A GIS-BASED SIMULATION APPLICATION TO MODEL SURFACE RUNOFF LEVEL IN URBAN BLOCKS.

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Abstract

Simulation of flood inundation in urban areas longer important, given the magnitude of potential loss and disruption associated with non-river based, urban flooding. The complexity of the urban environment and lack of high-resolution topographic and hydrologic data compromise the development and implementation of models. Low impact development (LID) is technical know-how on a collection of sustainable practices that mimic natural hydrological functions including infiltration, evapotranspiration or use of surface runoff. Several studies have been carried out to discuss the impact of urbanization scenarios in reducing the urban flood risk in watershed scale in Sri Lanka. Yet, there is a gap remains in simulating the effectiveness of LID-based planning practices to reduce flood risk with the complex built form scenarios. In such a situation, this study attempts to make a significant contribution to simulate the variations of flood regulation functions under different high-intensive urban development scenarios, particularly focusing on the urban metropolitan regions. The analyses were carried out utilizing SWMM (Storm Water Management Model) which is open-source flood inundation simulation approach with the help of GIS in a more qualitative manner. The simulation results indicate that expanding built form scenarios increase the flood venerability for city functions, increasing inundation duration and LID scenarios able to reduce the surface runoff to reduce flood vulnerability at a significant level. The simulation results had been verified with the real ground situation (mean percentage change < 15.5%) which able to capture the thresholds of built form variation, as well as dynamic land uses and infrastructure supply which can be used as a tool for future planning practices and decision-making.

Keywords: Urban Floods; LID; GIS-based simulation; Built form

1. Introduction

Rapidly expanding urban areas predispose a huge challenge for making cities resilient to extreme weather events. Climate change has multiplied hydro-meteorological hazard events into 3,253 over the past decade (2005-2015), which was five times greater than the 743 catastrophes reported in the 1970s (WMO, 2015) (WMO, 2014) (UNDRR, 2015). Global climate change, i.e., changing rainfall patterns, increased rainfall intensity, high frequency of storms; may lead to serious urban storm water issues, including property damage, loss of lives, economic and neighbourhood impacts and perturbations to the ecosystem services as well (Chen, et al., 2017). Flash floods due to increasing urbanization pose huge challenges in urban planning for a sustainable future (Jayasinghe & Munasinghe , 2013), (Abenayake, et al., 2016). Accordingly, there is an increasing need to learn how to live with floods by mitigating their consequences, in the present and future because 55% of the world's population live in cities, and that will be risen up to 68% by 2050 by pushing down to a precipice majority of the urban population risk of urban floods (UN, 2019) (Reduction, 2018) . Limited-availability and validity of accurate methods to predict future and existing flood situation with urban expansion scenarios become a critical challenge for decision-makers and urban planners (Abenayake, et al., 2020).

Natural flood defence mechanisms perform a vital role in reducing the exposure to floods, particularly the expanse of inundation and the flood height as an ecosystem service (ES[1]) that reinforce community's resilience to flood (Abenayake, et al., 2018) (Ranjan & Abenayake, 2014).

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[1] "All the benefits people obtain from ecosystems" have been defined as ecosystem services

