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# Effect of urbanization on flash flood risks and estimation in rural areas: A case study of Babol River in Iran

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## Abstract

The rapid urbanization and universal industrialization negatively affect flash flood risk. In this research we investigated the effect of urbanization on flash flood risk and its estimation in rural area. In line with that, we collected hydrological data (e.g. annual rainfall, annual runoff etc.), soil type and annual pick disgrace (Q) from 40 basins of Babol River in IRAN. It was observed that the annual runoff values in sub-basins number A, B, 6 - 11 and 17 were increased up to 40% due to urbanization and reducing the soil filterability in these basins. The results of the flood estimation through using Q-A graph revealed that, the k values increased from 0.0056 to 0.008 which means urbanization can affect flood estimation up to 42% lower than the actual flood of the high risk basin. This case study proved that urbanization in rural area can increase flood risk up to 50% (1.5 fold) which is a severe problem that should be address appropriately.

**Key words:** Urbanization; Flash flood risk; Flood estimation, Babol River



## 1. Introduction

Flash flood is a rapid and sudden local flood with a great volume which causes millions of dollars in property damage every year [1]. According to the American meteorological society states (SMSS), a flash is a flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area [2]. On the other words, the U.S. National Weather Service (UNWS) describes flash flood as a rapid and extreme flow of high water into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level, beginning within six hours of the causative event (e.g., intense rainfall, dam failure, ice jam) [3]. Typically, a flash flood is caused by coastal, fluvial and pluvial systems and convective thunderstorms as well as extreme events such as hurricanes, severe thunderstorm, tropical storms or tsunami [4]. Dam break, a levee break and snow melting in rivers during winter and spring months can result in flash floods [5]. Flash floods on watersheds smaller than 500 km<sup>2</sup> in Iran are a well-known phenomenon especially in the north part of the country where climate situation is subtropical humid with rainfall averages ~ 600 mm. People have had to learn to live with floods, particularly those whose livelihood depends on the productive functions of annual flooding. On the 10<sup>th</sup> and 11<sup>th</sup> August 2001, a major flood occurred in the Gorgan and Golestan rivers around the city of Gorgan, Iran which killed more than 247 people and caused around \$50 million of damage. Ten thousand people became homeless, and 150 km<sup>2</sup> of agricultural land and 100 km<sup>2</sup> of forest area were damaged. Another flood occurred on the 4<sup>th</sup> August 2001 in Neka, in which 100 people became ulcerous, more than 4000 stores and homes were inundated, and 400 km of road and 33 km of railroad flooded, causing damage totaling \$0.1 million. Similar floods have occurred several times in northern Iran in recent years, with increasing concern over how to improve flood warnings.

Human activities, in particular, urbanization in rural areas increases the regional impervious surface area which significantly reduces hydrologic response time and therefore increases the flash flood risks [6]. In fact, using paved impervious materials block water from natural penetration, decreasing the surface infiltration rate. When the precipitation rate is higher than the infiltration maximum rate, excess precipitation will move quickly as overland flow toward a stream channel and contribute to short-term stream response, leading potentially to soil erosion and flash flooding [7]. On the other hand, in natural areas such as forests and grasslands, rainfall and snowmelt collect and are stored on vegetation, in the soil column, or in surface depressions. When this storage capacity is filled, runoff flows slowly through soil as subsurface flow. In contrast, urban areas, where much of the land surface is



covered by roads and buildings, have less capacity to store rainfall and snowmelt. Construction of roads and buildings often involves removing vegetation, soil, and depressions from the land surface [8]. By urbanization, the permeable soil is replaced by impermeable surfaces such as roads, roofs, parking lots, and sidewalks that store little water, reduce infiltration of water into the ground, and accelerate runoff to ditches and streams. Even in suburban areas, where lawns and other permeable landscaping may be common, rainfall and snowmelt can saturate thin soils and produce overland flow, which runs off quickly [9].

