VALIDITY OF RAINWATER HARVESTING USING GREEN INFRASTRUCTURE IN EGYPT

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ABSTRACT

The northern coasts of Egypt are exposed to irregular directions of precipitation sometimes increase and decrease at other times, which requires specialists to look for new methods in dealing with rain in order to take advantage of rainwater for different purposes as well as to protect the infrastructure from the effects of increased rainfall in urban areas and protect human lives from increasing runoff in the streets. There are a lot of methods that using in the drainage system and preserve stormwater, modern countries used green infrastructure practices as One of the most effective methods to manage the stormwater to achieve sustainable solutions for excess runoff and keep a healthy environment for its citizens. This paper summarizes the most technics of the green infrastructure practices, produce a review of the most famous models of green infrastructure (GI) practices (RECARGA model, SWMM, WIN SLAMM, LIDRA TOOL, and CNT model), explain the conclusion of recent research about the development of SWMM model as it widely uses in all the world in the field of stormwater management and finally compare between these models and show the recommendation for the future research.

Keywords: urban stormwater, Bioretention cells, green infrastructure models, low impact development, SWMM model.

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Abbreviation list

GI:	Green Infrastructure
RWH:	Rain Water Harvesting
SWMM:	Storm Water Management Model
GIS:	Geographic Information System
LID:	Low Impact Development
RTC:	Real Time Control
UDS:	Urban Drainage System
MPC:	Model Predictive Control
WIN SLAMM:	Source Loading and Management Model for Windows
EPA:	Environmental Protection Agency
SUSTAIN:	System for Urban Storm Water Treatment and Analysis Integration
BMP:	Best Management Practices
ET:	Evapotranspiration
CNT:	Center of Neighborhood Technology
LIDRA:	Low Impact Development Rapid Assessment
O&M:	Operation and Maintenance
OOGIS:	Object Oriented Geographic Information System
GML:	Geographic Markup Language
BIM:	Building Information Management
SUDS:	Sustainable urban drainage systems
CSO:	Combined Sewer Overflow

1. INTRODUCTION

Green infrastructure is considered one of the modern methods of rainwater harvesting and reducing the risks of excessive runoff through innovative and low-cost methods. This field is witnessing an increasing growth in the recent period in European countries, as research has shown the effectiveness of green infrastructure in protecting the environment, optimizing the utilization of rainwater and increasing the economic value in urban areas where this technology is used. Mediterranean cities should develop adaptive systems based on storm water harvesting in a circular economy. The use of rainwater is a traditional technique based on collecting rainfall and was historically used in the Mediterranean and other semi-arid territories. In traditional societies where agriculture formed the basis of the economy, land and water were highly important. This paper highlights the importance of exploiting rainwater as a pure source of fresh water in Egypt, a review of rainwater harvesting with green infrastructure practices, models of evaluating these practices and a comparison between these models in terms of effectiveness, accuracy and applicability in different societies.

2. RAIN WATER IN EGYPT

The range of rainfall on the north coast is more than 100 mm/year. The mean recorded rainfall at Alexandria is 180 mm/year. Sometimes, rain reached 47.9 mm/year and 53.2 mm/year in one day at Alexandria and Giza respectively. It is noted that rainfall reached 168 mm/year during one month at Alexandria, which means 95% of the total one-year amount (ABDEL-SHAFY & ELSAHARTY, 2006; ABDEL-SHAFY & ALY, 2002) [1][2]. On the north-west coast, it varies between 120 and 150 mm/yr. It goes down to the east at Port-Said to 80 mm/year it decreases gradually to 50 mm/year in the middle of the Delta, 22 mm/year at Cairo and 1 mm/year at Aswan. The north of Sinai, it ranges from 50 to 100 mm. Rain is the principal source of water in the north of Sinai. The average annual precipitation is shown in Figure 1 as a distribution pattern, this figure shows that only the northern part has a moderate available rain amount within which rainfall can be harvest. The rest of the country is very poor in rainwater so Alexandria city suffers from excess runoff in the winter season and it is the best city to harvest rain water.

