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The rainfall – runoff simulation with Hybrid method (Case study: the catchment basin of Sofi Chay)

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Abstract

The rainfall – runoff simulation in the basin is the awareness toward the Hydrological answer of rainfall basin and due to its importance in managing and utilizing the available water resources (providing different drinking, agricultural and industrial consumptions, Flood warning system and designing water regulator structures), it was an evitable subject of hydrological researches in recent years. In hydrology, to show the flow direction and calculating the slope of regions, digital elevation model (DEM) is used that in the current study, the flow direction of each cell of basin to its output was determined using the digital elevation model and finally, the total volume of allocated water to each cell was identified. In this research, the rainfall – runoff process was survey by two hybrid and networking models using ArcGIS 9.3 software in the catchment basin of Sofi Chay locates in East Azerbaijan Province that in the study, the amount of Discharge output and the runoff resulted by rainfalls were measured. The results were about the correctness of hybrid model.

Keywords: Rainfall, Runoff, hybrid model.

Introduction:

The arid and semi-arid regions in world are facing with restriction of water resources. A wide range of our country is located in the arid and semi-arid part. In these parts, the rainfall is usually negligible and irregular and has severe locational and temporal changes (Bahat et al, 2009). In addition, the time of atmospheric precipitation is not in the line with needs that is a feature of arid regions and has a lot of effects on hydrological cycle and water resource. The recognition of arid regions hydrology is the requirement for recognizing these environments and distinguishing their vulnerability to change. The major source of uncertainty in hydrological modeling the arid and semi-arid regions is rainfall error. The lack of long-term observational data is the most major problem in arid regions (Pilgrim et al, 2009). In hydrological designing, there are always factors which are dependence to location and situation design;

means the regions characteristics in the terms of Land use, slope, and the availability of water supply and the position of surface water discharge point have direct influence on plan. The rainfall – runoff simulation in the basin is the awareness toward the Hydrological answer of rainfall basin and due to its importance in managing and utilizing the available water resources (providing different drinking, agricultural and industrial consumptions, Flood warning system and designing water regulator structures), it was an evitable subject of hydrological researches in recent years. The simulation of rainfall – runoff process is an effective step to manage the water resources, watershed management, flood control and water shortage crisis. Therefore, it seems essential to choose a model that can acceptably predict the runoff resulted by rainfall using the effective factors. This process is a complex and non-linear in catchment basin and due to the locational-temporal changes and effective factors, its simulation with physical and hydrological models needs more information and also difficult calculation times. The operations of the dam reservoirs, organizing rivers and essential actions in order to control the flood direction need precise estimations of rivers direction. In a basin as a hydro-system, there is always the possibility of flood danger during and after the rainfall. The factor of transforming ultra-rainfall into runoff is directly affected by the hydrological answer of upflow levels of the basin. As most of the catchment basins of country for measuring the flow Discharge are lack of hydrometric stations, the hydrologists have to develop and edit the correct rainfall-runoff and appropriate calibrated models with various catchment basins for estimating the floods resulted by storms. One of the actions is attempting to find a strong relationship between the hydrograph of basin unit with its physical structure especially its drainage network properties. The hydrograph which forms in the discharging point of catchment basin can show the hydrological reaction of the basin toward the rainfall characteristics so that the hydrograph form of output flow of basin is relying on the determinant conditions of water movement on the ground surface and waterways. The rainfall-runoff simulation in basins needs various physiography and hydraulic features that due to the lack of identification about how they affect the rainfall-runoff process in the basin is considered in the form of network which in this case, the physiography features of each network will be precisely identified and entered into the model. In Snyder model and Soil Conservation Society of United States (SCS), the important features of hydrograph such as peak discharge (Discharge), peak time, latency and base time of hydrograph are measured according to the experimental relationships and a curve can be fitted between these points which in addition to appliance of personal opinions, the simultaneous control of the area under the curve will take place (Bonia et al, 2005). One of different kinds of simulation models is rainfall-runoff hybrid model. The hybrid model is a conception that by an opinion conducts pairing the simulation process reservoirs. In this model, the input (rainfall) is entered into reservoir and then after passing the second reservoir will proceed until the end of hybrid unit so that at the output door exists as a hydrograph. This hydrograph is the first output of first hybrid or the answer of system to the input (rainfall). The first unit output is considered as the input for the second hybrid unit that has the feature of first unit with storing coefficients which are the first reservoir coefficient and second reservoir coefficient. In this research, the networking model of the basin was extracted using ArcGIS software and DEM digital map in the catchment basin of Sofi Chay locates in East Azerbaijan, and then two hybrid and networking models of the basin will be surveyed and assessed. In following these subjects, the below researches were conducted: White et al (2004) surveyed the relative effect of geomorphological and hydrodynamic characteristics on the hydrological reaction in the basin of Illinois River with scale increment. The geometric and hydrodynamic characteristics which were used in this study were obtained

from the DEM map and hydraulic equations for the sub-basins of Illinois River basin that were determined by Fock and Stahl (1968). The results showed that geomorphology Parameters have more effective role in determining the hydrological respond than hydrodynamic parameters. In the following, we will consider some researches from different areas of world and Iran. Jin Kong et al (2009) in a study to route the runoff that was developed according to the travel time and regarding to the temporal and locational changes of runoff production and flow routing in river network tries to simulate the runoff respond process resulted from storm using a simple method based on GIS. They broke down the basin surface into arid cells and channel cells in the river network by networking the basin and using DEM map. The flow travel time of each arid area cell was estimated combining the permanent status of systematic wave method, manning equation and travel time in each area of cell using manning and permanent continuity status. They considered the travel time of each cell to the basin output as equivalent of water passing time collection in each cell along the flow path. The flow of direct runoff of all temporal distances obtains by assembling the amount of volumetric flow from all involved cells in any relevant travel time.