Flash flood prediction and warning are basic measures implemented to reduce risks in flood prone areas [5]. The negative effect of urbanization on flash flood risk has been well accepted and reported by several researchers [10]. However, limited studies investigated the effect of urbanization on flash flood prediction. Many current forecasting technologies are based on numerical weather prediction models [11]. However it turns to a bigger challenge when it deals with ungagged watersheds. Generally, using Q-A graph which is plotted based on historical Q-A data of the nearby gaged watershed with same climate situation is the common and only method of flood estimation in ungagged basin. However, flood behavior and therefore flood magnitude (Q) is not only controlled by the climate situation and basin area, but also influenced by a range of factors that vary significantly with location, including soil filterability variation due to the urbanization, which need to be understood and managed [12]. Although in some literature, the effect of urbanization on flood prediction was studied [6], but they did not investigate the effect of soil type on Q-A graph by considering the effect of urbanization on flood prediction in un-gauged basins.

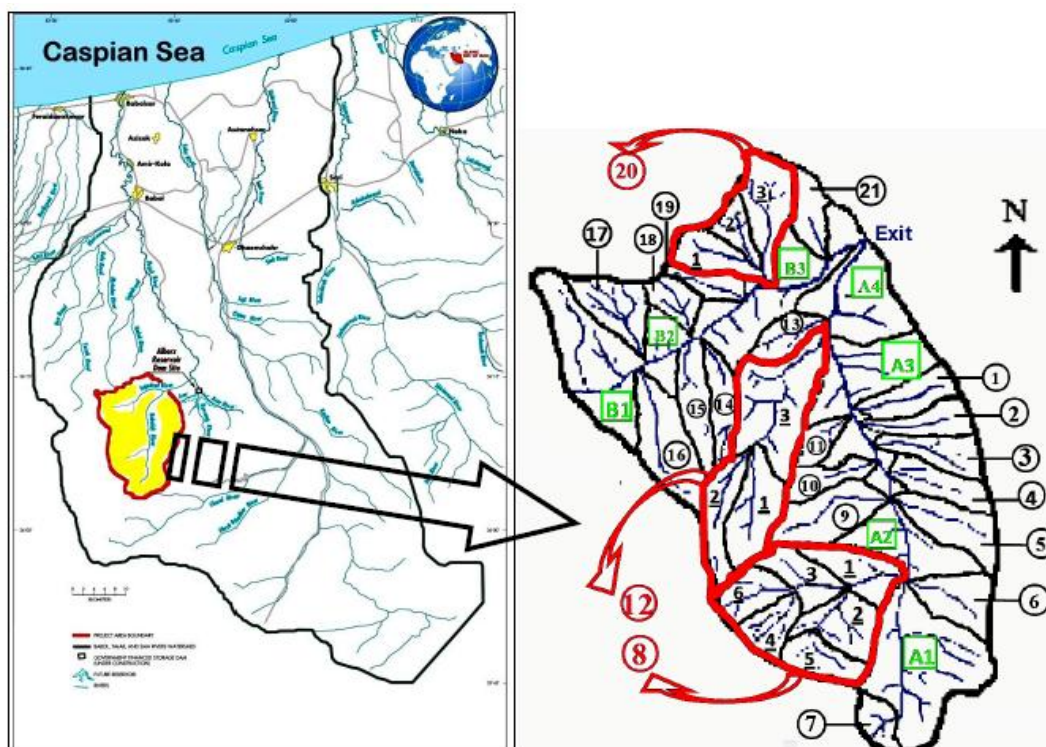
Therefore, the objective of this work was to investigate the effect of urbanization on flash flood risks and its estimation in rural areas. To do this, urbanization, filterability, soil type, annual rainfall, runoff and discharge of 40 sub-basins in Babol River basin were measured and analyzed. The soil type of each sub-basin was numbered based on The Soil Conservation Service (SCS) classification system. In addition, we modified the conventional Q-A method for flood estimation based on a regional relation between the watershed area and the mean annual pick discharge quantity (Q-A relation) and a local correction based on the effect of urbanization on the annual flood discharge values. The results of this study can be used for flood risk estimation in un-gauged watershed and urbanization management.



## 2. Materials and methods

### 2.1. Description of the study area

The Samagoosh basin is located at latitude 36°05′N - 36°12′N and longitude 52°33′E - 52°40′E, with an area of 7650 km<sup>2</sup>. The basin with several small villages is placed approximately 50 km south of Babol city, one of the main northern provincial cities of Iran (Fig. 1). The basin's main river is the Sajadroud River, which is 85 km. The basin is mountainous, with a 2437m difference between the highest and lowest elevation. The mean elevation of the basin is approximately 1400m and the mean slope is 47.1%. This basin itself is a sub-basin of the Caspian Sea basin. The rainfall averages around 600 mm and most areas of the basin have a humid climate, consequently, there are frequent rainstorms. Furthermore, most of the basin is located at a high elevation up to around 2500 m. Historical records indicate that floods normally occur in April and May. Generally, the high-intensity rainfalls are created by the convective and ascendant motion of the humid front on the high zone. Based on the conditions of the main rivers and major diversion channel, the basin is divided into two main sub-basins (A and B) which consist a total of 40 sub-basins with the characterizations described in Table 1.





