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INVESTIGATION OF APPLICATION OF GREEN INFRASTRUCTURE PRACTICES FOR STORM WATER MANAGEMENT IN URBAN AREAS: A CASE STUDY OF DIYATHA UYANA

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Abstract: With rapid urbanization, uncontrolled storm water runoff is one of the major problems facing urban areas at the present. Therefore, it can be seen as inducing flash flood events and water quality degradation in urban areas. In the Sri Lankan context, this same problem can be seen in urban areas. One of the issues facing urban areas is inadequate storm water drainage systems and limited space. At present, most urban areas have broadly used Green Infrastructure (GI) to reduce this situation in developing countries as an innovative and sustainable SWM approach. This Research is basically focused to examine the capability of reducing the impact of surface runoff using GI considering before- after situations (2005, 2021) in Diyatha Uyana and its surrounding as a case study area. When examining the research question, is explained the result with runoff retention index, runoff volume per watershed (m3), and runoff retention volume per pixel (m3) of the study area. Under various rainfall depths can be seen as a high retention index rather than before-situation of Diyatha Uyana.

Keywords: *Storm water management, Green Infrastructure, Urban runoff, Runoff retention, Runoff volume, Urban flood risk mitigation*

1. Introduction

Rapid urbanization, climate changes, and land cover changes have raised several undesirable impacts on the hydrological cycle in urban areas (Senes G. et al, 2021). With increasing impervious surface areas from growing cities have generated more and more runoff during storm events (Li N., Tao J. & Chen Q., 2017). One of the major issues in urban areas is flash flood events and water quality degradation. Therefore, urban areas are more focused on Storm Water Management (SWM) to adapt to climate change.

According to the US Environmental Protection Agency, SWM means the effort of controlling the surface water runoff coming from impervious surfaces and reducing urban flash flood events as well as upgrading the quality of water (EEC Environmental, 1995). From old times, cities used to manage stormwater using "grey" infrastructure methods such as gutters, pipes, tunnels, drains, and basins but with passing ages, they try to maintain the old infrastructure several times that the result was storm water runoff (Gyimah K.A., HamidH. S. & Oppong R. A., 2017).

At present, most urban areas have been provided conventional methods with limited space problems such as making drains rather than giving sustainable and innovative urban resilience solutions for SWM (Pathira-na U.P.L.V. et al., 2020). But some researchers are giving their attention to Green Infrastructure (GI) as a sustainable method for urban areas by now. Low impact development and GI has been broadly used to reduce this situation in developing countries (Li N., Tao J. & Chen Q., 2017). Green Infrastructure aspects can be applied at different scales such as urban scale, neighbourhood scale, building scale, landscape, or watershed scale. It can be divided into two groups such as structural and non-structural methods.

Under structural GI belongs green roofs, rainwater tanks, wetlands, bioswales, pervious pavement, storm-water detention systems, planter boxes, rain barrels, downspout disconnection, and so on. Non-structural GI means improving vegetation of a particular area or region, uplifting the capability of infiltration in the soil through the amending qualities, and designing the buildings and roads to reduce the imperviousness (Elliott & Trowsdale, 2007). Among these things, GI is considered as an innovative SWM approach that offers cost-effective solutions. GI is a sustainable approach to SWM. Moreover, it helps to protect and restore the natural hydrological cycle. GI is effective, and resilient, achieving economic, social, and environmental benefits, and quality of life (About American Rivers, 2021).

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The research articles were published during the last decade, have been given attention to introduce alternatives for storm water management (Pathirana U.P.L.V. et al., 2020), storm water management models and tools (Haris H. et al. , 2016), management policies within the governance structure (Saraswat C., Kumar P. & Mishra B.K. , 2016;), storm water management in public areas (Proske Z. & Zdarilova R., 2020), "Green Infra-structure Suitability Maps as a tool for land-use planning" (Senes G. et al, 2021), the formal and informal institutions' roles regarding storm water management (Bohman A., Glaas E., Karlso M., 2020), the green infra-structure usage, applications and hydrological benefits of green infrastructure, its barriers and strategies for storm water management (Li C. et al. , 2018), various issues and opportunities GI practices for industrial areas (Jayasooriya V. M. et al., 2020). However, the capability of reducing the impact of the surface runoff using green infrastructure has not been explored yet in the literature. Therefore, this study is focused on the capability of reducing the impact of surface runoff using GI.

