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RESEARCH PAPER

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Estimating the probable maximum flood (PMF) using HEC-HMS Model: A case study in Northwest Iran-Ajichay's Basin

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Abstract

Flood estimation is an important component of hydrology studies, water resource's projects and especially dam construction projects. In this study in order to estimate PMF of the Ajichay basin, we have selected HEC-HMS model among other precipitation-runoff mathematical models. Thus, the meteorological data records of 40 synoptic and rain gauge stations were gathered from the Bureau of Meteorology and the ministry of water resources (Tamab). Then, to estimate the basin's probable maximum flood, the main basin was divided into some smaller sub-basins and the physiographic characteristics of each basin were determined. The rainfall pattern was selected to base on a 24-hour rainfall type II pattern, and the largest 6-hour rainfall was extracted in different return's periods. Next, the HMS model was applied in order to create hydrographs of PMF at different return's periods and then hydrographs of PMF were drawn for various sub-basins. The amounts of PMF were calculated for all the sub-basin as well. The total PMF values at the return's periods of 2, 10, 25, 50, 100 and 200 years, were estimated accurately 18261, 33073, 42212, 49207, 55845 and 62198 in cubic meters per second respectively, over the Ajichay's catchment.

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Introduction

Floods are inherent phenomena of terrestrial hydrologic systems with wide-reaching impacts on society, including agricultural, economic and ecological systems (Smith and Ward, 1998). Uncontrolled flood waters are one of the most powerful and destructive forces in nature. Dams that are not designed to withstand major storms may be destroyed by them, increasing flood damages downstream. This damage is often catastrophic. The Probable Maximum Precipitation (PMP) is the greatest depth (amount) of precipitation, for a given storm duration, that is theoretically possible for a particular area and geographic location, while the Probable Maximum Flood (PMF) is the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area. Flooding is the most common of disastrous acts of nature among all catastrophes leading to economic losses and death (Sharma and Priya, 2001). A flood can be defined as a mass of water, which produces runoff on land that is not normally covered by water alternatively a flood is a fairly high flow, which overburdens the natural channel, provided for the runoff (Ward, 1978). Around 390,000 persons have died since 1988 to 1997 because of natural disasters in which about 58% belonged to the Flooding. The whole damages had been approximately 700 billion dollars over the 10 years that 35% are related to the flood (Payzad 2002). In this case, the alarming point is the ascending trend of flood's damages and losses in recent decades in the world. Here, high rates in population and belongings in the flood plains, hydro-system variations, and the deleterious effects of human activities, were identified as the main reasons of such climbing trend. Control constructions such as dams, barriers, and flooding canals are designed somehow to keep and preserve the regions under the flooding areas with certain return's periods. The safety level is usually built based on economic condition, the relevant society's propensities, bio-environmental effects, and so forth. Engineers can design the structures in a way that guarantee a high level of safety. The researches in the field Probable maximum flood are as follows:

Shiravand (2004) tried to evaluate the Golestan dam basin's probable maximum flood (PMF) by using probable maximum precipitation (PMP) synoptically. On her work, she has first estimated the PMP through a synoptically analysis of the severest storms occurred in the area, and then has applied a HEC-HMS model based on mathematic to simulate the basin's PMF. Mahtab Qods's consulting engineers (2001) estimated the PMF for Gaovshan's dam basin based on synoptic maxima rainfall by using HEC-1. Bostani (1999) evaluated the Karoon river basin's PMF until Shaloo's bridge. In that study, the important flood's hydrographs occurred in the Karoon river basin until Shaloo's bridges in the study stations were considered as the portion of various sub-basins The HEC-HMS model was used by Loukas *Et. al.* (1995) in order to estimate the severity of daily streams around Jermasoya located in the South of Sypros, and three procedures to estimate the daily hydrograph's climaxes were examined. Those three methods were: the adjusted Clark's method, hydrograph of Snyder's unit, and SCS method. Soltani *Et. al.* (2008) calculated PMP values for the area around Tehran City. In a recent work, 24-hour and annual PMP values in northern Tehran, Dooshan Tapeh, Geophysics and Mehrabad synoptic stations were estimated, with 24-hour PMP results varying from 192 to 216 millimeters based on at for the stations studied. Johnson *et al.* (2001) were applied HMS model by using Arcview to do a network hydrologic analysis in river's basin of Sanjasinto in around 325 miles toward the East of Fork. Casas *et al.* (2011) estimated the probable maximum precipitation in Barcelona (Spain). Ohara *Et. al.* (2011) estimated maximum precipitation over American River watershed.

