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Identifying and ranking factors involved in creating urban water Inundation (Case study: Karaj City)

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Abstract

Expansion of housing and municipal infrastructures because of the ever increasing population on one hand and the conversion of agricultural, pasture and forest lands to urban areas on the other hand have led to many natural problems like agitated ecosystems and unbalanced hydrological status in different areas. Sensitivity analysis serves as a way of identifying influential factors in shaping final model's output. This study strives for the identification of influential factors in water Inundation using SWMM model. To this end, of the 9 primary factors of the model, 15 and 30 percent reduction or addition were made and the resulting peak flow was examined in each case. The results showed that the most sensitive parameters to low orders of sensitivity include the percentage of impermeable area, channel roughness coefficient, Manning's roughness coefficient of impermeable areas, width of the equivalent rectangle, slope, curve number (CN), impermeable areas storage, Manning roughness coefficient in permeable zones. Since the use of impermeable surfaces in urban areas is inevitable, new methods based on the criteria of sustainable development, long-term planning and existing facilities could be devised in order to at least reduce the damage caused by the floods. By restoration of natural cycle of water remarkable leaps could be taken to conserve current water resources and maintaining current development and future progress.

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Introduction

Increasing trend of flood in many parts of the world and its related damage reveals the need to provide a solution to deal with this natural phenomenon. High-intensity rainfall, Permeability reduction due to urban development and also existing runoff collection systems with high longevity are the major causes of flood events in urban areas (Radmehr, 2010). in urban areas, If the water flow rate be higher than infiltration rate in soil, is created flow on the street surface that reaches to normal flow of cannel water centralized or widely and leads to increasing water volume of channel. The simultaneous surface flow cause to increasing water and occurs flood subsequently. If main channel have not capacity of connected pathway for passing the urban flood, rushes and converts the city to ruins (Moghimi, 2010). During recent years, researchers have tried to create a better relationship between rainfall and the resulting runoff. In this regard, several hydrological models are presented. Better understand of effective factors in watershed hydrological process and the processing of high volumes of data in short time are some of the abilities of these models (Nasser Abadi, 2013). Hydrological models are designed with two goals. The first goal is a better understanding of the hydrological behavior and how behavior change and its effects. The second goal is synthesizing hydrologic data for water resources planning, flood control, water flow adjustment and overall, flow forecasting and planning (Khalighi, 2009). Storm water management model (SWMM) is one of the models that has acceptable accurate and much attention has been addressed in recent years (Ahmadian, 2012 ., Moafi, 2012). SWMM Model or surface runoff management model is a dynamic model to simulate rainfall-runoff and could be applied for an event or continuously simulate quantity and quality of runoff for urban area (Gironas *et al*, 2010). Models are often complex and involve many different parameters. Due to the high variability of these parameters and economy and time limitation, exact values of these parameters are not well known. Sensitivity analysis done to determine how much is sensitive a model to change the score of parameters and structure of the model. Therefore, during this practice, Sensitive parameters are known and take places focus on these parameters and by reducing uncertainty, Increases accuracy of the results and leads to saving time and costs (Avrand, 2006). Hosseini (2014) was performed sensitivity analysis of parameters using a single parameter at a time (OAT) to determine the important and sensitive parameters of the SWAT model and were examined the effect of various parameters based on four important component of the water balance, including surface runoff, lateral flow, groundwater and evapotranspiration. In a study that was conducted to determine the sensitivity of the HEC-1 model, the number of curves and primary storage were considered as the most sensitive parameters. Also the results showed that this model is not sensitive to changes in the concentration time and the lag time (Avrand *et al*, 2006). In a study in Karoun watershed, HEC-HMS model was used to identify effective geomorphology variables on flood. The results of study showed that the number of curves is one of the important and effective parameters on watershed peak discharge (Shiran, 2007). Rostami Khalahi (2012) by performing sensitivity analysis of input variables in SWMM model stated that increase the percentage of impermeable areas have the greatest impact on peak flow is recognized as the most sensitive parameter of model and on the other hand, percentage of impermeable area without surface storage has the least impact on peak flow in studied region. In a study in Mahdasht, was used SWMM model to reduce the risk of flooding. Sensitivity analysis showed that the most sensitive parameter is the percentage of impermeable surfaces and the lowest sensitive parameter is related to storage height factor and roughness coefficient in permeable areas (Shahbazi, 2012). The aim of this study was to determine the important and effective parameters on urban flooding to reduce the risks of flooded in urban areas by identifying the important and effective parameters on flooding and urban runoff.

