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Hydrological Modeling & Flood Design in Rudbar Lorestan Dam & Power Plant Project

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Abstract

Accurate modeling of the drainage basin, including its spatial and temporal distribution of hydrological parameters and rainfall-runoff process, is very important in many applications. As an example, design flood estimation in hydraulic structures, which has the main role in the construction cost, is a result of rainfall-runoff simulation. The Rudbar Lorestan dam project is a part of the hydroelectric development projects complex in the Dez River basin. This project is located in a mountainous zone 200 Km away from Isfahan on the Rudbar River and 100 Km away from the south of Aligudarz. The aim of the Rudbar Dam and power plant project was to use the hydroelectric potential that is caused by the different elevations between the dam position and the power plant location. Due to the About 300 Meters difference in elevation from the dam axis to the power plant location set as one of Iran's prominent hydroelectricity projects. There are many consulting engineers in these projects, previous studies, and their main study result (flood design) shows a 17% difference from each other. due to the significant mentioned difference caused by using experimental methods and personal judgment, an effort was made in this research to simulate a large part of the Rainfall-Runoff process and model the water movement current on the basin surface with WMS software, and by taking the results of previous studies, the results of executing point of view and theory point of view had been compared. For this purpose, two internal and external representative basins were simulated, and the results were compared to evaluate the ability of the model. Simulating the main basin refuses the older studies by the difference near 20%, and confirms the newer studies by a difference of about 10%.
Keywords: Flood Design, Modeling, Rainfall-Runoff, Rudbar Lorestan Dam, WMS.

1. Introduction

A basin is the area of a zone in which it is runoff naturally and completely conducted to the unique point named point of concentration. All of the waterways that perform runoff discharge are called river networks some of them are permanent, seasonal, or exist during rainfall. When rainfall intensity is more than soil infiltration capacity, some of the water obtained from rainfall remains at the surface of the basin. This water flows along the slope after filling the ground surface potholes and overruns the basin through the main river. This part of rainfall that can be measured in the river is called surface runoff.

Some specifications are impressive on basin hydraulically response including basin geometrical features (area, shape, waterway length), basin soil features (soil type, erosion capability, permeability) plant cover (envelope distribution, plants type, transpiration), hydrology (surface maintenance, permanent and seasonal waterways), geology (stone’s structure, cracks, faults), weathering (weather temperature, quantity, type and frequency of rainfalls) sediments (erosion, convection, sedimentation) and human ingredient (agricultural relation, installation).

Temporal and spatial distribution problem of rainfall is always noteworthy for hydrologists especially in flood estimation and floodgate potential in basins, to design and authorship of hydro-structures for water supply, surplus water discharge, reduction of flood loss in urban, villager, and industrial zones, and also planning and designing of Basin Management operation, hence their main notice is on the resultant runoff of rainfall. According to Shah (1996), the time and location distribution of rainfall influences flood hydrograph, but its influence decreases due to basin area growth, and in large area basins, its influence becomes less. The Uniform rainfall assumption is one of the limitations that some presented models have, such as HEC-1. This assumption does not make any particular problem in small basins but not in large basins. Eagleson and Milly (1988) investigated the effect of thunderstorm quantity on rainfall-runoff relation in partly large basins, and the result was surplus runoff larger than infiltration is very sensitive to thunderstorm quantity and its location distribution in a large area. As usual local variable rainfalls produce more surface runoff rather than uniform rainfalls with the same volume, therefore hydrological distributive models applying are very important in these regions.

1.1. Project position and basin specifications

Rudbar Lorestan reservoir dam is located south of Aligudarz city in Lorestan province on Rudbar River, one of the Dez main branches with a geographic position 49º 41' eastern length and 32º 54' northern width and axis elevation 1620 meters at the top of MSL. Rudbar River which has several names at different locations on its path is the main branch of the eastern branch of Dez or Bakhtiari River. This river, after passing the Tang-e-panj location and joining the Sezar River, constitutes the Dez River. The main branches of the Rudbar River include the Kalayan River inclusive Dare-Dozdan, Dare-Daei, and Dare-Leko branches, and Kakolestan (Khak-e-Batie) rivers and the Vahregan River in a mountainous zone. This river rounds around U-shaped mountains from northwest to southeast and on the other side is named Alkan. The schematic plan of the basin of Rudbar Lorestan Dam and Dez Dam is shown in Fig. 1.