The study area of this research is Ajichay's basin in Northwest Iran and belongs to one of the most important sub-basins of Urmia Lake. Geographically, it is located between $37^{o}\ 42^{/}$ to $38^{o}\ 30^{/}$ North, and 45^{o}

40′ to 47° 53′ East. This basin begins at 3400m heights of South and Southwestern hillsides of the Sabalan Mount around 33-kilometers of the Northeast Sarab city (in Aghmion village) and ends with passage of North Tabriz in West Azarshahr, in the height of 1270m to the Urmia Lake. The whole basin's circumference is nearly 12790 square kilometers. Fig. (1) Shows the geographic location of the Ajichay's basin with regard to the whole country. With respect to the aforesaid necessity in determining the PMP and PMF for water construction, this paper aims are:

Estimating the probable maximum flood (PMF) by using HMS model in the Ajichay river basin.

Enhance the capability to use the existing procedures for PMF determination.

Identifying the problems and obstacles, and offering modern techniques by taking computer tools.

Helping to build dams and reduce the damaging effects of floods in the basin.

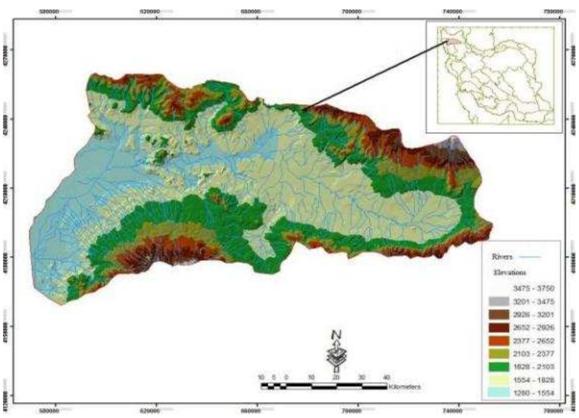


Fig. 1. Geographic position of Ajichay's basin and the underlying topography.

Materials and methods

At the present research, a hydrologic simulation method in converting the precipitation-runoff over the sub-basins as well as trending in the main watercourses to extract the flood's outlet hydrograph has been applied. Hourly and daily discharge data of the basin's hydrometric stations and also data records of hourly and daily precipitation for synoptic, climatology, and rain gauge stations were collected from Water Resources Researches Organization (Tamab) and the Iranian Meteorological Organization for a period of 30-years (1976-2005).

The catchments' map was produced by using a digital-elevation model of HEC-GeoHMS through GIS and then the study basin was divided into 30 sub-basins with respect to the region's attributes (Fig. 2). As it is shown in Fig (2), the Ajichay's basin is composed of 4 middle sub-basins called IB1 to IB4. To simulate the whole basin's hydrograph in the HMS model, it is required that the flood's hydrograph to be trended between the above scales. In flood trending, also, it is essential to determine the concentration and delay times of length and width segments of the river in which the concentration and delay times are computed through the following equations:

The California equation was used to compute the concentration time:

$$T_c = \frac{L}{1.5\times D} \times \sqrt{\frac{A2}{F}} \qquad (1)$$

Where:

Tc: the concentration time (hourly);

L: the length of main watercourse (km);

D: circle diameter of the same level of the basin (km);

A: the basin's circumference (km^2);

F: the average slope of watercourse at meter per 100m (%).

