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Analyzing the Effects of Urban Development on Flooding in the Cities (Case Study: Birjand City)

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Abstract
It is increasingly recognized that the land-use change, especially urbanization has influenced hydrological attributes intensely. But in most urban designs, flood prediction is considered through type of land use (residential, industrial, and so on) and density. However, experiences show that this method has not been very successful. As a result, the present study aims to investigate and explore a different method in Birjand city. The study primarily emphasizes on the relationship between parameters of hydrologic models and features of urban development as well as scenarios considered in comprehensive plan. Data required for the study were obtained through investigation of existing documents and studies, particularly regarding comprehensive plan of Birjand City. Evaluation has been performed using urban hydrologic models and applying geographic information systems regarding prediction of surface currents corresponding to different urban scenarios. The results showed that in comprehensive plan the effects of increasing impervious surfaces and their effect on increasing water runoff have not been emphasized. This issue has led to an increase in runoff and consequently flooding. The model used in the study indicated that in heavy rains with return period of 25 years, flooding is mainly associated with blocking of water flow at the mouth of bridges. Moreover, this method is compatible enough with conditions of Iran and can be used in similar situations.

Keywords
Birjand City, development features, type of land use, urban designs, urban floods.

1. Introduction
Most studies in the field of flooding and floods have been performed in watersheds where emphasis has been on natural as well as climate factors for prediction of floods. This is while urban managers and policy makers suffice to estimate the frequency and extent of potential floods using types of land use and density while these predictions are neither consistent nor compatible with field realities (Habibi et al., 2016: 269). Although in many cities density and types of land use have undeniable effects on production of water runoff, these factors cannot determine the extent of flooding and the resulting damage alone. Moreover, the costs of flood control in urban areas are so high that most municipalities don't access sufficient financial resources to construct protective fortifications (Saberifar, 2006). Most effective control actions at present are accompanied by prediction of effects of potential urban developments. In this regard, at the stage of planning control actions, these predictions are added to urban comprehensive plan which subsequently can reduce future damages and costs.

In general, activities associated with flood and flooding has not been developed in urban areas and as a consequence, most methods used in this area are traditional and lack basic innovation. This

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is while existing studies indicate that annually about 196 million people are at risk of flood in over 90 countries of the world (UNDP, 2004) and this risk is important in cities that are almost located at watershed outputs and have allocated high population density to themselves. The most significant issue is that in urban areas the proportion of impermeable surfaces is extensively increasing. These surfaces are not able to absorb rainfall and consequently their runoff volume will increase with the lowest rainfall (Lindh, 1994: 2). Urban development and lack of practical as well as exact plans for prevention through reduction of runoff or its targeted management is probably one of the reasons of more floods and damages in recent years (Abdi, 2007:200). Investigation of literature shows that studies done in this regard have mainly emphasized on the flood hazard zoning in cities (Mahmoodzadeh et al., 2016; Amir Ahmadi et al., 2012). However, to determine intensity and frequency of floods regarding features of urban areas, impermeable surfaces which are the result of urban development should be first determined. Yet, most people who develop urban designs believe there are no suitable models available in this regard. This is while there is strong theoretical background in this area. First it should be noted that hydrologic parameters which are used to indicate urban development features include:

- Impervious surface area which is determined as ratio of the area where rainfall directly enters into drainage network of surface water; and
- Focus time and speed of water in the basin.

Investigation of worldwide experience indicates that there are numerous studies on each parameter. For example, a lot of models have been introduced to determine impermeable surfaces and one of them is a model for estimation of impermeable surfaces (SCS, 1975:476) in which the volume of surface runoff is estimated based on type of soil and urban development features (such as the area of land assigned to residential, business, and industrial use compared to other types). Another reference in this area is a work done by Motta and Tucci (1987:26) in Brazil where data obtained from Porto Alerge were used to determine the relationship between urban density and impermeable surfaces. Moreover, Tucci (1987:65) used indirect methods to determine the relationship between impermeable surfaces and density of occupied area (urban parts). In another study, data obtained from Sao Paulo in 11 basins have led to favorable results (Campana, 2001:114).

