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EVALUATION OF THE HYDRAULIC AND HYDROLOGY PERFORMANCE OF THE GREEN ROOF BY USING SWMM

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ABSTRACT

In the last few decades, urban flooding has been considered a serious and unavoidable problem for many cities worldwide. Climate change and rapid urbanization have contributed significantly to the increase in flood risk. To reduce the risk of floods, green roofs are one of the solutions to efficiently control rainwater. Within this work, the green roof was simulated by using the Storm Water Management Model (SWMM) with the Low Impact Development (LID) Controls module. This research aims to show the potential of green roofs for the reduction of peak flow and runoff; at the same time, the impact of vegetated roofs on drainage capacity is presented. Thus, the hydrology and hydraulic performance between extensive and intensive green roof types on the retention of storm water runoff are discussed.

Keywords: green roof, runoff, flood, surcharge, SWMM model

INTRODUCTION

Urban pluvial flood events in Algeria have significantly increased over the last two decades. This occurs when precipitation cannot be fully assimilated by a city's drainage system. Pluvial flash floods can cause significant material damage and claim lives (Hachemi et al., 2016, Cipola et al., 2016; Aroua; 2020; Hafnaoui et al., 2022). The expansion of urbanization has contributed significantly to the increase in flood risk. Forest and farmland are replaced by buildings, asphalt roads and commercial and industrial areas. These transitions have led to a rapid increase in impervious areas, and the natural hydrological cycle has changed greatly, such as a reduction in infiltration and evapotranspiration and an increase in runoff volumes. Climate change has also contributed substantially to the occurrence of urban floods. Moreover, flooding causes surcharging of manholes and pipes and may contaminate groundwater through infiltration and pollute receiving waters (Hamouz et al., 2020).

To reduce the risk of floods, green roofs are one of the solutions to efficiently control rainwater. Green roof practices are designed to capture surface runoff and provide some combination of detention, infiltration, and evapotranspiration (Rossman, 2022).

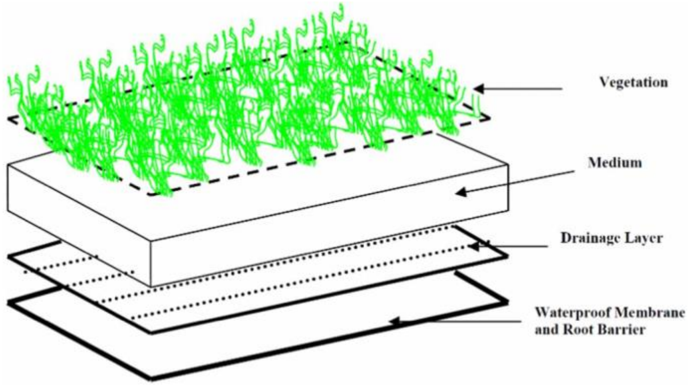


Figure 1: Conceptual model of green roofs (Aviva G et al., 2018)

Green roofs are becoming an alternative to impermeable roofs and aim to integrate the built infrastructure into the landscape and are made up of a vegetation layer, substrate layer and drainage layer (Fig. 1). Based on the thickness of the substrate layer, there are two types of green surfaces: extensive and intensive. The maximum depth of the substrate layer for extensive green roofs is 150 mm, but for intensive green roofs, it is more than 150 mm (Mentens et al., 2006).

A number of studies have proven that green roofs retain 40% to 80% of rainwater and thus can be considered a type of flood protection (Burszta et al., 2013).

Hamouz et al. (2020) showed from the PCSWMM model that the peak flow decreases when the area for green roofs increases. Stovin et al. (2015) found from experiments on nine green roof test beds that the retention efficiency was greater than 80% where the rainfall depth (P) was less than 10 mm but significantly lower when P > 10 mm. Ronja et al. (2021) used EPA SWMM to improve the representation of the coupled soil–vegetation system of green roofs. Mentens et al. (2006) assessed that rainfall-retention capability on a yearly basis may range from 75% for intensive green roofs to 45% for extensive green roofs. Additionally, the retention of rainwater on green roofs is lower in winter than in summer.