2. Methodology

2.1 CASE STUDY AREA

Figure 1: Selected Case Study - Diyatha Uyana and Its Surrounding Area (*Source: Google Earth Pro*)

Diyatha Uyana and its surrounding area was selected as the case study for this research. It is located at Polduwa junction, Battaramulla near the Water's Edge Hotel (Figure1). This Park has been built on marshy land on the banks of the Diyawanna Oya that works as a natural water retention action against floods (G. Nadira, 2019). The extent of the selected study area is 43.7 Ha.

This Research is investigated in urban areas. So, this area is located in a suburb of Colombo (Kalupahana C., et al., 2015). Diyatha Uyana can be pointed out as a good example of using green infrastructure in the urban context to control the storm water runoff. Several types of green infrastructure can be seen here which are green paths and alleys, permeable pavements, and natural marshy lands (G. Nadira, 2019).

Figure 2: Green paths and alleys, permeable pavements, and natural marshy land (*Source: Compiled by Author*)

For this research, the situation of the case study area before and after the construction of Diyatha Uyana was considered 2005 and 2021 years were selected to examine the before and after situations respectively. In this study, year-2005 was selected for examining the before situation prior to introducing Green Infrastructure to the study area. Diyatha Uyana was opened on September 15, 2012, for the public (Wikipedia, 2016). However, the project activities related to Diyawanna Oya and current Diyatha marshy land were started in 2010 to control the floods. Therefore, the year-2005 was selected to analyse the before condition.

2.2 MODEL AND INPUT DATA

For this research purpose, the 'Urban Flood Risk Mitigation' model is a recent product of InVEST version 3.8.6 added to Natural Capital Project's tools that are used to explore urban runoff retention. UFRM model does not consider the spatial and temporal dynamics of the storm event. Five different types of input data are required to investigate the capability of reducing the impact of surface runoff,

- **Watershed (vector) –** This study is focused on the Kelani River watershed boundary to delineate the sub-basin of the case study area. Here, stream networks and outlets related to the study area are given priority for delineating the sub-basin accurately (Figure2).

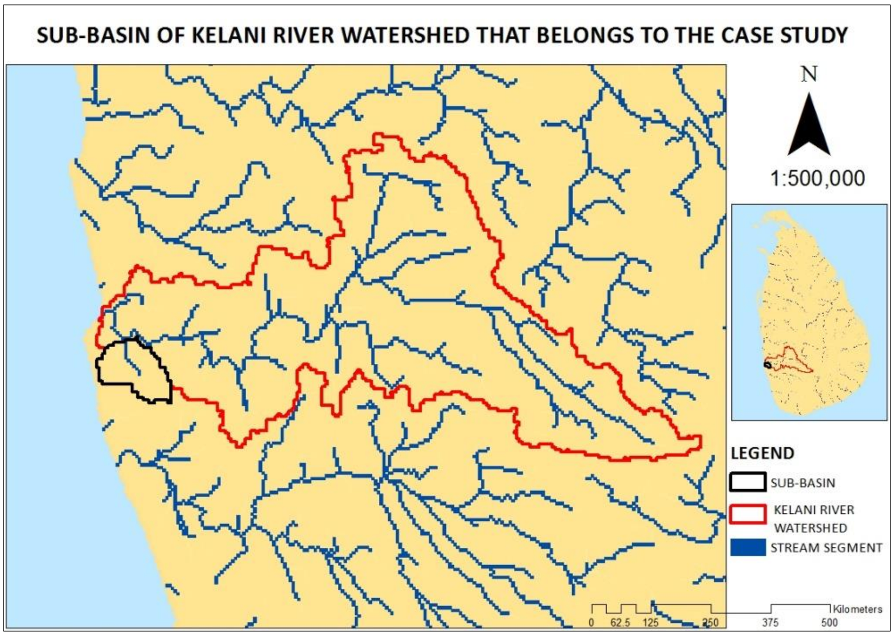

Figure 3: Sub-basin of Kelani River watershed that belongs to the case study (*Source: Compiled by Author*)

- **Numeric value of rainfall depth of a single extreme rainfall event (mm) –** This research considered a unique value of rain's amount (in mm) related to one of the stations (Hanwella) of the Kelani River watershed boundary close to the study area. Here, the analysis continued under two different stages. In the first stage, it considered single design storm events of 12 h duration rainfall in 1463 sq. Km with a depth of 143 mm based on hydrological annual 2018/19 for analyzing of before-after situations in the case study to identify the condition of runoff retention capability under the single rainfall depth (Irrigation Department, 2020). The second stage, the before-after situations in the case study were considered under the five different types of rainfall depths of 232,255,88,135 and 78 corresponding to 2005/06, 2009/10, 2011/12, 2015/16 and 2017/18 respectively.