Fig. 1. Schematic plan of Rudbar Lorestan dam basin

The difference in elevation of the bed river on both sides of the turning is about 300 meters, so by a water conveyance tunnel, the suitable potential for hydroelectric energy production will be provided. The power plant of the Rudbar Lorestan project will be next to the Alkan River, located at 1315 meters on top of the MSL and the area of the catchment to the construction place of the power plant is 3239 km^2. Alkan River, after turning around mountains, continues first at the southwest vector and then east-west. Alkan River is named Ab Zalaki River, after the receipt of several small branches, and finally is known as Bakhtiari River after the jointing of the Sarkoul River. The Basin confined of this river in selective site for dam construction is at 49º 14' to 50º 15' east length and 32º 45' to 33º 20' north width of geographic coordinates. The area of the basin of the river to the dam site is 2255 km^2. The aim of the Rudbar Lorestan power plant and dam plan implementation is to use the considerable hydroelectric potential caused by different elevations between the dam construction location and the power plant place. The difference in elevation of about 300 meters between the dam axis site and the power plant location caused this plan to be one of the most significant hydroelectric projects in Iran. The elevation difference is due to the natural turning of the river and its U-shape length of about 38 kilometres from the dam site construction to the power plant site location. The most important specifications of the Rudbar dam include a natural difference of elevation of more than 300 meters between the dam axis and power plant, variation in climate of the zone, steep topography, difficult access zone, deprivation of the region, and geological conditions.

1.2. Basic modeling and existent types of hydrological models

Generally, by applying rainfall-runoff models, parameters of quantity and water relocation in different phases of the hydrological cycle can be predicted. These models are based on the mathematical definition of different components of the hydrological cycle and usually try to a quantitative description of rainfall end corresponding reverse component to atmosphere due to evaporation, the part that infiltrates to the deeper zone of the earth to attach to groundwater and a part that constitutes runoff. Moreover, some of these models can predict the time distribution of resultant runoff. In recent decades, the simulation of rainfall-runoff ratios and their relation in hydrological research have been more noteworthy, and many offered manners in different models have been presented in this case. Generally, these models basically can be classified as metric, conceptual, and physical models (Beck, 1990).

Principally, the difference between runoff models is in the methods to produce runoff and its routing in the length of the basin. Likewise, they are different in the aspect of available control functions, necessary data, and contrast with the operator; of course, this difference usually is small and negligible in the computational runoff. These models are ever-completing. Applied models in the past time, did not assimilate different phases of the hydrological cycle. They applied simplified mathematical ratios between rainfall and the final response of the basin instead. This type of Modeling belongs to half of the 19th century by using rational simplest one parameter (Mulvaney, 1851) peak of runoff due to defined rainfall phenomenon can be predicted at the outfall of the basin. This method had been applied pervasively in post cause of its simplicity, minimum necessary data and so needless high fiscal availability for hydrologists, which of course, applies for some basins (Hromadka and Whitley, 1994).

It is worth noting that the logical method predicts only the amount of runoff and doesn't represent Information about the time distribution of runoff occurred by rainfall. With more development in rainfall-runoff models like the level-time method by Clark (1944-1945) and the hydrograph unit method by Sherman (1932), the time distribution of the final runoff occurred by rainfall will be announced perfectly. The appearance of computers caused development in the conversion of the components of different hydraulic cycle models into computer models. The leaders in this field were Crawford and Lindsley (1960) that introduced conceptual models for the Stanford basin.

Later on, a huge amount of models in this area were developed mostly by Singh in 1995, subsequently, another class of models was introduced that tried to combine all of the physical details known in any basin. The first definition of these models was presented by Freeze and Harlan (1969) and used later by Stephenson and Freeze (1974).

The AWBM model, developed by Button in 1990, is one of the many rainfall-runoff models that can calculate runoff from daily or hourly rainfall. The results of this daily model are used in water management studies, and the results of the hourly model are used in flood design calculations. This model simulates the parameters in the basin by dividing the variability of storage capacity into three storage capacities and estimating the levels of each one of these storage capacities, the runoff caused by each of these levels using the daily rainfall, water flow, vaporization, and optimization of the parameters. Results of the use of this model in the Australian basins show the ability of this model in forecasting runoffs.

