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Analysis of the Sensitivity of the Variables Affecting Urban Flood through Two Rational and SWMM Methods by SSA

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ABSTRACT

Today, in every corner of the world, management and collection of surface water and urban floods, which are among the hydrological and hydraulic processes, are of high importance. Precision of the simulator models output of these processes is dependent on the precise determination of the input model parameters This study examines the sensitivity analysis of the input variables SWMM model in order to accelerate economic and engineering calculations in the design of surface runoff collection and conductivity system of industrial town of Kavian in the margin of Mashhad-Freeman road in Freeman. It was found that the model is very sensitive to the roughness coefficient parameter of the impermeable areas (Nimp), sensitive to the parameters of the slope (S) and equivalent width of the basin (Eqw), and is less sensitive to the parameters of impermeable areas (Imp%), depth of the surface storage of permeability and impermeable (Dp, Dimp). Finally, it was concluded that small change in the estimation of sensitive parameter imposed immense cost on the project cost. Typically, 15% and 30% reduction in roughness coefficient of the impermeable areas resulted in the imposition of 6.8 and 8.8 percent of an additional charge on the project executives.
Keywords
Sensitivity analysis- SWMM-Rational method- SSA

INTRODUCTION

Surface runoff from the rainfall is a part of the atmospheric precipitation that flows during rain or shortly after the completion of rain on the ground. The task of collection surface water networks is to collect, transmit, and conduct surface water to the nearest acceptable exit point. All of these tasks should be done at the right time and with the least damage and inconvenience. Today, in addition to the discharge of surface water from the city that is considered as one of the first requirements of a city, doing any other urban project, such as bridges, airports, highways, power plants, buildings, roads, and so forth are practically useless, expensive, time-consuming and non-economic regardless of flood risks in urban and extra-urban areas [1].

In order to overcome the problems caused by the floods, amount or volume of the flood discharge should be determined by conventional techniques practically and systematically. Rational method is one of the common methods in this field, which is widely used despite its simplicity. Another method that is proposed in this context is the advanced method of SWMM [1].

Most of the hydrological models are complex, include various parameters, and the exact values of these parameters are not exactly known due to the high variability of these parameters and the time and economic constraints. In addition, accurate measurement of these parameters is not possible directly. Therefore, calibration process is necessary and inevitable for accurate estimation of each parameter. During the calibration process of the model, the input parameters to the model are moderated and corrected by changing in their allowable limit in order to have the best fit to the observed data. However, when the number of parameters is large, the calibration process is very complex and requires extensive and time consuming calculations. In this case, sensitivity analysis can be considered as a basic method, by which the effects of input parameters are examined as independent variable on the outputs of the model

(dependent variable). Therefore, critical parameters are known and the focus will be on these parameters. Thus, reduction in uncertainty leads in the increased accuracy of results and saves time and cost [2].

Sensitivity analysis provides an overview of the study of the results that will be important to predict the potential risk or reduce risk. Sensitivity analysis can be done in partial or total scale. In the partial scale (absolute), the effect of each parameter is calculated by keeping the other parameters separately. In the overall scale, all parameters are allowed to vary in a given time and its' functions is on the basis of random selection of the parameters and probabilistic methods [5].

Variables are eight parameters of impermeable areas, slope, equivalent width (Width), and Manning's roughness coefficient in permeable and impermeable areas, storage height in permeable and impermeable areas, and percent of the non-storage permeable zones for the SWMM model. In this research, partial sensitivity analysis (absolute) was used to examine the sensitivity of the SWMM model variables. In this way, 15 and 30% of the initial value of each parameter were decreased and increased with respect to the acceptable range of changes, and the model was run based on and changes in the rate of runoff were examined. Given the importance of each input of software, engineers and designers in similar projects of the collection of surface water could spend more time and precision on more important parameters.

Rostami et al. (2012) studied the sensitivity of variables affecting urban flood peak flow using SWMM model in Imam Ali (AS) town in Mashhad [3]. The results showed that with a 30% increase in the amount of impermeable areas, the peak flow rate increased to 3.38 that had the greatest impact on peak flow and was known as the most sensitive parameter of the model. On the other hand, percent of impermeable areas with no surface storage had the least impact on peak flow in the studied area.