Planning to design an urban drainage network is a process that should be done when the basin is still in its natural conditions and urban development has not begun yet. However, since these conditions are not available in most Iranian cities (Rasouli, 2015), the present study aims to consider population density and type of land use along with scenarios for each urban industrial area as main parameters. If hydrologic model used for prediction of volume and time of urban runoff distribution is satisfying, urban features in the scenario along with urbanization introduced by the proportion of impermeable area and drainage network features should be related to parameters of hydrologic model (Campana, 2001). Accordingly, the relationship between parameters of hydrologic model and urban development features should be first investigated.

Campana and Mendiondo (1994) applied fuzzy mathematics for estimation of impermeable surfaces through land-set TM images. They used data from Sao Paulo, Curitiba, and Porto Alerge (with 16, 2.5, and 3 million people respectively) to determine the relationship between urban density and impermeable surfaces. Their results obtained through remote measurement methods and field data didn’t show significant differences. In other words, for areas more than 2 km^2, error was less than 10% and for areas under this figure, the rate of error was 20%.

Data obtained by the above method didn’t show a significant difference between types of urban land use (industrial, business, and residential); however, it mostly coincided a combination of residential and business areas. Consequently, this method was explicitly useable for these urban scenarios. Accordingly, in the present study an upgraded version of the model provided by Campana and Mendiondo is used along with the curve set for the relationship between impermeable surfaces and urban population density.

Another influencing factor on the study of flooding in urban areas is the time of concentration. Density time or the time of maximum hydrograph of an urban area is usually determined through experimental equations using equations provided for rural basins. These equations are suitable for a primary rough estimate; however, it won't be satisfactory for all local conditions. Concentration time of an urban basin can be considered as parameter from two components: time spent until water reaches from branches to main drainage network; and time spent until water reaches from main drainage network to output point. Along with time, concentration on controlling the amount of surface runoff is also important. This component can be obtained by cinematic wave equations (relation1) whose assumptions include rainfall in constant p at the time of t_r where $t_r \leq t_c$ and t_c indicates concentration time. Next factor is runoff due to a plain with semi-infinite width and eventually Manning equation which represents slope ration. Simons and Stevens' equation (1975: 411) is as follows.

$$t_{cb} = t_r + \frac{L}{a} - \frac{(Pt_r)^b}{p} / b(pt_r)^b \quad (1)$$

where L is plain length (meters), P rainfall intensity (m/s), a equals $s^{\frac{1}{2}}/n$ which s indicates slope, N is Manning roughness coefficient, and b equals 0.6.

Along with the above parameters, concentration time has also an important and specific role. This parameter can be calculated by single Equation (2).

$$t_{cc} = \frac{l_c}{v} \quad (2)$$

where t_{cc} shows concentration time based on seconds, l_c is channel length based on meters, and v is speed based on m/s which can be calculated by Manning equation. Concentration time for the basin is obtained according to the following formula:

$$t_c = t_{cb} + t_{cc} \quad (3)$$

Using these models and some other parameters will make it possible to determine hydrographic features of the study area and consequently access the following information which can be useful in investigation of the effects of development on produced runoff and eventually potential flooding in each urban area such as Birjand:

- The amount of rainfall regarding intensity, duration, and return period;
- Features of watersheds such as the area, type of soil, and vegetation;
- Features of urban areas such as waste (drainage) network regarding engineering, structure, and local as well as total permeability conditions.

Obviously, development of urban areas in watersheds will lead to increased maximum (instant) discharges, reduced density time for the peak of instantaneous discharge, and increased runoff volume. However, the extent and rate of this increase as well as its measurement has not been considered in urban plans yet. Therefore, the present study aims to investigate these conditions in Birjand City and in one of the most important runoff discharge channels named Kabutar Khan Channel.

2. Study area

Birjand City is located in Lut desert basin. The main drainage of this city is Shur River which is created by joining of two main streams and flows in the western part of the city. This area is located in longitude of 43-58 to 45-59 from east and latitude of 32-34 to 8-33 from north and it is limited to Min Abad Mountains from north, Min Abad Heights and Sesan Mountain from east, Bagheran Mountains and Raj Mountain from south, and Gorank Mountain from west (Javan & Fal Solomon, 2007: 38). Although overall area of Birjand plain is 3155 km (Velayati, 1992: 247), flooding of 25 rivers which is sub-basin of the eastern plain with an area of about 1885 square kilometers enters into the city (Khorasan Agricultural Jihad, 2002). However, what flows inside the city as flooding includes eight sub-basins with overall area of about 251 km^2 and overall length of 82.5 km (Fig. 1). Although some rivers originate at altitude of approximately 2000 m, inside the city there are altitudes of 300 m (Fig. 2). Development of urban areas started from middle parts of the basin and gradually expanded up and downward. Since investigation of the entire city was not possible due to costs and time, in the present study a limited part of the city (Kale Kabutar Khan Basin) was studied. Distribution of constructed areas which have not been established was calculated through fuzzy model and accordingly, impermeable surfaces (Fig. 3), rural areas, and areas between these two have been separated (Fig. 4).

