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Optimization of Locations for Bioswales Stormwater Management Using BMP Siting Tool - Case Study of Sulaymaniyah City-KRG-Iraq

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ABSTRACT

Today, urban Stormwater management is one of the main concerns of municipalities and stakeholders. Drought and water scarcity made rainwater harvesting one of the main steps toward climate change adaptation. Due to the deterioration of the quality of urban runoff and the increase of impermeable urban land use, the treatment of urban runoff is essential. Best Management Practice (BMP) and Low Impact Development (LID) approaches are necessary to combat climate change consequences by improving the quantity and quality of water resources. The application of Bioswales along urban streets and roadways can reduce the stress on water resources, recharge groundwater and prevent groundwater pollution. While Sulaymaniyah City has a combined sewer network, the application of Bioswales makes wastewater treatment possible in all seasons. This study aimed to determine suitable locations for LID as one of the methods of urban runoff management in Sulaymaniyah City, KRG Iraq. The research modeled and optimized the placement of Bioswales using the BMP Sitting Tool (BST) in the ArcGIS program. Results of the study suggested a total area of 104329 m^2 in 530 locations for the installation of the Bioswale system. Also, results showed that land use parameters and soil hydrological groups could be considered important factors in selecting a suitable location for Bioswale system establishment.

Keywords: Urban Runoff, LID-BMPs, Bioswales, BMP Sitting Tool, Sulaymaniyah

استمثال المواقع لوحدات معالجة مياه الامطار (Bioswales) باستخدام أداة BMP Siting Tool دراسة حالة لمدينة السليمانية – كردستان–العراق

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الخلاصة

في الوقت الحاضر، تعتبر معالجة مياه الامطارمن المهام الرئيسية للبلديات وأدارة المدن. الجفاف وشحة المياه جعل تجميع وحصاد مياه الأمطار إحدى الخطوات الرئيسية نحو التكيف مع تغيرات المناخ. تدهورالنوعي لجريان السطحي للامطار في المناطق الحضرية وزيادة مساحات وسطوحات غيرالنافذة ، جعل معالجة مياه الامطار ضرورة حتمية، كاستخدام افضل ممارسات الادارة (BMP) والتنمية منخفضة التأثير (LID) لمواجه عواقب تغير المناخ وإجراء تحسينات في مجالات كمية ونوعية الموارد المائية. تنفيذ وإنشاء Bioswales على طول الشوارع والطرق يؤدي إلى تقليل الضغط على مواردالمائية وإعادة شحن المياه الجوفية ومنع تلوث المياه الجوفية. في حين أن مدينة السليمانية تجمع مياه الصرف الصحي والامطار في شبكة واحدة ، إستخدام Bioswales تجعل معالجة مياه الصرف الصحي ممكنة في جميع الفصول. كان الغرض من هذه الدراسة هو تحديد المواقع المناسبة لإنشاء منظومات LID كأحد طرق إدارة الجريان السطحي الحضري في مدينة السليمانية - إقليم كردستان- العراق. في هذا البحث تم أختيارالمواقع المناسبة لتنفيذ Bioswales باستخدام أداة BMP Sitting Tool (BST) في برنامج ArcGIS . اقترحت نتائج الدراسة مساحة إجمالية قدرها 104329 م^2 في 530 موقعا لتركيب انظمة Bioswales. كما أوضحت النتائج أن معاملات استخدام الأراضي الحضرية والمجموعات الهيدرولوجية للتربة لها أهمية وتأثير في اختيار المواقع المناسبة لإنشاء النظام.

الكلمات الرئيسية :جريان السطحي للمدن، LID-BMPs، Bioswales، BMP Sitting Tool، السليمانية.

1. INTRODUCTION

Urbanization resulted in the expansion of impermeable surfaces in the form of roadways, parking lots, rooftops, and sidewalks inside cities. The decrease in pervious surfaces has been specified as a major cause of hydrological changes such as extreme runoffs and floods, which deteriorate water quality in the urban area **(Shuster et al., 2005).** Examples of hydrological consequences due to urbanization are increased runoff, erosion of riverbanks, degraded quality of water in water bodies, and reduced groundwater recharge **(Rose and Peters, 2001).**

Urbanization deteriorates natural landscape features, and the change of previous natural landscapes into impervious urban areas increases surface runoff intensity and volume, which has multiple effects on the watershed worsening, such as impaired water quality and reduced river baseflow due to lower infiltration into groundwater **(Brandes et al., 2005) and (Jefferson et al., 2017).**

Thus, the implementation of -Best Management Practices (BMPs) and Low Impact Development (LID) in developing areas can work as temporary storage facilities that enable innovative urban stormwater management practices **(Palermo et al., 2018).** Today, the performance of these sustainable solutions has attracted a great deal of attention from researchers and urban planners **(Jia et al., 2015),** and researches had been dedicated to LID design, uses, and simulation models of their behavior and benefits **(Pirouz et al., 2019).**

Urban runoff can be considered a threat to the environment, which washes out pollutants from impermeable surfaces such as city streets and parking lots into adjacent drains and water bodies. Therefore, applying BMPs is useful in reducing the release of these pollutants from stormwater runoff. These stormwater management systems can protect the surrounding lands and other water resources from washed-away pollutants, e.g., heavy metals and other chemicals **(Parkinson, 2003).** The term BMP includes structural and non-structural practices, structural practices such as engineered or constructed infrastructure, non-structural practices such as operating or procedural practices, and regulations such as minimizing the use of chemicals **(Fletcher et al., 2015).**