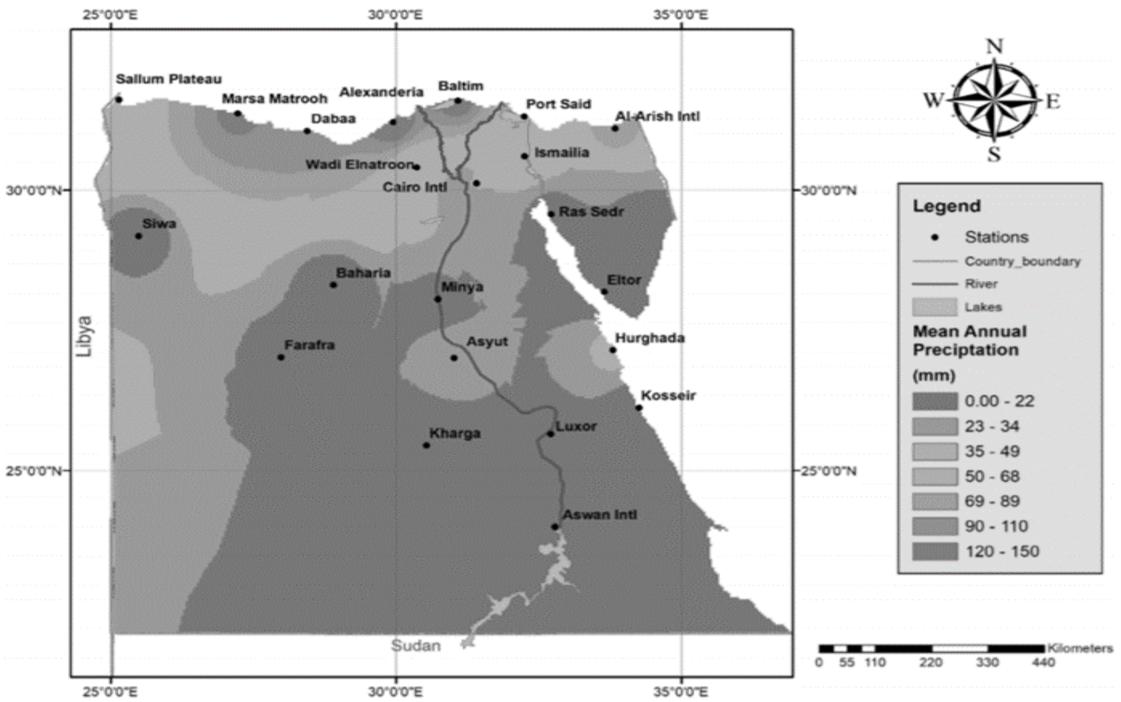

Figure 1: Distribution Pattern of the annual Rainfall on Egypt (Gado et al .2019)

2.1 Harvesting rainwater of urban area in Egypt

(Abd Elshafy et al. 2010) [3] mentioned in his research that Harvesting Pilot Plant was constructed and implemented in Alexandria for the first time at the National Institute of Oceanography, located directly on the Mediterranean Sea. It was used to harvest the rain water with three declining roofs of areas of 38x4, 38x4 and 20x6 m with a slope of 2% each were selected. Gutter pipes were connected to these roofs to collect the falling rain. These gutters were finally connected to storage tanks, from which the harvested rainwater was pumped to irrigate the surrounding landscape areas. (Gado et al. 2019) [4] in his research the groundwater recharge and surface runoff estimation were analysed in a case study of the 5th settlement region in Cairo, for two situations: No–RWH and RWH system by implementing recharge wells. The results indicate that the development of recharge wells to store rainwater in groundwater has an important impact on the regional water cycle. The implementation of RWH system can increase the effective infiltration coefficient from 10% (No–RWH) to 75% (RWH) in the case study. Consequently, groundwater recharge will increase by about 650% over the status of No-RWH. For the estimate of surface runoff, the runoff coefficient can decrease from 0.8 for RWH No. to 0.15 for RWH. This can reduce the case study run-off volume by about 82% less than the RWH-free state.