Sonei et al. conducted a study to compare rational methods and SWMM in determining flood flow of ravines. Applying two above-mentioned methods on three major ravines of Mashhad, they have come to the conclusion that in general, the flood discharge values obtained by the rational method was much more of the SWMM and this difference was caused by the two methods [2].

The results showed high sensitivity of all relationships with low areas so that small changes at low levels had a great impact on the amount of output of the model; that is, flood peak discharge. Moreover, in most of the relationships in the high areas, the impact of changes of this parameter on the values of the flood discharge was less than the changes in coefficient of the zone so that the increased quantity of the basin area reduced its effect on the peak flow rate of flood. Some relationships, such as Fuller's method are very sensitive to changes in the return periods than the lower return periods. In general, it should be added that the most and least important factor (in terms of impact on the flood discharge) are different in different ways and for different domains of interest [4].

MATERIALS AND METHODS
### The studied zone

Phase III development area of Kavian Industrial town with approximately 168 hectares of area has been located adjacent Phase 1 and 2 lands of the above-mentioned town with geographical coordinates 59 degrees and 45 minutes east longitude and 35 degrees and 53 minutes north latitude and altitude of 1250 meters (average height above sea level). Figure 1 shows the location of design phase to phases 1 and 2. According to the topographic map of the site, general slope of the site varies between 1 to 5%, in which this amount sporadically increases in some parts of the site, especially in the direction of ravines within the site (central parts) as limited to 5%; however, most parts of the site are located in areas with a slope of 2%. The general slope is inclined from the southwest to the northeast.

Figure 1: Location and establishment of the development phase within Kavian industrial area

All parts that are in the industrial town are the design components. These include 1. industrial zones, 2. Service buildings and infrastructure facilities and urban equipment, 3.green space, and 4. Channel networks, given the conducted studies on the land allocation criteria the area allocated to each of the components of Kavian industrial town has been calculated with an area about 95 hectares.

According to the main channels entering the study area, two catchment basins were detectable at upstream industrial area that affected the intended town. Surface currents of these sub-basins, due to the slope that is from the southwest to the northeast, entered into the industrial area and were collected by eastern-western levee established in the northern corner of Phase 3 and conducted by the channel in the north of the area to the outside of the site area. Figure 2 shows the location and boundary of sub-basins to the area.
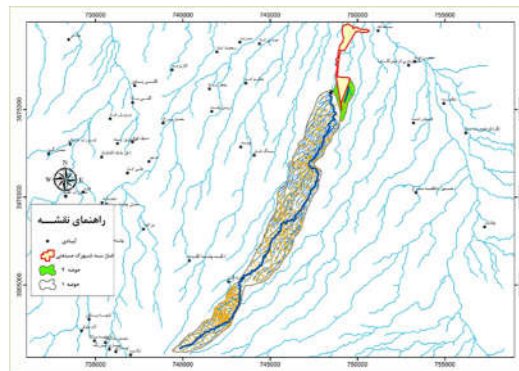

Figure 2: Location of upstream basins of Kavian industrial area

The study consisted of two steps. The first step is to find an appropriate model for simulating rainfall-runoff for Kavian basin between two SWMM model (using single data and the observed hydrograph) and rational models and then to analyze the selected model sensitivity as the optimal model.

SWMM model

This advance model has been developed by U.S Environmental Protection Agency for quantitative and qualitative simulation of the phenomena associated with complex channels during 1969 to 1971. In this method, each catchment basin is divided into smaller one-branch catchment basins, and physical specifications of each sub-basin, specifications of the catchment basin drain, and specifications of rain are given to it as input data. Each catchment sub-basin is simulated as a non-linear reservoir, and then a unit hydrograph is calculated according to the given specification. Then, the hydrograph is routed to outlet of the catchment basin as a kinematic wave and finally the output discharge of sub-basin is determined. This is an advanced technique because all possible parameters, such as snow melting, rain (as rainfall or duration intensity), data of evaporation, information of drainages or channels and basins are fully received.

First, Phase 3 of Kavian industrial town was divided into 66 sub-basins with ARC GIS software and surface water was drained through seven outlets out of drainage area of town (Figure 3).
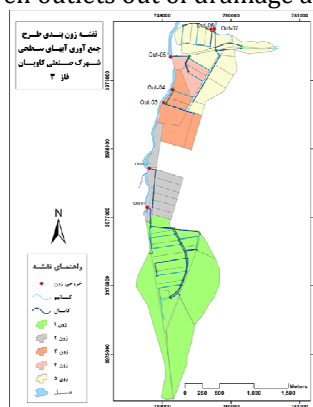
Figure 3: Map of basins and outlets of each zone

SSA software was used to implement the SWMM model.

