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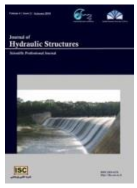

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Investigation of the Potential Threat of Urban Flood at Mountainous Areas through Low Impact Development Techniques (Case Study: Ardabil City)

Faryad Ebrahimi [1]
Atabak Feizi [2]
Taher Baher Talari [1]

Abstract

Mountainous areas are highly exposed to storm rainfalls due to the climate conditions in these regions. The current study mainly aimed to identify the channels and potential regions for inundation and flooding in Ardabil, a mountainous city in Iran, using molding capabilities of the SWMM software. Additionally, the functionality of low-impact development (LID) techniques in decreasing the floods of urban mountainous areas (Ardabil city) was investigated. In this research, the existing conditions in the study area, including the region's slope, the dimensions of the surface run-off collection channels, and the surface water disposal method, were evaluated by reviewing the existing reports and conducting field visits. To calibrate and validate the SWMM model outputs, the amount of rainfall and run-off height within the channels settled in the basin were field-measured during two storm rainfall events. In the current research, green roof, porous asphalt, infiltration trench, and rain barrel scenarios were applied as the LID techniques. In the section of single scenarios, a green roof was the most effective one reducing the run-off by 12%. In the combination of green roof and porous asphalt scenarios, the run-off water volume dropped by 19%. Finally, by combining all the LID techniques, a 30% decrease in the run-off volume was observed. This study also revealed that the use of LID techniques in combining scenarios is superior to the application of single scenarios. Meanwhile, a combination of two scenarios is preferred owing to the ease of implementation.

Keywords: Urban flood management, Surface run-off, Run-off management, SWMM, LID techniques.

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[1] Department of Civil Engineering, Faculty of Engineering, University of Mohaghegh Ardabili, Ardabil, Iran.
[2] Department of Civil Engineering, Faculty of Engineering, University of Mohaghegh Ardabili, Ardabil, Iran. Email: a_feizi@uma.ac.ir **(Corresponding Author)**

1. Introduction

Pavements and asphalted avenues are generally indispensable components of an urban system designed for fast discharge of run-off. However, over the recent years, short periods of heavy rain have occurred, which were almost out of the capability of urban systems' components [1]. A significant increase in surface run-off is due to the expansion of urban fabric and conversion of virgin areas to impermeable lands [2]. The volume of run-off naturally increases due to the expansion of urban areas and elimination of vegetation throughout an urban region [3]. The urban catchments mainly confront impermeable surfaces, which leads to the formation of short duration hydrographs with a high peak discharge rate and faster run-off. [4]. Nowadays, urban flood, as a result of global climate changes, population growth, urbanism, and incompatibility of drainage systems, has become a major issue which should be addressed [5]. Low-impact development (LID) techniques are suitable solutions for preventing these issues in the catchments. LID techniques have gained popularity over the past years owing to their applicability. Porous asphalt, garden streams, green roofs, and infiltration trenches are among the most applicable LID techniques [6]. These techniques preserve the natural water circulation system by converting the impermeable areas to urban permeable regions. They are also considered as suitable solutions to the problems faced in urban areas with a high population density [7]. Numerous researchers have worked on urban flood management, including the followings:

Beak et al. [8] assessed a new water quality module of the SWMM model for evaluating the LID techniques in urban watershed catchments. In their study, through the modification of the water quality module in the SWMM model, the performance of the enhanced module for stimulation of total suspended solids (TSS), Chemical Oxygen Demand (COD), total nitrogen (TN), and total phosphorus (TP) were evaluated. They reported that the modified module has a suitable efficiency. Chen et al. [9] investigated the effectiveness of LID techniques in the Jinan watershed catchment in China using the ArcGIS software and SWMM model. Their results indicated that the efficiency of the combined LIDs methods is more useful for controlling the peak discharge. Moreover, as the spatial scale increases, the effectiveness of combined LIDs gradually decreases. Hadi pour et al. [10] worked on LID techniques for reducing the effects of floods resulting from climate change. They concluded that porous asphalt did not significantly affect the drop in peak flow resulting from storm rainfall while bio-retention cell was more effective for withstanding the floods resulting from long-duration heavy rain. Hou et al. [11] ranked the optimized urban location priorities for LID techniques under different return periods. It was shown that the most suitable situations for implementing LID-BMP could be found in the regions where the soil moisture deficit occurs. Taghizade et al. [12] combined the SWMM model with Particle Swarm Optimization (PSO) to control the quality of urban run-off considering the LID techniques. The three methods of infiltration trenches, bio-retention cells, and porous asphalt were considered along with an urban drainage system. Their results revealed that the concentration of the total suspended solids (TSS), total phosphorus (TP), and total nitrogen (TN) respectively dropped by 97%, 68%, and 72%. Hassan Mohammad et al. [13] modeled the impacts of climate change and floods on the sanitary sewage system using the SWMM model. They reported that the normalized mean square error coefficients (NMSE) and R coefficient equaled 0.123 and 0.68, respectively. Meanwhile, the change in the return period from 2 to 25 years led to an increase in flood discharge from 2504 to 8868 cubic meters. Ben-daoud et al. [14] investigated the effect of a decrease in urban floods in an urban region using the LID technology. They showed that the combination of permeable asphalt and rain storage reduced the run-off by 57%, having the best performance among other scenarios. Nazari et al. [15] addressed the management of urban run-off in region 1, district 11 of Tehran Municipality with the approach of optimizing LID methods and combining