In a forested ecosystem, surface runoff is little as 10% of precipitation due to the functions of evaporation and infiltration (EPA, 2000). Unplanned urban developments, wetlands reclamation, removing vegetation cover and deforestation for developments; weakening natural flood defence mechanisms. For example, water holding capacity of a wetland (i.e., swamps, mangrove, marshes, paddy lands, forests) is four times higher than a river which can quickly absorb excess water and gradually release by the water retention and detention functions (USGS, 2015) (Shiklomanov, 1993). The global extent of natural wetlands declined by 30% between 1970 and 2008 (UNEP, 2015). Overall, the growth of built-up areas causes the cities in downstream to expose to floods six to eightfold higher than it would have been under the natural land cover (Morris, 2020). In cities the built-up areas cover the land with impermeable surfaces such as roads, buildings, pavements that affect the natural flood defence mechanisms, particularly, infiltration and surface runoff. A typical city with over three-fourth of impervious surfaces discharges 50% of the precipitation to water bodies which is five times higher than the discharge of a natural surface (Abenayake, et al., 2016) (Aswathanarayana, 2001).Within in this context, increasing the infiltration level has become an important way to reduce storm water runoff while minimising its negative impacts (refer figure 1).
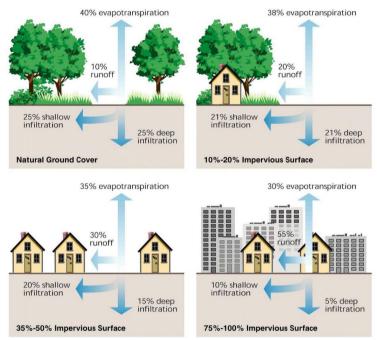

Figure 1: Effects of Imperviousness on Runoff and Infiltration
Source: (EPA, 2000).

There have been several sustainable building initiatives to reduce infiltration have been proposed globally as; water-sensitive urban design (WSUD) in Australia (Wong, 2006), (Wong & Eadie, 2000) , best management practices (BMPs) in the US and Canada (Field & Tafuri, 2006), sustainable drainage systems (SuDS) in the UK (Ashley, et al., 2015) (Stovin, et al., 2013), and Low Impact Development (LID) in the USA (EPA, 2000) to addresses the urban impact on flood regulating ESs. The LID approach has been recommended as an alternative to traditional storm water design. Some countries have already incorporated LID into urban planning regulations yet it demands more research works on popularising LID in making cities resilient (Dale & Saville, 2011) (Palla & Gnecco, 2015). In this milieu, the study is focused on research works related to the spatial simulations on the effectiveness of LIDs in reducing the fragility of natural flood defence mechanism.

Several studies have been carried out to discuss the impact of the urbanization scenarios in reducing the urban flood risk in watershed scale (Hu, et al., 2017) (Qin, et al., 2013); (Palla & Gnecco, 2015); (Zhang, et al., 2015). Moreover, rainfall-runoff, rational method, hydrograph method correlation studies, inlet methods which are outdated with accuracy and less technological

basis. Further, several urban inundation simulation models such as Mike Flood, PCSWMM2011, MOUSE GIS, Info Works ICM (Integrated Catchment Modeling), Flo-2D, and (EPA) Storm Water Management Model (SWMM), XP-SWMM used to simulate the impact of LID on hydrological aspects under flood mitigation (Wanniarachchi & Wijesekera, 2012) (Rossman, L. A, 2010). Most of them are commercial applications and the SWMM is free and open-source applications which used for urban flood simulations in this study. Understanding of the complexity of the urban land uses are essential planning practises (Jayasinghe, et al., 2015) and more case study based approaches are demanding in urban flood modelling in Sri Lankan urban context (Abenayake, et al., 2020). But none of those studies not considered the change of regulatory built form changers impact on urban flood situations and the compatibility of building regulations with projects under LID in Sri Lankan urban practices. Yet, there is a gap remains in simulating the effectiveness of LID-based planning and building regulations in building community resilience to flood. Hence, further studies are required to simulate the variations of flood regulation functions under different high-intensive urban development scenarios, particularly focusing on the urban metropolitan regions. This study is focused on assessing the effectiveness of alternative built-up scenarios along with LID-based solutions as a guide for decision-makers when determining flood-resilient built forms.