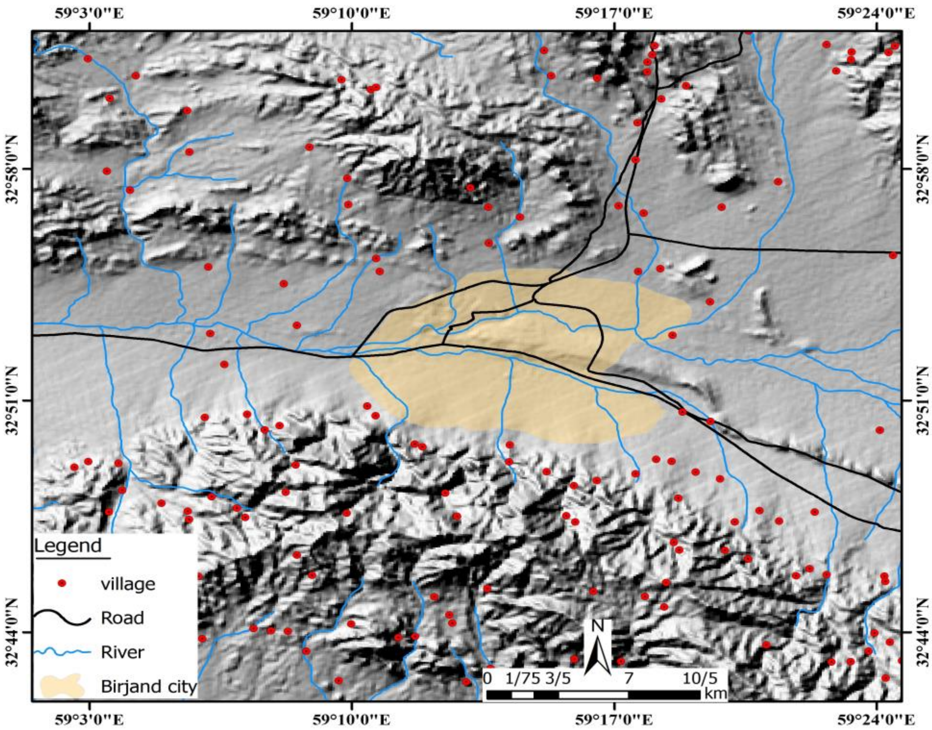

Fig. 1. Location of the city and river in the plain

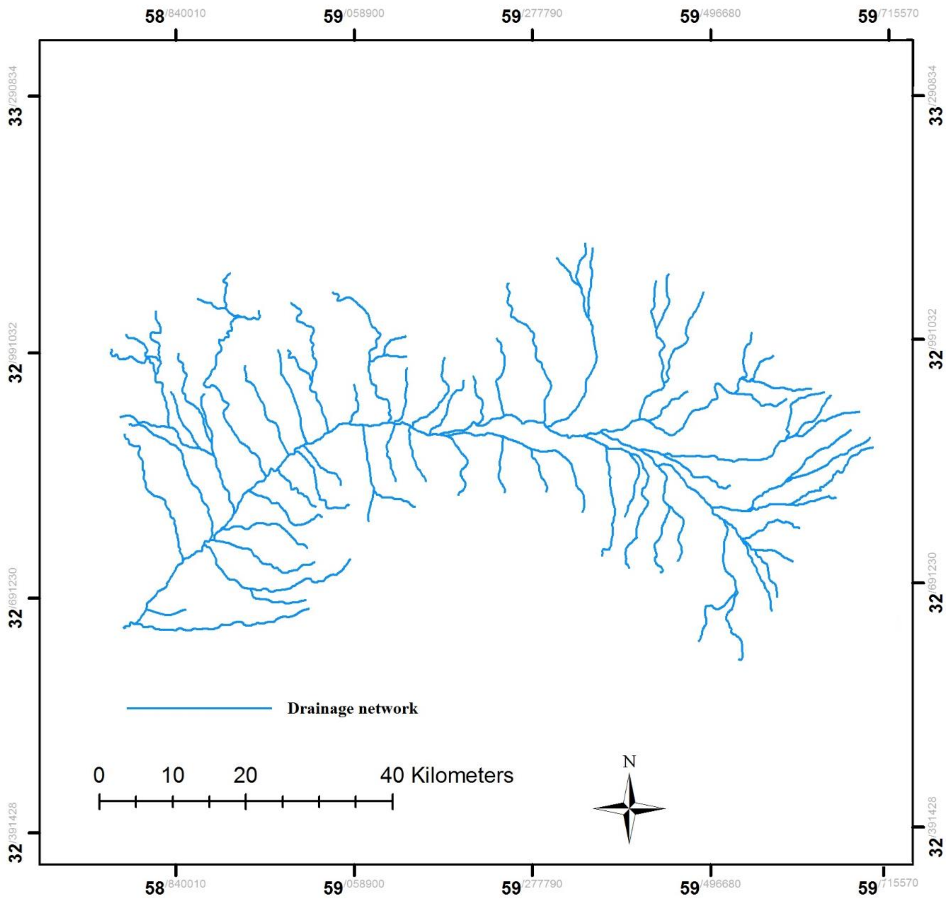

Fig. 2. Main streams entering into the Birjand city (from Iran 1250000 topography map)

3. Materials and Methods

This research was a descriptive-analytic study which aimed to predict surface runoff corresponding to different urban scenarios through urban hydrologic models and geographic information systems. Accordingly, first using statistics of responsible organizations and field studies the relationship between hydrologic factors and development was determined with the help of associated models. Moreover, impermeable surfaces were estimated through experimental and theoretical methods and then concentration time, density time, and surface runoff as well as channel concentration time were all determined. Given the necessity of determining runoff direction in urban basins and their difference with rural areas, digital model of land (DTM) proposed by Jensen and Doming (1988: 1597) was used. In this model, the basin is divided into smaller components with the size of 30×30 meters using square cells. In order to estimate hydrographic design, information resources, geographic information system (GIS), and hydrodynamic-hydrologic model have been used. Although determining these factors and their related components needs numerous statistical formulas and computations, the performed studies make it possible to estimate them based on algorithms tested in other areas.