SWMM and SUSTAIN models. To this end, six scenarios of green roof, rain barrel, biological cell, Porous Pavement, Vegetated Swale, and dry pond with different combinations were utilized. They stated that the percentage of run-off reduction in scenarios 1 to 6 was 53%, 4%, 66%, 72%, 31%, and 34%, respectively. Yang et al. [16] worked on urban flood and its pollution due to climate change using LID methods. They applied the following three methods: green roof, porous asphalt, and infiltration trenches. Their results shed light on the volume of run-off, peak discharge, and pollution. Huang et al. [17] studied the optimization methods for LID techniques using a genetic algorithm. It was shown that combining the LID techniques for long-lasting simulations of 10 years contributes to the best result. This study also proved that the use of the genetic algorithm in combination with the SWMM model is highly beneficial for the evaluation of LID techniques.

He et al. [18] worked on the simulation of the LID techniques and their advantages in a mountainous area. Considering the obtained achievement and using four LID plans, the peak discharge of the run-off was lessened by 40%. Aghili Mahabadi et al. [19] determined the run-off values and prioritized LID methods in order to manage and reduce urban flooding in Sepahan-Shahr town of Isfahan. For this purpose, SWMM model, as well as TOPSIS and Fuzzy TOPSIS methods were used. The results showed that in the TOPSIS method and in the same weighting modes, the combined scenario of the rain barrel-bioretention system was selected as the appropriate scenario. In the Shannon entropy weighting mode, the rain barrel scenario was selected as the best one. Furthermore, in the Fuzzy TOPSIS method, the biological maintenance system scenario won the first rank. Zanjanian and Sarang [20] addressed quantitative and qualitative modeling of run-off in region of district No.10 of Tehran Municipality, through the use of LID methods. SWMM software was utilized for modeling. Their obtained results implied that the effectiveness of LID methods in reducing the decrease in qualitative parameters is more than that of the quantitative mode.

Ardabil city is located in the northeast of Iran. This city is geographically located in a mountainous area and is always exposed to severe storm rainfalls. According to the reports and field inspection of the area, channels, and public passages would confront numerous inundations. In this research, the central areas of the city which faced inundation were investigated using the urban flood management software (SWMM). We also evaluated the efficiency of the LID techniques in reducing the flood hazard potential in these mountainous areas. The result of this research can be used for mountainous areas with similar climate.

2. Materials and Methods

2.1. Study area

Ardabil is located in the $38° 14'$ N latitude and $48° 17'$ E longitude in Iran. The study area is a part of the Balikhly Chai watershed catchment in the center of Ardabil city. In Fig. 1 illustrates the geographical situation of Ardabil on Iran’s map and its restricting area along with the study area. The highest and lowest heights are 1353.23 and 1342.05 meters, respectively. The central part of the city was targeted to be investigated in terms of urban flood management during storm rainfalls due to the dense buildings, low vegetation, and virgin land, along with reports indicating the inundation of public passages.