2. Method and Materials

2.1. SELECTION OF A CASE STUDY

The Colombo Municipal Council (CMC) area selected as the case study because, the major flood events occurred island-wide continuously, the highest number of affected people was reported from the Colombo district (DMC, 2018). The highest urbanization rate and highest number of flood affected population will lead the research to focus on CMC area. In CMC area 77.6 % (3/4th) of population lives in urban areas and the population density is 13,800 persons per sq.km having more than 92% covered by built-up coverage.
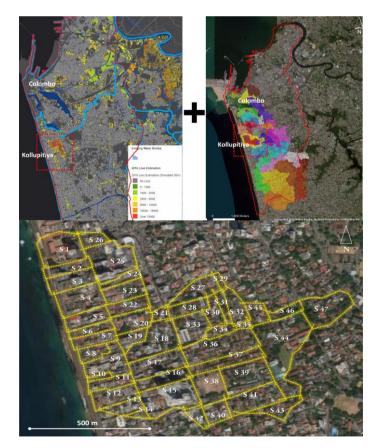

Figure 2: Selected study area
(a.) Past flood inundation areas (b.) Sub-watersheds in CMC and (c.) Selected study area.

First, the sub-watersheds have been identified using hydrology analysis using Arc GIS 10.3 (12 m resolution DEM - Alaska Satellite Facility: NASA Earth Data) in CMC. After dividing those main watersheds, into sub-watershed are considered the Floor Directions using Stream Network and Watershed Delineation in Spatial Analyst Hydrology Tools in Arc GIS 10.3. Next, refer the past flood data (i.e., 2010, 2016 and 2017) in CMC area which published by Center for Urban Water, Sri Lanka (CUrW) (Center for Urban Water, 2019) in order to identify the watershed with the highest number of affected population from urban floods. Further referred to the density zonation mechanism in 2030 Colombo Plan. After overlaying all the 03 maps, the case study area, the urban watershed will be identified for this research (Figure 2) which belongs to both high-density and low-density development zones by introduced density zonation the mechanism by 2030 Colombo Plan.

2.2. MODELLING SURFACE RUNOFF

In this study model the surface run off using the EPA SWMM (United States Environmental Protection Agency Storm Water Management Model) is a free and open access flood inundation model which can be used under deterministic modeling scenarios to simulate water inflows, outflows, and storages within a sub-catchment. Amongst urban stormwater modeling, EPA SWMM 5.1 has recorded a reliable outcome in model calibration and verification (Abenayake, et al., 2020) (Wanniarachchi & Wijesekera, 2012). This tool used by several location-specific applications in worldwide planning and urban flood analysis (i.e. CSO-LTC plans in Philadelphia, Cincinnati, Indianapolis, Seattle, city of New Haven, etc.) (EPA, 2010) (Chen, et al., 2017).

SWMM is governed by the conservation of mass and momentum Eq. (01) given below.

$$\frac{\partial Q}{\partial t} + gAS_f - 2V\frac{\partial A}{\partial t} - V^2\frac{\partial A}{\partial x} + gA\frac{\partial H}{\partial x} = 0 \tag{01}$$

Where,
Q = Discharge through the conduit
V= Velocity in the conduit
A= Cross-sectional area of the flow
H= Hydraulic head (invert elevation plus water depth)
Sf = Friction slope

The following hypostatical assumptions were made in model simulation by applying recorded peak rainfall for Colombo, Sri Lanka.

1. There are no inflows of stormwater occurred from outside to the selected sub-catchment area.
2. The selected study area consisted of the same soil type and the same permeability rate. The infiltration mode set as Green- Ampt for the simulation model.
3. 150 mm of dally rainfall used for model simulation because that is the benchmark rainfall to issued early warning for heavy rainfalls according to the Department of Meteorology, Sri Lanka.
4. Except for building footprints, all other remaining open areas are 100 percent permeable in the study area.
5. The entire drainage network has the same capacity everywhere.

2.3. SENARIO BUILDING

The main objective of this study was to simulate surface runoff under different built form scenarios and hypothetical LID scenarios to evaluate the change of surface runoff which can be developed as a decision-making tool in predicting flood situations.

2.3.1. The proposed regulatory built form scenarios

Plot coverage based on existing built-up surfaces was considered as the Business as Usual (BAU) Scenario (i.e., Scenario 1). The average existing built-up coverage is 54.8%. As per the future proposed plot coverage by development plans, three scenarios were opted as follows (Figure 3).