The practices of LIDs especially emphasize the more suitable management of urban stormwater through increasing pervious surface cover and infiltration adjacent to impervious surfaces **(Medina et al., 2011).** LID systems include but are not limited to Bioretentions and Raingardens, Bioswales, Green roofs, Dry and wet ponds, Infiltration basins and trenches, Porous pavements, Vegetated filter-strips, Stormwater wetlands, Rainwater harvesting and water reuse **(Florida, 2019)**. Application of BMPs can enhance the recharge of groundwater by increasing the rate of stormwater infiltration, which can reduce the drawdown of groundwater recedes **(Florida, 2019) and (Huseen, and Abed, 2020)**

In developing countries such as Iraq, cumulative urbanization and an amplified number of vehicles steered to the deteriorated environment and water resources **(Zakaria et al., 2013).** Rainfall runoff from streets and impervious urban areas can carry away pollutants to downstream water bodies such as lakes, rivers, and groundwater. On-road operative vehicles can release heavy metals and other pollutants to road surfaces resulting from the tearing and wearing vehicle parts such as brake pads and tires **(Hamaamin, 2018)**.

Bioswales or grassed swales are a linear form of bioretention used to treat water quality, reduce flood potential, and direct stormwater to locations far from critical infrastructure. Bioswales can be in a wide range of scales and types to treat runoff from any surface, but they are typically associated with linear features along roads or parking lots. Bioswales can also provide a landscape perspective of green space in a developed environment **(Florida, 2019)**.

Urban runoff simulation and LID-BMPs optimization modeling tools, such as SUSTAIN (System for Urban Stormwater Treatment and Integration), SWMM, and BST, can be used as successful tools for the design of LIDs and BMPs **(Elliott and Trowsdale, 2007), (Lee et al., 2012), and (Fletcher et al., 2013).**

Despite many studies on the efficiency of BMPs in quantitative and qualitative runoff control, the possibility of placing these systems in the current urban space has received less attention. Only a few studies have addressed the importance of the location of these systems. **Kirk (2006)** selected the best management strategies for runoff management in Melbourne, Australia using the Life Cycle Assessment evaluation method to select the best BMPs locations. In Kansas, the capabilities and applications of the SUSTAIN model introduced by the EPA examined all aspects of the application of modern surface water collection methods, including the evaluation of the optimal location, the type of method, and the cost of using it **(Lee et al., 2012)**. The best locations for the stormwater collection were studied in Australian catchment outlets, considered the most prone places for surface water collection storage **(Inamdar et al., 2013)**. The BST SUSTAIN module was used to identify potential green stormwater sites and infrastructure projects for mixed wastewater communities seeking to reduce their Combined Sewer Overflow (CSO) discharge in Allegheny County, southwestern Pennsylvania **(Shamsi et al., 2014)**. The right location for BMP application can increase their efficiency and effectiveness in quantitative and qualitative control of runoff **(Inamdar et al., 2013) and (Shamsi et al., 2014)**. The BMP Siting Tool was developed to find appropriate sites for LID techniques or BMPs in *SUSTAIN* (**Shoemaker et al. 2009)**. Therefore, it is necessary to use a tool that can locate these systems according to the physical condition of the city. While LID and BMP are onsite methods of pollution treatment, the key to the system's success is determining the most appropriate locations for optimal performance. Based on these conditions, this study can provide a suitable method for sustainable water resources planning and management in Sulaymaniyah by selecting the best place to implement Bioswales. This study aimed to select the best places to implement Bioswales BMP along streets and roadways in Sulaymaniyah City as an urban runoff management method using the BST plugin tool in ArcGIS.

2. MATERIALS AND METHODS

This research selects one of the best management practices (BMP) for urban runoff management (Bioswales) for street stormwater runoff treatment. The data used include statistical data obtained from relevant organizations and spatial information layers and maps prepared using the area's up-to-date satellite images using ArcGIS software. By reviewing the resources and obtaining the physical criteria necessary for BMP location optimization using the BMP Siting Tool (BST), potentially suitable areas for Bioswales implementation were suggested.

2.1 Different types of BMPs

The U.S Environmental Protection Agency (USEPA) represents stormwater BMPs as methods, actions, or structural controls used for a given set of necessities to manage the quantity and enhance the quality of stormwater runoff in a considerably cost-effective method. Two classes of BMPs are usually indicated. Structural BMPs are planned and created methods, whereas non-structural BMPs consist of pollution deterrence methods developed to prevent contaminants from entering receiving water bodies **(US EPA, 1999)**.
BMPs have become a common means of preventing runoff quality since the earlier 1990s, and their efficacy has been considered through studies performed in the United States, Europe, and other regions of the world **(Roesner et al. 2001).** BMPs can be categorized based on the type of intervention or location in the hydrologic cycle where changes are made:

- Pollution source technologies (Porous Pavements, Green Roofs, Rain Barrels, Cisterns, and Dry Wells) are located near or on the pollution generation site representing the impervious surface.
- Detention and retention techniques (detention ponds, extended detention ponds, and retention ponds) temporarily hold the runoff and then release it slowly via a pipe or other outlet system into streams and other water bodies. Capture and treat technologies (constructed wetlands, filtration basins, underground filters, sand filters, grassed swales (Bioswale), vegetated filter strips, water quality flotation inlets, coreceptors, CDS – continuous deflection separation) **(BF Environmental Consultants, 2004) and (Florida, 2019)**.