3. RAINWATER DRAINAGE SYSTEMS IN URBAN AREA

In the past, storm water management consisted of “end-of-pipe” treatment methods, meaning that the runoff would quickly drain from landscapes to a centralized treatment facility (David 2009) [5]. Rainwater sewers and collections in storage tanks are the primary ways to get rid of the rain. Figure (2) summarizes the old and modern rainwater drainage systems.

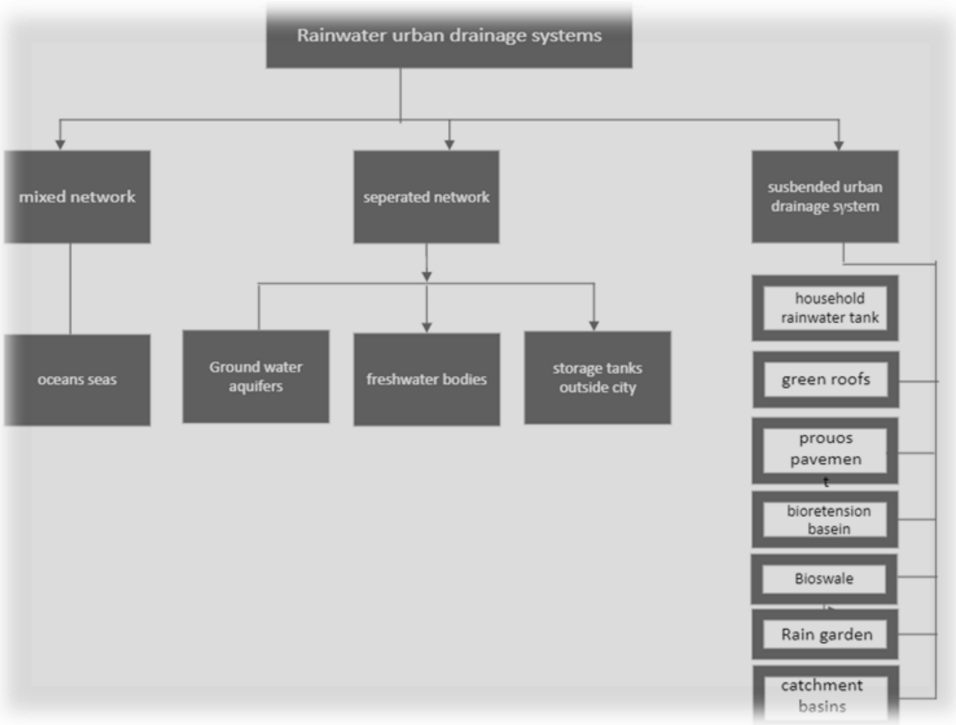

Figure 2: Rainwater urban drainage systems

4. METHODOLOGY AND APPROACH

There are a lot of methods and green infrastructure practices (Figure 3) are used to reduce the runoff and preserve the water to fresh water body like canals or ponds or in ground water such as: Rain water tank (Sharma et al.2016) [6], Green Roofs (j. Trincheria et al.2017) [7], Porous pavement, Rain Garden (C. Hinman.2013) [8] Bio retention basin (Jotte et al.2017) [9], Bioswales (S. Echols et al.2015) [10], Catchment basin (Hernandez et al.2020) [11], Urban Stream Day lighting.

Figure3: Green infrastructure technics (Image credit as noted under each)

5. MODELS AND TOOLS

In recent research, there are a lot of models are developed to design and planning the green infrastructure practices and to measure their effective impact in the hydrologic water cycle as reduce surface runoff, their role in improving water quality, recharge groundwater and reduce pollution of runoff. Also, there are some models are developed to calculate the economic cost of constructing these practices and comparison between them from the economic side. There are some models have a couple of two function measure the benefits of use these practices and calculate their cost. In the next category, we will discuss some of these models.

