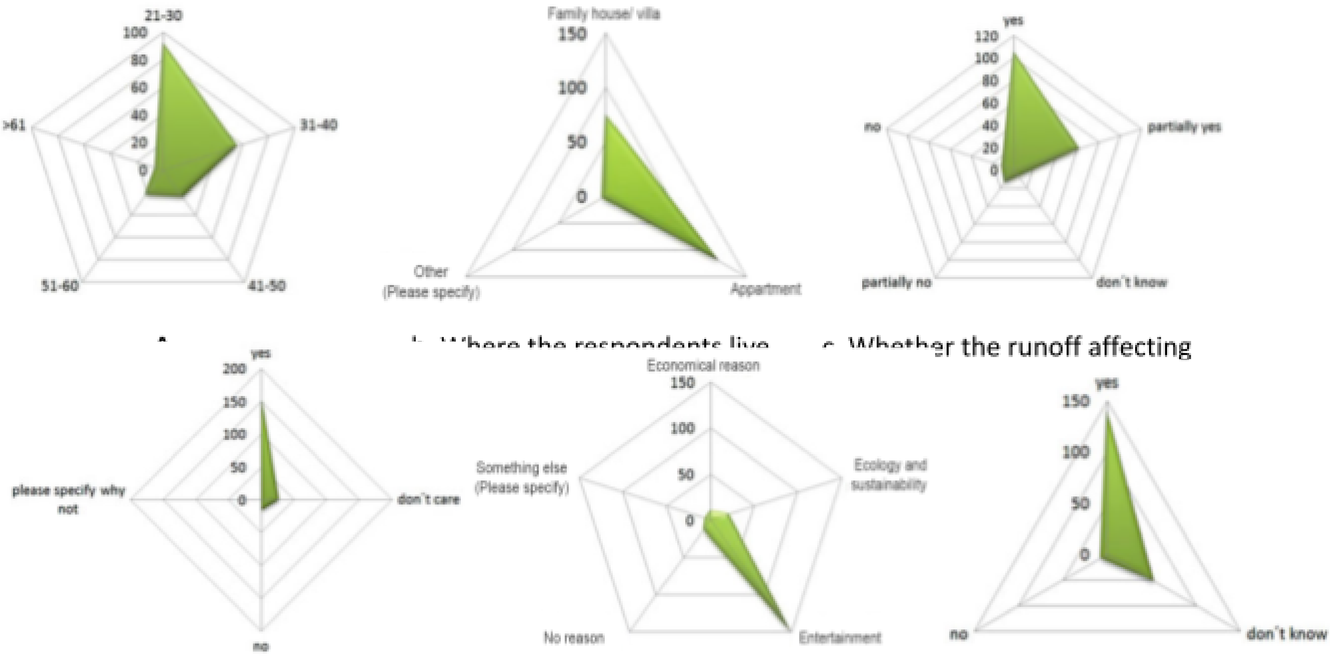
However, Sustainable Water Management Improves Tomorrow's Cities' Health (SWITCH) has been introduced to the city to set the stage for Alexandria to be among the leading cities in implementing integrated urban water management. SWITCH is a research partnership followed up by Center for Environment and Development for the Arab Region and Europe (CEDARE). Its report in 2009 suggested the following approaches to improve stormwater management in Alexandria: (a) Overflow management plans should be created for combined sewer systems; (b) Where separate sewer systems are constructed, appropriate treatment and discharge facilities should be constructed; and (c) Street designs should integrate elements that reduce peak stormwater flows. Reducing peak stormwater flows is a solution that should be applied across the governorate. Different ideas have already been put forward, all of which should be seriously considered over the next twenty years. One of those ideas is the increasing use of green roofs as they provide some source of stormwater control (CEDARE, 2009).

4.4. The Questionnaire

A questionnaire was conducted to a sample of inhabitants as a pilot study. It began with basic information about the respondents: their gender, age, education and where the respondents live. The questionnaire asked about the impact of stormwater runoff on the respondents.

Then the questionnaire focused on the respondent's opinion about green roofs, desire to have one, reason to install one, green roof economy and respondent's objections.