In this study, the green roof was simulated by using the Storm Water Management Model (SWMM) with the Low Impact Development (LID) Controls module (version 5.2.1). This paper aims to show the hydrology and hydraulic performance of green roofs in terms of the reduction in peak runoff and flow and the impact of vegetated roofs on the drainage capacity. Thus, the goal of this work is to compare the hydrology and hydraulic performance between extensive and intensive green roof types on the retention of storm water runoff. The numerical results obtained after the addition of green roofs are compared with computational results obtained without green roofs.

MATERIAL AND METHODS

City H'raik is located in Wilaya de Tlemcen. It is administratively attached to the municipality of Djebala, daira of Nedroma (Fig. 2). The sanitation network of the city of H'raik is unitary. The urban catchment surrounded by the circle (Fig. 3) is selected to assess the performance of a green roof on peak flow reduction. The portion of the combined drainage network corresponding to this catchment consisted of 15 combined pipes with a total length of 390 m and 15 junctions (DWR of Nedroma city, 2013).

The Storm Water Management Model (SWMM 5.2.1) is a dynamic rainfall–runoff model developed by the United States Environmental Protection Agency (EPA) for urban/suburban areas (Rossman, 2022). The SWMM is used for the simulation of water quantity, quality and LID controls in urban areas (Kourtis et al., 2018). LID controls include green roofs, bioretention cells, infiltration trenches, rain barrels, rooftop disconnection, rain gardens and porous pavements. The characteristics of the green roof applied in this work are presented in Table 1. Infiltration computations for the entire study area were based on the GREEN_AMPT method.

Fig. 3 shows the study area.

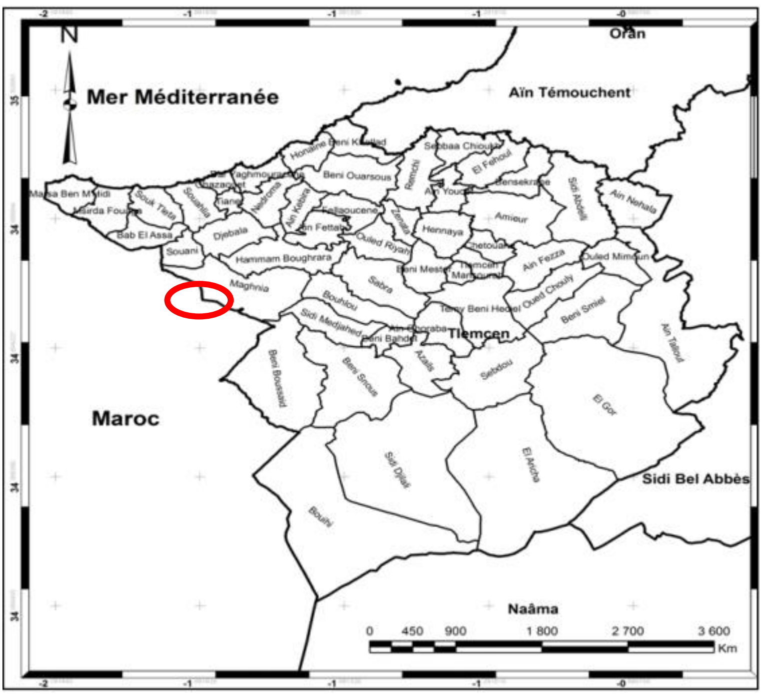


Figure 2: Location of the municipality of Djebala (surrounded by the circle) in Wilaya de Tlemcen (ONM 2018)