2.2 Bioswales

Bioswales or grassed swales are a linear form of bioretention used to partially treat water quality, reduce flood risk, and transport stormwater to areas far from critical infrastructure **(Florida, 2019).** According to the availability of water, the surface of a swale has two different types, grass surface and rock surface infiltration swales **(Hamaamin, 2018).** Grassed Bioswales are gently sloping canals with dense vegetation or grass to treat storm runoff collected from rooftops, streets, and parking lots **(ES-CPO, 2004).** After receiving runoff water, Bioswales direct excess runoff to storm sewers or directly to surface waters **(NRCS, 2005).** Bioswales can be a replacement or complement to traditional stormwater management. The vegetation embedded in them slows down the runoff, filters it out, and then allows it to penetrate the ground or into the storm drain, uptake pollutants through their roots thereby improving water quality. typically, urban runoff contains pollutants such as heavy metals, organic matter, and other contaminants from roads, roofs, and impervious surfaces. Filtering and removing these pollutants before entering the water resources system are very important for the stability of rivers and streams. The structure and function of the Bioswale are shown in **Fig.1** and **2**. In cases where soils do not drain water well, Bioswales typically transfer runoff to dry wells or trenches. Swale vegetation should have specific criteria for maintaining canal stability and improving the Bioswale's ability to filter pollutants from stormwater. Moreover, Bioswales have many environmental advantages, such as reducing and delaying floods in downstream areas, reducing the heat island effect in cities, and making wastewater treatment feasible, especially in cities using combined sewer networks and recharging groundwater. The used grass should be approved to withstand the area's chemical, physical, biological, and climate. Depending on the aesthetic effect, meadows, perennial shrubs, drought-resistant, coastal or non-native plants compatible with the area, and paving can be used **(ES-CPO, 2004) and (Florida, 2019).**

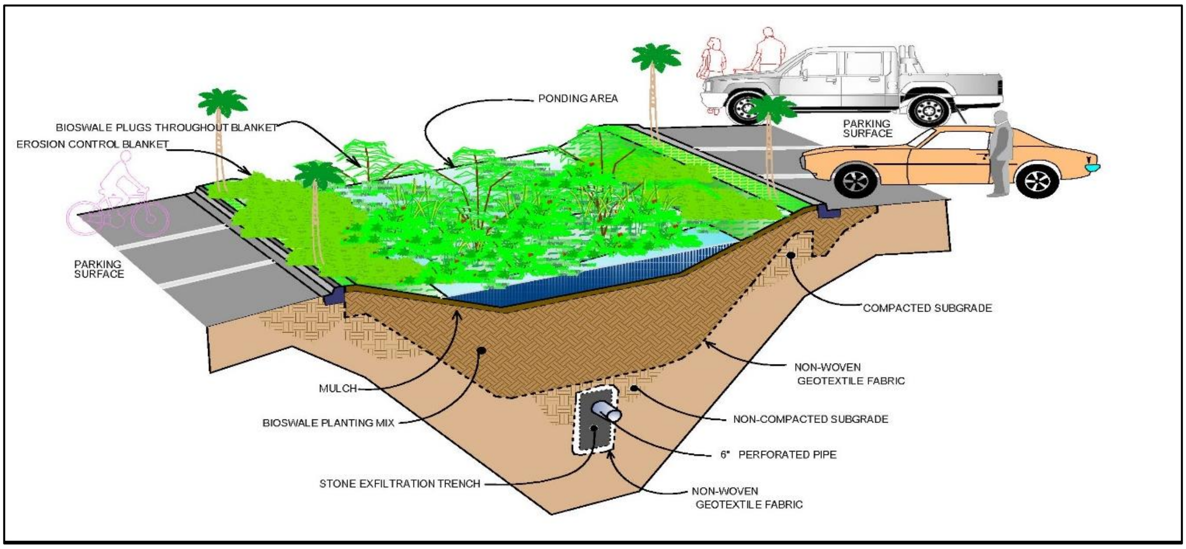

Figure 1. Bioswale concept diagram, structure and operation.

2.3 BMP Siting Tool Software

The EPA Best Management Practices Sitting Tool (BST) suggests potentially suitable locations/ areas for implementing different types of BMPs or low-impact development (LID) techniques. To select the appropriate locations, the following criteria and parameters must be defined for this plugin: Drainage area, slope, soil hydrological group, depth of groundwater table, road buffer, stream buffer, and building buffer. The BST plugin tool was released in 2014, and its latest version 1.2 in August 2014. This plugin needs ArcGIS software version 10.1 and above as an operating system with Microsoft Visual Basic (Visual Studio 6.0) specifications and Service Pack 1 and Windows 7 (32-bit or 64-bit) or later versions **(BST user's Guide, 2013)**.