In the past 30 years, there have been hundreds of developing conceptual models such as IHACRES by Jackman et al. in 1990, VIC by Wood et al. in 1992, MODHYDROLOG by Mcmahon and Chiew in 1994, HBV by Bergstrom in 1995 and SWM by Crawford and Lindsley in 1996.

Kokkonen and Jackman (2001) compared and reviewed conceptual methods and metric methods in rainfall-runoff modeling in calibration simulating and parameter invariance. They studied this information with the use of two models that are similar in complexity (like having the same number of parameters) but different in conceptualization for two basins with different climates.

Freeze in 1972 developed the first physical-based model that used the finite-difference method to solve Richard's equation for saturation flow in two dimensions. Richards's equation describes water transfers within unsaturated soils. Later, other models were presented in this category, such as the SHE model by Abbott et al. in 1986 and the IHDM model by Beven et al. in 1987 that developed according to the same mathematical equations. In recent years Rezaie-Balf et al. (2017) studied three kinds of soft computing methods, namely artificial neural networks (ANNs), model tree (MT), and multivariate adaptive regression splines (MARS), which have been employed and compared for rainfall-runoff process simulation.

Namin and Boroomand (2012) present a time splitting algorithm for numerical solution of Richard's equation. The mentioned authors used numerical techniques presented in other researches, including the application of jets in solar jets (Vasheghani Farahani et al., 2021). Vidyarthi and Ashu Jain (2023) proposed four semi-distributed rainfall-runoff models using a simple lumped model in a distributed sense by gradually enforcing spatial distribution in terms of hydro-meteorological and physiographical features in a basin. Their Results show that while using SPPs solely can provide accurate predictions, significant improvement can be obtained when this data is integrated with ground monitoring data. Also, Strapazan et al. (2023) present a comparative analysis of different methods applied to determine curve numbers from local data in four watersheds located in the central part of Romania.

Lee et al. (2023) studied re-evaluated the CN model by testing its reliability and performance using data from Malaysia, China, and Greece. The results of this study showed that the CN runoff model can be formulated and improved by using a power correlation.

2. Materials and methods

2.1. WMS mathematical model

The WMS basin modeling system is a general hydrological modeling environment. This model is a tool for all basin modeling phases containing auto basin, descriptive sub-basin, calculations related to geometric and hydrologic parameters like CN, concentration time, rainfall, etc., and visualize the results. The results of using this software in hundreds of research facilities, private and governmental all over the world, show the huge potential of this model in the analysis and simulation of the basins.

WMS model uses FHWA and TR-55 to calculate travel time and concentration time so that in these models, equations are defined into three categories, sheet flow, shallow concentrated flow, and open channel flow. For sheet flow usually occurs in the first 300 feet of the beginning of the stream, travel time is a function of the roughness coefficient, flow distance, flow intensity, and the slope path. Both models presented equations using these parameters and a couple of experimental coefficients. In a shallow concentrated flow that appears after the first 300 feet in the TR-55 model, travel time is a function of flow distance and flow velocity, and in the FHWA model, this parameter is a function of the flow distance, slope of the surface and an experimental coefficient called intercept coefficient. This coefficient is presented in the software guide. Both models use the Manning formula for the open channel flow range.

2.2.Model verification

To ensure verification operations of the model in simulation of the basin and estimate output hydrograph, they will use software Modeling of both the basins that had more reliable data and the results can be controlled. This matter, in addition to verifying the function of the model, will extract the initial settings of the model. That way, the Kan basin in Iran, Shown in Fig. 2, will be considered because it has more valid data those other basins in Iran.