**Figure 1. Map of the study area**

## 2.2. Rainfall and hydrological data collection methodology

All 40 sub-basins were gaged and the annual peak discharge (Q) data were collected from streamgauge stations for all basins. Table 1 presents a summary of the morphometric and topography of the Samagoosh basin

**Table 1. A summary of the morphometric and topography of the Samagoosh basin**

N.	Basin	Area (hc)	Slope (%)		Elevation(m)			Perimeter (m)	Drainage density (m/day)	Time of concentration (h)
			Basin	Stream	Max.	Mean	Min.			
1	1	72.8	48.7	40.27	1650	1399	1018	3800	1.95	0.11
2	2	65	37.8	33.69	1760	1423	1094	4050	2.92	0.13
3	3	182.5	38.8	31.89	2100	1715	1149	6625	2.3	0.21
4	4	101.2	39.6	41.16	2206	1764	1232	5350	1.75	0.14
5	5	127	41.5	40.93	2300	1849	1264	6000	1.89	0.18
6	6	113.2	45.1	41.24	2526	2111	1520	5700	1.68	0.15
7	7	57.5	31.9	19.6	2970	2879	2700	3475	3.26	0.15
8	8	979	58.9	30.23	3087	2362	1520	12075	2.78	0.27
9	8-1	215	52.1	39.97	3082	2454	1698	5970	2.64	0.21
10	8-2	205	57.3	43.3	3022	2407	1698	5625	3.02	0.19
11	8-3	190	59.01	43.1	3087	2634	2080	5661	3.12	0.14
12	8-4	103	60.1	53.13	3087	2675	2200	4349	3.61	0.11
13	8-5	123.5	57.1	44.46	2942	2525	2000	4802	2.73	0.13
14	8-6	142.5	46.6	41.62	3000	2578	2080	4975	2.64	0.21
15	9	132	50.0	35.48	2400	1817	1264	5850	2.31	0.18
16	10	111	51.7	37.22	2120	1681	1188	5375	2.44	0.15
17	11	83	52.0	33.19	1830	1460	1080	4100	3.3	0.13
18	12	948	43.4	23.63	2784	1775	830	14700	2.36	0.47
19	12-1	295.7	45.0	37.81	2640	2051	1380	7250	1.80	0.18
20	12-2	247	37.1	34.01	2784	2150	1380	9825	1.7	0.29
21	12-3	405.3	46.2	28.12	2524	1677	830	8625	3.50	0.38
22	13	89	38.0	20.32	1240	1010	792	5725	3.23	0.15
23	14	189.5	55.9	27	2040	1377	838	7500	3.15	0.25
24	15	204	52.4	31.43	2120	1470	900	7150	2.85	0.21
25	16	373	36.2	29.16	2520	1761	1071	10000	1.85	0.26
26	17	233	49.3	28.6	1860	1471	1005	6775	3.4	0.21
27	18	148	42.0	24.6	1620	1217	880	5500	2.78	0.18
28	19	113	26.2	19.6	1400	1077	780	6425	2.65	0.27
29	20	636	35.0	14.23	1525	1136	760	11125	3.05	0.34
30	20-1	247	35.7	15.88	1520	1131	800	8250	2.95	0.30
31	20-2	132	25.0	18.82	1340	1127	800	6600	3.07	0.28
32	20-3	236.3	41.0	21.7	1525	1173	791	6800	2.75	0.24
33	21	128	43.9	28.09	1440	1023	680	7150	2.81	0.18
34	A1	556	41.8	22.54	2780	2150	1520	10948	2.55	0.31
35	A2	161	39.7	21.4	2530	1943	1355	7251	1.87	0.21
36	A3	489	43.6	15.5	2950	2575	2200	8546	2.3	0.18
37	A4	254	36.5	14.3	2015	1333	650	6830	2.1	0.15
38	B1	476	51.3	21.4	2980	2840	2700	9870	2.81	0.26



39	B2	116	44.2	20.1	1635	1442	1050	4520	2.3	0.12
40	B3	397	27.5	18.4	2500	1575	650	11386	2.5	0.36
<b>TOTAL</b>		<b>7650</b>	<b>47.10</b>		<b>3087</b>	<b>1621</b>	<b>650</b>	<b>41250</b>	<b>2.6</b>	<b>-</b>

The mean monthly and annual rainfall data were available from rain-gauge records. Table 2 illustrates the mean monthly rainfall for each sub-basin.