The following formula has been suggested by SCS to evaluate the time lag, which in case of being available the Curve Number (CN), it can be used:

$$T_p = \frac{\Delta t}{2} + T_{Lag}$$

$$T_{Lag} = \frac{L^{0/8}\,(s+1)^{0/7}}{1900 W_s^{0/5}}$$

$$S = \frac{1000}{CN} - 10 \qquad (2)$$

Where:

T_{lag}: time lag of the basin (hourly);

L: the length of Main River;

Ws: the basin's average slope;

S: an index of water storage over the basin's surface;
CN: the curve number related to the basin's surface.

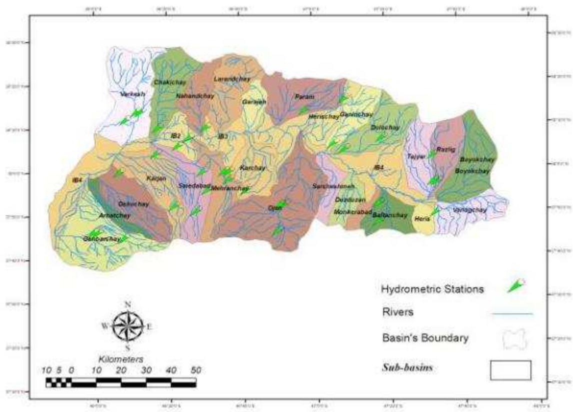


Fig. 2. Several sub-basins of Ajichay basin

Therefore, the concentration and time lag in each segment were determined through the relevant equations. Hydrographic characteristics of various sub-basins of the Ajichay's basin have presented in Table (1). HEC-HMS model is a hydrologic model system belonging to the engineering group of the United States' army, a new generation software for precipitation-runoff simulation in which includes a substitute software package of flood hydrograph HEX. This program includes a graphical screen for user, advanced analysis sections of hydrology, data storage, management tools, and useful graphical & reportage programs. This model displays the basin as a coalesced system along with hydrologic and hydraulic components. Each model's component shows an aspect of precipitation-runoff process inside a part of the basin, which is usually considered as sub-basin. On the other hand, different components are combined to simulate the basin's physical system, and each component is responsible for merely a part of the required computations for a full hydrograph.

Table 1. Hydrographic attributes of various sub-basins for Ajichay's basin.

Sub-basin's names	*Area (km^2)*	*Circum-ference)km)*	*Max. Elevation*	*Min. Elevation*	*Main Watercourse Length (km)*	*24-h rainfall*	*Concen-tration Time*	*Time Lag (h)*	*6-h rain-fall*
Biok Chay	500.1	108.3	3750	1700	46.5	40	3.5	2.6	27
Vanegh Chay	342.2	88.9	3101	1700	34.8	56	3.2	1.9	37.8
Tajiar	322.3	85.2	3400	1700	34.6	35	3.2	1.9	23.6
Baftan Chay	263.1	74.8	3200	1625	24.3	52	2.25	1.4	35.1
Dozdozan	193.7	65.9	2538	1625	24.6	60	2.27	1.4	40.5
Sarcheshmeh	180.5	80.01	2400	1580	29.2	63	2.7	1.6	42.5
Ojan	1054.4	162.9	3500	1580	73.6	73	6.8	4.1	49.3
Karchay	357.8	87.4	2510	1500	42.7	68	3.9	2.3	45.9
Mehran Chay	345.5	118.3	3656	1400	63.9	68	5.9	3.5	45.9
Kar Chay	479.5	114.2	3280	1362	43.8	63	4	2.1	42.5
Razligh	505.5	83.6	3335	1359	38.1	35	3.5	2.1	23.6
Esko Chay	458.7	98.9	3342	1317	47.2	46.7	3.5	2.6	31.5
Varkosh	703.3	135	3802	1299	52	55	4.8	2.9	37
Asb Froshan	102.2	39.4	2700	1400	16.4	55	1.5	0.9	37
Nahand Chay	285.2	88.5	2800	1500	36.2	90	3.3	2	60.8
Larand Chay	443.5	96.2	2672	1500	46.8	85	3.5	2.6	57.4
Qarajeh	156.7	55.7	2827	1500	25.1	52	2.3	1.4	35
Param	492.5	102.9	2797	1500	40.8	47	3.7	2.2	31.7
Haris	183.5	79.2	3103	1593	40.4	48	3.7	2.2	32.4
Qanlo Chay	257.2	80.4	2650	1590	33	46.5	3.1	1.9	31.4
Chaki Chay	4302.3	104.2	3000	1590	46.5	54	3.5	1.8	36.4
Monker Abad	82.9	55.3	2200	1625	25.1	60	2.3	1.4	40.5
B1	509.2	159	2000	1500	70.4	56	6.5	3.9	38
B2	194.9	71.4	2336	1500	24.1	52	2.2	1.3	35
B3	510.8	199.8	2239	1293	55.4	63	5.1	3.1	42.5
B4	559.7	184.3	3168	1280	89.1	49	8.2	4.9	33
Saeidabad Chay	432.7	117.2	2956	1320	54.6	73.5	5	3	42.6
Arbat Chay	126.5	83.5	2740	1450	40.5	48	3.7	2.2	32.4
Gonbar Chay	721.8	125.9	2950	1500	54.8	48.5	5.1	3.1	33
Gomanab	438.3	110	2760	1400	39.2	56	3.6	2.2	38