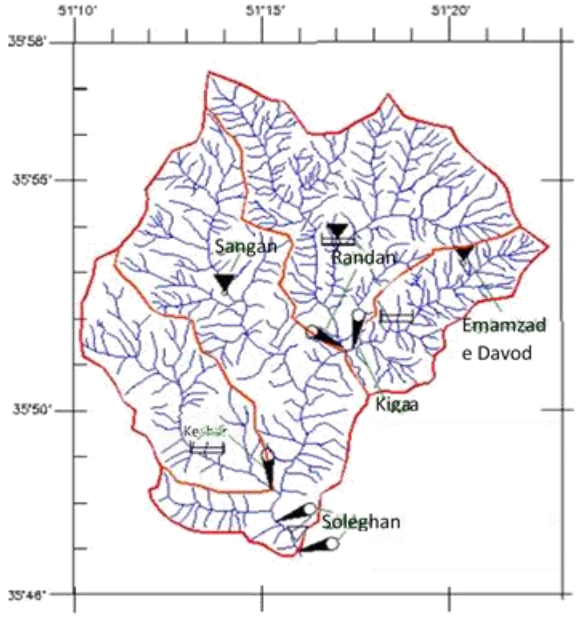

Fig. 2. Kan basin and Hydrometric and Wheather stations

The rainfall that occurred on March 29, 1997, in the Kan basin was simulated and the results presented of the output hydrograph model compared to the observed hydrograph. The distribution of rainfall in the biggest sub-basin of the Kan basin called Randan is shown in Fig. 3.

Also for more assurance, from international basins, the Walnut Gulch basin has been chosen, and the hydrograph calculated from the WMS model has been compared with the observed hydrograph from the basin. To select the flood to be simulated, after reviewing the available information, the flood of August 27, 1982, which was also used in other research conducted on this basin, was selected and the corresponding data of the rainfall of the mentioned flood was extracted.

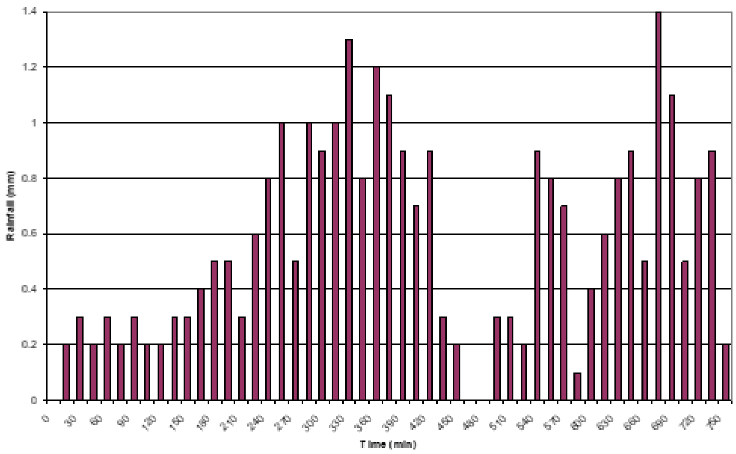

Fig. 3. Rainfall distribution in Rendan sub-basin on March 29, 1997

It is worth noting that in this stage, many basins were studied. Because of a lack of data or gross errors in the data gathered, they were deleted from the program. This stage has taken a lot of time of this research.

3. Results and Discussion

3.1. Kan basin Modeling

The Kan basin is located in North West of Tehran with a 206.38 square kilometres area. Since 1996, it has been chosen as the representative basin. This basin has 4 hydrometric stations, 3 evaporation test stations, and one rain gauge station located in Figure 2. This basin is located between 35° 45' to 35° 57' latitude and 51° 53' to 51° 29' longitude.

Fig. 4 shows the simulation of the basin using WMS software. Fig. 5 also shows a comparison of the output hydrographs calculated by the WMS with the observed hydrograph.

As can be seen, the results show very good agreement with the measured and computational results. Of course, the importance of deriving concordant results is how to apply the coefficients and initial adjustments. This is especially true for catchments with observational statistics, as Fig. 5 confirms. This will be discussed in more detail in the conclusions section.