**Table 1. Mean monthly rainfall (mm) for each sub-basin**

N.	Sep.	Aug.	Jul.	Jun.	May.	Apr.	Mar.	Feb.	Jan.	Dec.	Nov.	Oct.
1	12.90	10.99	11.11	38.03	91.44	72.73	87.40	61.15	45.21	59.72	56.67	30.80
2	13.00	11.07	11.19	38.31	92.12	73.27	88.06	61.60	45.55	60.17	57.09	31.03
3	14.13	12.04	12.17	41.65	100.15	79.65	95.73	66.97	49.52	65.41	62.06	33.73
4	14.33	12.20	12.34	42.23	101.55	80.77	97.06	67.91	50.21	66.32	62.93	34.20
5	14.63	12.46	12.60	43.13	103.71	82.49	99.14	69.36	51.28	67.74	64.27	34.93
6	15.66	13.34	13.49	46.18	111.02	88.30	106.12	74.25	54.89	72.51	68.81	37.39
7	18.65	15.89	16.06	54.98	132.19	105.14	126.35	88.40	65.36	86.34	81.92	44.52
8	16.64	14.17	14.32	49.04	117.92	93.79	112.71	78.86	58.30	77.01	73.08	39.71
9	14.53	12.38	12.51	42.84	103.01	81.93	98.47	68.89	50.93	67.28	63.84	34.69
10	14.00	11.93	12.06	41.28	99.26	78.95	94.88	66.38	49.08	64.83	61.52	33.43
11	13.14	11.19	11.31	38.74	93.14	74.08	89.03	62.28	46.05	60.83	57.72	31.37
12	14.36	12.23	12.37	42.34	101.79	80.96	97.30	68.07	50.33	66.48	63.09	34.28
13	11.40	9.71	9.81	33.59	80.77	64.24	77.21	54.01	39.94	52.75	50.06	27.20
14	12.82	10.92	11.04	37.79	90.85	72.26	86.84	60.76	44.92	59.34	56.31	30.60
15	13.18	11.22	11.35	38.84	93.40	74.28	89.27	62.46	46.18	61.00	57.88	31.45
16	14.30	12.18	12.32	42.17	101.38	80.64	96.91	67.80	50.13	66.22	62.83	34.14
17	13.18	11.22	11.35	38.84	93.40	74.28	89.27	62.46	46.18	61.00	57.88	31.45
18	12.20	10.39	10.50	35.95	86.45	68.76	82.64	57.81	42.74	56.46	53.58	29.12
19	11.65	9.93	10.03	34.35	82.60	65.70	78.95	55.24	40.84	53.95	51.19	27.82
20	11.88	10.12	10.23	35.03	84.22	66.99	80.50	56.32	41.64	55.01	52.19	28.36
21	11.44	9.75	9.85	33.73	81.11	64.51	77.53	54.24	40.10	52.97	50.27	27.32
A	14.67	12.50	12.63	43.25	103.99	82.71	99.40	69.54	51.42	67.92	64.45	35.02
B	12.46	10.62	10.73	36.74	88.34	70.26	84.44	59.08	43.68	57.70	54.75	29.75

### 2.3. Characterization of the urbanization

The effect of urbanization has been characterized by measuring the infiltration ability of the soil. The Soil Conservation Service (SCS) has conducted comprehensive research into the division of soil types according to their effect on runoff (kumar et al., 2021)[20]. Table 3 shows the categorization based on the SCS soil category.