Area, width, slope, percent impermeable, the water movement on the surface, length of the main channel, Manning roughness coefficient on permeable and impermeable surfaces, pothole storage and the basins infiltration parameters are parameters related to the sub-basins that must be introduced into the model.

One of the features of the SSA software is the input and output capabilities of the GIS data. For this reason, in the large surfaces, in which calculation of physical properties of basin is time consuming and difficult, this information can be entered into SSA by GIS with further savings in time.

In order to run the SWMM model, specification of connections, channels, and structures of dewatering and weather information would be entered into the software. Data available in hydrometric station of chelate Rahman was used for the study. According to the information, the desired event was a storm with a continued 2-hour rainfall that has rained in March 2006-2007.

Rational Model

This is one of the methods used to estimate flood peak discharge. This method has been developed based on the rainfall with uniform intensity across the entire basin and assuming the smallness of basin; that is, duration of rainfall equal to or more than of the basin focus time. The maximum surface current is a function of rainfall intensity at the basin focus time, the runoff coefficient, and the basin area.

Difference between the two methods in terms of entering the sub-basins data into the software SSA is that in the rational method, we introduced the main channel length into the model whereas in the SWMM method, equivalent width of the basin was introduced into the model. Furthermore, since the rational method is an empirical one, it does not need a roughness coefficient and percentage of impermeable areas and only the factor runoff is necessary.**2.4 Selection of the optimal model**To calibrate and select the optimal model, it is necessary to implement two methods SWMM and rational, and default values of the parameters must be changed in the permissible range so that the output hydrograph of the models provide acceptable results compared to the observed hydrographFigure 4 shows the hydrographs of SWMM and rational models with the observation model for comparison of their correlation with the observed model. Although, the peak discharge of hydrograph obtained from the rational model to the intensity of 1 mm/hr was very close to the observed hydrograph, there were many differences between the two diagrams that explain inappropriateness of rational model to simulate rainfall-runoff of the studied area. Output of the model SWMM had a very high correlation with the observed values. Therefore, sensitivity analysis of the SWMM model is discussed as the optimal model below.
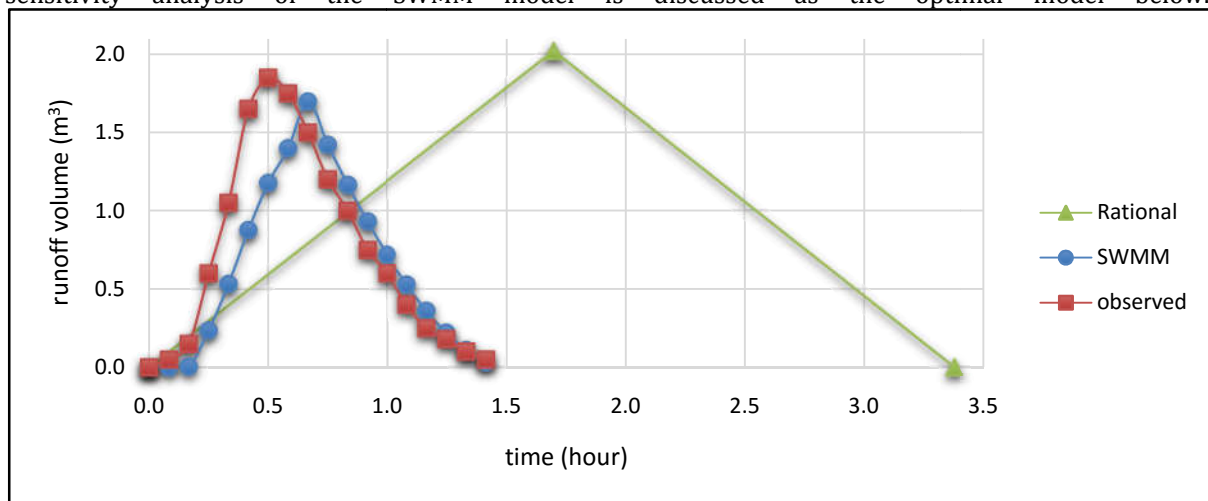

Figure 4: Comparison of the correlation of observed hydrographs and the hydrographs obtained from two rational and SWMM models

Analysis of the sensitivity of SWMM model

Sensitivity analysis examines the impact of the range of changes in each input on the model output. Thus, any input range must be determined. Values are chosen in a way that the range of changes in parameters and mean changes are coordinated with each other and not violate each other. Table 1 shows the initial value and range of the changes in parameters. Given the number of parameters and range of each parameter, it is required to run the SWMM model 40 times.