Material and methods

Study area

Karaj city is located in 48km of northwest Tehran in Alborz province with longitude 51° 00′ 30″ E and latitude 35° 48′ 45 ″ N. Karaj with 175.4km2 area and 178.9km2 buffer zone is located in the downstream of central Alborz mountains. The height of this city is 1297m from sea surface (railway station). Karaj is one of the main and submontane cities of Iran and its population was estimated 1605000 people in 2010. Mean annual rainfall is around 251 mm with 1.24% coefficient of variation. Minimum and maximum rainfall is 89.3 and 374.4mm respectively. Winter season with 3.42% and summer season with 5.1% have highest and lowest share of annual rainfall respectively. Absolute minimum and maximum temperature is -20 and 42 degrees Celsius respectively and annual average is 11.4°C. study area is located in central position of Karaj city with 15ha area that is presented its location in figure 1.

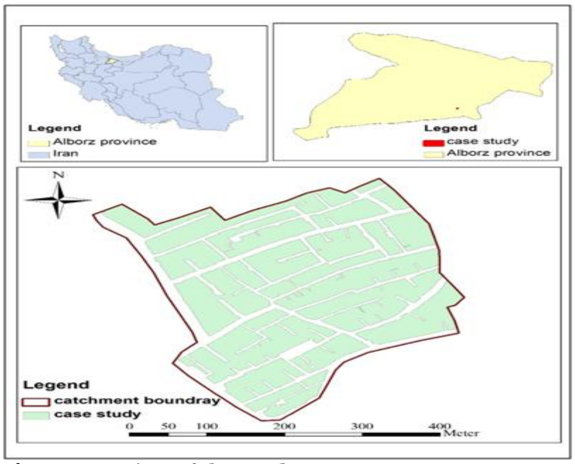

Fig. 1. Location of the study area.

Methodology

SWMM model was used in order to simulate rainfall – runoff. Frontier delimitation of basin and sub-basin was identified using 1:2000 topographic maps, city maps (including streets, boulevards, gardens, etc.), field visits and also considering to the slope and movement mode of water in sub-basin (Fig 2). Then, In order to obtain the required information to running the model, were used related formulas, model manual, supplementary tables or field visits. Width of equivalent rectangle is used for calculating the equivalent width. To determine the roughness coefficient of flow on permeable surfaces, impermeable and waterway and also determines the height of the storage for permeable and impermeable area is used model manual and supplementary tables. A soil conservation service of America (SCS) is applied for determining infiltration rate.

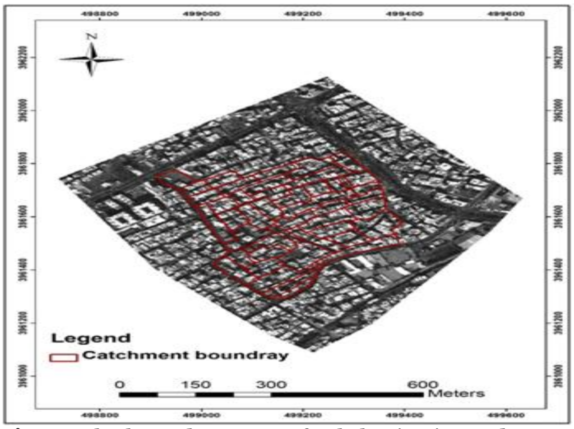

Fig. 2. The boundary map of sub-basins in study area (Google Earth, 2014).

Information about culverts (form, maximum depth and length of culvert), information of junction (number of waterway floor in the junction and maximum depth of junction), well data (height, form and width of the entrance) and finally output data that is included floor number of output node, is done through field visits. Also, Information about the area, slope and Elevation classes of the study area have been extracted by GIS software that are used in different parts of the model.

To determine the project rainfall is needed to determine the concentration time initially. Bransly Williams equation (Equation 1) was used for calculating the concentration time.

Equation (1)

$$T_{c=}\frac{0.96L^{1.2}}{H^{0.2}A^{0.1}}$$

Tc= Concentration time (h), A= Catchment area (Km2), L= Main channel length (Km2), H= Elevation difference between the lowest and highest point in the catchment (m).

After calculating the concentration time using the intensity - duration - frequency (IDF) curves, were calculated cumulative rainfall amounts and Finally, storm hyetograph for the return period of 20 years in time of concentration using alternating block method, was prepared as input to the model. In this study, partial sensitivity analysis (absolute) was used for performing a sensitivity analysis of input variables for the SWMM model (Rostami Khalaji, 2012). Among existing parameters, were selected 10 parameters including: Percentage of impermeable area, slope, equivalent width, curve number (CN) of Manning roughness coefficient in permeable and impermeable areas, storage height of impermeable area, storage height of permeable area and channel roughness coefficient. Among the different results of this software, flood peak flow is selected as dependent variable for evaluating that this variable is the most effective parameter for estimation the flood. Finally, with 15% and 30% rise and fall of the selected parameters and their impact on the flood peak flow of watershed outlet, were determined important and effective parameters.