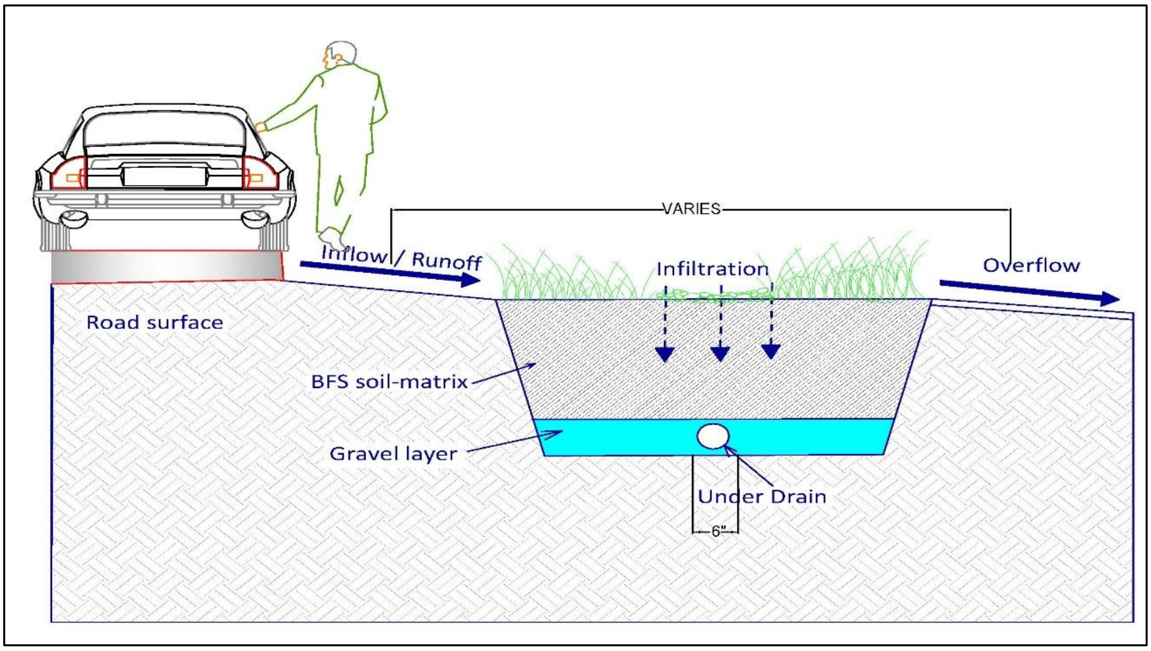

Figure 2. Bioswales components **(Florida, 2019)**.

2.4 Data required for BST

The data required by the BST Tool is a thematic map in raster and shape file format for the data layer in ArcGIS. The thematic maps needed in the data layer include; slope, soil type, urban land use, percent impervious, land ownership, roads, water table depth, stream location, and drainage area.
The appropriateness of physical data in the area is considered the dominant factor in identifying potential locations **(USEPA, 1999a).** Using ArcGIS analysis and up to eight base data layers, the location tool helps users to identify suitable locations for structural BMPs

based on appropriate criteria such as elevation, slope, soil type, urban land use, and road identification.

2.5 Parameters used in BST

In the BST locator tool, the matrices are presupposed and defined in the BMPs according to the defined parameters and embedded in the model. Users can change them according to their preferences or knowledge of the area. **Table 1** describes eight layers of GIS data that are used as primary input data for the tool, and the default criteria are shown in **Table 2 (US EPA 2004a, 2004).**

The result of processing the BST plugin is a spatial map that identifies areas that meet the default criteria selected by the user or to place existing BMPs. Multiple spatial maps can be created for project areas based on various criteria selected by the user.

Table 1. Required data and data format for BST location tool **(BST user's Guide, 2013)**.

ArcGIS Layers	Format data	Description of data
DEM (Digital Elevation Model)	Raster file	The digital elevation model (DEM) is used to calculate the drainage slope and drainage area which are used to identify the suitable locations for BMPs.
Land use	Raster and Table file	The USGS Multi-Resolution Land Characterization (MRLC) land use grid is used to eliminate the unsuitable areas for BMPs.
Percent impervious	Raster file	
Urban Land use	Shape file	The urban land use data contain the boundaries for the buildings and the impervious areas needed to identify suitable locations for LIDs.
Road	Shape file	The road layer is used to identify suitable locations for some BMPs that must be placed within a specific road buffer area.
Stream	Shape file	The stream layer is used to define a buffer so that certain BMP types can be placed outside the buffer to minimize the impact on streams.
Soil	Shape and Table file	The soil data contain the soil properties such as hydrological soil group and the soil permeability which are used to identify suitable locations for BMPs.
Groundwater Table Depth	Shape file	The groundwater table depth layer is used to identify suitable locations for the infiltration BMPs.
Land Ownership	Shape file	

Table 2. Default criteria for each parameter in the BST plugin **(BST user's Guide, 2013)**.

BMP	Site Suitability Criteria							
	Drainage Area (ha)	Drainage Slope (%)	Imperviousness (%)	Hydrological Soil Group	Water Table Depth (ft.)	Road Buffer (ft.)	Stream Buffer (ft.)	Building Buffer (ft.)
Bioswale (Grassed Swale)	< 2	< 4	> 0	A–D	> 2	< 100	--	--

3. RESULTS AND DISCUSSIONS

3.1 Study Area

The study area for this research was Sulaymaniyah City in the Kurdistan Region of Iraq. Geographically, Sulaymaniyah is located at 35° 30' 17"- 35° 36' 38" North Latitude and 45° 21' 20"- 45° 29' 48" East Longitude. This region is located in northeastern Iraq on the border with Iran and includes ten districts. Sulaymaniyah district is the most rapidly growing area that faces intensive development and urbanization. The city has a combined sewer system that collects the stormwater and sanitary sewage together in a single pipe system that drains the sewage downstream of the city without any treatment plants. The total area of the Sulaymaniyah study area is 7065.5 ha. The climate is hot and dry in summer with an average temperature of 31.5 ° C, while in winter, the average temperature is 7.6 ° C. Rain begins with light rain in October, intensifies in November, and continues until May. The average annual rainfall varies between 328 mm for dry years and 848 mm for wet years **(Hamaamin, 2017) and (Hamaamin, 2018)**. **Fig. 3** shows the location map of the study area.