**Table 3. Categorization of basins according to basin soil type.**

Basin Soil type	Min Infiltration (mm/hr)	Runoff potential	Soil Type Number (N <sub>ST</sub> )
Class A	7.5 – 11.5	Low	4
Class B	3.8 – 7.5	Moderate	3

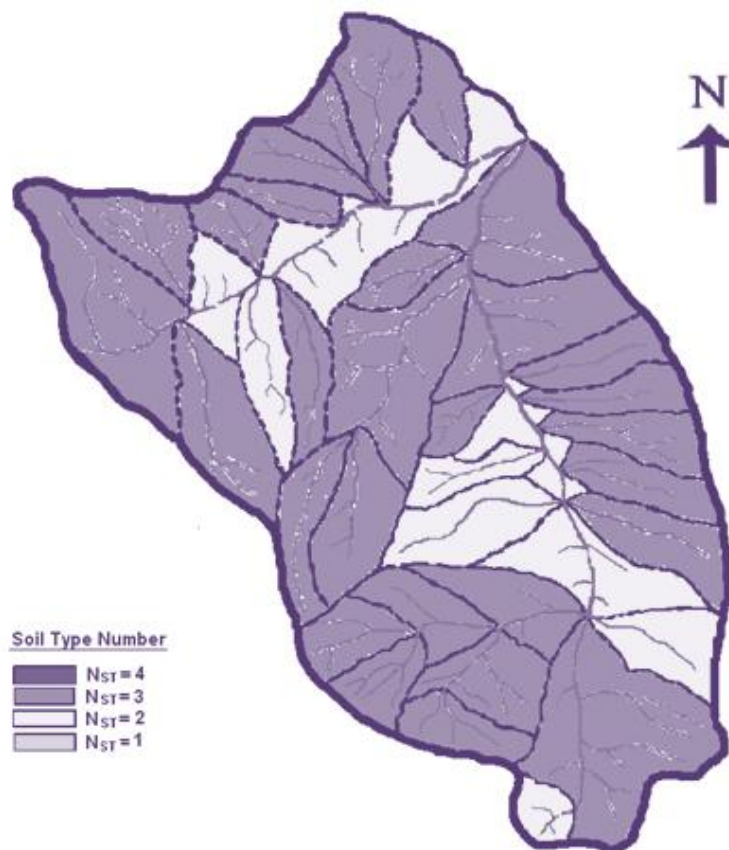


Class C	1.3 – 3.8	Moderately high	2
Class D	0 – 1.3	High	1

### 3. Results and discussion

#### 3.1. Effect of urbanization on flood risk

Figure 1 illustrates the whole basin and categorizing sub-basin based on table 3. As can be seen from the figure, most of the basins near the rivers showed lower soil type number ( $N_{st}$ ) which indicates lower permeability (Class D). This is due to urbanization and building houses and asphalt by humans. However, sub-basins at higher elevation mostly in the forest area demonstrated higher soil number ( $N_{st}$ ) which means higher filterability due to soft soil and presence of trees and green land.