Table 1: Built form scenarios

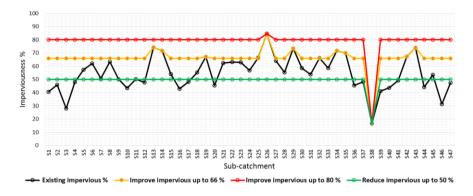| Scenario	Description
Scenario 1	Existing built-up (Existing impervious area) coverage
Scenario 2	If existing regulatory built up coverage increased up to 66% impervious.
Scenario 3	If existing regulatory built up coverage increased up to 80% impervious.
Scenario 4	If 50% of the regulatory open areas are converted to green.

Figure 3: Change of built-up coverage (imperviousness) under each scenario

The study area has been subdivided into 47 sub-catchments (Figure 2) based on the drainage network and the plot coverage. The change of imperviousness is illustrated in Figure 3 which describes four scenarios. 150 mm of daily average rainfall was distributed into hourly rainfall hypothetically; as a normal distribution of a bell-shaped line in the model simulation. The sub-catchment no. 38 was fixed in built-up coverage under each four scenarios because it consisted of an open- playground. The plot coverage regulations generally do not applicable to mandatory open spaces. Flood simulation model parameters and their variation ranges are presented in table 2.

Table 2: Key Model Parameters

Parameter	Units	Range	Parameter	Units/ type
Area	ha	0.2 - 4.6	Infiltration model	Green Ampt.
Imperviousness	%	16.7 - 84.7	Routing Model	Dynamic Wave
Rainfall	Inches	0 – 0.88	Conduit depth	Fixed as 2 feet
N-Imperv.	Manning's n	0.01 – 0.4	Conduit shape	Circular
Time step	Seconds	10	Elevation	Meters

Secondly, the model remodelled the flood levels under three hypothetical LID scenarios as follows;

1. If the surface runoff under scenario 1 to 4 is further decreased by 50% by applying rain garden as a LID strategy.
2. If the drainage capacity under scenario 1 to 4 can be improved then the level of capacity improvement required to make each zone a flood free environment.
3. If rainwater harvesting is possible to be implemented as a LID strategy then the percentage decrease of rainfall intensity is required to make each zone a flood free environment.

2.4. DATA ACQUISITION AND STUDY FRAMEWORK

Table 3: Data acquisition for the study

Purpose	Data requirement		Data source and details
Delineating sub-watersheds	Digital Elevation Map of the area (DEM)		Alaska Satellite Facility: NASA Earth Data
Run-off Modelling	Rainfall data	Intensity	Meteorological Department

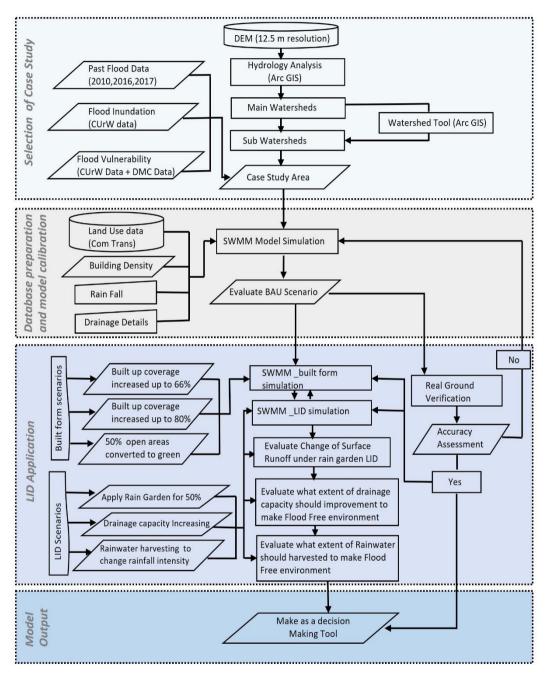|	Built form	Land uses Surface area Imperviousness	Survey Department of Sri Lanka
	Conduits (drainage network)	Names of inlets and outlet nodes Conduit length Manning's roughness Cross-sectional geometry	Website National Water Supply and Drainage Board

Figure 4: Study Framework

3. Analysis and Results

The main objective of this study was to simulate surface runoff under the BAU scenario (existing), three existing regulatory built form scenarios, and three hypothetical LID scenarios. Finally, verifying results in order to identify gaps if any and to statistically cross validate possible relationships between simulated results and measure flash flood heights.