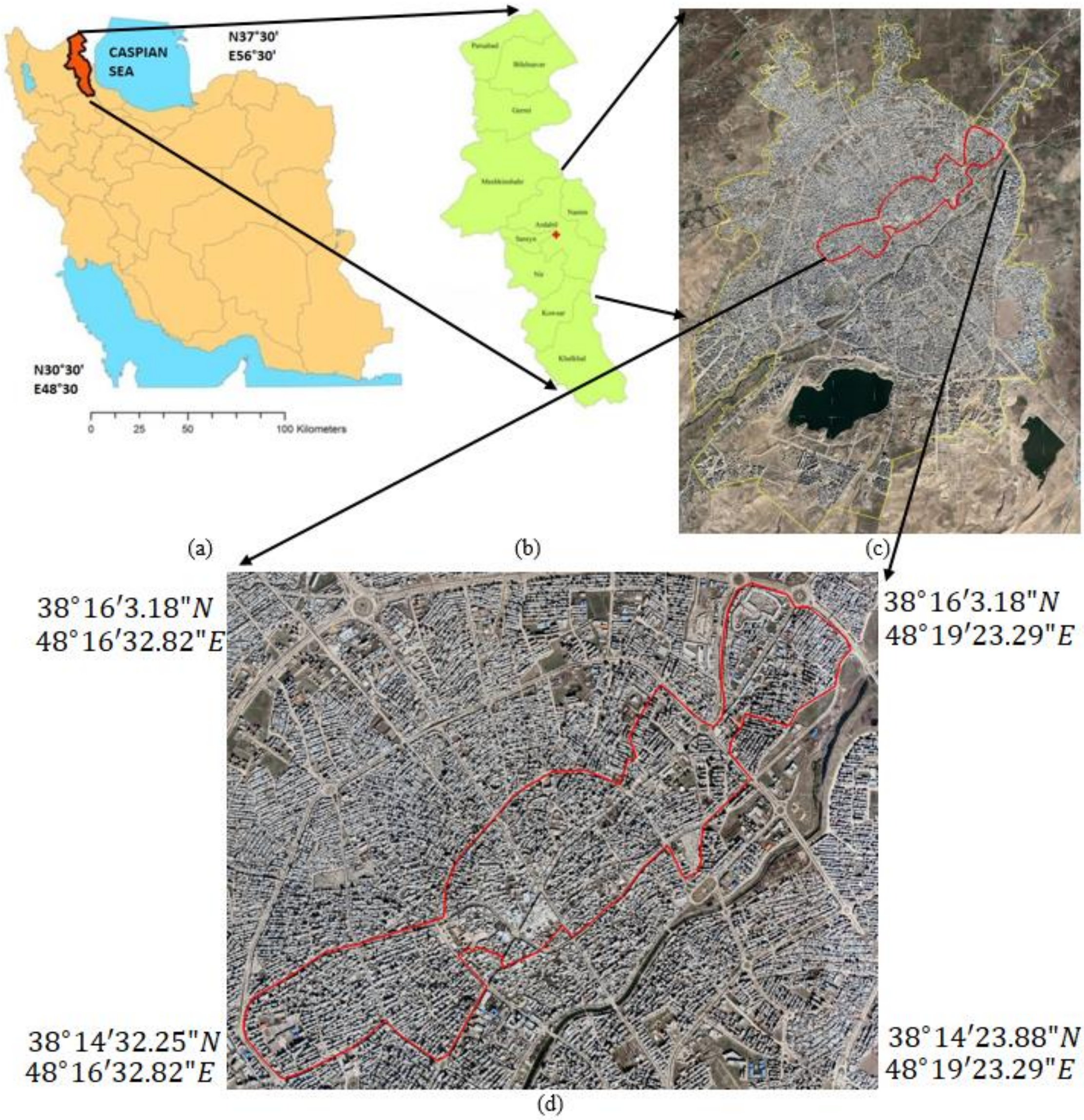


Figure. 1. (a): Iran; (b): Ardabil state; (c): Ardabil city; (d): Study area.

2.2. Necessary data collection

2.2.1. Physical characteristics of the study area

Fig. 2(a) illustrates the numerical model of the restricted study area obtained through the point maps. Each point consists of two geographical directions and one height direction achieved using an interpolation algorithm via the ArcGIS software. One of the significant factors in the movement system of surface water, is the surface slope of the basin. Sloping was performed through the ArcGIS capabilities along the surface of the basin. Fig. 2(b) depicts the slope of the area under study. We calculated the land use based on the comprehensive design plan of Ardabil city. In this research, the CN coefficient was utilized to consider the permeability.

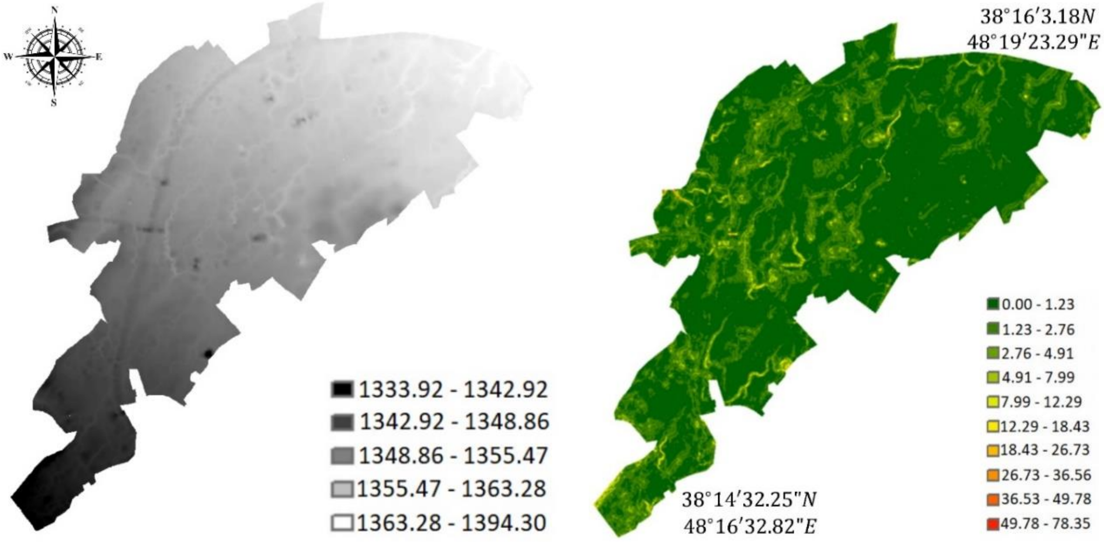


Figure. 2. (a): Topographical model in height direction (meter); (b): Slope of the region (%).