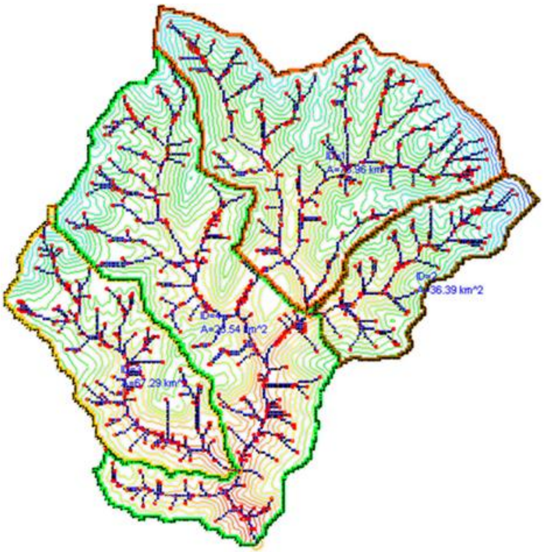

Fig. 4. Kan basin simulation in WMS software

3.2. Walnut Gulch Basin Modeling

The US Agriculture Research Office in 1953 named the 150 square kilometres Walnut Gulch basin as the representative basin. The location of this basin is shown in Fig. 6. This basin has 23 hydrometric stations and 134 rain test stations. Fig. 7 shows isohyetal curves in the basin on August 27 1982 that are simulated.

Fig. 8 is the simulation with WMS software, and Fig. 9 is the comparison between the calculated hydrograph by WMS and the observed hydrograph.

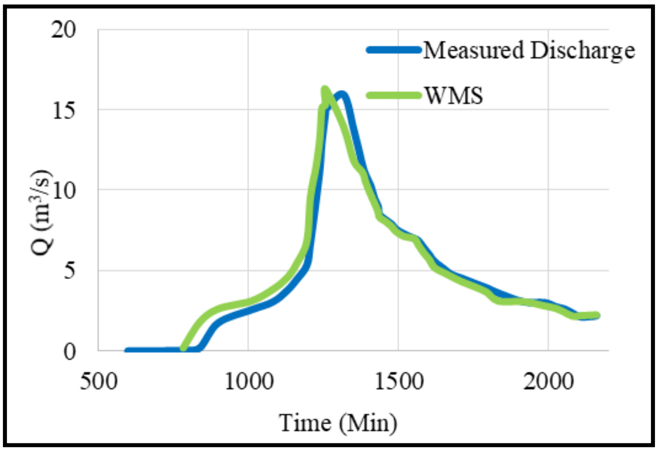

Fig. 5. Comparison of Output Hydrographs Calculated by Model and Measured Discharge in 1997 Flood

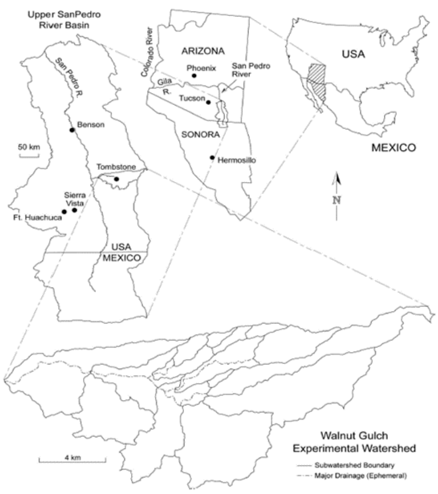

Fig. 6. Location of Walnut Gulch basin

Fig. 7. Precipitation Storm Event August 27, 1982 (mm)

Fig. 8. Walnut Gulch basin simulation in WMS software

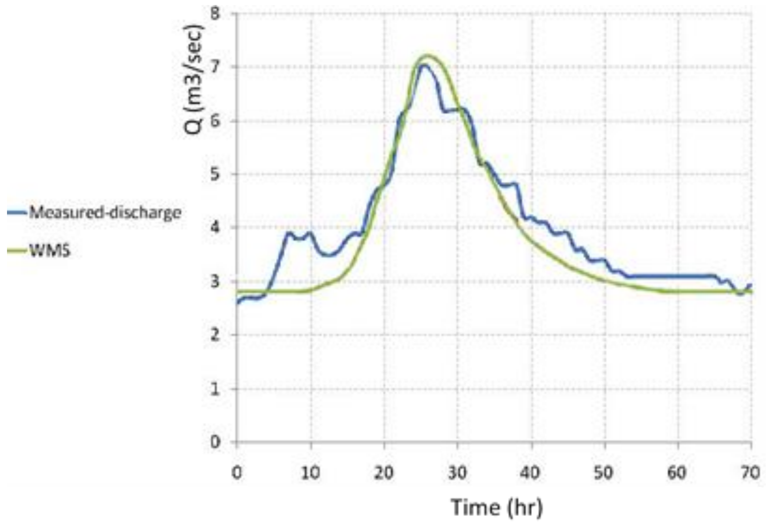

Fig. 9. Comparison of Output Hydrographs Calculated by Model and Measured Discharge in Walnut Gulch Basin

As can be seen in this basin, there is a good agreement between observational and computational data. Of course, the model does not fully cover the recorded hydrograph fluctuations, and this is quite evident. These discussions are worthy of discussion in the basin simulation results, which will be discussed in the conclusion section.