In Iran, similar studies have conducted in the field of estimating runoff using the rainfall information of geomorphological features in basins such as Ghahraman (1994) with selecting two basins of Emameh and Kasilian has used the geomorphological and geo-climatic momentary hydrographs models for some suitable rainfall – runoff events. They reached this conclusion that in events that there aren't significance changes in rainfall severity, both models obtain a same result in events with more complex rainfall and severe temporal changes, the geo-climatic method has higher capability in recovering the hydrograph.

Erfanian (1998) in his study in the catchment basin of Semnan obtained the mathematical relationships of determining the shape of hydrological reaction of 3 to 5 as a function of rainfall characteristics; the dynamic parameters of flow rate and Horton's geomorphological ratios by extending the theories of geomorphological and geo-climatic momentary unit hydrograph; and through the statistical comparison of measured and observational hydrographs showed that the geomorphological and geo-climatic momentary unit hydrograph has very great performance and accuracy than the common SCS method in extracting the unit hydrographs and estimating the form of runoff hydrograph in studied catchment basin. Delafroz et al (2007) extended the geomorphological rainfall –runoff model in the basin of Emameh using GIS model. This model has formed based on the concept of cascade linear reservoirs. Two features of this model are: A) the effect of basin characteristics in modeling and B) having just one estimable parameter. The results of presented model in this study with the Nash Model for Emameh Basin were compared. The achieved results indicate that the presented model has fairly better capability in simulating the rainfall- runoff in the mentioned basin due to the utilization of geomorphological characteristics in the basin. Salehi et al (2007) simulated the runoff resulted from rainfall in the catchment basin of Emameh using a mathematical model based on GIS with the time area diagram method. In this way that the topographical and hydro-morphological features of the basin quantitatively and in the form of raster were defined as topography indexes. Then, the path of each cell flow from digital elevation models (DEM) of the basin to the output were identified using ADEQUATE semi- two-dimensional algorithm. Also, he estimated the amount of distributed flow of each cell to one of the adjacent cells and finally determined the total allocated water mass to each cell. He measured the balance time for all cells assuming that the allocation to each cell reaches as the systematic wave to the output and he developed a temporal map by conducting this process.

Methods material:

Study region

The catchment basin of Sofi Chay is in the geographical coordinates 3˚46 to 30˚46 east longitude and 8˚ 37 to 44˚37 north latitude and has been located in the southwestern of East Azerbaijan province with a surface area of 292 square kilometers and from north is restricted to the basin of Lighvan Chay and Kan Chay; from east to river basin of Gharanghoo Chay and from west to ghale Chay and Uremia's Lake and also from south to Malekkandi and Miandoab. Images (1 and 2) show the location of Sofi Chay catchment basin. Sofi Chay River is emanated from southwest highlands of Sahand Mountain or Height of 3700 meters above sea level and after passing 72.75 kilometer flows to Uremia's Lake. The reservoir Dam Alavian with the profitable volume of 4/123 million cubic meters has the capability of 35 million cubic meters' water extraction from the seasonal flows. The diagram of basin is stretched at least to the 3460 and 1550 meters above sea level, respectively.

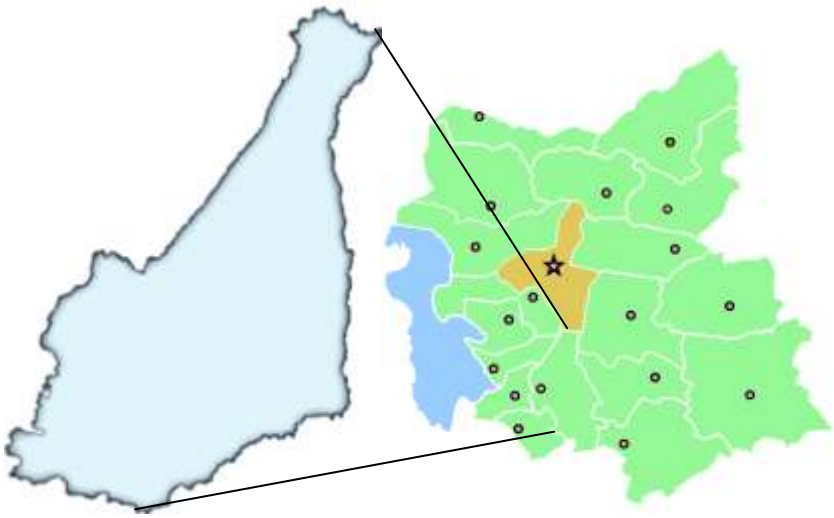


Image (1): The geographical location of Sofi Chay catchment basin in East Azerbaijan Province

The region morphology

The morphology of this basin is generally affected by tectonic phenomena governing the area and more resulted from volcanic activity of Sahand Mont. A part of region includes old terraces that are widespread as hilly ground along the amplitudes and have high heights in some parts. The valleys have low-depth but in the path of rivers. The high points of region are covered by calcareous layers.

The Structural Geology

The tectonic phenomena of this basin are mainly affected by the final Alpine mountain-building movements and Sahand eruptions which are appeared in the form of folds and faults. Some old faults in the eastern north are mostly normal and a special categorization cannot be made for them (Image 2).