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3.1. FLOOD SITUATION UNDER THE PROPOSED REGULATORY BUILTFORM SCENARIOS

As per the BAU scenario, the existing total runoff is 163.06 inches. Under the regulatory scenario 2 and 3, if imperviousness increased up to 66% and 80% then the total runoff will be increased by 19.1% and 38.6% respectively. Under the regulatory scenario 4, if imperviousness is reduced up to 50%, then the existing runoff can also be reduced by 7.3%. Figure 5 clearly illustrates, how surface runoff, drainage capacity and node flooding situation under four different scenario varies. Flood retaining duration also fluctuates when changing the plot coverage. With existing imperviousness flood occurring duration is1h:40 min. with 1.75 CFS (Cubic Feet-per Second) peak flood. If imperviousness increased as 66% and 80% flood remaining duration increased as 3h: 20min and 5h: 30min respectively, with making 3.25CFS and 6.5CFS peak flood. If reduced imperviousness by 50%, flood remaining only 3min with making 0.2CFS peak flood (Figure 6).
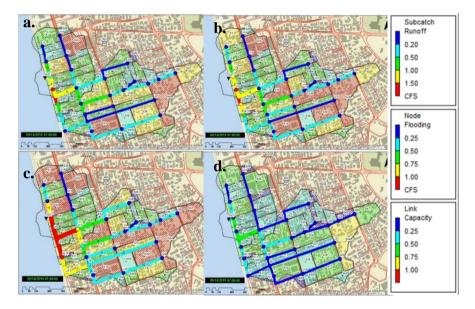

Figure 5: Runoff, node flooding and drainage capacity by changing imperviousness under scenario 1 to 4
Runoff, node flooding and drainage capacity; (a.) Scenario 1(BAS) (b.) Scenario 2 (c.) Scenario 3 (d.) Scenario 4
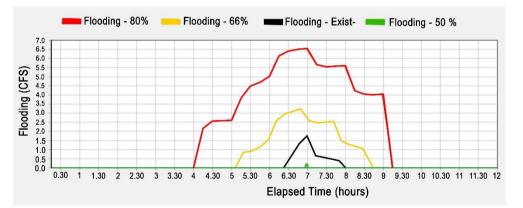

Figure 6: Duration of flooding the study area for scenarios 1 to 4
Flood retaining duration: 80% impervious (in red); 66% impervious (in yellow); existing imperviousness (in black); and 50% impervious (in green).

3.2. Flood situation under the hypothetical LID scenarios

The first LID approach simulated was to reduce surface runoff by introducing rain gardens. If 50% of the existing open area is converted into rain gardens as a LID strategy then the total runoff under scenario 1 can be minimized by 50% (81.5 inches). If the same option applied to scenario 2

and 3 then the total runoff will be decreased by 36.2% and 18.5% respectively. If the same LID strategy is applied under scenario 4, then the surface runoff can be reduced by 90.6%. Accordingly, if rain gardens were introduced, then there will be no flooding under scenario 1, 2 and 4. However, under scenario 3, there will be a minor flood of 14 min with 1 CFS flood during the peak hour (Figure 7).

Secondly, the LID was approached by assuming an improved drainage capacity. In order to make a flood free environment, the existing drainage capacity should be increased by 90%. If the plot coverage is increased by 66% and 80% (scenario 2 and 3) then the existing drainage capacity should be further increased by 120% and 135% respectively. Alternatively, if the plot coverage is reduced up to 50% as per the scenario 4, then the existing drainage capacity required a 50% improvement in order to make a flood free environment. Under all of the considered scenarios, drainage system need a major improvements where technical feasibility and cost-effectiveness should seriously be worked (Figure 8).