In this investigation, one of the important factors was related to the effects of vegetation and similar barriers on flooding and channels overflow. Moreover, it should be noted that rain which falls in the basin may also fall in other impermeable surfaces such as concrete or iron roofs as well as roofs of buildings or parking lots and lawn surfaces or it can even fall in permeable surfaces where it can penetrate into the land. Percentage of impermeable surfaces (AINP) is a model parameter and can be used for calculation of effective rainfall. In impermeable surfaces, runoff flow is called surface flow until it reaches drainage channel. Numerous models are required to calculate each of them and for the sake of being brief one of them is introduced. For instance, in the present study Horton equation has been used in order to remove the amount of water due to storage in soil (for proof of equations refer to Campana, 2001; Tucci, 1987). This formula is follows:

$$I = I_b + \left(I_o + I_b\right)e^{-kt} \tag{4}$$

In this model, I the amount of penetration, I_0 indicates virtual penetration, I_b shows eventual penetration, K is a constant, and finally t refers the time. In these conditions, the amount of penetration (T) to groundwater can be calculated through Equation (5).

$$T = I_b + \left(1 - e^{-kt}\right) \tag{5}$$

where T shows the amount of penetration, continuity equation of the soil top layer is as Equation (6).

$$\frac{ds}{st} = 1 - T \tag{6}$$

In this equation, S indicates soil storage. With use of equations 5 and 6 into equation7 and merging as well as placement of known 1 and 2 variables will lead to Equations (7-9).

$$\frac{ds}{st} = 1 - t \tag{7}$$

$$S = \frac{-I_o^2}{\ln h\left(I_o - I_b\right)} + \frac{I_o}{\text{lN}\, h\left(I_o - I_b\right)} L \tag{8}$$

$$S = \frac{-I_o}{\text{lN}\, h I_b} \tag{9}$$

where, the equality $h = e^{-k}$ holds.