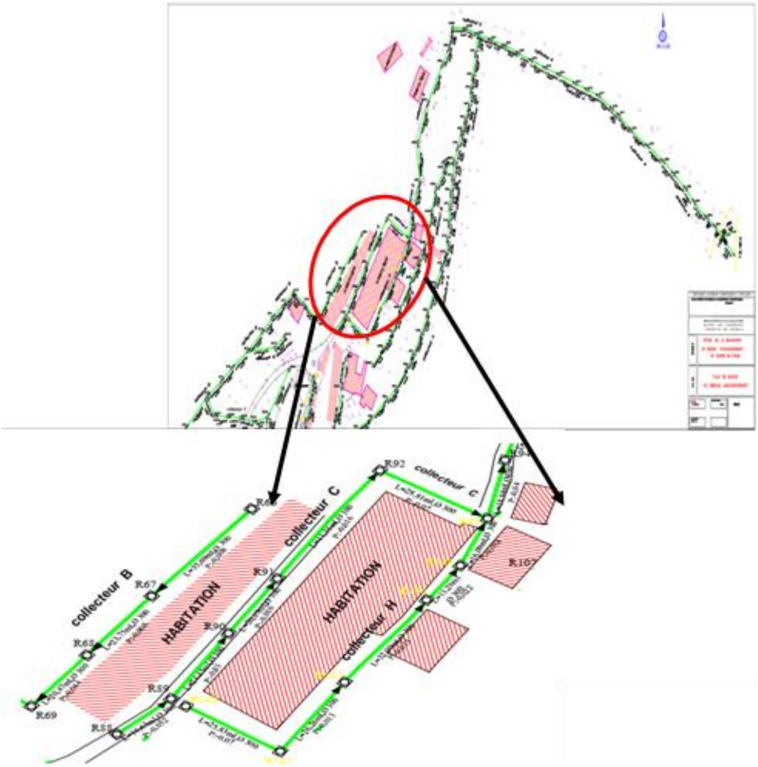


Figure 3: The ground plane of the study area (Direction of Water Resource of Nedroma City, 2013) SWMM model

Table 1: Parameters of green roofs in the storm water management model (SWMM) (Bay et al., 2019)

Surface	Berm Height (mm)	Vegetation Volume Fraction	Surface Roughness	Surface Slope (%)
	50	0.2	0.13	1
Soil	Thickness (mm)	Porosity	Field capacity	Wilting Point
	200	0.5	0.3	0.1
Drainage Mat	Thickness (mm)	Void fraction	Roughness	-
	60	0.43	0.03	-

The dynamic wave model was used for hydraulic calculation. The design storm used in our calculations is relative to an intensity duration frequency (IDF) curve for a return period of 10 years, and it is applicable in Algeria, as cited by Marc et al. (2010):

$$I = \frac{4}{\sqrt{t}} \tag{1}$$

where I = rainfall intensity (mm/min); t = rainfall duration (min)

Several sewerage networks in Tlemcen have been dimensioned using this formula, such as the sanitation network of the city Chetouane and Marsaa Ben M'hidi (Fandi and Benazza, 2017; Bensayah and Lekhel, 2017).

The study area of approximately 2.3 ha was divided into 13 subcatchments, defined as a function of land use and the surface slope (Fig. 4).

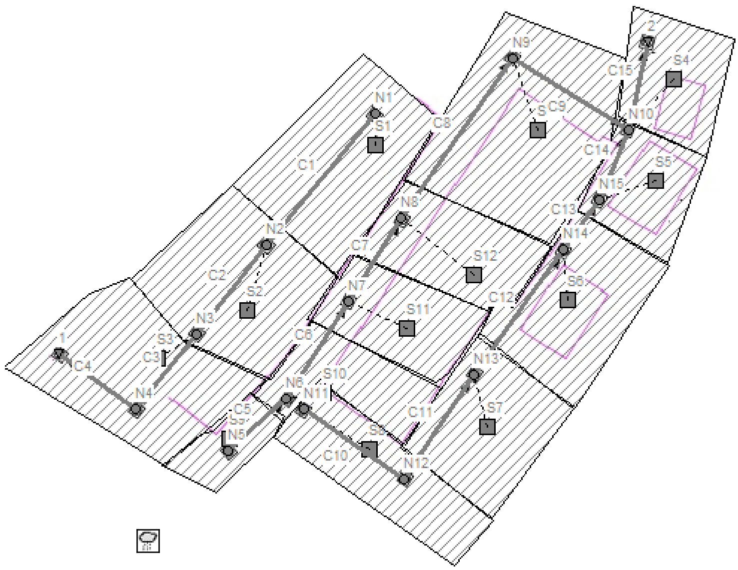


Figure 4: Division of the study area into subcatchments by SWMM

RESULTS AND DISCUSSION

To analyze the hydrological performance of LID control, the green roof was installed in the zone of habitation, and its mean roof surface was converted into a green roof.