The questionnaire was accessible online during January 2021 using email accounts and different social networks and 200 respondents answered it. The respondents were from 6 different districts in Alexandria.



c. Whether the runoff affecting

d. Desire to have a green roof
e. Reason of having one
f. Get financial support

Fig.6. Questionnaire Responses

Through field observation, meetings and the questionnaire analysis, the results came as the following SWOT analysis (Table 3):

Strengths	**Weaknesses**
The majority of respondents have a desire to have a green roof.	In most areas of Alexandria no appropriate stormwater conveyance and management exists.
	Deficient stormwater management, outdated wastewater collection network, poorly supervised connections, together with high water table, lead to high rainwater-derived Infiltration and Inflow.
	Many people suffer from floods in Alexandria every winter.
	The community lacks the environmental awareness despite the high rate of education.
	Many roofs are occupied by satellite dishes and water tanks.
	Bad construction condition of some roofs.
	The extreme diversity of buildings height decreases green roofs implementation.
	Repairing a green roof can be very difficult.
	Green roofs are more expensive than the standard roofs.
Opportunities	**Threats**
Stormwater management plans have been formulated during CEDARE project.	The precipitation trends extremely increase in the further.
There are many active NGOs concerning environmental issues in Alexandria.	Together with the not existing stormwater collection and conveyance, flooding will augment.

Table 3. SWOT analysis

4.5. The extent of the potential to implement green roofs in Alexandria

To manage stormwater, the most appropriate type of green roofs could be implemented in Alexandria is the extensive green roof. This type is suitable for regular roofs of the city which are covered with asphalt coating (the bituminous layer) and tiles. This type has very shallow soil depth; therefore, no additional structural support is required. Consequently, load can be carried by most existing structures and it will not affect the bad construction condition of some roofs in the city.

To estimate the potential reduction of the runoff by greening the roofs in Alexandria, the following assumptions were made:

- 10% of the buildings may have an extensive green roof. This percentage is quite realistic considering the extreme diversity of buildings height, as shown in Fig. 6, that increases the percentage of overshadowed and partially overshadowed buildings. Therefore, a large area of the existing stock is considered unsuitable for green roofs retrofit on the basis that insufficient sunlight reaches the rooftop for planting to flourish. Furthermore, using roofs as a storage place or for satellite dishes and water tanks, as well as bad construction condition of some roofs decrease the possibilities of green roofs implementation.
- A substrate layer of only 100mm is assumed. This type of extensive green roof can be installed on almost all roof conditions.

Runoff reduction would be as large as 4.96% of the total estimated runoff (without green roofs) for the city. Although this looks rather small, we should be aware that the benefits of green roofs are many and varied.

This reduction is not distributed equally over the entire region because the amount of built-up area varies widely and decreases from the city center to the outskirts. The reduction in runoff accomplished by green roofs in the city center is higher than in the suburbanized areas. Active NGOs concerning environmental issues in Alexandria should contribute in an ambitious project concerning green roofs installation in the city. There are two leading NGO's in Alexandria that aim at improving the environment. These are the Friends of the Environment Association, and Pioneers of the Environment. Through their actions, they can help implement green roofs project in Alexandria.

Fig.6. Aerial view of building masses in Gomrok, the old core of Alexandria

Conclusion and Recommendations

Demands on stormwater management are currently greater than ever, as expanding urbanized areas and their impervious surfaces are resulting in higher volumes of runoff. Stormwater runoff is a major concern because it carries pollutants, debris, and other environmentally degrading of urban areas. One simple way of managing stormwater is green roofs. They have the capability to aide with stormwater retention, particularly reducing peak storm flow runoff, which reduces pollutant flow into rivers and other water bodies. This depends on the type of the green roof, the climatic conditions and the amount of precipitation.

In Alexandria, as a case study, the annual precipitation is low but increasing. Although destructive flooding is rare, less severe storms can result in public safety hazards, health risks, and environmental threats. One of the most appropriate solutions is extensive green roofs. However, some factors must be taken into account:

- Raising environmental awareness to encourage green roofs implementation.
- Developers can earn credits by incorporating enhanced stormwater management and water conservation features into their projects, including the use of green roofs.

- There is a need for policy, by-law and procedural changes in order to move green roof technology from the experimental stage to an urban design standard in Egypt.

Finally, it is clear that roof greening alone will never fully solve the urban runoff problem and it needs to be combined with other runoff reduction measures (e.g. storage reservoirs in urban green or under infrastructure, rainwater cisterns, an increase of green areas etc.).

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