Given the amount of rainfall, P in the rime interval of t to $t + \Delta t$ there will be three conditions which are completely dependent on the amount of rainfall compared to penetration at t times:

a) When rainfall (P) is more than penetration, effective rainfall can be calculated through merging Horton equation during determined time interval:

$$V = \Delta t \left(p - I_b \right) - \frac{\left(I_t - I_b \right)}{\ln h} \left(h^{\Delta t} - L \right) \quad (10)$$

where I_{t+1}, S_{t+1} and T_{t+1} can be determined by Equations (5) and (7).

b) When P is smaller than I_b, all the rainfall penetrates and surface runoff share is zero. Replacing equation7 in equation 6 and placing I=P will lead to:

$$S_{t+1} = S_t e^{\Delta t/b} + P_b \left(1 - e^{-\Delta t/b} \right) \quad (11)$$

where $b = \frac{-I_o}{(L_n\, h L_n)}$ is calculated by Equation (8). If T_{t+1} is bigger than rainfall, only calculation of T_{t+1} through Equation (9) will suffice.

c) When P is bigger than T_{t+1}, the curves of penetration capacity and rainfall will be crossover and using Equation (8) for I=P, the time that two curves intersect will be calculated through Equation (12).

$$\Delta tx = -b\, l_n \frac{t_{t+1} - p_b}{S_t - p_b} \quad (11)$$

Time interval of (t, Δtx)will be calculated based on (B) and interval of (Δtx, $t+\Delta t$) will be calculated based on (A). When penetration volume is needed this parameter is calculated through continuity considerations (Campana, 2001:117).

4. Results and Discussions

Investigations indicate that comprehensive plan of Birjand City (Zysta Consulting Engineers, 2005) has not been able to achieve its real objectives and in deed, influx of immigrants to this city and formation of informal settlements has led to the current structure of the city without considering drainage network limitations (Saberifar, 2013). As a result, at the moment, maximum rate of urban land use (the highest area which can be occupied by the buildings) is observed in the city. Although constructed empty spaces have been predicted around each area, the area of these spaces is limited. Therefore, these areas which should provide water permeability and reduce the effects of urban development on water runoff cannot perform well. As a result, it seems that the plan has not felt any necessity to consider impermeable regions and this has led to problems associated with safe discharge of urban runoff. The present study aims to deal with some of these problems.

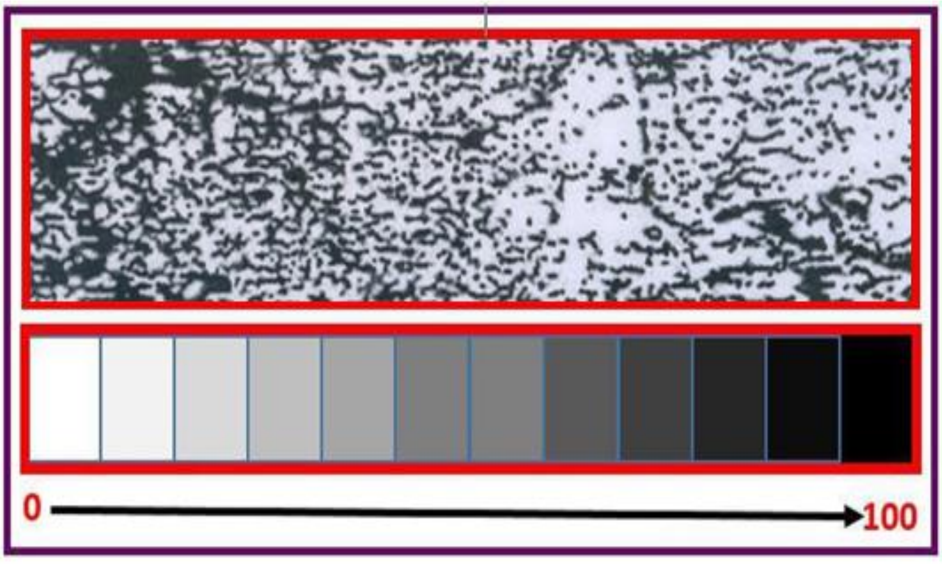

Fig. 3. The status of permeability in Kale Kabutar Khan Basin

4.1. Main features of the basin

Soil existing in the basin has been categorized using SCS categorization method (soil categorization standard). Information in this part has been obtained using three resources: a) geological maps, b) analysis of satellite digital images, and c) field surveys.