Fig. 5 shows the longitudinal water surface profile between node N5 and the exit (outfall) before and after implementation of the green roofs. Fig. 5a displays how the surface of the water in manholes rises above the top of the sewer pipe, and the sewer is under pressure between node 9 and the exit. Due to the large volume of runoff during storm events, sewer pipes are surcharged. However, by converting the roof surface into a green roof, the combined drainage network is partially filled and can handle runoff (Fig. 5b).

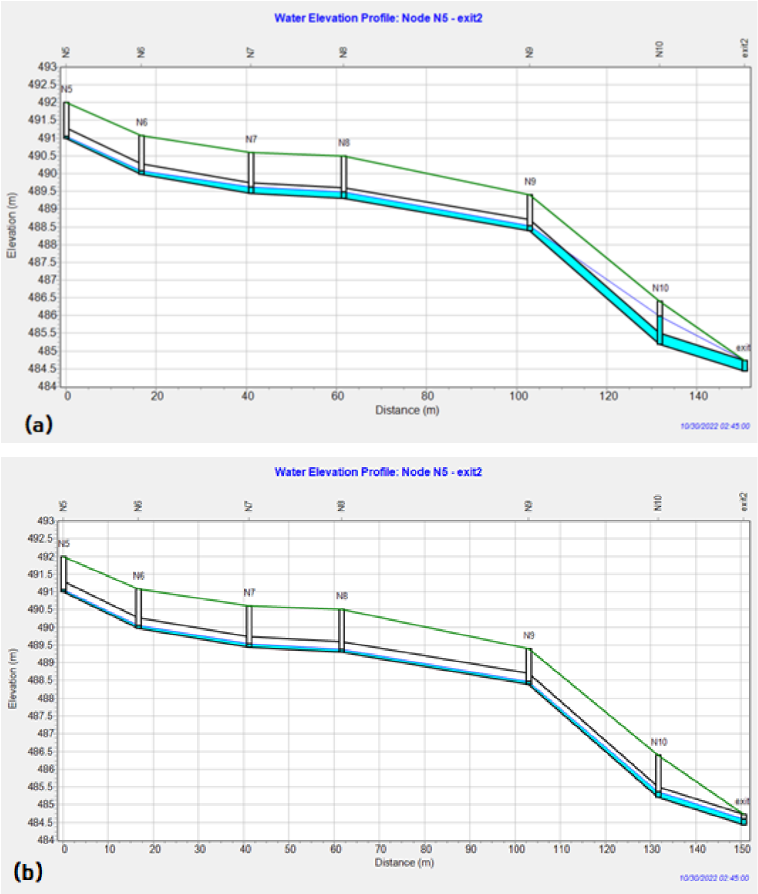


Figure 5: Longitudinal profile: (a) without a green roof, (b) with a green roof

Fig. 6 compares the total runoff before and after the addition of green roofs. This figure shows that green roofs are very efficient in reducing runoff in most subcatchments. The reduction is due to absorption of the water in the green roof system and through increasing evapotranspiration of water (Mentens et al., 2006).

It should be noted that SWMM calculates the physical evaporation rate but does not account for the biological transpiration of plants (Frauke and Jens 2020). Hörnschemeyer et al. (2019) and Frauke and Jens (2020) used the upgrade of the original SWMM version called SWMM-UrbanEVA. The SWMM-UrbanEVA was developed at the University of Applied Sciences Münster (Germany) to calculate evapotranspiration more precisely. Hörnschemeyer et al. (2019) found that the evapotranspiration rate changes by vegetation type and decreases during the winter months. Since the simulation is performed during precipitation in this study, evapotranspiration was ignored.

To study the effect of green roof type on the retention of storm water runoff, Fig. 7 illustrates the simulated peak runoff for extensive and intensive green roofs in subcatchments. This figure demonstrates that the abatement of peak runoff is more important in intensive roofs. From Fig. 8, the runoff reduction reached 92% for intensive green roofs, while for extensive green roofs, the maximum reduction was 67%.