- **Land Cover Map**
- **Soils Hydrological Group raster –**

Table 1:Hydrological soil groups according to USDA classification
(*Source: Hydrologic Soil-Cover Complexes (USDA handbook- Chapter 9)*)

Pixel values	Description
1	HSG-A: low runoff potential (>90% sand and <10% clay)
2	HSG-B: moderately low runoff potential (50-90% sand and 10-20% clay)
3	HSG-C: moderately high runoff potential (<50% sand and 20-40% clay)
4	HSG-D: high runoff potential (<50% sand and >40% clay)

This process allows obtaining a soil's associated runoff curve number (CN) which is used to estimate direct runoff or infiltration from precipitation surplus. Certainly, HSGs are fundamental components of the USDA Soil Conservation Service (SCS) – runoff curve number (CN) - method for estimation of storm water runoff. According to USDA classification (Table 1), Soils have been fundamentally classified into four standard classes of HSGs—A, B, C, and D. A has the least runoff potential and D has the most (NRCS-USDA, 2007; Chap. 7). For this modeling purpose, this input data is required as a raster layer related to the case study. Here, raster with values equal to 1,2,3,4 corresponding to HSGs—A, B, C, and D.

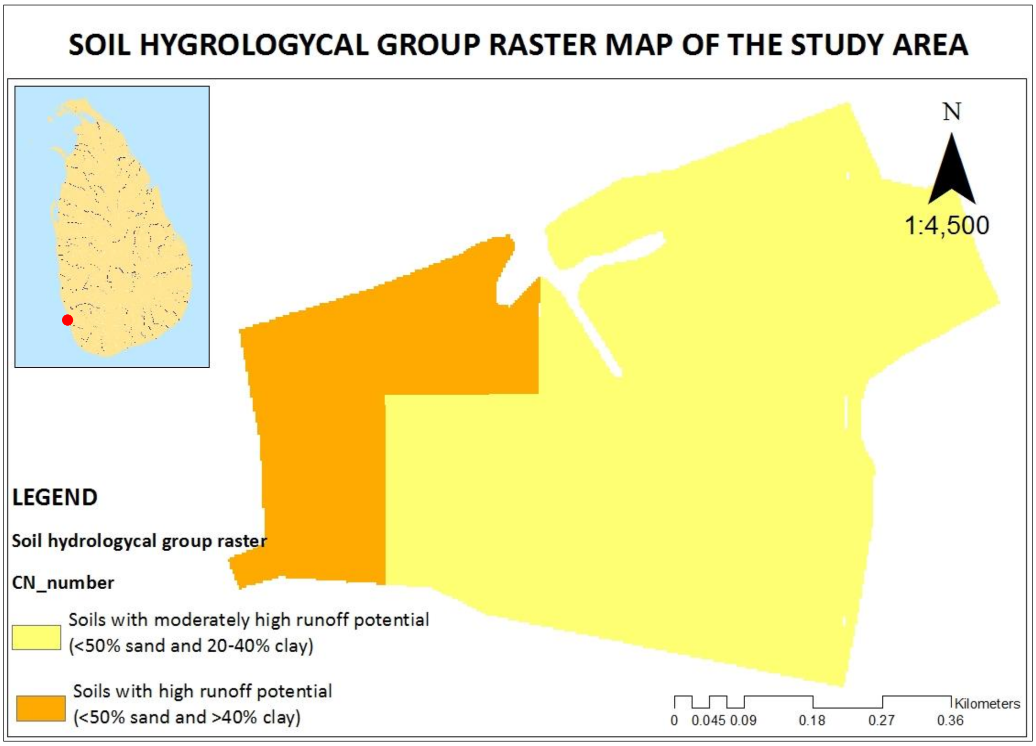

Figure 4: HSGs raster map of the study area (*Source: Compiled by Author*)

- **Biophysical table -** containing the value corresponding to each land use classes in the Land Cover Map (Table 2 and 3).