2.2.2. Classification of catchments in the study area

Considering the slope of the region and the river crossing the city (Balikhly Chai River), the majority of the channels distributed in the town overflow toward this river. Classification of the study area was done based on the elevation points and field visits. Regarding the slope of the region and based on the constructed channels in each region, the output of the catchment was considered as a unit point. Fig. 3 illustrates the basin division based on the slope and the constructed channels. Meanwhile, the dimension of the catchment channels was obtained in the field. The first and second exits that flow into the Balikhly Chai River and the Jandarmeri Junction, which is the location of the control elevation points in the canal, are marked in Fig. 3.

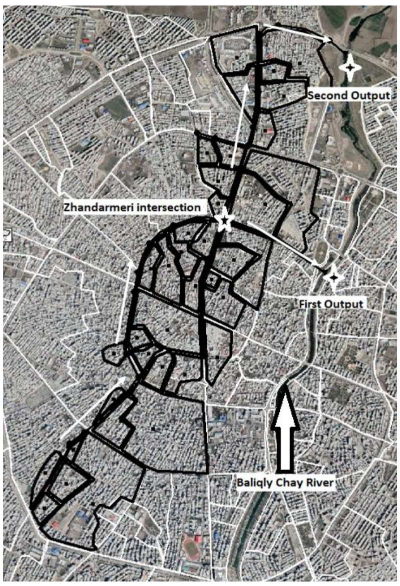


Figure. 3. Sub-basins and the movement of water through the channel.

2.2.3. Information about storm rainfall

The SWMM model utilizes several parameters as inputs. Therefore, it is necessary to access the storm rainfall information and water elevation in channels to calibrate the model.

In this regard, rainfall data related to the storm rainfall that occurred on 05-05-2021 in Ardabil were investigated via rain gauge (accuracy of ±0.5 mm).

Additionally, water elevation at duration periods of 2 minutes at channel No. 44, placed over the first outlet, was recorded using a gauge with an accuracy of ±1 mm (located at the Jandarmeri Square, Fig.3). Table 1 shows the height of precipitation in the rain gauge placed in the study area. The data were measured in the field with 2-minute intervals. The intensity-duration-frequency curve of Ardabil city was used for investigating the effects of different return periods on the intensity of rainfall in the studied area. Basically, storm rains mostly occur in a short time and with high intensity; accordingly, the intensity values of 15-minute rains were extracted from the intensity-duration-frequency curve, which are represented in Table 2.

Table 1. Storm rainfall data on date 05-05-2021

Duration(Hr)	Rain height(mm)
18:45	0.1
18:47	0.6
18:49	1
18:51	1.2
18:54	1.5
18:57	1.6
18:59	1.7
19:01	1.8
19:05	2
19:10	2.2

Table 2. Rainfall intensity of 15-minute lasting rain with different return periods (mm/hr)

Time(min)	2-year	5-year	10-year	25-year	50-year	100-year
0	0.555	0.833	1.023	1.444	1.667	1.887
2	1.110	4.669	1.996	2.865	3.336	3.785
4	1.665	2.499	3.025	4.332	5.010	5.668
6	2.223	3.332	4.089	5.776	6.669	7.558
8	2.775	4.165	5.123	7.223	8.336	9.443
10	3.338	4.996	6.187	8.664	10.003	11.337
12	3.886	5.831	6.998	10.108	11.669	13.226
14	4.448	6.663	8.032	11.552	13.335	15.112
16	4.996	7.497	9.103	12.996	15.003	17.001

2.3. The SWMM model and LID techniques

Herein, we employed the SWMM 5.1 software [21] for modeling the urban flood. This model is used to simulate the rain run-off hydrologic phenomenon, water quality, and hydraulic flow within the channels. It was developed by the environmental maintenance agency of the United States of America. This software can simulate a unique event or provide a long-lasting simulation and surface and underground modeling. In addition to the quantitative modeling (run-off volume), this software is capable of quality simulation (run-off quality). Using this model, it is possible to simulate a generation of pollution and a decrease in the pollution in catchments. In this research, the software mentioned above was utilized for simulating the urban flood in Ardabil city.

LID methods are novel techniques to prevent the flow of surface run-off on the surface of basins. These methods aim to mimic and preserve the inherent hydrologic characteristics of developing sites or regions. The aforementioned techniques are multi-purpose approaches to reviewing the urban developments along with expanding the previous ones. Green roof, porous asphalt, infiltration trenches, and rain storage are among the methods used in this research as the LID techniques.