The HMS model consisted of 3 main parts of basin model, climatic model, and control indexes. The land use map with a scale of 1:100000 published by the ministry of agriculture and the map of soil hydrologic categories belonging to the agriculture institute's researches of Eastern Azerbaijan province were digitalized using GIS, and after coalescing with the land use (Fig. 3) and soil hydrologic categories maps, in the long run the Curve Number (CN) map of the region was generated.

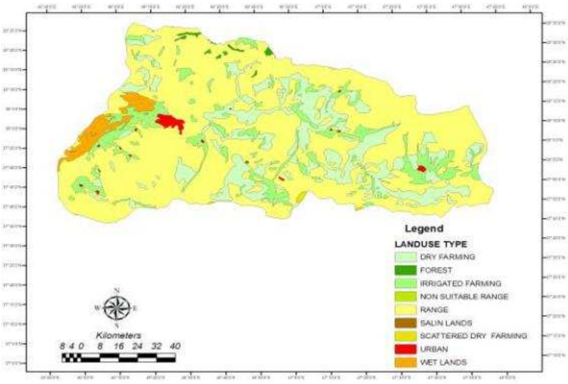


Fig. 3. Land use map of Ajichay basin.

In SCS method, the design hydrograph is extracted based on 6-hour rainfalls, provided that the basin's concentration time is less than 6-hours. The maxima 6-hour rainfall can be obtained through maxima 24-hour rainfall. To do so, the maximum 24-hour rainfall values should be divided by 1.48 to acquire the maximum 6-hour rainfall values. After obtaining the amount of 6-hour rainfall by the SCS hydrograph, the time distribution pattern of cloudburst must be determined. Following this procedure in this research, method recommended by soil conservation organization of USA, which has been approved by world meteorological organization (WMO), was used. For this purpose, first the maxima 24-hour rainfall happened over each sub-basin was ascertained within the investigated period, and then their return's periods were established by using SMADA powerful software. In continuation, the maximum 6-hour rainfalls were obtained through the 24-hour rainfalls using the aforesaid method. Having prepared the required data for the model's hydrologic ingredients was drawn schematically, and the relevant data was added to the model in 3 steps. In the basin's model section, the data related to the base water, wastes, and transition were also entered. In the climatic model's section, the precipitation data were put in the model. Thus, the maximum 6-hour rainfall values had been obtained based on the maxima 24-hour rainfalls; they were entered in the model in different gages. Finally, the control indexes of start, ending and the rainfall duration were introduced to the model. The schematic diagram of Ajichay's basin is shown in Fig. (4).