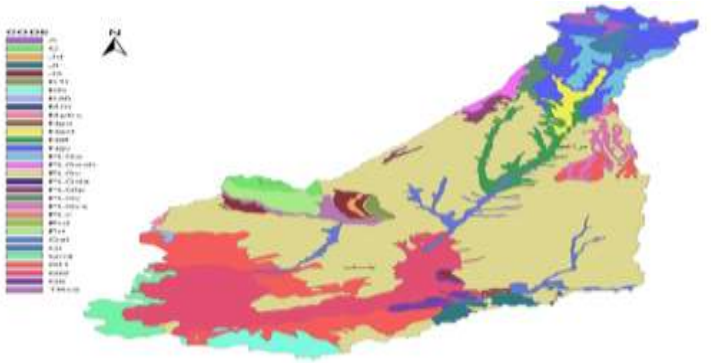


Image (2): The geological map of Sofi Chay catchment basin

The extraction parameters of hybrid model

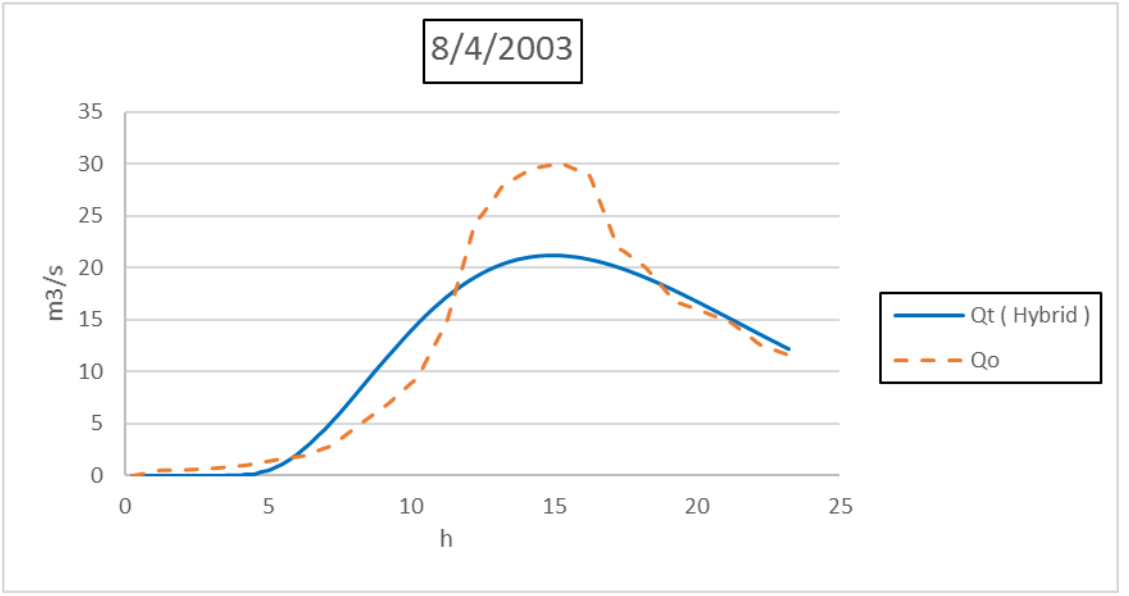
The parameters of hybrid model are reservoir storing coefficients. The basins can be assumed as reservoir, rainfall after entrance to the basin and penetrating, flow on its surface and until reaching to the waterway and exiting from basin, passes a path through it and due to the friction and slope decrement, their speed will be decreased and the momentary flow will be decreased, too; and basin behave like a reservoir after rainfall. The storing coefficients of K1 and K2 are connected with surface features of the basin and tendency toward the flow storing decreases so in this case, the storing coefficients will decrease, too. After measuring the observational one hour unit hydrograph related to each event and identifying the peak time and peak discharging in one hour unit hydrograph, the storing coefficients of K1 and K2 were measured in each event. For identifying these parameters, a program was written in FORTRAN that by its usage, the amounts of K1 and K2 are gradually change with 0.1 steps and the difference between observational direct runoff hydrograph and measured (The amount of error function) direct runoff hydrograph is measured; and also the measured direct runoff hydrograph is shown through the hybrid model. The hybrid model has acceptably estimated two units of peak time and peak discharging. Table (1) show the reservoir storing coefficients amounts in Sofi Chay catchment basin.

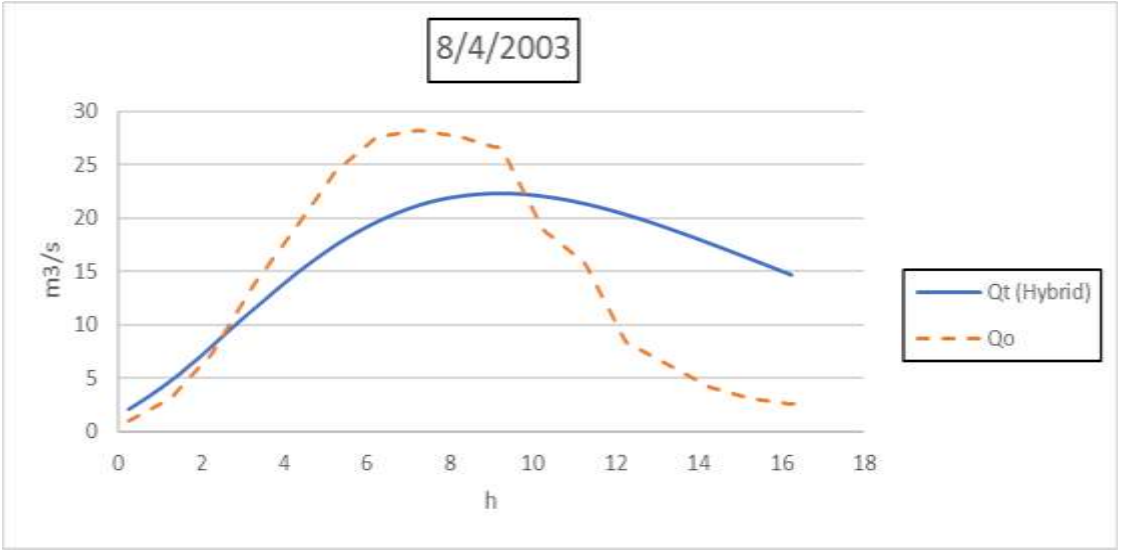
Table (1): The hybrid parameters in Sofi Chay catchment basin