Thirdly, roof rainwater harvesting was assumed as the next possible LID strategy and the flood levels were remodelled under each scenario. In order to make a flood free environment, the roof rainwater harvesting systems should be installed with the capacity 52% of the total rain-fall under the scenario 1. If the imperviousness increasing by 66% and 80%, the rainfall intensity should be reduced by 67% and 78% respectively to make a flood free environment. If imperviousness reduced by 50%, the rainfall intensity should be reduced by 45% (Figure 7).
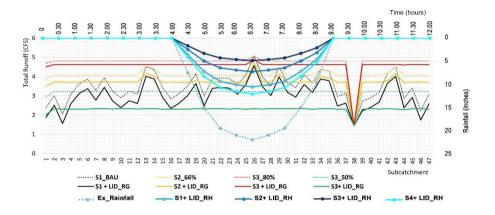

Figure 7 : LID scenarios; Rain Garden application and Rainwater Harvesting in study area.

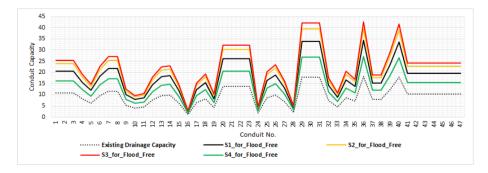*Note: RG= Rain Gardens | RH= Rainwater Harvesting*

Figure 8: LID scenario; Improving drainage capacity in study area

3.3 MODEL ACCURACY VALIDATION WITH THE REAL GROUND SITUATION.

SWMM application is suitable for applying micro-level study areas with high accuracy level. The ground verification carried out under two main sections; Flood height and inundation duration.

The simulation outcome (i.e., flood height and inundation duration) was cross validated with a community participatory flood mapping. The comparison of statistical summary of the community perception survey (n= 80). The BAU simulation results close-similar to each other (mean percentage change < 15.5% for flood height and inundation duration) and there is a probability to develop this model to get a more accurate result, as a tool of urban flood modelling. Moreover, this study attempts to develop three hypothetical LID scenarios to reduce the existing flood situation by introducing a rain garden LID option, increasing drainage capacity and changing rainfall intensity to make a flood-free environment as a tool for spatial planning and decision-making.

4. Conclusion

In general, urban built-up area expansion increases the risk of urban flooding and waterlogging. In such a situation this study develop an urban flood simulation framework with alternative built-form scenarios on urban flood situations and introduce LID practises to achieved disaster resilience city as the main objective. First, this paper analysed flood levels according to the existing built-up situation and three regulatory plot coverage scenarios. As per the three built-up coverage scenarios: 66%, 80% and 50%, the third scenario which simulate a situation where 50% of the land kept unbuilt is the best for making a flood free environment in the selected sub-watershed area. Nevertheless, Colombo has high land values and increasing demand for built-up areas. Hence, the proposed development plan has increased the plot coverage up to 66%- 80% in the existing and proposed urban development plans in Colombo. Unfortunately, this situation leads to severe urban flooding situation in future. Hence, this study has simulated three hypothetical LID scenarios (i.e., 50% open spaces converted to rain gardens, increasing drainage capacity and application of roof rainwater harvesting mechanism), to examine the effectiveness in controlling urban floods while optimising the plot coverage.

Most of the cities in developing countries faces flash flooding caused by extreme rainfall event and triggered by unplanned developments, lack of planning instruments to control the built form. Hence, this study attempts to introduce an innovative approach to simulate the impact of land-use and density zoning over surface runoff with hypostatical LID approach. This model is sensitive to future scenarios of population growth, uncontrolled urbanization (sprawl), changers of built form as an advanced regulatory tool for formulating development plans in order to make flood free environment in future. But this simulation approach has high accuracy with local or site level applications rather than large scale catchment areas (i.e., regional or national level). Further, the details of the entire drainage system are essential for model simulation as the limitation of this application.