With the acceptable results from matching the results of the model and observed data in both representative basins, also extracting the setting of the model, we enter the main purpose of the research, which is to simulate the Rudbar dam in Lorestan and the initial results of modeling including physiography and related points are extracted.

3.3. Rudbar dam basin modeling

3.3.1. Physiography

In order to identify the type of rainfall and how the water flows, important information will result in physiographical studies. Physiography is the study of geometric features and topography conditions of the basin that have a special role in climate details and the basin`s hydraulics. A physiological detail of the basin has a direct effect on the yearly runoff, maximum flow, and volume of floodwater and an indirect effect on climate and ecology.

The basin of Rudbar Dam has unique features from topographical and morphological sight. This basin is located in the middle of Zagros wrinkle. This area has a High discharge power and compressed river system and highland topography because of being in Zaardkooh and Oshtorankooh mountains or being at 4040 meters high above the sea surface.

Fig. 10 shows the results of the Rudbar Dam simulation, the sub-basins such as Ghalayan, Kazem Abad, Vahregan, and the middle sub-basin, also have been simulated.

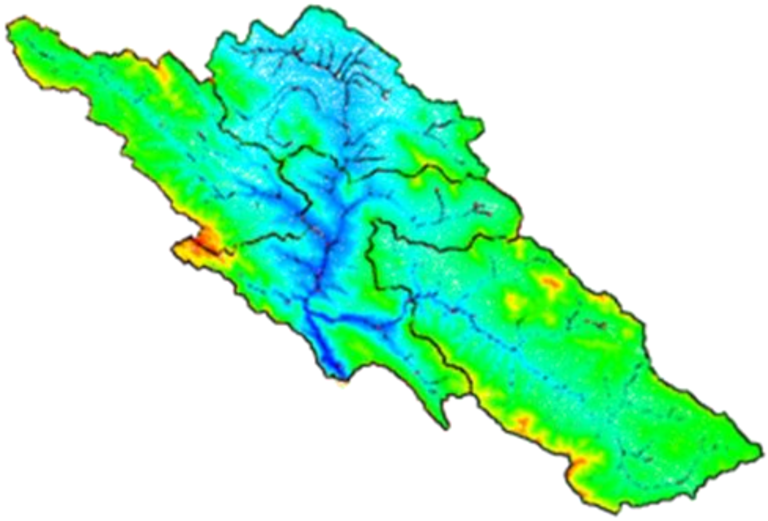

Fig. 10. Rudbar dam basin (included sub-basins)

3.4. Height frequency and surface changes with Rudbar dam basin`s height

Basin’s height has a massive effect on rainfall, temperature, and its change, evaporation, transpiration amount, and generally the climate. Knowing the average height of the basin, the different heights of the basin, and how the surface changes with height, will help in understanding the climate. The height frequency curve and change of surface with the height curve are the results of the basin`s Modeling in Table 1.

3.4.1. Height features in Rudbar Dam basin

- The maximum height is 4040 meters above sea level in Vahergan sub-basin
- The minimum height is 1620 meters above sea level in the riverbed, the location of the Rudbar Dam construction site.
- The average height in the basin is 2537 above sea level Height with a maximum frequency of 21.7 percent is 2500 meters above sea level and height with a frequency of 50 percent is 2713 meters above sea level.

3.5. Length, surface, and slope features in Rudbar Dam basin

Length, surface, and slope are calculated by the model`s output, details are in Table 2. Also, the amounts related to any sub-basin are in Fig. 11.