Given the above conditions and based on information of urban land use which has been considered in comprehensive plan, 25% of urban area has been used for streets and alleys and 75% has been used for buildings, while exact information about other parts or sub-parts of the same group is not available. Therefore, since such a study has not been performed in Birjand City, these ratios have been taken from equations used in other cities of the world and Iran (Shiea, 2004:175).

Time period of the present study included 1972 to 2012 solar year and base station was Birjand synoptic weather station. Data obtained from the station have been used for adjustment of model parameters and evaluation of fitness in review course. Given that there has been no detailed measurement of the streams, experimental data from similar areas have been used with statistics. Model adjustment has been done in two steps:

1. Hydrologic model adjustment for secondary basins: In this step, three events of sub-basins under study were selected and their information was used for estimation and assessment of model parameters.
2. Hydrologic-Hydrodynamic model adjustment for overall basin.

Border status of the upper part was calculated using hydraulic scale and criterion and border status of the lower part was fixed based on water level. Adjustments were done using two parts. Three selected events for secondary basins included hydrologic parameters which had been obtained using factors described above. Manning roughness coefficient was 30% for each part of natural channel and 16 percent for each path channel along the foot.

4.2. Urban scenarios and risk of flooding

The effects of urban development have been evaluated through simulation of basin behavior for existing as well as future steps. The risk of flooding for each urban scenario has been considered during 30 past years. These results have been calculated using rainfalls with return period of 2, 5, 10, and 25 years.

4.3. Rainfall design

Overall rainfall design has been provided using the curves of intensity, duration, and frequency at Birjand station. Spatial distribution of rain at basin surface has been obtained based on a critical event selected from historical data. SCS method has been used for distribution of overall rain based on time.

4.4. Prediction

Figure 4 represents potential estimation for 5 different scenarios in the study area. Accordingly, heavy rainfalls with return period of 2, 5, 10, and 25 years have been introduced well. According to the results, for all return periods under study and different scenarios, existing channels don’t have the capacity to move runoff. The only exception in this regard is heavy floods with return period of 25 years which occur in scenarios 3 and 4. In this case, most streets will be flooded. These flooding conditions are mainly due to special bridges which block ordinary water passage. The following results are clear:

1. Scenarios where planned urban development is considered will have increased runoff between 20% to 50% in downstream areas.
2. Adjustment of regulations to consider open spaces in areas used for construction can reduce this effect up to 5%.
3. Improvement of bridges and directing urban areas toward surrounding areas can prevent flooding with return period of 25 years. This method can be used to identify the effects of other regulations which have been designed for prevention of flooding; in this case heavy water flows may be witnessed in sub-basins.

Prediction of concentration time for investigated basin in Birjand City is provided in Figure 5. In this analysis three scenarios have been considered.