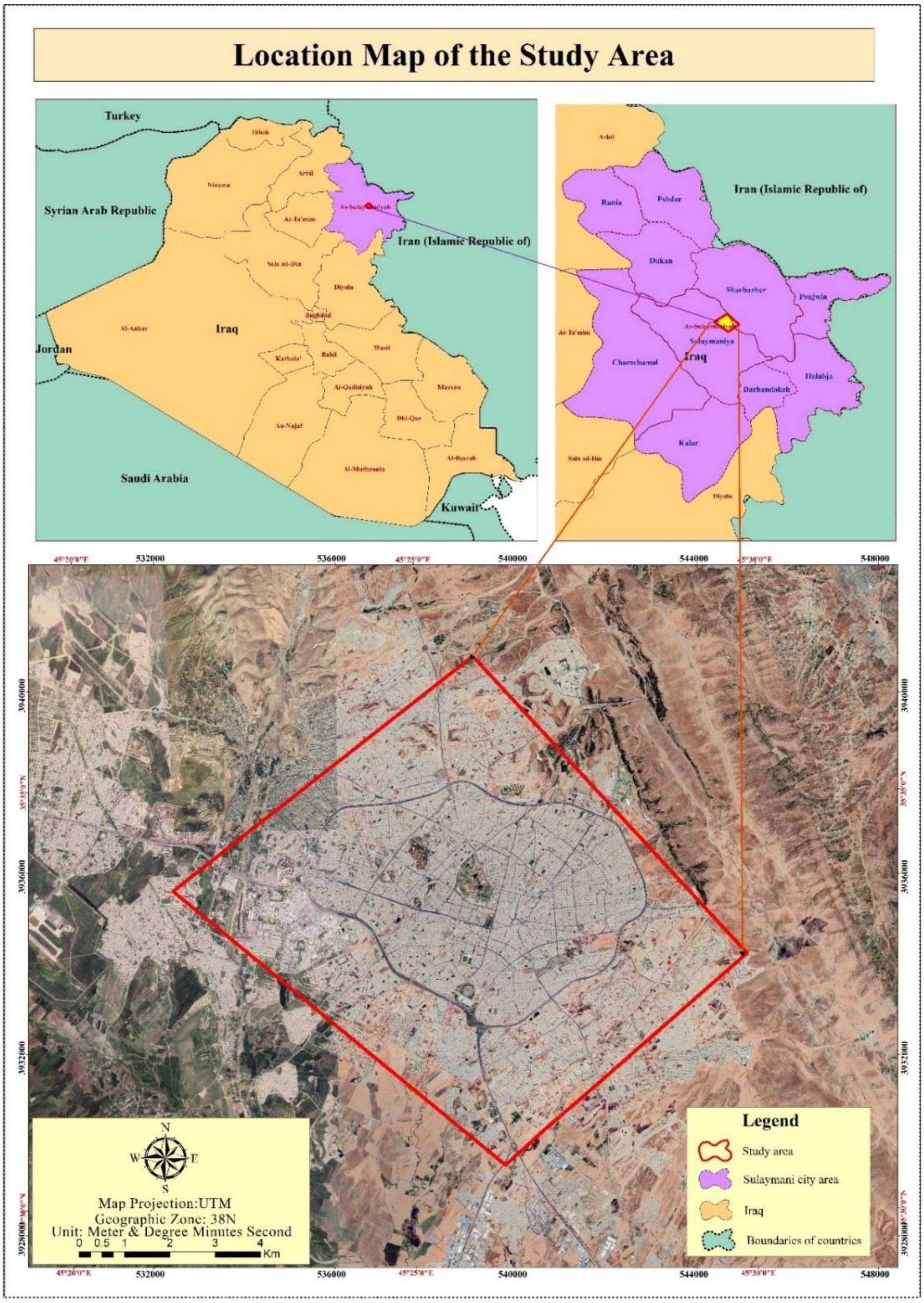

Figure 3. Location map of the Study Area.

3.2 Bioswales location criteria in the Study Area

The land use layer is extracted from satellite images with high spatial resolution; thus, high-resolution satellite images are first downloaded from Google Earth and then digitized in the ArcGIS software environment after orthophoto and rectification. Land uses, including buildings, roads and highways, green spaces, parking lots, and other tolls, are extracted.

Descriptive information about the extracted uses is prepared and completed according to the model format **(Rashed and Hussein, 2020)**. The layer of percent impervious, urban land use, and land ownership is prepared from land use data. A Digital Elevation Model (DEM) was prepared from the stereo satellite image of the SRTM satellite with a Cell size of 30 meters for slope extraction and waterway network **(U.S. Geological Survey, 2022)**. The soil information layer and soil hydrological group were prepared by the U.S. Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) **(Ross et al., 2018)**. Groundwater depth layer obtained from the groundwater directorate of Sulaymaniyah City. **Fig. 4** shows the physical parameters prepared for the study area. **Fig. 5** also shows the land use map of the study area, which is one of the most widely used layers for various urban analyzes.

Based on the land use map processing results in the study area, it has been determined that the area of residential use and construction with the defined classifications is a total of 4032.8 hectares, which occupies **57.077%** of the total area. Open space includes public open space and green spaces with an area of **2287.38** hectares **(32.374%).** The total area of roads, transportation routes, and parking lots is 745.32 hectares, which is **10.549%** of the total area of the study area.