Table 2:Biophysical table with land use and curve numbers – 2005

Lu code	Description	LU Type	CN_A	CN_B	CN_C	CN_D
6	Pervious area	Open space (Fair condition - grass cover 50–75%)	49	69	79	84
7	Pervious area	Marshy land	1	1	1	1
11	Pervious area	Scrub and Pasture	39	61	74	80
15	Pervious area/ Impervious area	Newly graded area	77	86	91	94
20	Impervious area	Main road	98	98	98	98
22	Impervious area	Minor road	83	89	92	93
23	Pervious area	Foot path	51	68	79	84
33	Impervious area	Built up area	77	85	90	92
44	Pervious area	Open space (Poor condition - grass cover <50%)	68	79	86	89
53	Water	Canal	1	1	1	1

Table 3:Biophysical table with land use and curve numbers – 2021
(*Source: Hydrologic Soil-Cover Complexes (USDA handbook- Chapter 9)*)

Lu code	Description	LU Type	CN_A	CN_B	CN_C	CN_D
6	Pervious area	Open space (Fair condition - grass cover 50–75%)	49	69	79	84
7	Pervious area	Marshy land	1	1	1	1

11	Pervious area	Pasture	39	61	74	80
15	Pervious area	Permeable surface	51	68	79	84
20	Impervious area	Main road	98	98	98	98
22	Impervious area	Minor road	83	89	92	93
23	Pervious area	Foot path	51	68	79	84
24	Pervious area	Green path and alley	49	69	79	84
33	Impervious area	Built up area	77	85	90	92
43	Impervious area	Open area	77	86	91	94
44	Pervious area	Open space (Poor condition - grass cover <50%)	68	79	86	89
47	Impervious area	Parking lot	98	98	98	98
53	Water	Canal	1	1	1	1

2.3 EXAMINING THE CAPABILITY OF GI TO REDUCE THE IMPACT OF SURFACE RUNOFF
Under this section, the relevant input data was applied to run the model to find the runoff volume, runoff retention index, and runoff retention volume of the case study for two different years. To examine the situation prior to the case study, the relevant input data sets (2005 and 2021) such as the watershed vector layer, depth of rainfall (mm), landcover raster layer, HGS raster layer, and biophysical table were separately added into the model at the first stage. This case study event is considered a single rain event of 143 mm (Irrigation Department, 2020). 'WGS 1984 UTM 44N' was used as a projected coordinate system for spatial layers.

At the second stage, based on the different rainfall depths, the possible changes of the surface runoff are investigated in the study area related to the before-after situations. According to the hydrological annual reports have maximum rainfall depths (mm) of 232,255,88,135,78 and 143 corresponding to 2005/06, 2009/10, 2011/12, 2015/16, 2017/18, and 2018/2019 respectively. Here, it wants to check that able to get the same result from examining the capability of runoff retention using GI. Also, here as before, two data sets are entered separately related to years (2005 and 2021) into the UFRM model.

3. Research Findings

The results of the UFRM model provide data about the runoff process and identify values for both flow retention and surface runoff volume. Table 6 shows the explanation of the model's output in terms of the watershed considered in the analysis situated in the case study - Diyath Uyana and its surrounding. Table 4 indicates the indices on runoff retention, the absolute volume of retained water in cubic meters, and the runoff volume per extension of the sub-basin (cubic meters/Ha.). This output includes a single design storm event of 12 hours duration with a depth of 143 mm, representing the case study—Diyatha Uyana and its surroundings.

Table 4: Flood Risk Mitigation model outputs within the single rainfall depth (*Source: UFRM model*)

Different situations in the study area	Area (Ha.)	Rain depth (mm)	Runoff retention index (%)	Runoff retention volume per pixel (m^3)	Runoff retention volume (m^3)/Area (Ha.)	Runoff volume (m^3)/Area (Ha.)
Before situation	43.7	143	25.5	1,5973.53	365.53	1,065.75
After situation	43.7	143	33.5	2,0896.87	478.19	950.00

In comparison, the year-2021 has shown a high value of retention rather than the year-2005 (Table 4). The runoff retention index has shown that has increased the runoff retention capacity by 8% from the before condition.