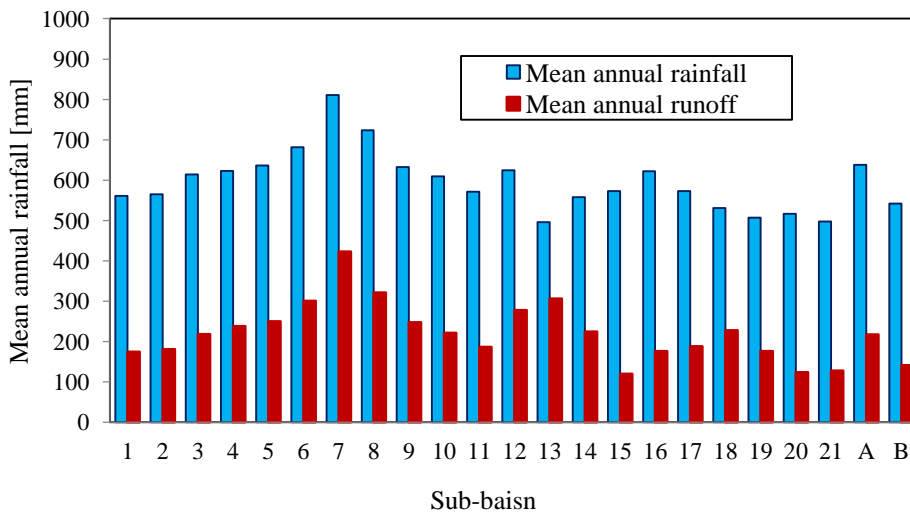






**Figure1: Effect of urbanization on soil infiltration**

Figure 2 shows the mean annual rainfall and runoff in different sub-basins. According to the results, the sub-basin number A, B, 6, 7, 9, 10, 11 and 17 showed less infiltration and higher runoff (almost half of the rainfall) due to the urbanization. For example in sub-basin number 7, approximately 400 mm of the annual rainfall (~ 60%) turned to runoff which results in to flash flood and only 30% of the rainfall was infiltrated into underground water. In contrary, in the basin with higher soil number ( $N_{st}$ ), less portion of mean annual rain fall turned to runoff due to higher infiltration because of the soil type and presence of trees. For example in basin number 1, the mean annual rainfall and runoff were recorded as 561 and 174 mm respectively which means almost 70 % of the rainfall was infiltrated into the ground water and only few present (30 %) turned to runoff.



**Figure 2: Mean annual rainfall and runoff in each basin**

**3-2- Effect of urbanization on flood estimation.**

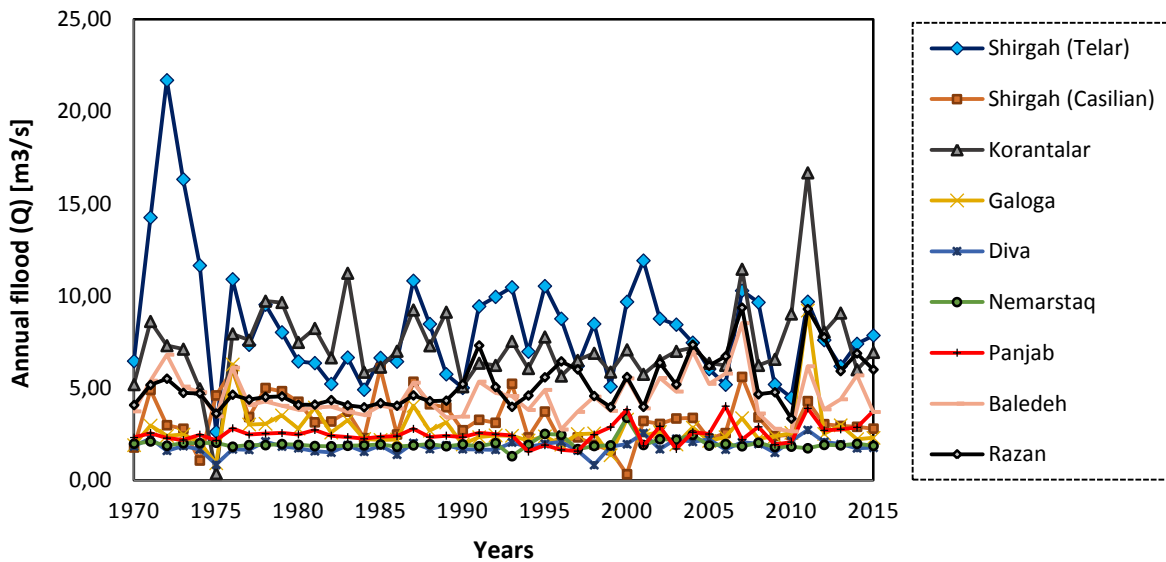
In order to estimate the flood values of the ungauged sub-basin in this study, we used Q-A graph which have been plotted by using data collected from 10 gauges station in the same area of Babol River. Table 4 presents the characterization of the 10 rivers in the main basin of Babol Rive which have gauge stations for recoding flood during the last 50 years. The total area (A) and the mean annual flood (Q) of the 10 rives are presented in Table 4. In addition,



Figure 3 represents the variation of the annual flood (Q) variation during the last 50 years in the 10 gauged rivers in the Babol River area.

**Table 4.** The characteristics of stream gauge stations in the area of Babol River

Elevation (m)	Latitude	Longitude	Area (km <sup>2</sup> )	Station	River	Mean annual flood Q (m <sup>3</sup> s <sup>-1</sup> )
270	36° 17'	52° 53'	1373	Shirga	Talar	8.32
270	36° 18'	52-53	343	Shirga	Kesilian	3.31
150	36° 17'	52-47	1193	Korantalar	Babolrood	7.31
100	36° 18'	52-38	261	Galoga	Sajjadrood	2.76
160	36° 18'	52-34	136	Diva	Kelarood	1.82
2500	36° 06'	52-05	120	Nemarstaq	Heraz	127
800	36° 06'	52-15	276	Panjab	Nemarestaq	2.50
2000	36° 12'	51-48	672	Baledeh	Noor	4.52
230	36° 11'	52-11	730	Razan	Noor	5.21
220	36° 16'	52-22	6057	Karahsan	Heraz	25.38



**Figure 3:** Annual flood values (Q) recorded during last 50 years in the gauged rived

Figure 4a shows the Q-A graph obtained from the 10 gauged rived data (Table 4) in the Babol River area. As can be seen from the figure, mean annual flood values of the basins showed a linear relationship with the area of the basin according to the following Eq.