The study area's Hydrological Soil Group (HSG) is in groups C and D, which has soil conditions with medium runoff potential and low infiltration rate with an infiltration rate of **1-4** mm per day. The groundwater level in the study area is **29.7-151.35 ft** below the surface. **Tables 3, 4,** and **5** show the results extracted from the physical parameters in the study area.

Table 3. Summary of the values of physical parameters in the study area.

Physical Criteria	Value
Area	7065.5 ha
mean Slope	0-8.1%
Build area	57.077%
Green open space	32.374%
HSG	C-D
Groundwater table depth	29.7-151.35 ft.

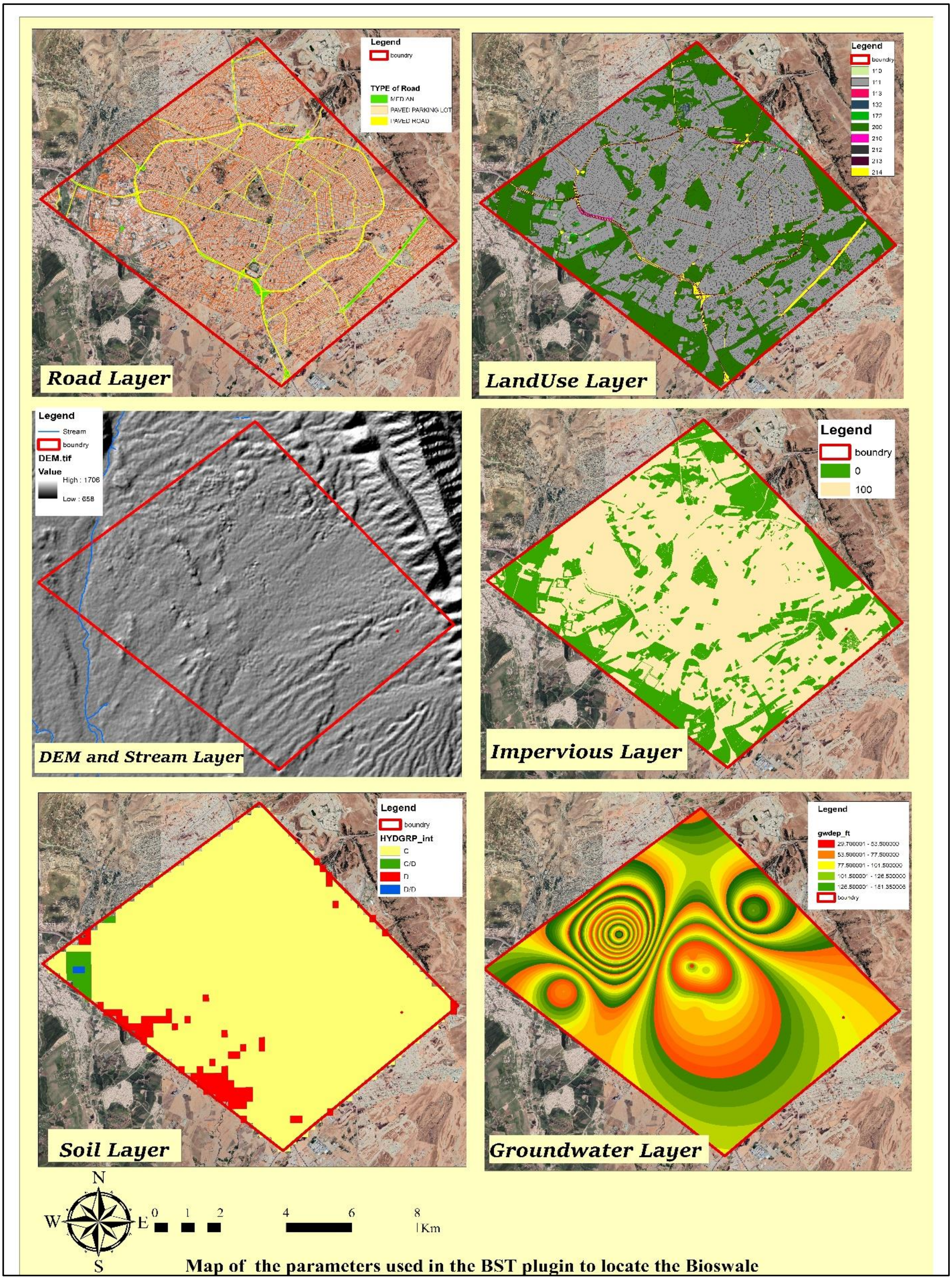

Figure 4. Map of physical parameters prepared from the study area.