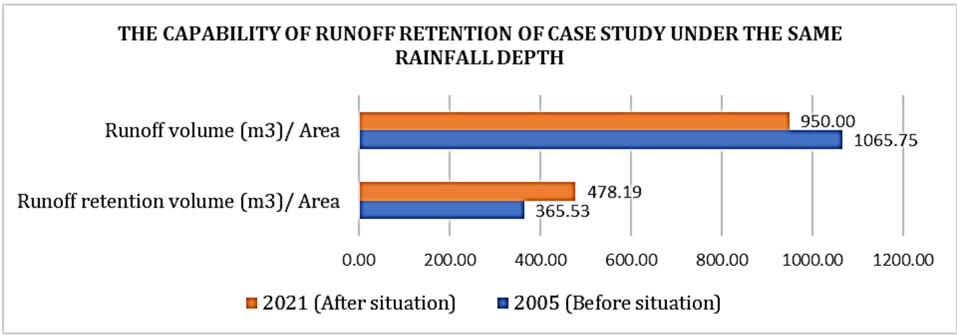

Figure 5: The capability of runoff retention of the case study under the same rainfall depth (*Source: Compiled by author*)

Figure 5 has represented how to consist the runoff volume and the capability of runoff retention in the study area under the same rainfall event by the bar chart. It shows the runoff volume reduction of 115.75m3 in the study area. And also, it has mentioned a runoff retention increment of 112.66m3rathere than before situation. According to table 4, Flood volume has been gone to reduce after applying the Green Infrastructure into the case study at a significant level.

Figure 6 shows the model outputs in terms of the capability of runoff retention of the case study as location maps respectively 2005 and 2021 considering its pervious and impervious surfaces. These maps show the value of the runoff retention per pixel (m3). According to the Hydrological annual reports 20018/19 (updated version on web portal of Irrigation Department), the depth of rainfall is143 mm for model outputs. According to the below maps, marshy lands and waterbodies shows the highest capability of runoff retention. According to these maps and analysis, can be derived that natural green infrastructure options contribute a huge service to controlling the storm water runoff. Because natural marshy lands and pasture shows a high retention value to control the surface runoff. The contribution of green paths and alleys and permeable pavements for controlling the surface runoff is very less compared with others. However, Green infrastructure adaptation is the better solution to control the increasing more impervious surfaces.