2.4. The LID Techniques

LIDs are one of the most practical methods in flood management in developing urban areas. These methods provide conditions for better flood management through the use of hydrological recovery and the natural conditions of the basin. Furthermore, low-impact development methods, by using natural and artificial conditions in the basin, significantly reduce the amount of flow and the volume of run-off. There are several types of low-impact development methods used in this project: green roof, rain barrel, porous asphalt and infiltration trench. [22, 23]

Green roof

A roof partially or entirely covered with soil and green plants is called a green roof. Plants will grow on the surface of green roofs and can be used in green roofs that are tough and resistant to storms, freezing and lack of water.

Rain barrel

Rain barrels include a number of conventional barrels with a similar approach to flood control tanks. The rain barrel stores the run-off collected from the roof and is indirectly effective in reducing the hydrograph peak and peak discharge volume.

Porous asphalt

Asphalt mixture with discrete granulation and having approximately 20% empty space is called porous asphalt. The available empty space creates a network of currents in the asphalt mixture, which directs the rain towards the sides of the main road when it rains and infiltrates the asphalt.

Infiltration trench

Infiltration trenches are long and narrow trenches made with coarse particles and pieces of stones. The surface sewage entering this system is temporarily stored in the space between the stones and gradually seeps into the soil through the floor and walls. These trenches can be used on sidewalks, around streets and highways, public places with high traffic and in parking lots.

2.5. Procedure for evaluation of the model

In the current work, Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Relative Error (RE) were applied using Eq. 1 to Eq. 3, respectively.

$$MAE = \frac{\sum_{i=1}^{n} \left| F_{t_i} - F_{e_i} \right|}{n} \tag{1}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left(F_{t_i} - F_{e_i} \right)^2}{n}} \tag{2}$$

$$RE\% = \frac{\sum_{i=1}^{N} \left| \left(Ft_i - Fe_i \right) \right|}{\sum_{i=1}^{N} Ft_i} * 100 \tag{3}$$

where F_{ei} represents the observed values, F_{ti} shows the simulated value, and n denotes the number of observations.

In these equations, as the values of MAE, RMSE, and RE coefficients approach zero, the efficiency of the model and the appropriate correlation between observational and simulation parameters are revealed.

3. Results and Discussion

In the present study, various scenarios were defined in order to decrease the flood volume in different return periods of rainfall in urban mountainous areas. The procedure began with investigating the existing situation of the area under study, as the first scenario. Afterwards, five LID techniques were utilized for urban flood reduction: roof garden, porous asphalt, rain storage, stream garden, and rain-storage gardens.

Initially, each of the aforementioned methods was applied to the model under a single scenario, and the results of the scenario in flood reduction were evaluated. Subsequently, two of the best single scenarios were combined and finally, all the scenarios were applied as a combined scenario.

3.1. Calibration and validation of the model

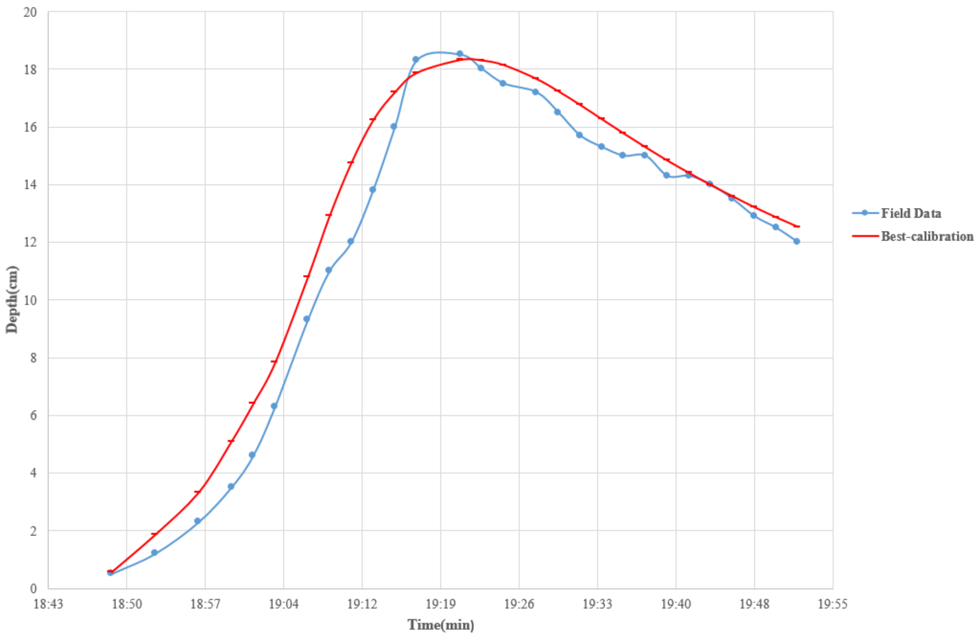
In this study, the following parameters were calibrated: Manning’s roughness coefficient for channels, manning’s for impervious area, depth of depression storage on the impervious area, depth of depression on the previous area, and finally, percentage of the impervious area with no depression storage. Table 3 presents the final calibrated coefficients for the SWMM model. In addition, to validate the model, storm rainfall data and water elevation in Jandarmeri Junction Channel on 27-07-2021 were recorded and the parameters obtained in the calibration step were thus subjected to validation. Fig. 4(a) illustrates the final calibrated picture. As per the conducted calibration, the values of RE, RMSE, and MAE parameters were 12.44, 0.166, and 0.031, respectively. Referring to Fig. 4(b) and Table 4 (evaluation parameters), it is observed that the constructed model properly simulates the storm rainfall.