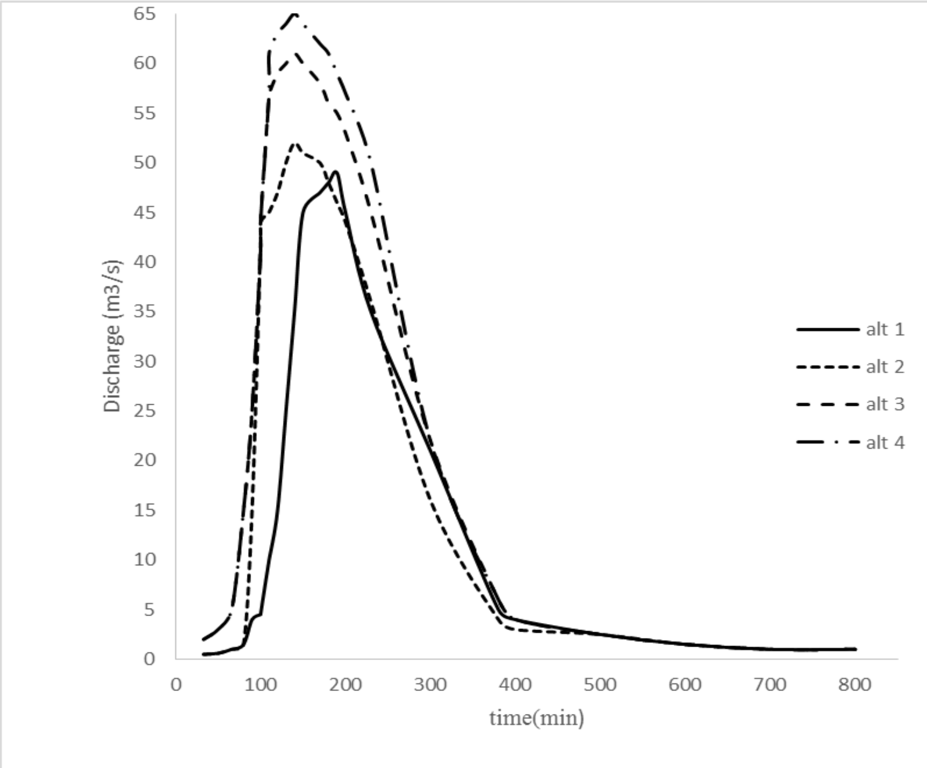

Fig. 4. Estimation performed for four different scenarios in Birjand city

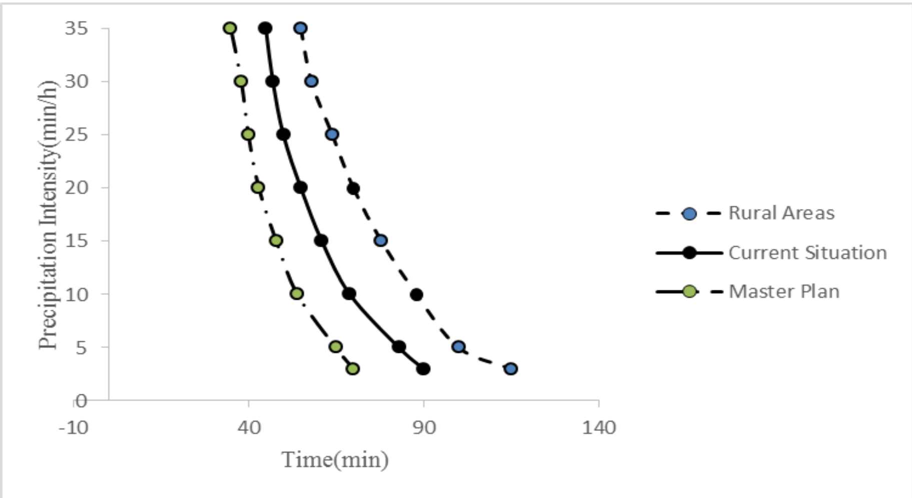

Fig. 5. Prediction of concentration time in different conditions of the basin

a) Rural conditions before urban development;
b) Existing conditions;
c) Predicted conditions in comprehensive plan.

In initial parts of the basin and intermediary step between rural areas and what has been proposed in comprehensive plan can be observed. This is while in distal parts of the basin the conditions are mostly rural and the middle part is completely urban.

5. Conclusions

As it was stated through the study, one of the main challenges in planning and transferring runoff is due to precipitation. Preparation of predictive models is an undeniable necessity in order to recognize the potential effects of urban development on the amount of water produced. On the other hand, types of land use and density should be considered in a way that the potential flooding is generally dealt with or at least reduced. In conclusion, planning of transferring urban runoff requires access to reliable tools so that exact prediction of potential floods is possible given different scenarios of urban development (Equation 1-13).

In this study, hydrograph plan has been provided for future scenarios using the relationship between urban plans and hydrologic parameters. This relationship has been considered for impermeable surfaces and concentration time for Birjand City in the present study and determines prediction of concentration time with different degrees of urban development in a basin. Accordingly, hydrologic-dynamic model and GIS system have been used along each other to predict flooding conditions based in the amount of rainfall during different return periods. The model obtained before adjustment and improvement, gave results which were relatively compatible with real recorded figures (Fig. 1).

Birjand basin is an extensively urbanized area in South Khorasan. In this area, urban development has started from the middle part of the basin and has gradually developed to upper and lower parts. These conditions have increased the potential risk of floods in the constructed areas where flooding damages will incur heavy costs. Comprehensive plan in this city has been developed without considering the effects of drainage network and planned developments. As a result, future studies should pay attention to these considerations and permeable surfaces need to be predicted consistent with the amount of impermeable surfaces and provided based on real conditions.

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