Parameters	**Events date**					
	19/1/1382	19/1/1382	4/2/1383	12/2/1383	27/1/1384	12/2/1389
K_1 (hr)	2	0.1	0.2	1.3	2.1	1
K_2 (hr)	3.89	3.29	0.4	3.89	3.89	2.79

In this survey, the presented hybrid model by Bonia et al (2005) were used for extracting the direct runoff hydrographs and finding the relationship between rainfall – runoff model parameters with networking model of the basin, and as it was mentioned above, the hybrid model is Nash optimized model and provided in the direction of eliminating the restrictions and defects of Nash model. The hybrid model in the contrast of Nash model has two reservoirs with different storing coefficients. Therefore, it will be able to simulate the storing changes due to the flow process toward the downstream of the basin and speed reduction better than Nash model. In this model, the reservoir is considered for reducing the flow movement and reducing the greatness of its peak; the second reservoir storing coefficient (K_2) is greater than first reservoir storing coefficient (K_1) which is notifying in the physical term because the flow movement in the basin in general sense is in the direction of slope reduction; it decreases its keenness and tendency toward tendency toward storing in the basin will increase. In addition, the storing changes resulted from slope variation in the basin with two reservoirs that have different storing coefficients can be better simulated. The respond function in Nash model is two-parametric gamma function that its skew-ness is left-oriented and cannot appropriately predicts the floods with weak skew-ness and also floods with normal-distributed hydrography. While, the hybrid model has more flexibility in estimating such floods; this model can cover the slopes of greater basins because the flow process can be better simulated in the basin with two reservoirs than one reservoir, and also the flow dullness characteristics and peak discharging reduction in the downstream can be better transmitted by hybrid model (Ahmadin, 2008; Fazelmodares, 2011; Bonia et al, 2005; Sing et al, 2007).

In this research, we will try to introduce the bases and foundations of momentary unit hydrogaph extraction methods in the basin through the hybrid and networking models as well as surveying the hybrid model performance in extracting the momentary unit extraction according to the statistics of studied Sofi Chay basin and the following results have been obtained. In this study, the comparison between momentary unit hydrograph simulated by two hybrid and networking models and observational momentary unit hydrograph was conducted. In image (5), this comparison was conducted for 6 events.