Table 3. Obtained coefficients for the SWMM model parameters in the study area at the calibration stage

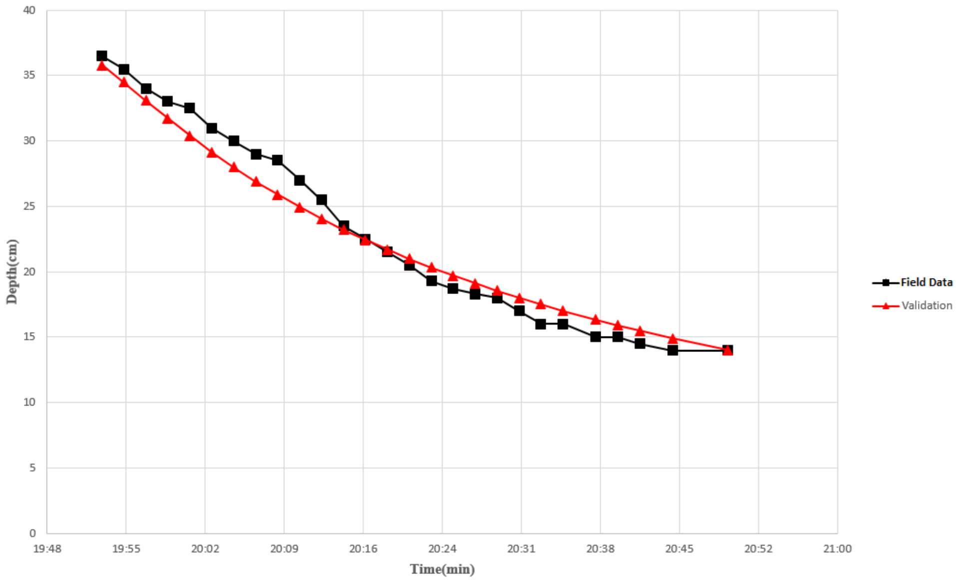
Coefficients	Parameters
Manning's roughness coefficient	0.010
Manning's n for impervious area	0.013
Manning's n for previous area	0.13
Depth of depression storage on impervious area	0.07
Depth of depression storage on previous area	0.3
Percent of impervious area with no depression storage	25

Table 4. Evaluation parameters' values and accuracy of the model in the validation stage

RE%	RMSE	MAE	CC
4.944443	0.2155441	0.041481481	0.99325



(a)



(b)

Figure. 4. Results of modeling the region at outlet point No. (1): (a) Calibration stage; (b) Validation Stage.

3.2. Flood simulation considering the existing situation under rainfall with various return periods

In this paper, the existing conditions in the study area were evaluated and sub-basins and channels with a potential of flood at the catchment were identified under various return periods. Table 5 shows the results of the run-off in the study area, considering different return periods, but without using LIDs. As seen, with the increase in the return period, the output run-off also rises.

Table 5. Results of the model with regard to the existing situation of the study area

Return period	Number of inundated channels	Number of inundated sub-basins	Total hours of channels' inundation status	Run-off volume in outlet 1 (10^6 lit)	Run-off volume in outlet 2 (10^6 lit)
2-year	10	0	8:46	4.285	4.691
5-year	13	3	11:21	4.493	4.887
10-year	17	3	13:09	4.608	4.975
25-year	22	7	15:31	4.708	5.084
50-year	25	7	17:40	4.802	5.145
100-year	27	10	19:21	4.833	5.168

3.3. Flood simulation by applying single scenarios pair of LID techniques

In this study, each bulk of the stored rain had an approximate volume of 2 to 3 cubic meters and it was feasible to increase the number of this storage in each building. The rain barrel decreased the run-off volume of the two existing outlets in the surface of the basin by roughly 2 to 3%. The dimensions of the green roofs varied depending on the situation. In this research, an area of about 100 square meters was considered for each roof. Green roof lessened by about 12 to 14% of the output run-off for various return periods. Infiltration trenches were not of specific dimensions; thus, they can be implemented in any target place. Therefore, they are highly applicable for small places with a high rate of communication. Infiltration trenches resulted in a 6 to 7% drop in output run-off for different return periods. Porous asphalt is among the best LID techniques. This technique is the best fit for the urban basins owing to the large area of main streets and pavements. Herein, the main streets of the studied region were considered for applying the porous asphalt method. The output run-off in the study area was lowered by about 8 to 11% for various return periods.