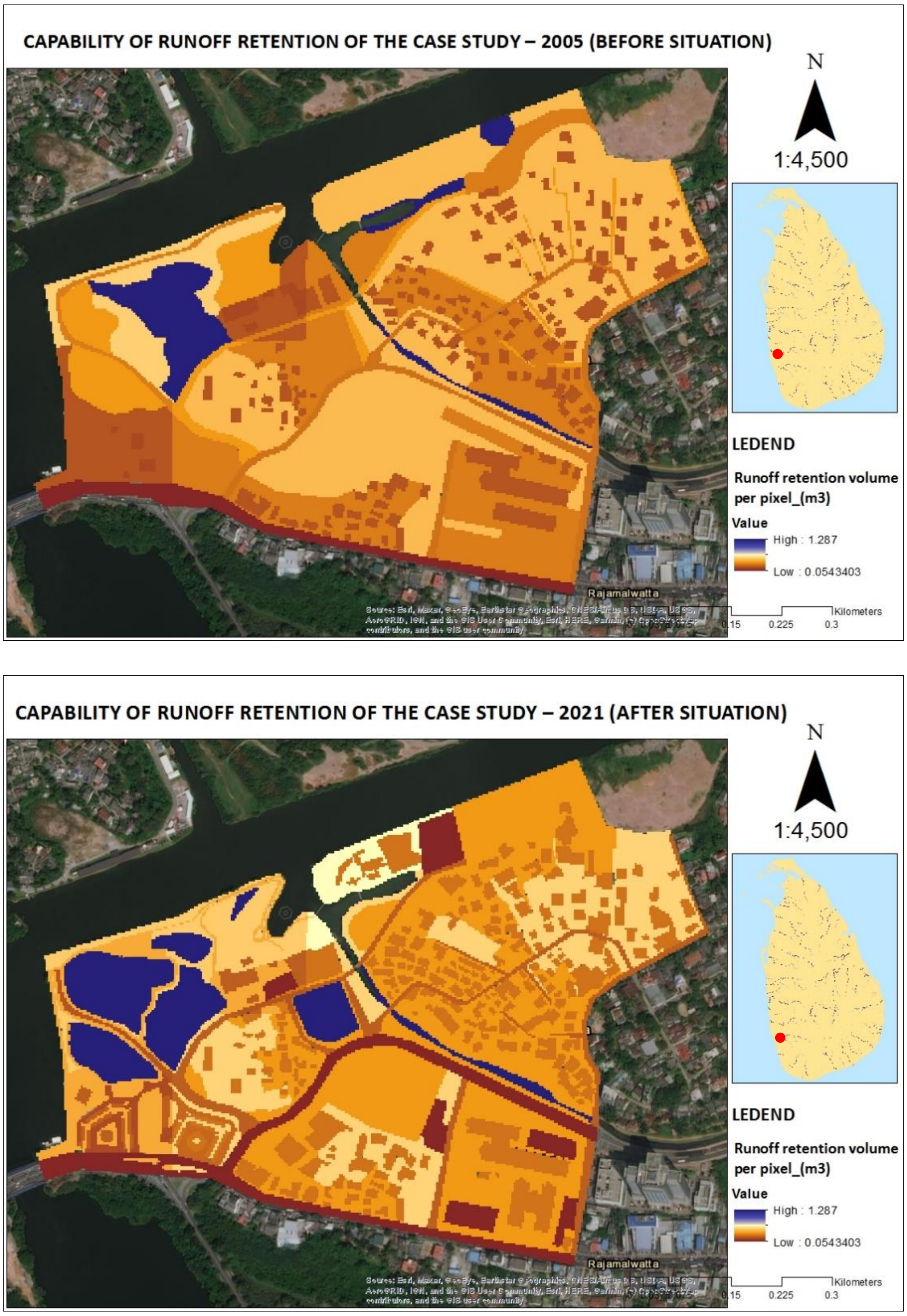

Figure 6: The capability of runoff retention per pixel – 2005 and 2021 (*Source: UFRM model*)

3.1 CHANGES OF SURFACE RUNOFF IN THE STUDY AREA UNDER THE DIFFERENT RAINFALL DEPTHS (MM)

Table 5: Flood Risk Mitigation model outputs under the different rainfall depths (mm) (*Source: UFRM model*)

Different situations of the study area	Area (Ha.)	Rainfall depth (mm)	Runoff retention index (%)	Runoff retention volume per pixel (m^3)	Runoff retention volume (m^3)/Area (Ha.)	Runoff volume (m^3)/Area (Ha.)
Before situation	43.7	232	18.7	1,8932.17	433.23	1,888.85
After situation			25.7	2,6030.29	595.66	1,721.40
Before situation	43.7	255	17.6	1,9609.05	448.72	2,103.56
After situation			24.5	2,7223.41	622.96	1,923.81
Before situation	43.7	88	35.0	1,3490.22	308.70	572.09
After situation			43.7	1,6784.17	384.08	494.81
Before situation	43.7	135	26.5	1,5661.83	358.39	992.81
After situation			34.6	2,0367.93	466.09	882.20
Before situation	43.7	78	37.8	1,2907.27	295.36	485.34
After situation			46.6	1,5858.82	362.90	416.11
Before situation	43.7	143	25.5	1,5973.53	365.53	1,065.75
After situation			33.5	2,0896.87	478.19	950.00

Table 5 shows the outputs of runoff retention index, runoff retention volume, and runoff volume (m3). Also, under selected different types of rainfall depths can be seen a high retention index rather than before the situation of Diyatha Uyana. The runoff retention index has been increased 7.1%, 6.9%, 8.7%, 8.0%, 8.8%, 7.9% corresponding to 232, 255, 88, 135, 78 and 143mm of rainfall depths respectively. Figure 7 and 8 represent the variation of the runoff volume (m3) and the runoff retention volume of the study area by the line charts separately.