5.1 RECARGA model

This model is developed at the University of Wisconsin, Madison (Jayasuriya et al 2014) [12]. It was developed to simulate bio retention cell and rain garden, infiltration basins and evaluate the performance of these green infrastructure practices according to their ability to reduce the volume of runoff and increasing ground water recharge. (Atchison, D.; Severson 2004) [13].in this model there are three simulation types' continuous, single event and user input Figure (3). (Dietz 2007, Atchison et al 2006) [14][15] use the recharge model to performance and evaluate the bio retention, rain garden, and infiltration practices.

Input data is hourly rainfall or event precipitation, hourly evapotranspiration, drainage area, impermeable area, curve number for previous area, soil properties, and properties for rain garden. MATLAB program is used to develop the interface of **RECARGA** model.

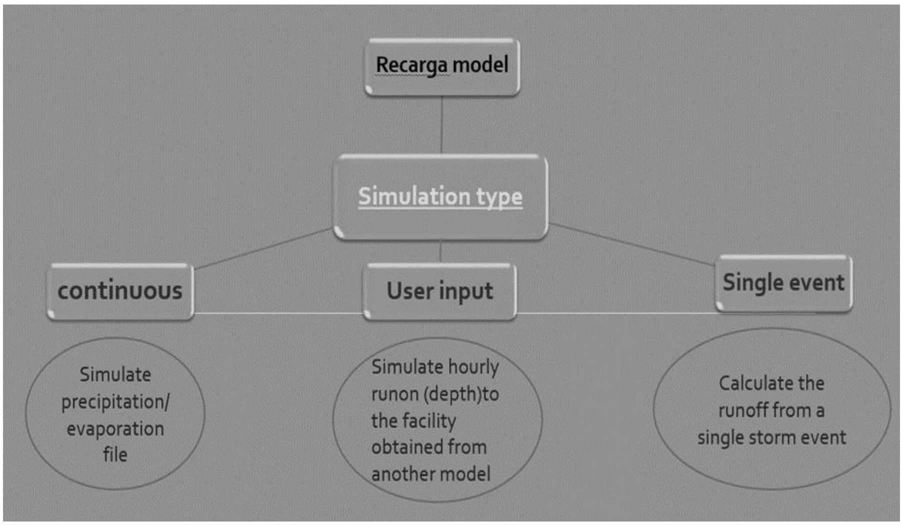

Figure 4: type of simulation in RECARGA model

5.2 SWMM MODEL

The Storm Water management model is a hydrologic, hydraulic and water quality model with optional continuous simulation and also it can simulate a single storm event. It gives detailed analyses for watershed with storage focused LID. It was nearly the first model simulate the green infrastructure practices (1971) and it is widely used in all the world as a storm water model. It can design and size drainage system component for flood control. SWMM is composed of four elements, 'RUNOFF,' 'EXTRAN,' 'TRANSPORT,' and 'STORAGE/TREATMENT (S/T) blocks used to model various hydrological cycle stages (Tsihrintzis & Hamid 1998) [16]. The studies and researches used this model to evaluate the performance of Bio retention, infiltration trenches, porous pavement, rain barrels, vegetative swales, green roofs, street planters, amended soils (Huber 1995; Tsihrintzis and Hamid 1998; Huber 2001; Khader and Montalto 2008; Rossman 2010),[17][16][18][19][20] The following paragraph explains the recent researches about SWMM model. (Ji et al 2015) [21] In this study a new sub-catchment division approach for swum is introduced by using geographic information system (GIS) to improve the simulation result of SWMM. (Quijano et al.2016) [22] MATSWMM is a new open-source MATLAB, python and Lab VIEW-based software package for design and analysis real-time control (RTC) in urban drainage system (UDS).