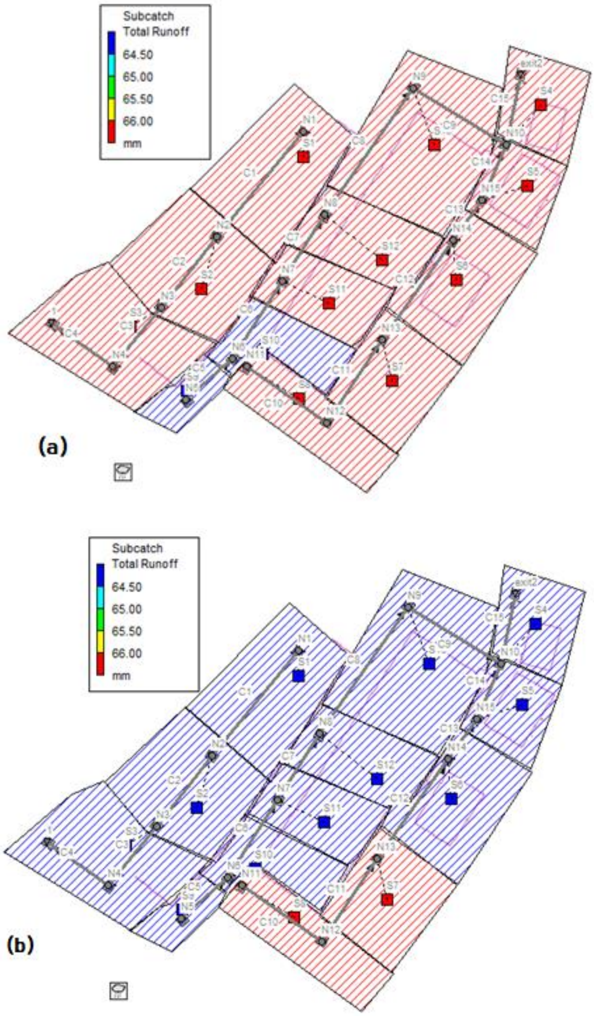
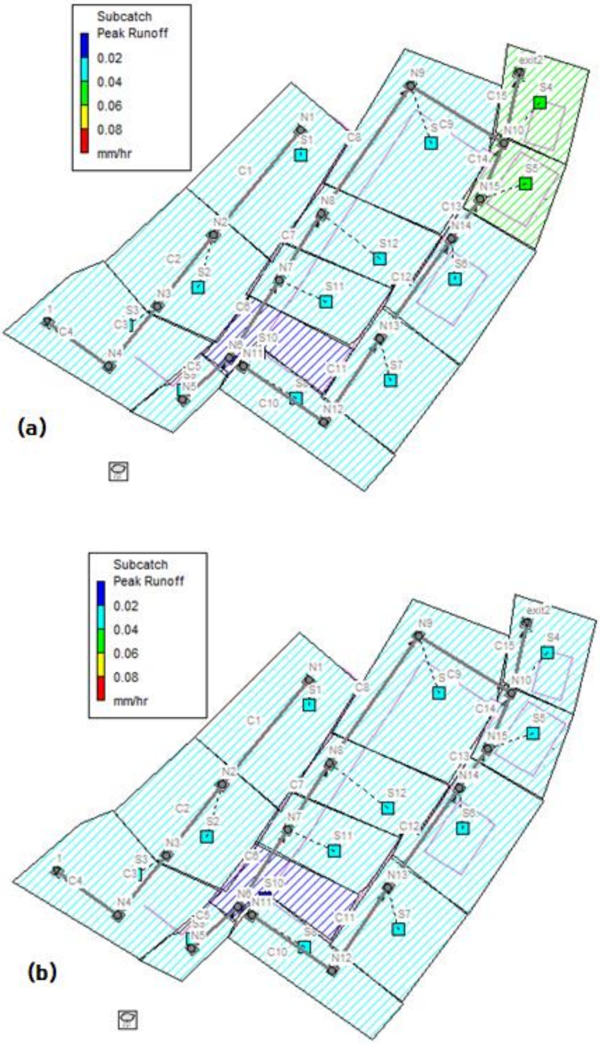