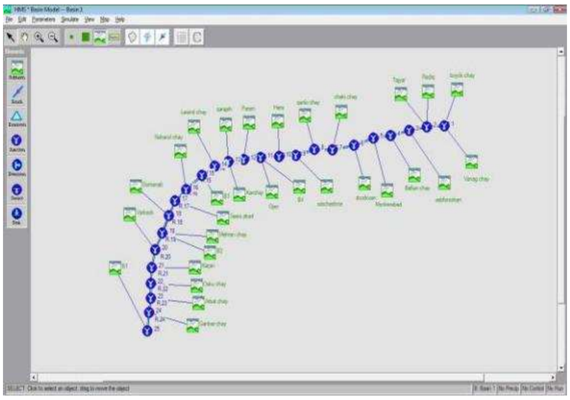


Fig. 4. Schematic diagram for Ajichay's basin.

Results and discussion

Having the inlet information completed to the model, it is the time to run the model in order to simulate the occurred rainfalls. After computing the rainfall volume both for the whole basin, and also for each sub-basin separately, the model reduces the initial wastes value and then extracts the runoff depth. The peak discharge and apex time are obtained after computing the artificial unit hydrograph. Having peak discharge computed, it is possible to evaluate and draw the flood's hydrograph resulting from the precipitation. In regard to the investigation on outlet peak discharge of each sub-basin it is observed that in the sub-basins ranked 1st and the last regarding area, the priority of their outlet peak discharge, has been based on their priorities with respect to the area which shows the relative effect of area in making the peak discharge for each sub-basin. The outlet results obtained from the model were compared with those of the available observational results, and eventually the final results of each sub-basin were acquired. Table (2) shows the PMF of various sub-basins for the Ajichay's basin in return's periods of 2, 5, 10, 25, 50, 100, and 200 years. The most probable flood among the sub-basins of the Ajichay's basin belongs to the Ojan's sub-basin with a discharge value of 11272 cubic meters; on the contrary, the Asb Froshan's sub-basin holds the lowest probable flood with a value of 1612 within a 50-years return's period. The hydrograph for each sub-basin of the Ajichay's basin was drawn in various return's periods, after calculating the PMF for all of the sub-basins. We brought the PMF hydrographs for sub-basins of Biok Chay, Vanegh Chay, and Razligh Chay as a sample, which are presented in Fig. (5) to (7) in various return's periods.

Finally, the probable maximum flood for the whole basin of Ajichay were obtained in going into the Oromiyeh Lake, and the basin's PMF in return's periods of 2, 10, 25, 50, 100, and 200 years were evaluated 18264, 33073, 42212, 49207, 55845, and 62198 $m^{2/s}$, respectively. Since in this research, the wastes value was considered zero in most sub-basins, the obtained results might seem a little bit over estimated and unlikely to occur in the nature. Such flooding as well as the outcomes attained from the model are based on a condition that the runoff caused by all sub-basins is reaching to the last one, while such a thing in the nature usually doesn't occur due to reasons like making dam over the sub-basins. The PMF hydrograph of Ajichay's basin in various return's periods are illustrated in Fig. (8).

Table 2. Results derived from the PMF in various return's periods over the Ajichay's sub-basins.