(Shahed et al 2020) [23] Ostrich-swum was developed to include more than a dozen heuristic optimization algorithms that can be used to optimize GI investment. (Sadler et al.2019) [24] This paper introduces SWMM-MPC software for simulating model predictive control (MPC) for urban drainage system using open-source map (python-EPA SWMM5). (MACRO et al 2019) [25] In this paper Ostrich-SWMM was developed for single and multi-objective automatic calibration of SWMM model.

(Tuomela ET al.2019) [26] In this research total suspended solids, total nitrogen total phosphorus, lead, copper and zinc were modelled with SWMM. (Zhang et al.2020) [27] SWMM-MODFLOW was developed in this study to assess the surface runoff and ground water table dynamics of GI of different locations at catchment scale. (Shojaeizadeh et al 2021) [28] GIP-SWMM is an optimization approach coupled with SWMM to select and strategic placement of green infrastructure practices.

Input data: Rain gauge properties, sub catchment properties, junction properties, outfall properties flow divider properties, storage unit properties, conduit properties, pump properties, orifice properties, weir properties, outlet properties, map label properties. (Rossman, 2010) [20]

5.3 WIN SLAMM

Source Loading and Management Model for Windows (WinSLAMM) this model is used to develop some green infrastructure practices such as Infiltration/biofiltration basins, street cleaning, wet detention ponds, grass swales, filter strips, permeable pavement (Pitt and Voorhees 2002). [29] Researches show that this model can Evaluates how effective the GI practices in reducing runoff and pollutant loadings and it can calculate the cost effectiveness of practices and their sizing requirements. Islam model can facilitate continuous and single event simulation, it can simulate runoff for hourly or shorter time steps.

(V. M. Jayasooriya et al 2014) [12]. Recent researches on WIN SLAMM :(Tiveron et al,2018) [30] make a study on 19 numerical models of the models that use to design the green infrastructure practices and they found that win SLAMM model is the only software that can model TSS reduction through the bioretention cell.

5.4 EPA SUSTAIN Model

EPA System for Urban Stormwater Treatment and Analysis Integration Model (SUSTAIN) is a distinct model since it incorporates all essential instruments into a system for modeling, Like GIS gui, BMP siting suitability research, a wide variety of interfaces, Range of simulation algorithms of stormwater quantity and quality for multiple optimization methods, both watershed and BMP modeling, to find a least-cost solution or create a cost-effective solution and a number of assessment structural BMP options. SUSTAIN blends modeling techniques that are publicly accessible, objective study of various alternatives to water quality management by taking into account the interacting and competing variables such as location, size, and price. (Lee et al. 2012) [31]. studies used this model for measuring the performance of LID practices such as Bioretention, cisterns, constructed wetlands, dry, grassed swales, green roofs, infiltration basins, infiltration trenches ponds, permeable pavements, rain barrels, sand filters (surface and non-surface), vegetated filter strips, wet ponds (Lai et al. 2006, 2007, 2009, 2010; Shoemaker et al. 2013)[32][33][34][35[36] SUSTAIN consists of seven main components: application manager, ArcGIS GUI, catchment module, BMP module, optimization module, The post-processor and directory of Microsoft Access (Lai et al. 2007)[33]. Input data: GIS data include (land use and land cover, soils, stream networks, DEM (use raster grid to calculate the drainage slope and drainage area), watershed/sub watershed, potential location of BMPs, critical pollution source information, etc.) and climate data (hourly precipitation data, daily or monthly ET rates, daily temperature data, etc.) and monitored water quality. (Lee et al 2012) [31].

5.5 CNT Green Values National Stormwater Management Calculator

The Center for Neighborhood Technology (CNT) is considered from the models that compare multi functions of green infrastructure practices such as reducing the quantity of runoff, increase water quality of run off and produce cost analysis for the LID practices. Input data for this model is distribution of land cover, soil type, objective of runoff reduction, and characteristics of the various GIS used for the study. (Jaffe 2011; Guo and Correa 2013) [37][38] used CNT model to assess GI practices as green roofs, planter boxes, rain gardens, cisterns, native vegetation, vegetation filter strips, amended soils, swales, trees, permeable pavements.