For sensitivity analysis, the model is run with allocating synthetic single hydrograph with a return period of 2 years to the model and making some changes. To evaluate the effect of each parameter, its value is separately introduced into the model by 30% increase and 15% decrease and the default value, and then it is run by the absolute method. Figures 5 to 11 show the results of these changes. For ach parameter, a graph is mapped, in which every single output of the stream is investigated.

Table 1: Initial values and range of acceptable changes in the variables of SWMM model

Variable	Initial values	Range of acceptable changes	Source
Percent of impermeable areas (Dimp)	80	30±	The studied area
Slope (S)	2	30±	The studied area
Equivalent width (Eqw)	Is calculated for each sub-basin	30±	The studied area
N impermeable (Nimp)	0.11	0.005-0.04	Houbro Dickinson
N permeable (Np)	0.4	0.05-0.8	Houbro Dickinson
Impermeable storage areas height (Dimp) (mm)	2	0.3-2.5	Temprano et al. Houbro Dickinson
Permeable storage areas height (Dp) (mm)	5	2.5-5.1	Tessineritzier and Hamid
Impermeable areas with no surface storage (noD)	50	50-60	Houbro Dickinson

Figure 5: Changes in the height of the storage permeable areas and its impact on peak flow
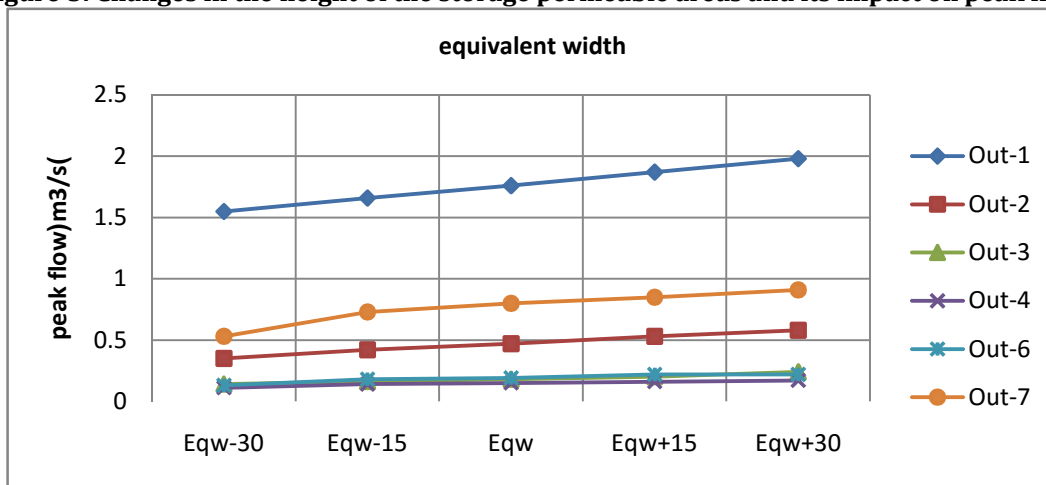