The proposed simulation approach has contributed to a qualitative technological framework for pre-evaluate disaster risk assessment by consolidating spatial indicators with a set of changing parameters as a simple analysis tool. It has the ability to compute and alteration ranges of parameters of dynamic urban land use within the user-friendly environment and visualize it geospatially with their intensity level numerically, to make cities resilient. This approach capable of catering urban planner, policymakers, academics, and researchers who more concerned with urban sprawl benefited based on the results presented in this research as well as the ability to develop as a land-use policy planning and decision-making tool. Nevertheless, more case studies (i.e., different land uses, different terrain conditions, with different LID strategies, etc.) have to be carried out to increase the accuracy level of this application.

5. References

Abenayake, C., De Silva, K. & Mahanama, P., 2020. Rainwater Harvesting Innovations for Flood-Resilient Cities. *International Journal of Innovative Technology and Exploring Engineering (IJITEE),* 9(3S), pp. 13-18.
Abenayake, C., Mikami, Y., Matsuda, Y. & Jayasinghe, A., 2018. Ecosystem services-based composite indicator for assessing community resilience to floods. *Environmental development,* pp. 34-46.
Abenayake, C., M, Y., Marasinghe, A. & Takashi, Y., 2016. Applicability of Extra-Local Methods for AssessingCommunity Resilience to Disasters: A Case of Sri Lanka. *Journal of Environmental Assessment Policy and Management,* 18(2), pp. 1-33.
Anon., 2018. *State of Sri Lankan Cities,* Colombo: UN-Habitat.

Ashley, R. M. et al., 2015. UK Sustainable Drainage Systems: past, present and future. *Proceedings of ICE-Civil Engineering,* 168(3), pp. 125-130.

Aswathanarayana, U., 2001. *Water resources management and the environment.* s.l.:CRC Press.

Center for Urban Water, S. L., 2019. *Center for Urban Water, Sri Lanka.* [Online]
Available at: https://www.curwsl.org

Chen, Wenjie, Huang, G. & Zhang, H., 2017. Urban stormwater inundation simulation based on SWMM and diffusive overland-flow model. *Water Science & Technology,* 12(76), pp. 3392 - 3403.

Dale, S. & Saville, J., 2011. *The Compatibility of Building Regulations with Projects under New Low Impact Development and One Planet Development Planning Policies: Critical and Urgent Problems and the Need for a Workable Solution,* s.l.: s.n.

DMC, 2018. *Monsoon rains in Sri Lanka,* s.l.:
http://www.dmc.gov.lk/images/dmcreports/20180528_Sri_Lanka_Situation_Impact_1200hours_Final__1527495971.pdf.

EPA, 2000. *Environemntal Assessment,* Washington, DC: Environmental Protection Agency.

EPA, 2010. *Storm Water Management Model User's Manual — Version 5.0.* s.l.:Environmental Protection Agency.

Field, . R. & Tafuri, A. N., 2006. The use of best management practices (BMPs) in urban watersheds.. In: *The Use of Best Management Practices (BMPs).* s.l.:DEStech Publications.

Frenkel, A. & Ashkenazi, M., 2008. Measuring Urban Sprawl; How Can We Deal With It?. *Environment and Planning B Planning and Design,* pp. 1-30.

Hu, M. et al., 2017. Evaluation of lowimpact development approach for mitigating flood inundation at a watershed scale in China. *Journal of Environmental Management,* pp. 430-438.

Jayasinghe, A. et al., 2015. *Participatory GIS (PGIS) as a tool for Flood Mapping in climate change adaptation: a study of Batticaloa city, Sri Lanka.* s.l., s.n.

Jayasinghe, A. & Munasinghe , J., 2013. A study of the urbanizing pattern in Kegalle district, Sri Lanka with connectivity analysis. *International Journal of Scientific Knowledge,* Volume 2, pp. 2305-1493.

Mei, C. et al., 2018. Modelling the ability of source control measures to reduce inundatin risk in a community-scale urban drainage system. *International Association of Hydrological Sciences,* pp. 223-229.