Results and discussion

To perform the sensitivity analysis, precipitations of 20 minutes period (depending on the estimated concentration time that is 2 to 20 minutes) with a return period of 20 years were used. The results of the sensitivity analysis is provided in Figs 3 to 7. As is clear from the figure, most sensitive to least sensitive parameters were: percentage of impermeable area, channel roughness coefficient, Manning's roughness coefficient impermeable areas, the equivalent rectangular width, slope, curve number (CN), storage volume of impermeable surfaces, storage volume of permeable Manning roughness coefficient in permeable zones. It should be noted that the peak flow did not show a significant change with the increase and decrease in the last four parameters.

With the increase of impermeable area, equivalent width and slope, peak flow rate increased meaning that peak flow is directly related to these parameters. However, Manning roughness coefficient of impermeable areas and channel's roughness coefficient are inversely related to the peak flow, i.e. by their reduction, peak flow increases.

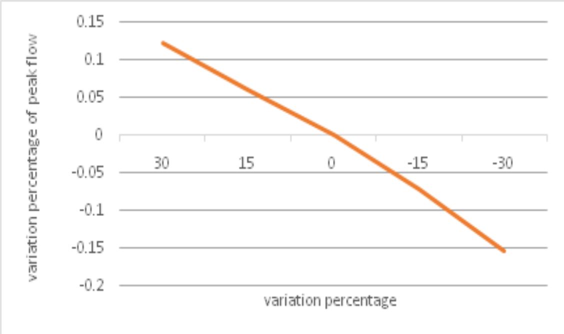

Fig. 3. Percentage change in impermeable surfaces and its effect on peak flow in percentage.

Altering values of model inputs can affect the model output in different ways. In general, only a small number of input variables could affect the value of a particular output variable at a specific time and place. So in the sensitivity analysis, only variables should be evaluated that are most determinant of final output data (Bozorg Haddad, 2013).

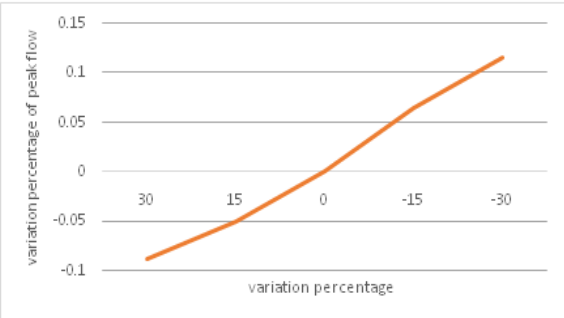

Fig. 4. Percentage of channel roughness coefficient of variation and its impact on peak flow in percentage.

In other words, sensitivity analysis is a way to show which of parameters can exert more influence on the results. Thus, according to the results of the 9 parameters, the greatest factor impacts were occurred in the impermeable land percentage, channel roughness coefficient, Manning roughness coefficient of impermeable areas, the equivalent rectangular width, slope, curve number (CN), impermeable areas storage, permeable areas storage and Manning roughness coefficient of permeable zones. The findings are consistent with Fallah Tafti (2005), Dalir (2009), Rostami Khalaj (2011), Moafi (2012) and Shahbazi (2012).

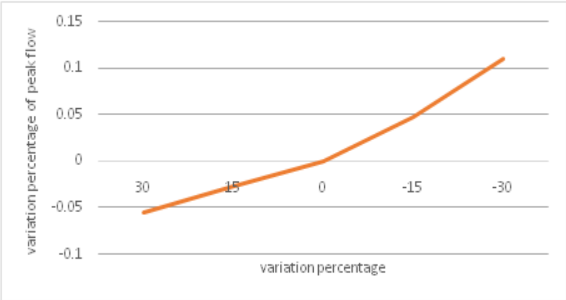

Fig. 5. Percentage of Manning roughness coefficient impermeable areas and its impact on peak flow in percentage.

Ahmadian (2012) using SWMM model in New Hashtgerd expressed that from the eight parameters (percentage of impermeable area, Manning roughness coefficient of impermeable areas, Manning roughness coefficient of permeable zones, equivalent rectangle width, permeable areas storage, sub watershed slope and percentage of no-surface-storage areas), the Manning roughness coefficient of impermeable areas, equivalent width, slope, percentage of sub watershed slope and percentage of impermeable areas have the highest impact on the peak flow.