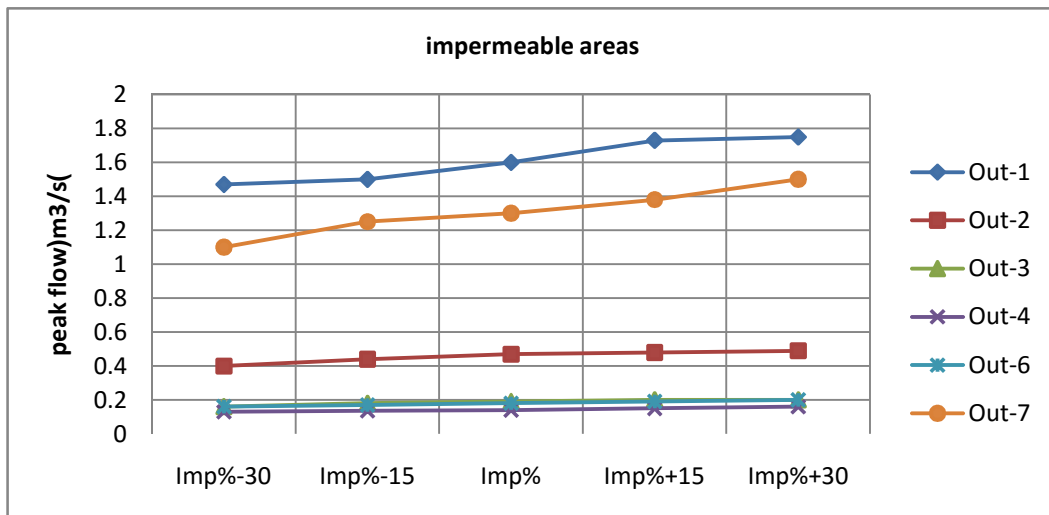**Figure (6): the equivalent width changes and their impact on peak flow**

Figure 7: Changes in the percentage of impermeable areas and its impact on peak flow
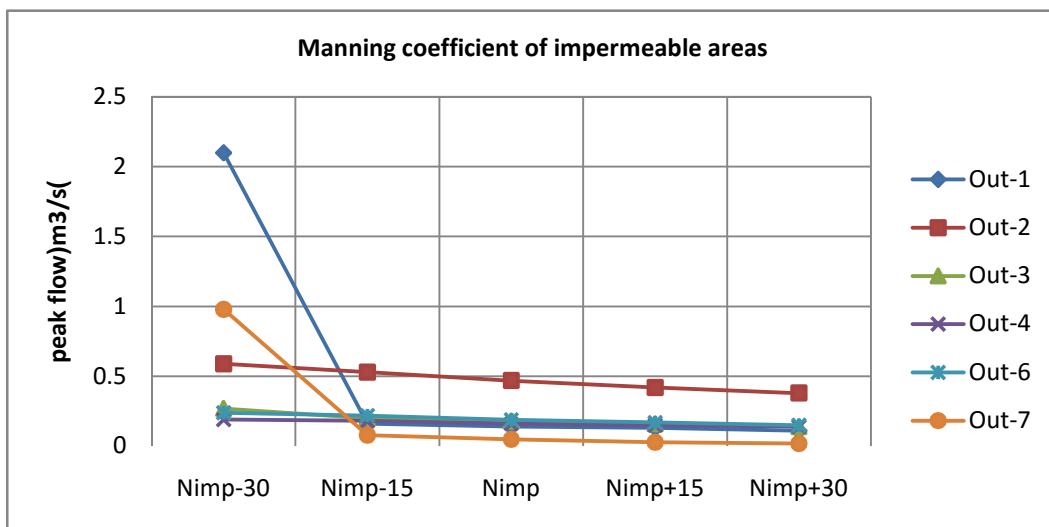

Figure (8): Manning coefficient changes in impermeable areas and its impact on peak flow
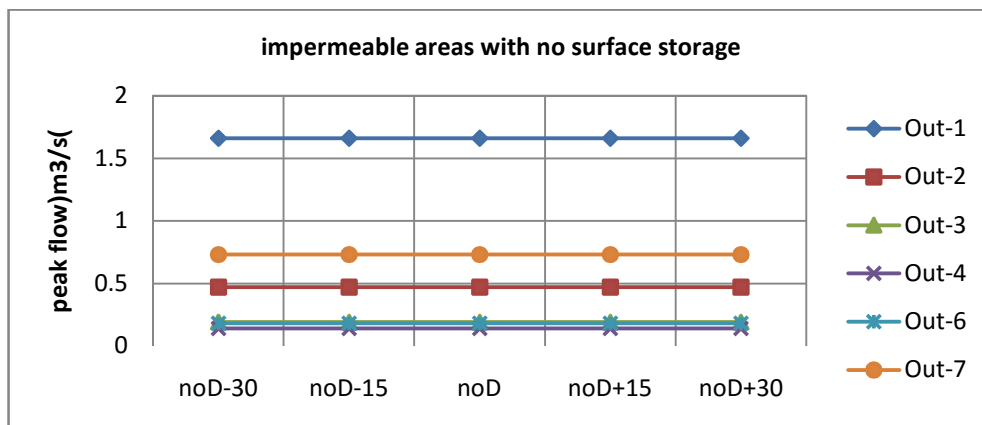