8/4/2003
35
30
25
20
15
10
5
0
m3/s
0
5
10
15
20
25
h
Qt (Hybrid)
Qo


8/4/2003
30
25
20
15
10
5
0
m3/s
0
2
4
6
8
10
12
14
16
18
h
Qt (Hybrid)
Qo

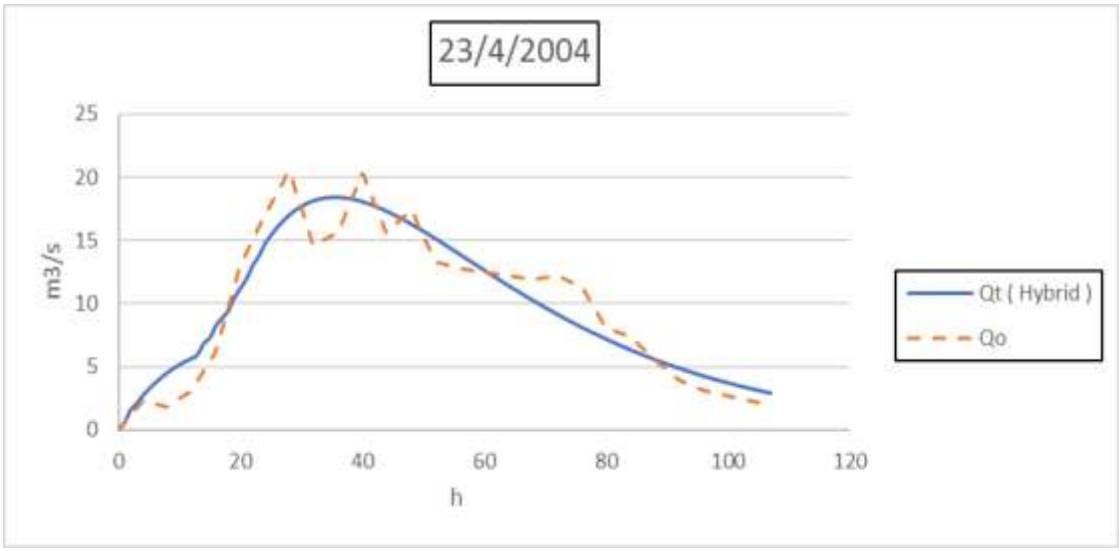
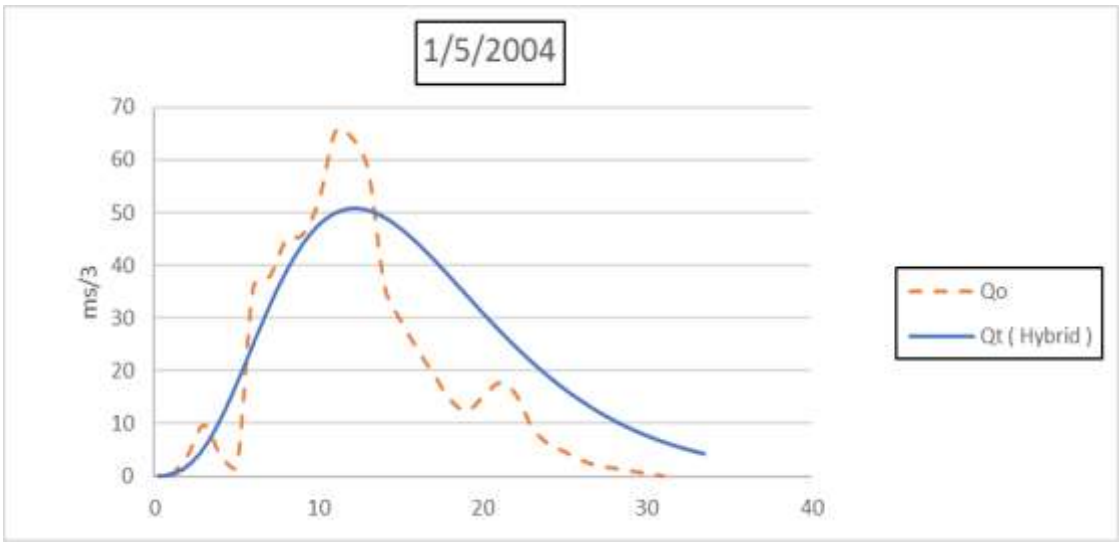
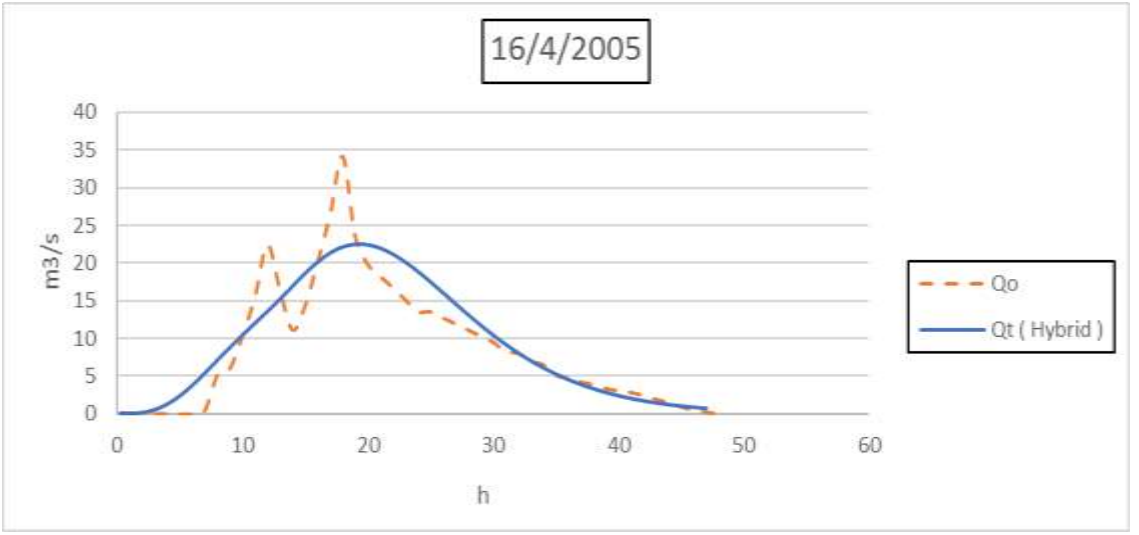
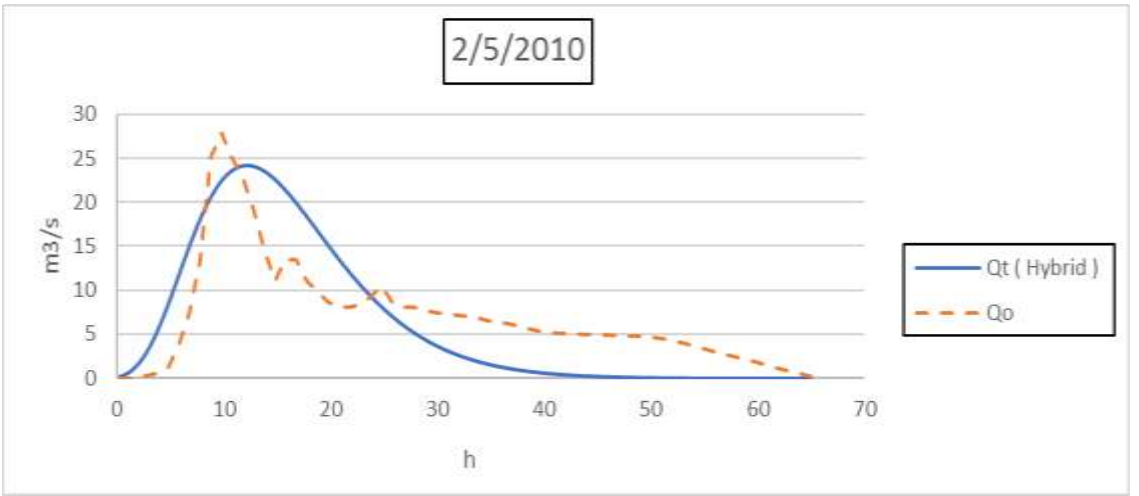


Image (3): The observational and simulated hydrographs of Sofi Chay catchment basin

The rest of image (3) is as follows:



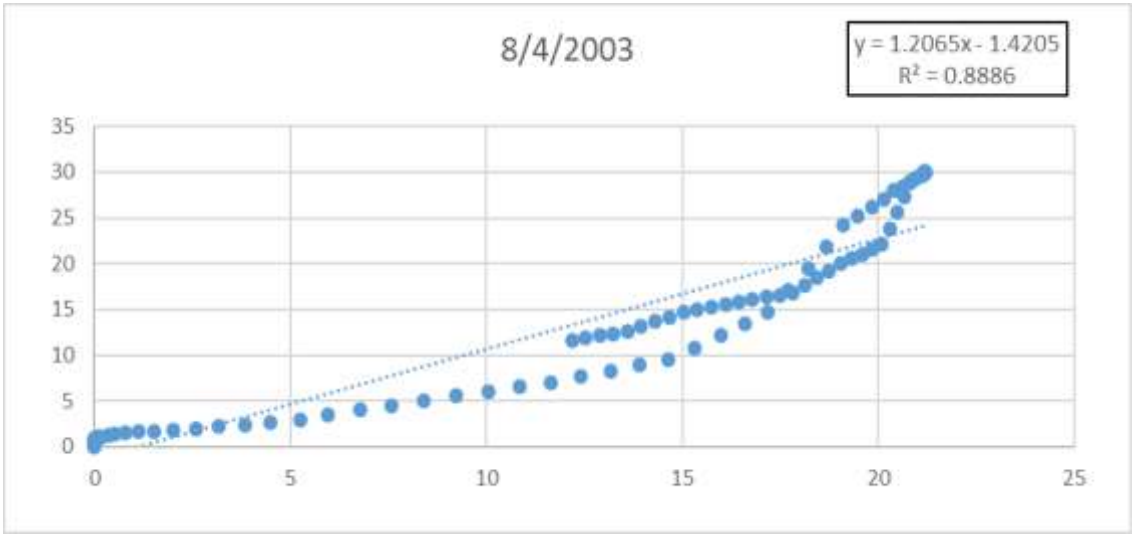


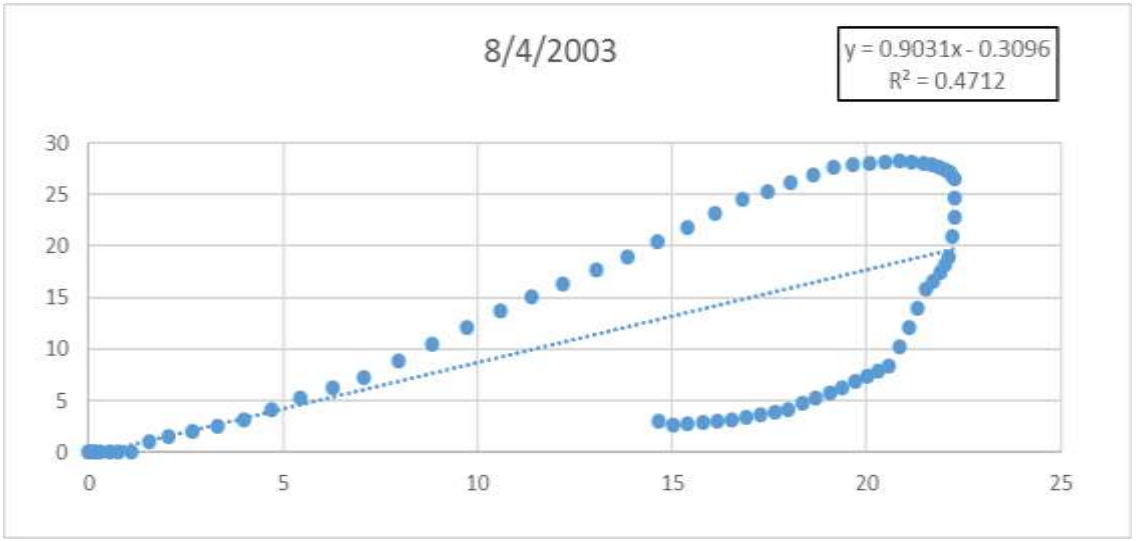


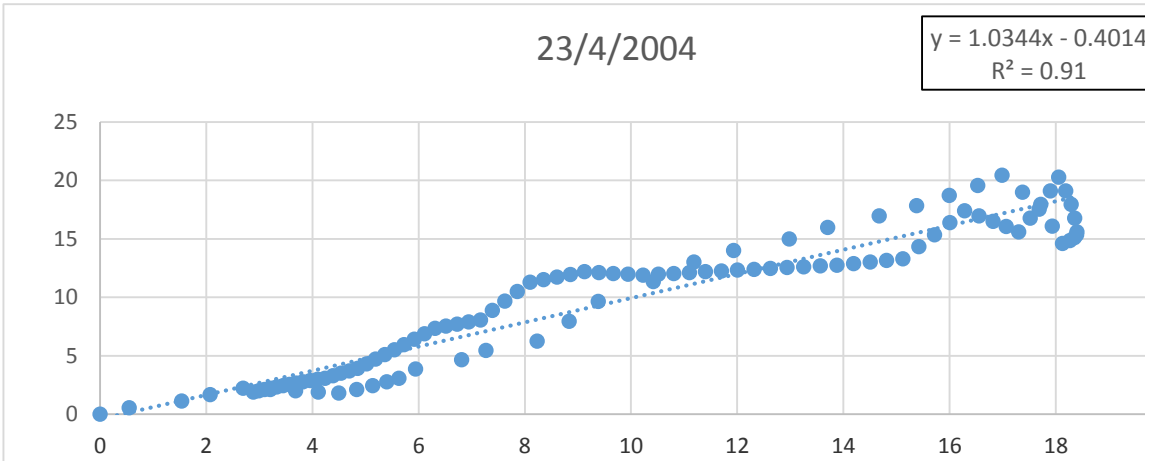
In hybrid model, the reservoir storing coefficients (K_1, K_2) are considered as optimization; means the lowest amount errors were considered per observations so the reservoir storing coefficients of K_1 and K_2 are amounts that are effective on the changing way of flow hydraulic amounts such as manning coefficient, vegetation and lack of uniformity in the drawn and optimized topography. The precise behavior transmission in hybrid model is well conducted. The achieved momentary unit hydrograph from hybrid model in simulating the both ascending and descending arms show a little difference with the observational amounts that it's highly matched with Bonia et al (2005) researches. The hybrid model predicts the amount of Discharge parameters and peak time in most of cases more than observational amounts. These results also confirm the Bonia et al (2005) researches.