Sub-basins	***Area***	***Concen-tration Time***	***Time Lag***	***CN Soil***	***24-h Storm***	***Max. Storm***	***Flood's Return Period ($m_{2/s}$)***						
							2	**5**	**10**	**25**	**50**	**100**	**200**
Biok Chay	500.1	3.4	2.6	81.6	40	40.5	1906	2943.7	3623.5	3984.4	4422	4785	5301
Vanegh Chay	342.2	3.2	1.9	82	56	62	1756.7	2522	3500	4227	4494.8	5058	5503
Tajiar	322.3	3.2	1.9	81.9	35	38	1379.3	2050.9	2425	2858	3137	3387.7	3626
Baftan Chay	263.1	2.25	1.4	82.1	52	60	1451.8	1996.8	2749.6	3349.5	3604	3897	4139
Dozdozan	193.7	2.27	1.4	82.2	60	67	1169	1448.7	2384	2776.7	3028	3317	3661
Sarcheshmeh	180.5	2.7	1.6	82	63	65	1606.2	1501	1993	2417	2832	3112	3408
Ojan	1052.4	6.8	1.4	82.1	73	65	4463.2	6384.6	7797	9747.5	11272	12926	14677
Karchay	357.8	3.9	2.3	81.9	68	68	1933.2	3066.5	3889.6	5054.6	6013	7016	8106
Mehran Chay	345.5	5.9	3.5	82.2	68	79	1797	2876	3665	4786	5713	6684	7741
Kar Chay	479.8	4	2.4	81.9	63	61	2392.3	3267.5	4381.7	5349	6299	6940	7619.8
Razligh	305.5	3.5	1.2	81.1	35	41	1239.5	1857.5	2204	2604	2863	3096.6	3317
Esko Chay	458.7	3.4	2.6	81.3	46.7	33	1779.7	2319	2833	3509	4014	4538	5064
Varkosh	703.3	4.8	2.9	82.3	55	58	2721	3839.5	5134	6802	7241	8299.7	8635
Asb Froshan	102.2	1.5	0.9	82.3	55	56	650.7	894	1171	1522.4	1614	1834	1904
Nahand Chay	285.2	3.3	2	80.9	90	90	2304.7	1560	3594	4227	5866	6662	7103
Larand Chay	443.3	3.4	2.6	81.4	85	85	3000.5	4011.8	4587.2	6031	7713	8851	9529
Qarajeh	156.7	2.3	1.4	81.7	52	53	859.4	1387	1635	1993	2146	2321	2466
Param	492.5	3.7	2.2	81.7	47	50	2195.2	2875	3667	4593	4943	5644	6263
Haris	183.5	3.7	2.2	82.3	48	48	852	1099.5	1350	1779	1894	2071	2424
Qanlo Chay	257.2	3.1	1.9	81.9	46.5	47	1199.7	1539	1883	2250	2752	3009	3422
Chaki Chay	4302.3	3.4	1.8	81	54	60	1690	2341.4	3135.6	4217.8	4481	5140.5	5454
Monker Abad	82.9	2.3	1.4	81.5	60	60	493.9	613	1015	1184	1292	1416	1564
B1	509.2	6.5	3.9	81.7	56	58	1604	2366	3362	4114	4391	4978	1542
B2	194.9	2.2	1.3	81.1	52	54	1075.8	1482.7	2042.5	2494	2684	2903	3084
B3	510.8	5.1	3.1	82.1	63	67	2107.9	2911	3921	4799	5664	4254	6887
B4	559.7	8.2	4.9	82.1	49	49	1462.4	1892	2386.8	3143	3539	3781	4067
Saeidabad Chay	432.7	5	3	81.7	73.5	75	1728.4	2683	3127.5	4021	4632	5119	5855
Arbat Chay	126.5	3.7	2.2	81.5	48	52	574	743.8	916	1211	1290	1412	1656
Gonbar Chay	721.8	5.1	3.1	81.3	48.5	49	2560	3614	4346.8	5432	6226	6699	7572
Gomanab	438.3	3.6	2.2	81	56	27	2030.9	2960.7	4162	5061	5391	6089	6641

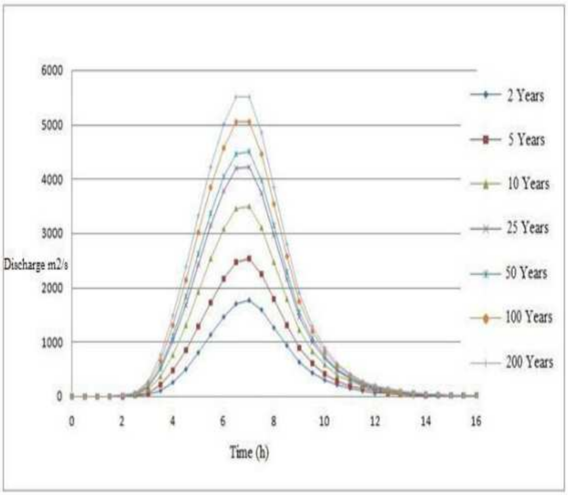


Fig. 5 . Flood's hydrographs of Biok Chay's sub-basin.