Figure 9: Changes in the percentage of impermeable areas without surface reserve and its impact on peak flow
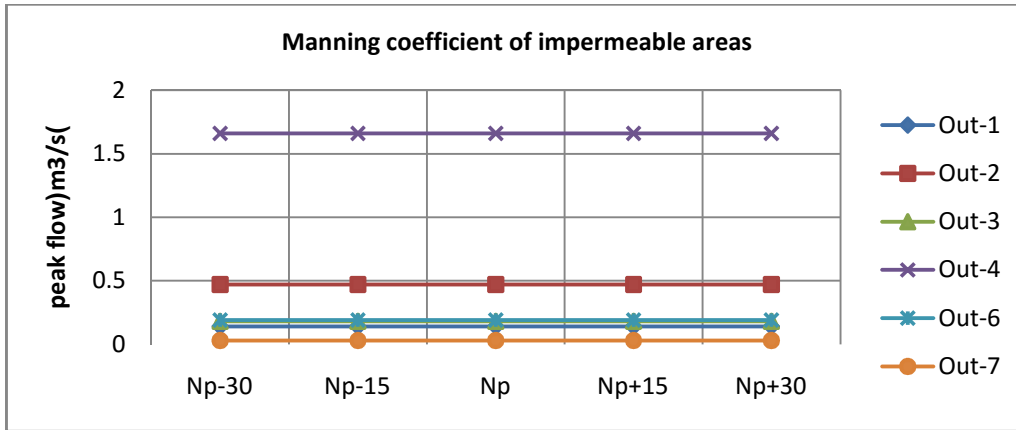
Figure (10): Manning coefficient changes of permeable areas and its impact on peak flow
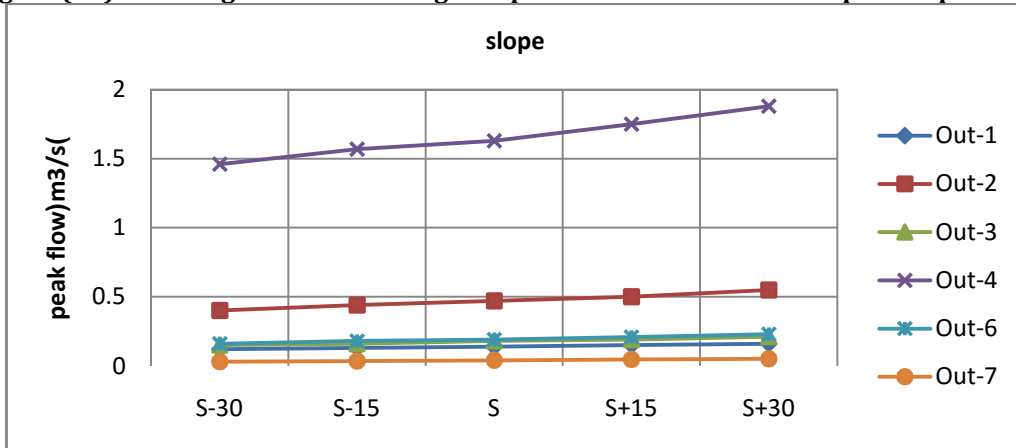

Figure 11: Changes in the slope and its effect on peak flow

ccording to the above diagrams, it is followed that the peak flow is reduced by increasing altitude of permeable and impermeable storage areas. Moreover, peak flow increases by increasing the equivalent width, the basin slope, and the percentage of impermeable areas. According to Figure 8, for 15 and 30% of reduction in Manning coefficient of the impermeable areas in the outlet 1, the peak flow reaches from 0.14 to respectively 0.16 and 0.21 m³/s. Since the percentage of permeable zones is very low in the industrial zone, therefore changes in Manning roughness coefficient cannot be discussed in these areas. Figure 10 illustrates this.