Figure 6: Total runoff: (a) without green roof, (b) with green roof


Subcatch
Peak Runoff
0.02
0.04
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Subcatch
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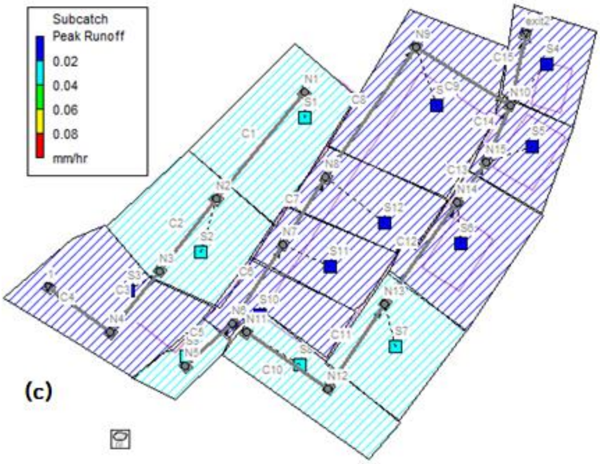

Figure 7: Peak runoff (a) without a green roof, (b) with an extensive green roof, and (c) with an intensive green roof.

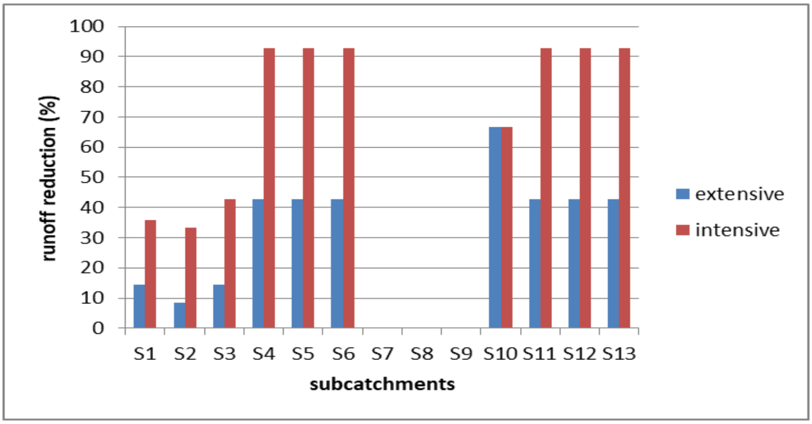

Figure 8: Comparison of runoff reduction between extensive green roofs and intensive green roofs

To affirm the priority of intensive green roofs on the decrease in runoff volume, Table 2 summarizes the flow reduction for various types of green roofs in pipes. Except for pipes C10, C11 and C12, where green roofs are not installed in the zones drained by these pipes, as seen from this table, the flow reduction attains 74.45% for intensive green roofs. However, for extensive green roofs, the maximum flow reduction is 31.95%.

Table 2: Flow reduction for intensive and extensive green roofs

	Without GR	Extensive green roof		Intensive green roof	
pipe	**Maximum flow (m^3/s)**	**Maximum flow (m^3/s)**	**Flow reduction (%)**	**Maximum flow (m^3/s)**	**Flow reduction (%)**
C1	0.034	0.032	17.24	0.027	20.58
C2	0.066	0.061	7.57	0.053	19.69
C3	0.083	0.077	7.23	0.067	19.27
C4	0.083	0.077	7.23	0.067	19.27
C5	0.023	0.02	13	0.02	13
C6	0.035	0.024	31.42	0.024	31.42
C7	0.07	0.05	28.57	0.027	61.42
C8	0.103	0.084	18.44	0.031	69.9
C9	0.137	0.118	13.87	0.035	74.45
C10	0.028	0.028	0	0.028	0
C11	0.028	0.028	0	0.028	0
C12	0.063	0.063	0	0.063	0
C13	0.097	0.066	31.95	0.066	31.95
C14	0.133	0.1	24.8	0.07	47.37
C15	0.305	0.251	17.7	0.108	64.6

CONCLUSION

Green roofs are becoming one of the solutions for reducing high runoff during rainfall. In this study, green roofs were simulated by the SWMM model. It was found that the green roof can eliminate the surcharging of manholes and pipes. The numerical results showed that green roofs are very efficient in reducing runoff in most subcatchments. It has been verified that the runoff reduction and maximum flow reduction with intensive green roofs reached 92% and 74.45%, respectively. However, for extensive green roofs, the reductions in runoff and peak flow reach 67% and 31.95%, respectively. The findings of this numerical study confirmed that intensive green roofs better mitigate peak runoff during rain events.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

AROUA N. (2020). Flood risk reduction strategy in Algiers, a brief modern history (XVIthC -XIXthC), Larhyss Journal, No 43, pp. 73-89.