Table 6 represents the run-off values of the single scenarios from the study area considering different return periods as well as LIDs. In the current paper, rain barrel scenarios, porous asphalt, green roof, and infiltration trench scenarios were separately applied to the model. The obtained results show that in all the return periods, the amount of outgoing run-off decreases whereas the impact of LIDs on reducing the amount of outgoing run-off is greater in the short-term return period compared to that in the long-term one. According to the obtained results, among the single scenarios, the most significant impact on flood reduction in all the return periods belonged to the green roof scenario. Fig. 5 illustrates the efficiency of the green roof technique in flood reduction in the study area. Green roof was ranked as the top method in terms of efficiency. According to the results, green roof, porous asphalt, infiltration trench, and rain barrel were the most effective methods in reducing run-off, respectively.

Table 6. Results of applying single-scenario LID techniques

Scenario	Return period	No. of inundated Channels	No. of inundated sub-basins	Total hours of flood status in channels	Decrease in hours a channel is engaged with flood (%)	Drop of run-off volume in outlet 1 (%)	Drop of run-off volume in outlet 2 (%)
First scenario (rain barrel)	2 year	10	0	8:30	3.40	1.003	4.10
	5 year	13	3	11:02	2.79	0.91	4.08
	10 year	17	3	12:38	1.97	0.88	3.94
	25 year	21	6	15:20	1.02	0.871	3.89
	50 year	25	7	17:32	0.78	0.85	3.52
	100 year	26	9	19:17	0.35	0.84	3.41
Second scenario (porous asphalt)	2 year	10	0	7:12	18.18	10.96	9.48
	5 year	13	2	9:26	17.78	10.26	9.26
	10 year	15	3	10:48	16.88	9.89	9.16
	25 year	21	5	13:05	15.68	9.38	8.73

	50 year	24	7	15:31	12.16	9.43	8.62
	100 year	26	8	17:11	10.19	9.37	8.32
Third scenario (green roof)	2 year	10	0	6:17	28.48	13.30	13.70
	5 year	13	0	8:23	26.11	12.57	13.38
	10 year	15	3	10:05	23.31	12.26	13.10
	25 year	21	4	12:10	21.56	11.85	12.90
	50 year	24	5	14:14	19.41	11.68	12.76
	100 year	26	7	16:12	16.25	11.46	12.48
Fourth scenario (infiltration trench)	2 year	10	0	8:07	7.76	5.32	7.61
	5 year	13	3	10:34	6.9	5.09	7.55
	10 year	15	3	11:48	6.12	4.96	7.53
	25 year	22	6	14:37	5.8	4.92	7.47
	50 year	25	7	16:37	5.23	4.83	7.46
	100 year	27	8	18:24	4.90	4.77	7.44

(a) **(b)**

Figure. 5. Comparison of the decrease in the inundated basins and channels for the return period of 25 years in two statuses: (a) Applying green roof scenario; (b) The existing situation in the study area.

3.4. Flood simulation by applying pair and combined scenarios of LID techniques

Given the results in Table 6, green roof and porous asphalt indicated the best impact on run-off reduction as single scenarios. In this regard, aggregation of these two methods was applied as a pair scenario (scenario No. 5). Afterwards, another scenario (No. 6), as the combination of the whole LID methods, was defined and investigated. Table 7 represents the results of the pair scenario and combined one. Fig. 6 shows the ability of the sixth scenario to reduce run-off in the 25-year return period.

As per achieved outcomes for the single scenarios, green roof and porous asphalt played the most important roles in run-off reduction. By combining these two scenarios, a pair scenario was created. The pair scenario's effect on the output run-off was about 17 to 20% for various return periods. Each of the LID scenarios indicated a desirable effect on the reduction of output run-off and the combination of all these methods resulted in a very suitable achievement. The combination of the rain barrel, infiltration trench, porous asphalt, and green roof resulted in an output run-off reduction of about 28 to 33% for various return periods.

According to the obtained results in this research and comparing them with the results reported by He et al. [17], a combination of green roof, permeable asphalt, rain barrel, and infiltration trench techniques could successfully reduce the run-off volume in mountainous areas. Hence, in this study, in the combined scenario, up to 33% of reduction in run-off was created. Nazari et al. [15] also reached the conclusion that the single use of LID methods was less effective in reducing urban flooding. Also, the combination of all LID methods was not sufficiently effective. Therefore, the best performance of LID methods in reducing runoff was between the two states mentioned above, which is in line with the results of the present study.