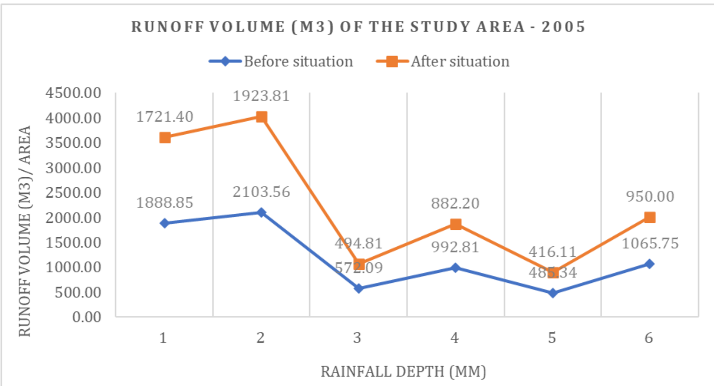

Figure 7: The capability of runoff retention under the same design storm event – 2005

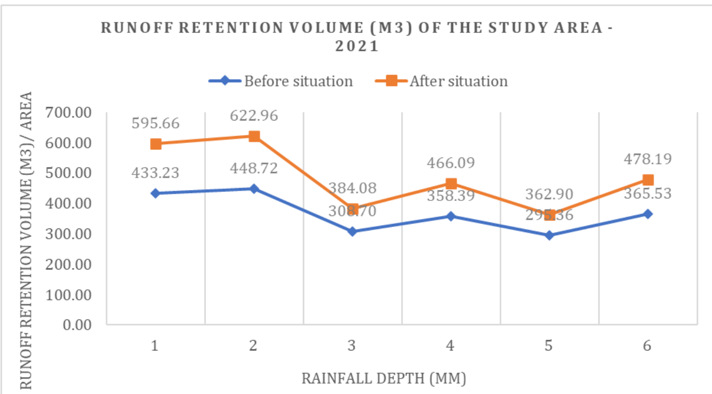

Figure 8: The capability of runoff retention under the same design storm event – 2021 (*Source: Compiled by author*)

4. Conclusion

By reviewing the literature, this study represents the first attempt to identify green infrastructure options as an urban resilience solution for SWM. A second attempt has focused on the InVEST-Urban Flood Risk Mitigation Model as a tool for the definition of adaptation planning strategies to cope with flash flood events due to extreme rainfall in an urban area. A comparative analysis was used to evaluate flash flood events at the watershed level after quantifying spatially direct runoff. Mainly, the estimated runoff has been considered from the land use and hydrological soil groups' raster maps. The model was performed twice by considering a single rainfall depth and different rainfall depths to determine runoff variation. Finally, the study area's runoff retention volume and volume were investigated using before-and-after scenarios.

After analyzing all the data sets, the key findings of this research can be elaborated. In the ‘Diyatha Uyana’ area can be identified green paths and alleys, natural marshy lands, and permeable pavements and surfaces can be identified as GI options. After establishing GI in this study area, it has the capability of reducing the impact of surface runoff to an insignificant level. Under the same rainfall depth (143 mm), it shows the variation: the runoff retention index has increased by 7.9% and the runoff volume has reduced to 115.75 m3, rather than before situation (2005) of the study area.

In this study, marshy lands and pastures show the high-water retention capability of the study area. But green paths and alleys and permeable pavements have a moderate level of ability for runoff retention. According to these analyses, only focusing on green infrastructure usage is not enough for urban areas to control storm water runoff. It is difficult to achieve with the limited space requirements in urban areas. Because if it wants to get good results from this, it should establish GI to a huge extent.

This research study relates to improving urban planning directly. According to the analysis, this study has demonstrated that green infrastructure can be used as an innovative method for storm water management in urban areas. As part of urban planning strategies, it can be activated as a flood mitigation element as well an urban heat controller. Investing in green infrastructure practices in urban areas will improve the quality of life and urban resilience (Yaella, D., 2021).

This study is basically focused on the capability of reducing the impact of surface runoff using Green Infrastructure. Moreover, it identifies that what are the Green Infrastructure options as an urban resilience solution for stormwater management in an urban area. But it is not discussed about the potential economic damage by overlaying data on flood extent potential and built infrastructure by this research. Therefore, future studies can be extended this research to examine the potential economic damage by overlaying data on flood extent potential and built infrastructure using the UFRM model (InVEST).

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