AVIVA G.L., KRISTINE J.B.M., JONGRAK B., (2018). Assessing the significance of evapotranspiration in green roof modeling by SWMM, Journal of hydro informatics, Vol 20, No 3, pp 588–596.

BENSAYAH N.A., LEKEHAL I. (2017). The study of wastewater collection and treatment systems of the urban group of Tlemcen, Master hydraulics, university Abou Bakr Belkaid, Tlemcen, Algeria. (In French).

BURSZTA-ADAMIAK E., MROWIEC M. (2013). Modelling of green roofs' hydrologic performance using EPA's SWMM, Water Science & Technology, Vol. 68, No 1, pp.36-42.

BAI Y., YUHONG L.I., RUOYU Z., ZHAO N., XIAOFAN Z. (2019). Comprehensive Performance Evaluation System Based on Environmental and Economic Benefits for Optimal Allocation of LID Facilities, Water, Vol. 11, Issue 2.

CIPOLLA S.S., MAGLIONICO M., STOJKOV I. (2016). A long-term hydrological modelling of an extensive green roof by means of SWMM, Journal of Ecological Engineering, Vol. 95, pp. 876–887

DWR (Direction of Water Resource) (2013). Study of the construction of the sanitation network in the center of H'raik, Nedroma City, Themcen, Algeria.

FANDI H., BENAZZA F.Z. (2017). Simulation of a rainwater network using the Software swmm (storm water management model), Master hydraulic, University Abou Bakr Belkaid, Tlemcen, Algeria. (in French).

FRAUKE K., JENS T. (2020). Long-Term Modelling of an Agricultural and Urban River Catchment with SWMM Upgraded by the Evapotranspiration Model UrbanEVA, *Water*, Vol. 12, Issue11.

HACHEMI A., BENKHALED A. (2016). Flood-duration-frequency modelling, application to Wadi Abiod, Biskra (Algeria), Larhyss Journal, No 27, pp. 277-297.

HAFNAOUI M.A., MADI M., BEN SAID M., BENMALEK A. (2022). Floods in El Bayadh city: causes and factors, Larhyss Journal, No 51, pp. 97-113.

HAMOUZ V., PER M.P., TONE M.M. (2020). Modelling runoff reduction through implementation of green and gray roofs in urban catchments using PCSWMM, Urban Water Journal, Vol. 17, Issue 9, pp. 813-826,

HÖRNSCHEMEYER B., HENRICHS M., UHL M. (2019). Setting up a SWMM-integrated model for the evapotranspiration of urban vegetation, In Proceedings of the NOVATECH Lyon 2019, Lyon, France, 1–5 July 2019; pp. 1–4.

KOURTIS I.M., TSIHRINTZIS V.A., BALTAS E. (2018). Simulation of Low Impact Development (LID), Practices and Comparison with Conventional Drainage Solutions, Proceedings, Vol. 2, Issue 11.

MARC S., BECHIR S., REGIS B. (2010). Sanitation Technical Guide, Edition Moniteur, ISBN 978-2-281-11477-5. (In French)

MENTENS J., RAES D., HERMY M. (2006). Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landscape and Urban Plannig, Vol. 77, pp. 217–226

ONM (Algerian National Office of Meteorology). (2018). Downscaling and climate modeling with an application to forest management in Algeria. (In French)

ROSSMAN L.A., MICHELLE A.S. (2022). Storm Water Management Model User's Manual, version 5.2, Center for Environmental Solutions and Emergency Response, Office of Research and Development: Cincinnati, OH, USA,

RONJA I., KRISTIAN F., DANIEL W., MARÍA H.P., GILBERT L. (2021). Robust Vegetation Parameterization for Green Roofs in the EPA Stormwater Management Model (SWMM), Hydrology, Vol. 8, Issue 1.

STOVIN V., SIMON P., SIMON D.V., CHRISTIAN B. (2015). The influence of substrate and vegetation configuration on green roof hydrological performance, Ecological Engineering, Vol. 85, pp. 159-172.