Table 7. Results of the pair and combined scenarios

Scenario	Return period	No. of inundated Channels	No. of inundated sub-basins	Total hours of flood status in channels	Decrease in hours a channel is engaged with flood (%)	Drop of run off volume in outlet 1 (%)	Drop of run off volume in outlet 2 (%)
Fifth scenario (porous asphalt and green roof)	2 year	9	0	5:20	39.39	20.53	18.54
	5 year	11	0	7:10	36.85	19.16	18.08
	10 year	13	3	8:47	35.20	18.51	17.62
	25 year	13	3	9:48	33.84	17.90	17.19
	50 year	18	4	11:44	33.58	17.61	16.94
	100 year	19	7	12:43	28.32	17.35	16.83
Sixth scenario (rain barrel, green roof, porous asphalt, infiltration trench)	2 year	5	0	3:10	64.01	33.72	30.59
	5 year	10	0	5:11	54.33	32.31	29.36
	10 year	10	0	6:05	53.73	31.53	28.18
	25 year	12	1	7:26	52.09	30.80	27.60
	50 year	13	3	8:16	51.23	30.30	27.30
	100 year	16	4	9:26	50.24	30.03	27.10

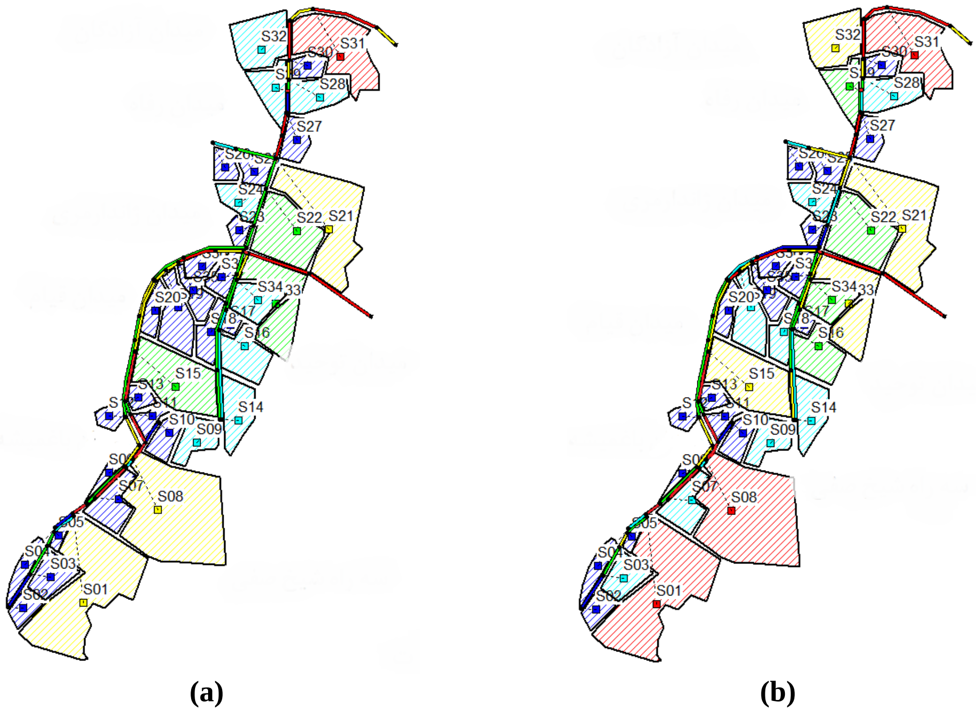


Figure. 6. Comparing the decrease in the inundated basins and channels for the return period of 25 years in two statuses: (a) Combined scenario; (b): Pair scenario.

4. Conclusions

The city of Ardabil is subjected to inundation in passages and streets as a result of most storm rainfalls since it has a high density of buildings and insufficient green environment while being mountainous. In the present work, the study area was Ardabil city center. By investigating the distributed channels in the city, it was concluded that the existing underground channels along the pass ways were completely subjected to flood during rains. Since the city is located in a central location, it is not possible to expand the channels. Thus, LID techniques could be recommended. In this research, LID methods, including green roof, rain barrel, infiltration trench, and porous asphalt, were implemented in the determined part of the city center.

One of the advantages of a rain barrel is that run-off can be exploited. However, this method is hard to implement for all residential buildings and the run-off reduction percentage is low. Hence, it is not recommended, particularly in regions with cold weather due to the probability of freezing. On the other hand, infiltration trench can be performed in any place, even the small ones. Nonetheless, this method is hard to implement and has a low capacity for run-off storage. Green roof is the best method for run-off reduction and efforts should be made to motivate owners to perform it. Therefore, single scenarios are not recommended for mountainous areas. In this regard, pair scenarios and even combined scenarios (of more than two LID techniques) could be more effective. The results obtained herein demonstrated that applying pair scenarios (green roof and porous asphalt), there would be an urban run-off reduction of approximately 22%. If all of the aforementioned methods are aggregated, the reduction percentage increases to 33%. the Pair scenario is highly recommended since its implementation is more cost-effective in these regions.

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