5.6 LIDRA Tool

Low-Impact Development Rapid Assessment (LIDRA) tool is a web-based model which can be access online. this model can evaluate the performance of about 30 different practices from GI practices with 16 different street (lee et al 2012) [31] and possibilities give cost analysis for these practices across their life cycle in terms of capital, operation and maintenance. (Montalto et al. 2007; Behr and Montalto 2008; Yu et al. 2010) [39][40][41] use LIDRA tool to evaluate green spaces. Input data: Datasets identify current levels of impermeability in the pre-LID watershed, an hourly rainfall time series for a normal rainfall year and the corresponding time of occurrence of each CSO occurrence that occurred during the time span, as well as regional construction, operation and maintenance (O&M) costs associated with each LID technology. (Aguayo et al.2013) [42].

6. COMPARISON AMONG EXISTING MODELS

there are many differences among these models such as the number of green infrastructures practices that can be evaluated with each model, input data, function of each model and accuracy of these models, in this section we will conduct a comparison between models.

6.1 Number of green infrastructure practices that each model can support

Most of the models have the capability to evaluate the performance and calculate the cost of wide range of GI practices while the other have a limit range of GI practices. SWMM, WINSLAMM, SUSTAIN can evaluate the performance of infiltration practices, rain gardens, retention ponds, constructed wetlands, and swales as a common set of GI practices. RECARGA can model bioretention, rain garden, and infiltration-based GI practices only. CNT is software can support the amended soil in addition to other practices. Also, it can model the impact of permeable pavement in different location. Table1 summarize GI that each model can support.

Table 1. Number of green infrastructure practices that each model can support

Model	Infiltration practices	Rain garden	Retention ponds	Constructed wet lands	Amended soil	Permeable pavement
RECARAGA	✓	✓	✓			
SWMM	✓	✓	✓	✓	✓	✓
WIN SALAMM	✓	✓	✓	✓		
SUSTAIN	✓	✓	✓	✓		
CNT	✓	✓	✓	✓	✓	✓
LIDRA	✓	✓	✓	✓		

5.2 Input data

All models of GI practices need similar input such as climate properties, characteristics of land use and soil type. Some models need to a lot of input data according to their multi functions as SWMM and other have a few data required as LIDRA, WINSLAMM, CNT and RECARAGA model. SUSTAIN has a GIS interface so there are required data belong GIS input such as digital elevation profile, land use, land cover and catchment information. All these data can be found in local mapping source. For data that concerning with cost in SUSTAIN, LIDRA and CNT there are a built-in data base in each model

5.3 type of simulation

Among the explained models there are models facilitate the continuous and single event simulation such as RECARGA, SWMM, SUSTAIN, WIN SLAMM and LIDRA but CNT can facilitate event-based simulation only

5.4 Regional Implementations

Although there are a lot of models that can be used to evaluate the performance of green infrastructure practices, most of these models can be access in the country or region which they are developed only. Few models can be access in any region in the world. Table 2 explain the regional implementation for each model

Table 2. The regional implementation for each model

MODEL	REGIONAL IMPLEMENTATION
RECARAGA	Use in the Department of Natural Resources (DNR) conservation practice standards for Wisconsin, USA.
SWMM	Can be used in any region in the world
WIN SALAMM	Initially uses in North America and recently it extends to use overseas
SUSTAIN	has an inbuilt database for specific context but also has a flexibility to be handle with other databases
CNT	Only limited to use in different cities in USA
LIDRA	has an inbuilt database for specific context but also has a flexibility to be handle with other databases

5.6 Function of each model

If we divide the models according to its functions there are nearly three functions of the models: evaluate quantity of runoff that each model can reduce it and evaluate the increase in water quality of stormwater that pass cross the GI practice and other models used to compute the effective cost of construction, operating and maintenance of the practice along its lifecycle. Table 3 explain the function of each model