In order to explore the impact of parameter changes on peak flow, they need to be considered as comparable to each other. For this purpose, the percentage of changes in peak flow for each parameter was used in all outputs. Sorting the values in descending order, it was determined that peak flow was more sensitive to what parameters

According to the above table, if the sensitivity is divided into three categories of very sensitive to the (Qmax% (40-60)), sensitive (Qmax% (20-40)), and low sensitive (Qmax% <20), it is concluded that the output flow of the SWMM model is very sensitive to the roughness coefficient of impermeable areas. Therefore, it should be taken carefully to determine parameter when entering the model. Basin slope and equivalent width parameters are also in the category of parameters that the model is sensitive to them and their determination needs more precision.

Table 2: Percentage of the changes in peak flow

Category of sensitivity	Average percentage of changes	Least percentage of changes	Most percentage of changes	Parameter
Very sensitivity	60.0	-60.0	60.0	Manning coefficient of impermeable areas
Sensitive	33.5	-33.8	33.3	Equivalent width of the basin
Sensitive	25.0	-25.0	25.0	Average slope of the basin
Low sensitivity	15.6	-15.8	15.4	Percentage of impermeable areas

Low sensitivity	15.0	-13.3	16.7		Height of the storage of permeable zones
Low sensitivity	13.2	-15.8	10.5		Height of the storage of impermeable areas

Effect of the sensitivity analysis on the channel dimensions

In order to determine the effect of sensitivity analysis on the channel dimensions, the most critical conditions were considered. Thus, the model was run 5 times by making the changes in roughness coefficient of impermeable areas, and dimensions of channels were designed according to existing types in each step. According to the results of Table 3, it is observed that dimensions of the sections and percentage of the used length are greater than the larger dimensions in the case of reduction in the roughness coefficient of impermeable areas.

Table 3: Total length of each type of channel used in the scenarios of changes in roughness coefficient of impermeable areas

	Type	(Nimp+30) Length%	Length% (Nimp+15)	Length% (Nimp)	Length% (Nimp-15)	Length% (Nimp-30)
35*40	**Type 1**	62.2	54.4	51.4	49.9	41.9
40*40	**Type 2**	8.4	15.9	15.0	12.0	14.7
40*55	**Type 3**	16.2	15.5	10.6	8.7	7.3
50*50	**Type 4**	0.6	5.6	5.3	9.8	8.6
50*65	**Type 5**	6.8	4.2	1.7	6.5	13.0
60*60	**Type** 6	0.3	3.8	5.1	2.2	1.7
60*75	**Type 7**	2.1		2.2	4.7	5.0
70*70	Type 8		1.8			2.2
70*85	**Type 9**	0.1	0.4	0.7	0.9	0.4
80*80	**Type 10**				1.8	
80*95	Type 11					1.8
90*90	**Type 12**	0.2	0.2	0.2	0.2	0.2
120*120	**Type 13**	3.3	3.3			
130*130	**Type 14**			3.8		
140*140	**Type 15**				3.3	3.3

Cost of the channels running in each scenario illustrates that 8.8% cost surplus in the scenario Nimp-30 (decrease in roughness coefficient by 30%) and 6.8% cost surplus in the scenario Nimp-15 (decrease in roughness coefficient by 15%) could be imposed on the project implementation than the Nimp scenario (the default roughness coefficient). Therefore, it is clear that precision in the estimates of various parameters had significant effect on the cost of the project. Thus, design engineer must be very accurate during the design of conductivity and collection network of surface water in order to estimate very sensitive parameters (roughness coefficient of impermeable areas) and sensitive parameters (percentage of slope and equivalent width of the basin).

CONCLUSION

SWMM model can readily simulate rainfall-runoff in Kavian industrial town but the rational model is not suitable for the study area because of overestimation. After the sensitivity analysis and determination of very sensitive and sensitive parameters, we can achieve more reliable results with little time spent on accurate estimates of these parameters. Of course, it does not ignore the importance of other parameters but implies that how a designer manages his or her time to achieve better results. Sensitivity analysis also has a significant impact on the overall cost of the project.

SSA software is very powerful in the simulation of rainfall-runoff process. Its abilities include a variety of usable and on place hydrological models (e.g., EPA SWMM, Rational, Modified Rational, 55TR, 20TR, etc.). Previously, researchers had to use SWMM5 model to simulate a single or continuous rain events and Sewer GEMS software to simulate rational model. On the other hand, routing by the three methods of

hydrodynamic, kinematics wave and uniform conditions make hydraulic calculations very easy and has resulted in more variety of hydraulic methods.

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