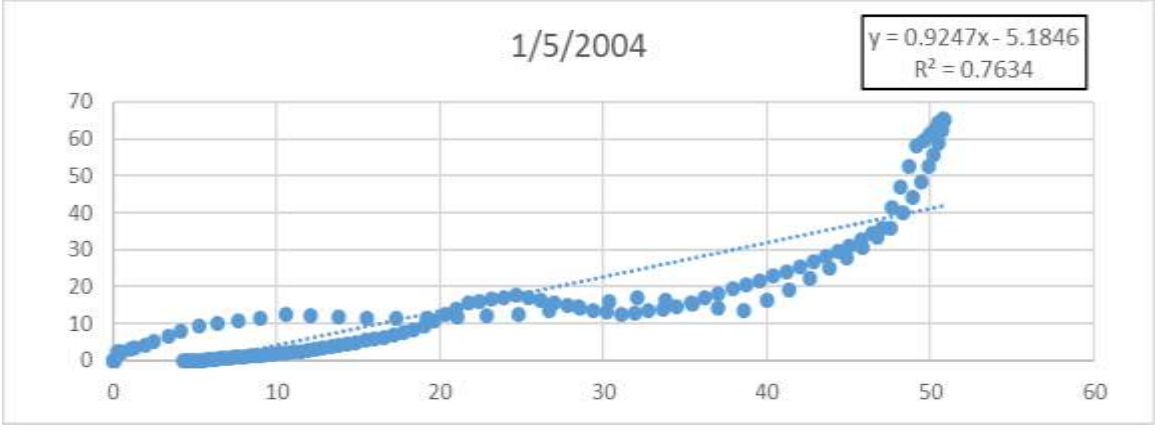
The correlation between hybrid model and observations

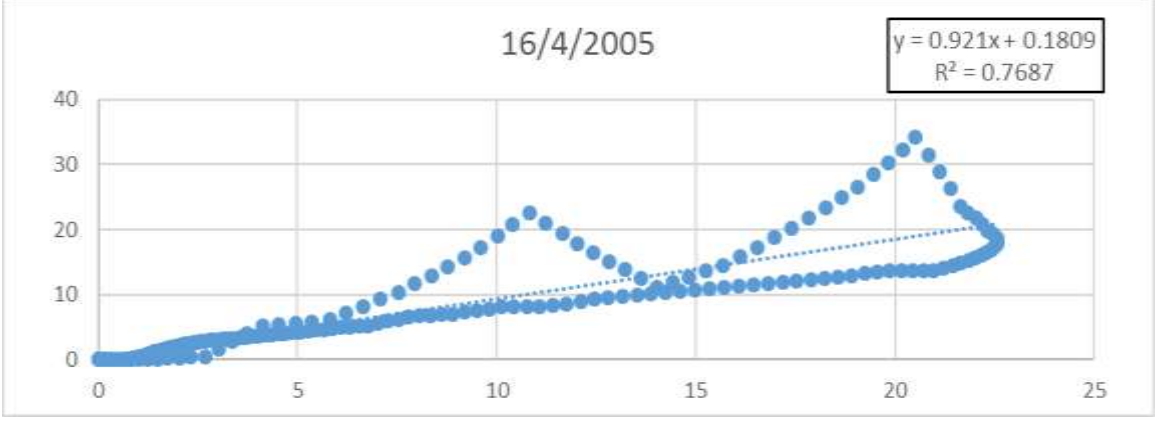
The correlation chart between observational and simulated discharges for hybrid model is provided in image 4 for 6 various events. As it can be seen, the measured discharges have a high correlation with observational data in hybrid model.






23/4/2004
y = 1.0344x - 0.4014
R² = 0.91
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
18


1/5/2004
y = 0.9247x - 5.1846
R² = 0.7634
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60


16/4/2005
y = 0.921x + 0.1809
R² = 0.7687
40
30
20
10
0
0
5
10
15
20
25

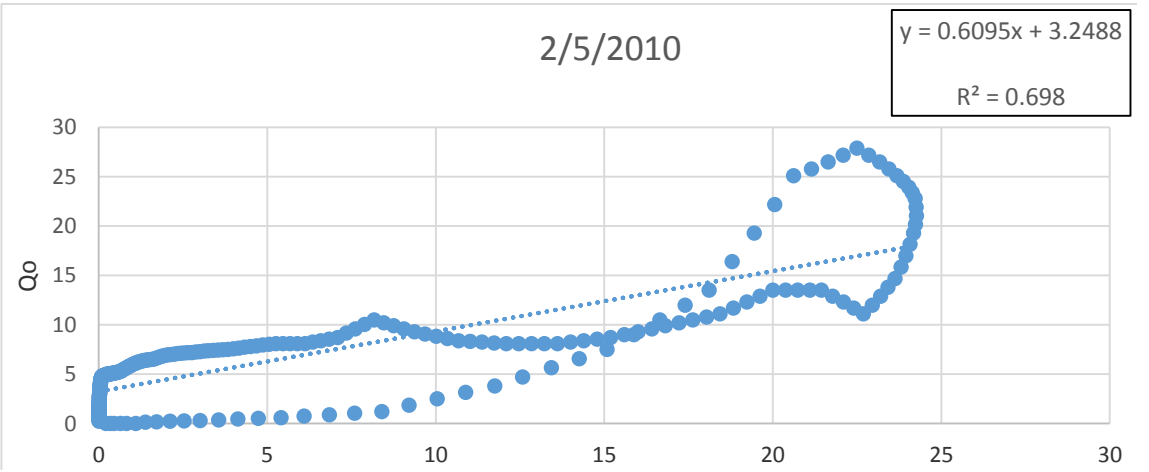


Image (4): The correlation chart of observational and simulated discharges in hybrid model

Conclusion

In order to survey the correctness of hydrological models, the various statistical criterions that conduct the comparison between observational and calculative data were used. The determinant coefficient (R^2) shows that what degree of correlation exists between the observational and simulated amounts. RMSE is error criterion that its decrement means the least difference between observational and simulated data and shows better performance of the model. In table (2), R^2 is determinant coefficient; RMSE is Root Mean Square Error; Δt_p is the difference of peak time in two simulated and observational hydrographs; ΔQ_p is the peak discharging difference of two simulated and observational hydrographs and ΔV is the runoff mass difference of two simulated and observational hydrographs.