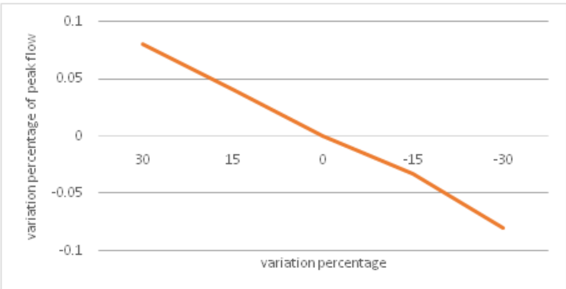

Fig. 6. The percentage change in the equivalent rectangle width and its impact on peak flow in percentage.

In this study, the most critical and influential parameter is the percentage of impermeable area. The reason behind is that in the areas studied by Ahmadian, impermeable areas compared with the permeable areas, formed a remarkable share which in return by each increase or decrease in the latter parameter, negligible changes would be observed in the peak flow.

Rapid expansion of urban housing and construction, destruction of natural environment and increased impermeable areas could all result in more flooding, less natural ground water recharge as well as greater volumes of urban runoffs (Sharifan *et al*, 2010 and Malekinejad and Ekrami2010).

Given the importance of impermeable area percentage in shaping the final discharge in the current study and inevitable use of impermeable areas in urban design, new methods based on the criteria of sustainable development, long-term planning and existing facilities could be developed in order to at least reduce the damages.

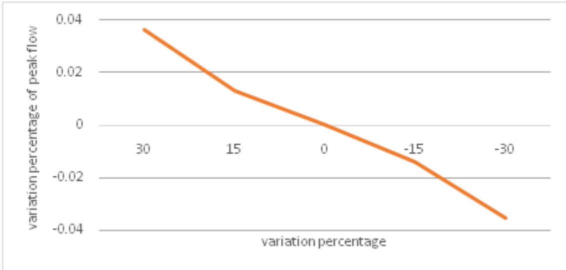

Fig. 7. Percentage of slope change and its impact on peak flow in percentage

Today, various ways are exercised to encourage water infiltration, improve waterways lag time in water conveyance (lengthening concentration time) and runoff reuse all of which trying to restore the environment after construction.

Urban flood management has been unsteady during recent years and different management methods have been developed so far from which below items could be suggested:

Storing rooftop runoff and gutter conveyance: large body of urban rooftops are devoted to impermeable surfaces, runoff of which could be collected for later reuse for greening the area. It seems that water storage systems in arid and semiarid areas, merely benefiting from rainfall for a few times, are not cost effective. In these cases, gutter runoffs could be harvested, instead of wasting to the waterways, for later reuse for greening intentions.

Water infiltration boreholes : penetration boreholes are cubic or cylinder in shape and once drilled, are filled with rocks and the walls are covered with a blade or sheath made of brick, blocks, precast concrete or polyethylene mesh rings while around and inside is filled with coarse material.

Development of green spaces below the impervious surfaces: in urban areas streets make up approximately 20 to 25 percent of impervious surfaces, thus transferring runoff from these surfaces to areas with high permeability is very useful in its control.

Permeable coatings: These coatings, with the temporary storage of water, are intended to meet goals such as reducing runoff, ground water recharge, and improving water quality. Permeable coating also have a high potential to improve the quality of urban runoff and treat it (Brattebo, 2004).

Permeable coatings can be replaced by a variety of urban impermeable surfaces, especially for sidewalks coating, parking lots, office buildings and public building spaces.

Garden waterways: garden waterways are wide and shallow earthen channels vegetated that facilitate water infiltration into the soil to prevent erosion.
Infiltration trench: infiltration trench are long, narrow trenches filled with coarse particles and rock fragments and usually has no outlet.

Bioretention systems: bioretention system is one of the new strategies to manage and co-exist with flood. This system includes an earth surface that is covered with non-invasive plants (tap-rooted plants).

Green roofs: green roof is a multi-layered system in which roof area is covered with plants that by retaining a proportion of rainfall and through evapotranspiration and water treatment decrease peak flow and runoff volume. This could lead to better water and air quality, urban aestheticism and less energy waste.

Iran is suffering from an arid and semi-arid environment in which water is lacking. Thus, providing water with adequate quantity and quality for different purposes is invaluable. Given the finding that impermeable surfaces play a major role in producing runoff, new methods could be exercised to reduce impervious surfaces in line with recharging groundwater. This in return could bring wells, rivers and water bodies back to life.

On the other hand, by collecting rooftop rain water during each rainfall (being a considerable amount regarding the roof area of an urban environment) stored water could be used later for washing, laundry cleaning and flushing. These ways could be taken to reduce the amount water consumption.

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