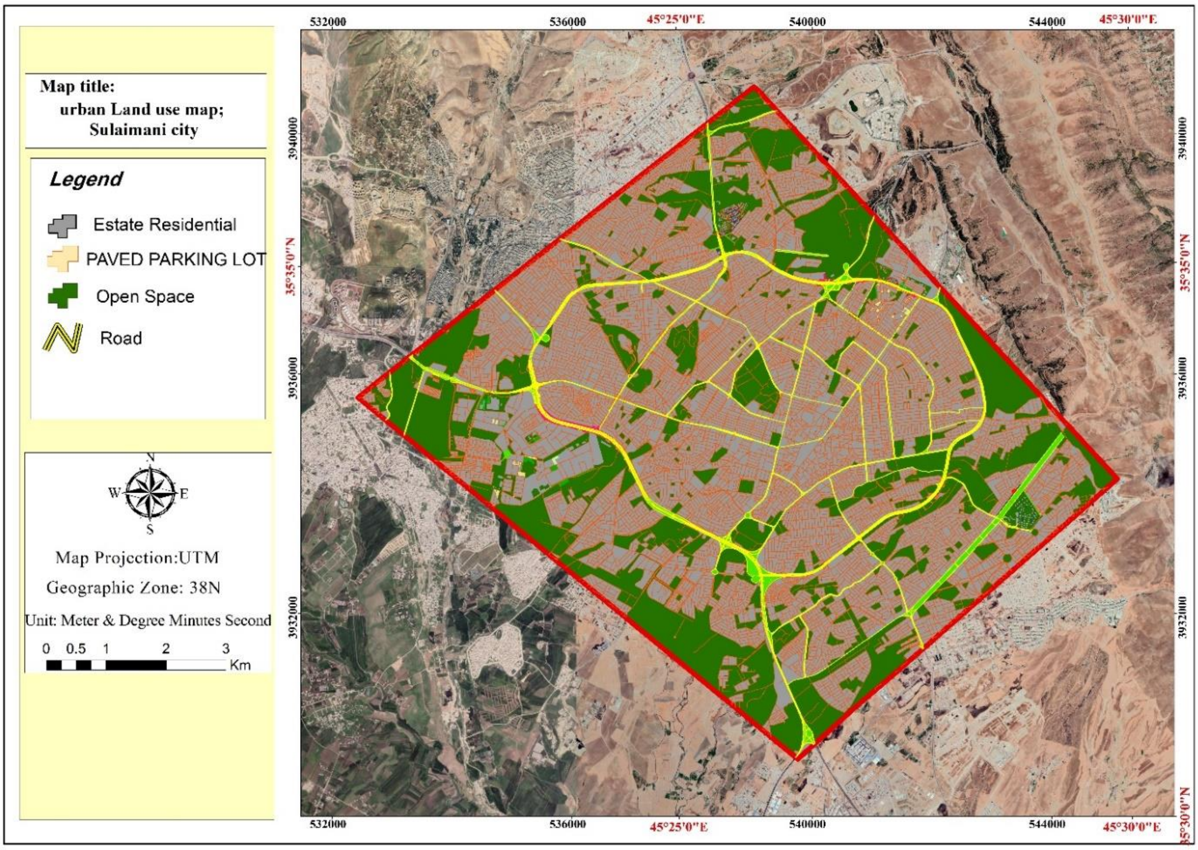

Figure 5. Land use map of Sulaymaniyah City.

Table 4. Area and percentage of different urban land use classes in the study area.

Land Use	Area(ha)	Area Percentage (%)
Estate Residential-Bldg	4032.80	57.077%
Estate Residential-Pervious	8.05	0.114%
Estate Residential-Road	0.30	0.004%
High Density Residential-Pklot	8.95	0.127%
Low Density Residential-Pklot	10.92	0.155%
Open Space-Pervious	2133.50	30.196%
Transportation-Pervious	8.98	0.127%
Transportation-PervRdMedian	136.85	1.937%
Transportation-Pklot	558.17	7.900%
Transportation-Road	166.98	2.363%
TOTAL	**7065.5**	**100.000%**

Table 5. Percentage of impermeability in the study area.

Land Use Groups	Area (ha)	Percent of Total Area (%)	Imperviousness (%)
Transportation	745.32	10.549	10.549
Residential	4032.8	57.077	57.077
Open Space	2287.38	32.374	0
Total	**7065.5**	**100.000**	**67.626**

3.3 Bioswales Location Map

Based on the analysis using input data and criteria processed by BST, the resulting layer in ArcGIS software shows the location for each BMP type and a composite map layer that shows all the appropriate combinations of BMP types in each location.
The reason for selecting only one type of BMP is due to HSG criteria. The soil hydrological group of the Sulaymaniyah region is in groups C and D. This means that the type of BMP used for infiltration, such as infiltration basin, infiltration trench, and porous pavement, cannot be applied because HSG is required by criteria A or B. In addition, land restrictions, roads, and building boundary regulations have led to the selection of Bioswales. The BMP Location Analysis Tool's output is a spatial map showing areas that meet the default or set criteria for placing selected BMPs. Based on the various criteria selected in this study, a spatial map of potential Bioswale areas can be created for the project. The output map and Bioswales location distribution are presented in **Fig 8** and **Table 6.** The results of this study suggest that the potential area for installing the Bioswales system by the BST location tool is a total area of **104329** square meters in **530** locations. If the city municipality demanded to implement proposed Bioswales, are of each unit and location can be determined from the BST output results. Sulaymaniyah City has a combined sewer network that collects sanitary sewage and stormwater in one single sewer network. During storm events, wastewater treatment is impossible due to the huge volume of combined wastewater. While Bioswales infiltrate some portions of rainfall-runoff collected downstream runoff and flood will be deceased, this makes treatment of wastewater possible even during rainfall events. The recharge of groundwater will increase due to rainfall water infiltration through Bioswales areas. Pollution, especially with heavy metals, will be removed from the infiltrated water due to many mechanisms, such as clogging inside soil layers and plant uptake of pollution. As it is obvious, the Sun radiation and heat are absorbed in a higher range by concrete and asphalt surfaces inside cities compared to soil and green surfaces and resulting in a temperature rise called heat islands inside cities. Other benefits of Bioswales applications are reducing the heat island effect inside cities. Also, the application of Bioswales gives a beautiful natural landscape view inside cities.