Table (2): The assessment hybrid model in Sofi Chay catchment basin

	Event	R^2	RMSE (m^3/s)	Δt_p (hr)	ΔQ_p (m^3/s)	ΔV (m^3)
Hybrid	19/1/1382	0.88	3.95	1.5	8.95	93.21
	19/1/1382	0.47	7.67	2.25	6.02	128.05
	4/2/1383	0.91	1.71	9	2.06	6.43
	12/2/1383	0.76	11.59	2.75	14.57	978.79
	27/1/1384	0.76	3.95	1.75	11.61	126.77

	12/2/1389	0.69	14.66	2.75	3.64	192.33

The obtained results showed that the minimum determinant coefficient in hybrid model is 0.47; and the maximum in hybrid model is 0.91. The minimum Root Mean Square Error in hybrid model is 1.71 percent; and the maximum Root Mean Square Error in hybrid model is 14.66 percent. The minimum and maximum amounts of peak discharging to the hydrograph of observations in hybrid model are 2.06 and 14.57 cubic meters per second, respectively. The minimum and maximum amounts of peak time of hydrographs to observations in hybrid model are 1.5 and 9 hours. The minimum and maximum amounts of runoff mass to the observations in hybrid model are 6.43 and 978.79 cubic meters.

References:

Abeb, N., Ogden, F. L. and Pradhan, N. R., 2010, Sensivity and uncerlainty analysis of the conceptual HBV rainfall- runoff model: Implication for parameter estimation, Jurnal of Hydrology, 389, 301-310.

Agirre, U., Goni, M. Lopez, J. J., Gimena, F. N. 2005. Application of a unit hydrograph based on sub watershed division and comparision with Nash's instantaneous unit hydrograph, CSTENA, 64: 321-332.

Aytek., Asce, M. and Alp, M. 2008. AN application of artificial intelligence for rainfall-runoff modeling. Journal of Earth System Seience.

Bahat, Y. and Grodek, T., Lekach, J. and Morin E., 2009, rainfall-runoff modeling in a small hyper and catchment, Journal of hydrology, 373, 204-217.

Green WH. and Ampt , GA. 1911. Studies of soil Physics. Part 1. The Flow of air and water Through soils. J. of agricalture. Sci., 4: 1-24.

Haan, C. T., 2002, Statistical Methods in hydrology, second edition, Iowa state press, 496p-900.

Hjalmarson, H.W. and B.E. Thomas .1992. New look at regional flood Frequency for arid lands. Journal of hydrologic engineering 118,868-886.

Hydraulics and Erosion Mechanicse, dited by A. J. Parsons and A.D. Abrahams, Chapman & Hall, New York, 1992.

Jena, R. I., Coon, G. C. 2003. True form of instantaneous unit hydrograph of linear reservoirs. J. Irrig. Drain. Eng. 129(1):11-17.

Jena, S, K. and Tiwari, K. N., 2006. Modeling synthetic unit Hydrograph parameters with geomorphologic parameters of watersheds. Journal of Hydrology 319, 1-14.

Jinkange, D., Hua, X., Yujun, H., Youpeng, X. and Chong- Yu, X. 2009. Development and testing of a new storm runoff routing approach based on time variant spatially distributed travel time method. Journal of Hydrology 369:44-54.

Singh PK, Bhunya PK, Mishra SK, Chaube UC,2007. An extended Hybrid model for synthetic unic hydrograph derivation. 336:334-360.

Singh, V. P. (1985). " Hydrological systems: Rainfall-Runoff Modeling", vol. 1, prentice Hall, Englewood, New Jersey.

Snyder, F. F., 1938. Synthetic unit graphs. Trans. Am. Geophys. Union 19, 447-454.

Soil Conservation Service (SCS), 1957. Use of storm and watershed characteristics in synthetic Hydrograph Analysis and application. Us department.

Strub, T. D., Melching, C. C. and Kocher, K. E., 2000. Equtions for estimating Clark unit hydrograph parameters for small rural watersheds in llinois. Urbana, II, U. S. geological survey. Water Resources Investigations Reports 0-4184.

Tarbotan, D. G. 1997. A new method for the determination of flow directions a upslope areas in grid digital elevation models. Water Resour. Res., 33(2):309-319.

Tarbotan, D. G. 2000. Watershed and stream network delineation. Hydro GIS short course, University of Padua.

Tarboton, D. G., The analysis of river basins and channel networks using digital terrain data, Sc.D. thesis, Dep. of Civ. Eng., Mass. Inst. of Technol., Cambridge, 1989. (Also available as Tech. Rep. 326, Ralph M. Parsons Lab. for Water Resour. and Hydrodyn., Dep. of Civ. Eng., Mass. Inst. of Technol., Cambridge, 1989.

White, A., Kumar, P., Saco, P. M., Rhoads, B., Yen, B. C. 2004. Hydrodynamic and geomorphologic Dispersion: scale effect in the Illinois River basin, J. Hydrol., 237-257.