Table 3. Function of each model

Models	Reference	Function
RECARGA Model	(Atchison and Severson .2004) [13]	Quantity of run off that the practice reduces it and the increase of quality of water as a result of using the practice
SWMM	(Hubber et al.1988; Rossman2010) [43][20]	Design, measure quality and quantity
LIDRA TOOL	(Yu et al.2010) [41]	Quantity of run off that the practice reduces it and the life cycle cost of the practice
CNT Green Values National Stormwater Management Calculator	(Center of neighborhood technology 2009) [44]	Quantity, quality and cost
EPA SUSTAIN Model	(Lai et al.2007) [33]	Quantity, quality and cost
Win SLAMM	(Pit and Voorhees 2004) [45]	Measure quality of runoff and quantity and get cost details about the practice

6. SMART GREEN INFRASTRUCTURE

Using the artificial intelligence in design and operation the green infrastructure practices called smart green infrastructure. Also, it means using smart technologies in water systems management such as sensing, communications and networking, computing, and instrumentations (Meng et al 2019) [46]. all these technologies import to facilitate the challenges of water management for example intelligent metering can help water utilities reduce labour costs for meter reading and increase information transparency to end-users (Boyle et al., 2013) [47]. Real-time sensed information and computational methods provide tools to support decisions, predict flooding, and evaluate risks to urban drainage systems (Baron et al., 2015; Barrile, Bonfa, & Bilotta, 2017; Hsu et al., 2013; Karnib et al., 2002; Savic et al., 2013)[48][49][50][51][52].This field has not a satisfy amount of researches so there isn't a lot of information or data about smart green infrastructure but there are some experiments say that smart GI may be more expensive than standard GI in construction but its more effective and more accuracy in operating and least cost of maintenance

7. SUMMING UP

1- Egypt is one of the countries with limited water resources, and therefore, attention must be paid to optimizing the exploitation of rainwater to reduce the gap between the increasing demand for water and the limited resources of it.
2- The studies that have been conducted on the climatic characteristics of the weather in Egypt show that the areas that are most exposed to heavy rainfall are the northern coasts and Sinai.
3- The state should pay great attention to rain harvesting in the northern coasts of the country to benefit from it in the multiple uses of fresh water, as well as reducing the risks resulting from the increase in surface runoff in addition to using this water to increase the stock of groundwater.
4- Most modern cities go to Sustainable urban drainage systems (SUDS) because they are more effective and less impactful on the environment.
5- There are a lot of green infrastructure practices that we can use in Egypt to benefit from rain water and reduce the runoff and recharge the ground water

Although there are a lot of numerical models that can be used to design and develop most of green infrastructure practices these models consider very rich space to future researches because of these reasons

1- The green infrastructure model can be more effective and less difficult when using the field of GIS and remote sensing techniques
2- There is an urgent need to develop web-based simulation as it presents more integrated models and access a lot of spatially distributed datasets and it facilitate the handling and allow to communicate with other users. Some of recent researches concentrate on this area like object-oriented GIS (OOGIS) and Geography Markup Language (GML) (Choi et al. 2005) [53].
3- The models of simulation GI practices need developing some methods to reduce the percentage of uncertainty the most important reasons of uncertainty for models is the number of parameters that use in simulation process so the monitor stations must be developed to introduce accurate and available datasets (Lee et al. 2012) [31].
4- The coupling of two functions of model is very important like the coupling of the models of atmosphere and the hydrologic models
5- Most of these models were developed to access the planning of GI practices in specific regions and cannot be assessable in other regions as they developed with data base which belongs to their regions only that can create a lot of opportunity to find many researches about models that evaluate the GI practices in deferent country or create global models can be accessed from any region in the world.
6- BIM technology can play an important role in design and evaluate green infrastructure practices if we make a combination between GI models and this technology

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