Table 6. Information on selected positions for Bioswales.

Number of locations selected	Minimum size(m^2)	Maximum size (m^2)	Total Area (m^2)
530	20	500	104329

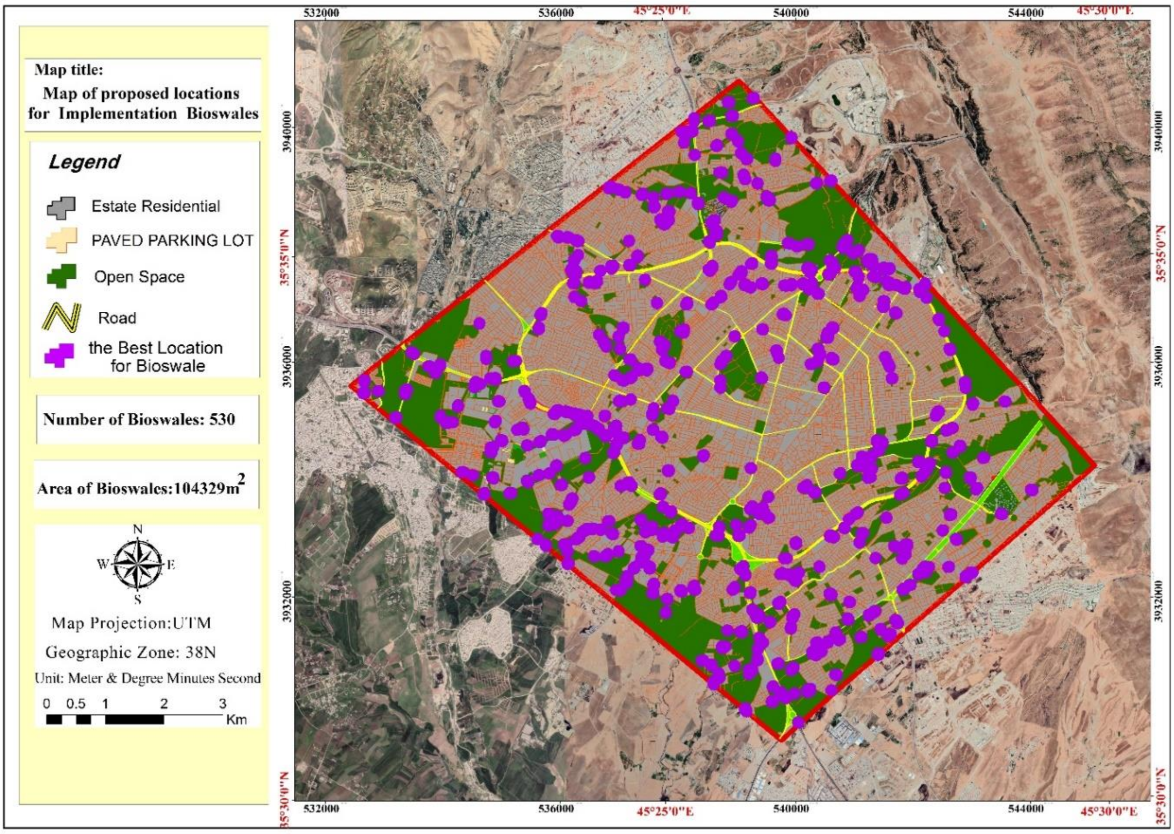

Figure 8. Bioswale distribution map in Sulaymaniyah.

4. CONCLUSIONS

Due to heavy urbanization and land developments, different types of pollutants are released into the environment. Quantitative and qualitative water resources management are vital for integrated sustainable urban development. Flood and pollution control can be considered the greatest environmental challenges facing city managers and stakeholders. BMPs and LIDs systems have been found to effectively remove pollution from urban storm runoff. This study determined suitable locations for stormwater management for runoff from Sulaymaniyah City streets. Bioswale from the list of possible BMPs was selected for water treatment based on the availability of the input data using the BST plugin software.
The results of this analysis suggest that the potential area for installing the Bioswales system by the BST location tool is a total area of 104329 square meters in 530 locations used as green infrastructure for urban stormwater runoff treatment in Sulaymaniyah.
Bioswales can improve water quantity and quality by delaying and retarding the runoff on a pervious vegetated area which cleans and infiltrate stormwater. The water quality of storm runoff can be improved by pollution removal through filtration and plant uptake of contaminants. Water quantity can be improved through the infiltration of stormwater through Bioswales recharging groundwater. Furthermore, constructing Bioswales along streets and parking lots can reduce temperature rise inside cities and give a better green landscape view. While Sulaymaniyah has a combined sewer network, the application of Bioswales makes wastewater treatment feasible in all seasons, especially during storm

events when a huge volume of mixed sanitary sewage with rainfall runoff is discharged downstream to the wastewater treatment plant.

To increase the use of this system and other methods of urban runoff management, when developing comprehensive plans, it should be considered a legal requirement that each region should be responsible for its runoff production load. In the present study, only the Bioswales system was used to locate BMPs. The implementation of several other BMP methods can also be evaluated.

For future works, more accurate and higher quality DEM satellite images, less than 30 m, can be used to obtain higher quality and resolution software outputs and results. Also, other types of BMPs can be considered secondary treatment units, such as Bioretention ponds constructed to receive effluent from Bioswales for a more advanced stage of treatment.

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