Morris, G., 2020. Classification of Management Alternatives to Combat Reservoir Sedimentation. *Water,* p. 861.

Palla, A. & Gnecco, I., 2015. Hydrologic modeling of Low Impact Development systems at the urban catchment scale. *Journal of Hydrology,* pp. 361-368.

Puri, A., 2019. *Satellite Towns/ City and there objectives.* [Online]
Available at: https://abhipedia.abhimanu.com/Article/IAS/Mzk5MwEEQQVVEEQQVV/Satellite-Towns-City-and-there-Objectives-Geography-IAS#:~:text=Satellite%20town%2Fcity%20is%20a,the%20large%20city's%20planned%20expansion.

Qin, H., Li, Z. & Fu, G., 2013. The effects of low impact development on urban flooding under different rainfall characteristics. *Jornal of Environmental Management,* pp. 577-585.

Ranjan, E. S. & Abenayake, C. C., 2014. A study on community's perception on disaster resilience. *Procedia Economics and Finance,* Volume 18.

Reduction, U. -. U. N. O. f. D. R., 2018. *UN 20-year review: Earthquakes and tsunamis kill more people while climate change is driving up economic losses.* [Online]
Available at: https://www.unisdr.org/archive/61121

Rossman, L. A, 2010. *Storm Water Management Model User's Manual — Version 5.0.* s.l.:Environmental Protection Agency.

Shiklomanov, I., 1993. World fresh water resources. In: P. H. Gleick, ed. *Water in Crisis: A Guide to the World's Fresh Water Resources.* New York: Oxford University Press.

Stovin, et al., 2013. The potential to retrofit SuDS to address combined sewer overflow discharges in the Thames Tideway catchment. *Water and Environment Journal.,* 2(27), pp. 216-228.

Tsai, Y. H., 2005. Quantifying Urban Form: Compactness versus 'Sprawl'. *Urban Studies,* pp. 1-23.

UN, 2019. *World Urbanization Prospects ,* New York: United Nations .

UNDRR, U. N. I. S. f. D. R. R., 2015. *The Human Cost of Weather-Related Disasters 1995-2015.* [Online]
Available at: http://www.unisdr.org/files/46796_cop21weatherdisastersreport2015.pdf
[Accessed].

UNEP, 2015. *New wetland indicator reveals decline in global extent of natural wetland.* [Online]
Available at: https://www.unep-wcmc.org/news/new-wetland-indicator-reveals-decline-in-global-extent-of-natural-wetland
[Accessed 21 January 2016].

USGS, 2015. *United States Geological Survey.* [Online]
Available at: https://ks.water.usgs.gov/flood-definitions
[Accessed 12 March 2016].

Wanniarachchi, S. & Wijesekera, N., 2012. Using SWMM as a tool for floodplain management in ungauged urban watershed. *Engineer: Journal of the Institution of Engineers, Sri Lanka,* 45(1).

Wenjie Chen, Guoru Huang & Han Zhang, 2017. Urban stormwater inundation simulation based on SWMM and diffusive overland-flow model. *Water Science & Technology,* pp. 3392 - 3403.

WMO, 2014. *Atlas of mortality and economic losses from weather, climate and water extremes (1970–2012) ,* s.l.: World Meteorological Organization.

WMO, 2015. *Building Climate Resilience through Disaster Risk Reduction.* [Online]
Available at: https://public.wmo.int/en/resources/bulletin/building-climate-resilience-through-disaster-risk-reduction-0

Wong, T. H., 2006. An Overview of Water Sensitive Urban Design Practices in Australia. *Water Practice & Technology,* 1(1).

Wong, T. H. & Eadie, M. L., 2000. Water sensitive urban design: a paradigm shift in urban design.. *10th World Water Congress: Water, the Worlds Most Important Resource,* p. 1281.

Zhang, X., Guo, X. & Hu, M., 2015. Hydrological effect of typical low impact development approaches in a residential district. *Natural Hazards,* pp. 389-400.