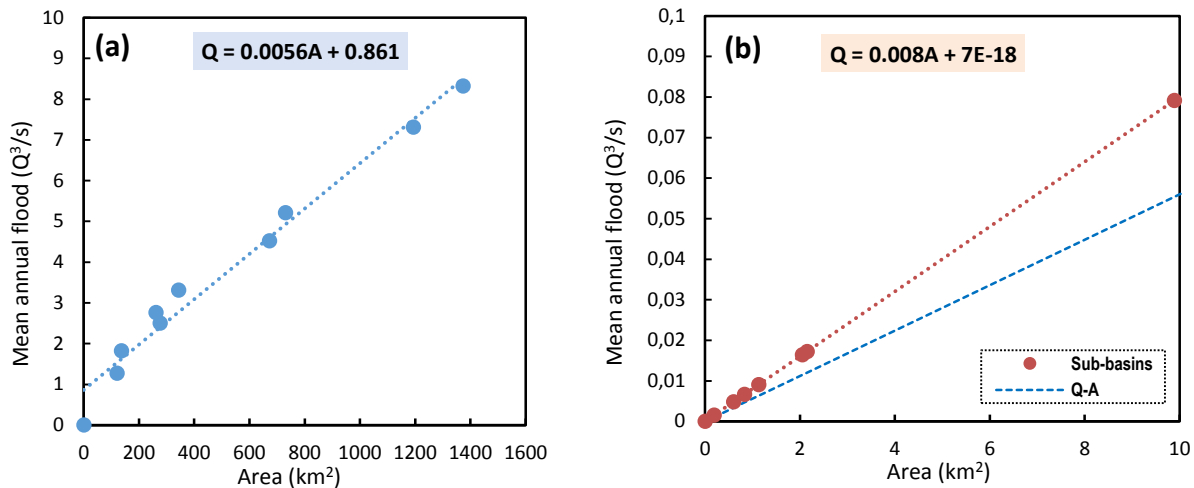
$$Q (m^3/s) = KA (km^2) \quad (1)$$

Where, Q mean annual flood ( $m^3/s$ ) and A is the area of the basin ( $km^2$ ). While, K is the slope of Q-A graph and was obtained as 0.0056.

Considering the similar characterization of climate and geology between the 10 gauged basins (Table 4) and the 40 sub-basins, Eq. (1) can be used for flood prediction of each sub-basins presented in figure 1 and table 1. However, the results of Q-A graph of the high flood risks sub-basins (e.g. A, B, 6, 7, 9, 10, 11 and 17) which is shown as figure 4b, illustrates the effect of urbanization on the flood prediction through Q-A graph. As can be seen from figure 4, the K value has been increased from 0.0056 to 0.008 when the soil number decreased for 4 to 1, respectively. The modified Q-A relation for high risk sub-basins after urbanization is calculated as Eq. (2):

$$Q (m^3/s) = 0.008A (km^2) \quad (2)$$

According to the results, urbanization can increase the slope of Q-A graph up from 0.0056 to 0.008. The results suggest that the flood risk can be increased up to 42 % due to urbanization and reducing the in filterability of the soil.



**Figure 4:** Effect of urbanization on flood estimation (a) Q-A graph based on gauged basins and (b) the actual flood values in high risk sub-basins

#### 4. conclusion

This work is a case study for investigating the effect of urbanization on flash flood risks and estimation in rural areas. The data obtained from 40 sub-basins of Babol River, Iran, proved that urbanization has significant effect of flash flood risk. The mean annual runoff values in some sub-basin were increased up to 40% after urbanization and reducing the soil filterability. The results of the flood estimation through using Q-A graph revealed that, urbanization can affect flood estimation up to 42% lower than the actual flood of the high risk basin. This case study proved that urbanization in rural area can increase flood risk up to 50% (1.5 fold) which is a severe problem that should be address appropriately.

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