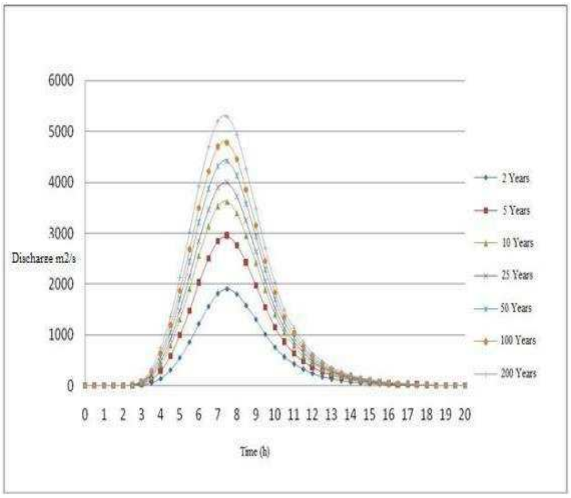
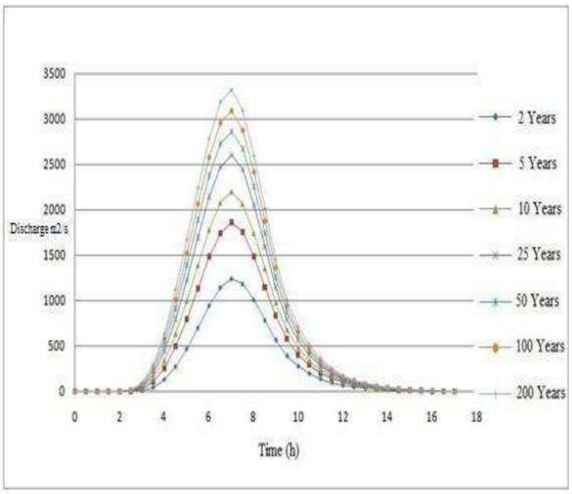


Fig. 6 . Flood's hydrographs of Vanegh Chay's sub-basin.



Figs. 7. Flood's hydrographs of Razligh's sub-basin.

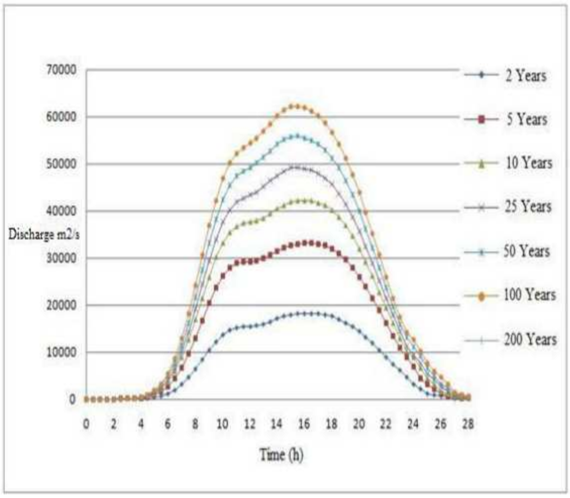


Fig. 8. Flood's hydrographs of Ajichay's sub-basin.

Conclusions

It is often expected that water store and distribution constructions are constructed in a way that lead the maxima floods with no serious damage and/or ruin. Although, such sensitivity with respect to hydraulic structures vary based on the importance of structure and various standards in different countries. In this paper, the HMS model has been applied to simulate the Ajichay basin's PMF. After investigating the outlet peak discharge of each sub-basin, it was determined that in the sub-basins ranked 1^{st} and the last regarding area, the priority of their outlet peak discharge, has been based on their priorities with respect to their area which shows the relative effect of area in making the peak discharge for each sub-basin. The most probable flood among the sub-basins of the Ajichay's basin belongs to the Ojan's sub-basin whereas the Asb Froshan's sub-basin holds the lowest one. Finally, the PMF's values in various returns' periods for all the sub-basins were calculated and then their hydrographs were drawn. The obtained results showed that the whole Ajichay basin's PMF in return's periods of 2, 10, 25, 50, 100, and 200 years possess values of 18261, 33073, 42212, 49207, 55845, 62198 $m^{2/s}$ respectively.

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