3.6.Concentration-time and Lag-time

One of the main parameters for estimating the amount of runoff in the basin is concentration time. Concentration time is the maximum time that will take for water to go from the furthest point in the basin (from a hydrological view, not a physical view) to the output point. The concentration-time in sub-basins is determined by the Kirpich formula. The Kirpich formula, Eq (1), in the Metric system is defined below:

$$Tc = 0.00032\frac{L^{1.155}}{(\Delta H)^{0.385}} \quad (1)$$

In this equation, Tc is the concentration-time in hour, L is the length of the main river in meters, and ΔH is the height difference between the start and finish point of the main branch of the river in meters. Also, lag-time is the time between the centres of the rainfall (the middle time of rainfall) till the peak time of the hydrograph. Lag-time in sub-basins is calculated by the SCS method. The concentration and lag-time of sub-basins are calculated in Table 3.

Table 1. Area percentage with height variation

Height (masl)	Area (km^2)	Cumulative Area (km^2)	Percentage (%)
1620-1800	9.8	9.8	0.4
1800-2000	54.7	64.5	2.9
2000-2200	392.2	456.7	20.3
2200-2400	393.7	850.4	37.7
2400-2600	489.0	1339.4	59.4
2600-2800	438.6	1778.0	78.9
2800-3000	250.9	2028.9	90.0
3000-3200	115.8	2144.7	92.1
3200-3400	58.0	2202.7	97.7
3400-3600	33.8	2236.5	99.2
3600-3800	14.9	2251.4	99.9
3800-4000	3.1	2254.5	100.0
4000-4040	0.2	2254.7	100.0

Table 2. Length, surface, and slope features in sub-basins

Sub-basin	Area (km^2)	Length (m)	Slope (m/m)	Periphery (m)	Average height (m)	Form Factor
Ghalayan	414.75	46304	0.3343	168120	2657.68	5.17
Kazem Abad	447.41	22482	0.1531	147190	2310.3	1.13
Vahregan	799.94	47793	0.2774	197050	2706.5	2.86
Middle sub-basin	562.62	30876	0.9774	250800	2437.8	1.69

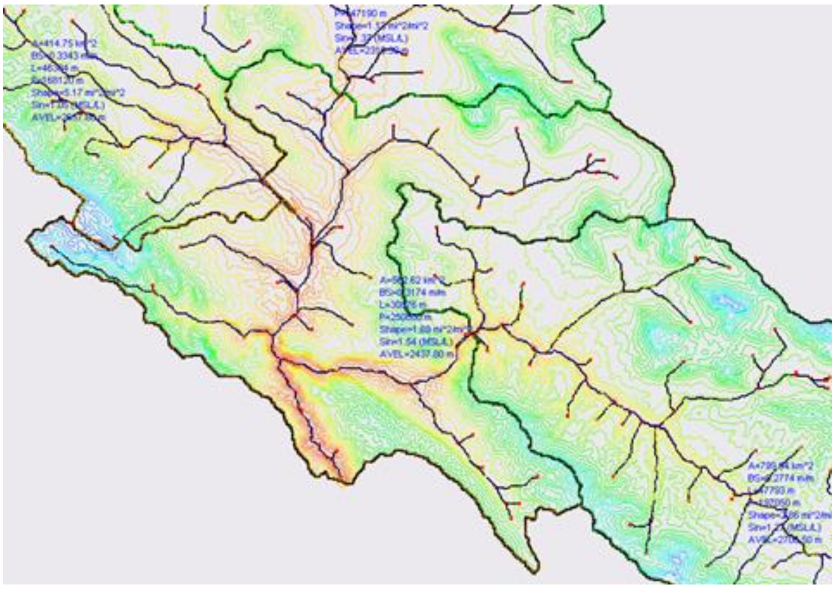

Fig. 11. Sample model results for extraction of waterways and characteristics of length, surface, and slope in sub-basins

Table 3. Concentration-time and lag-time in sub-basins

Sub-basin	Concentration-time	Lag-time
Ghalayan	5.37	3.46
Kazem Abad	3.59	3.75
Vahregan	7.90	4.51
Middle Sub-basin	5.47	3.56

3.7.Hydrological model

In the Rudbar Lorestan dam basin, there are three hydrometric stations on river branches: Ghalayan River, Kakolestan River, and Vahregan River. Also, downstream, the

Tang-e-panj hydrometric station is located on the Bakhtiyari River, and Telezang hydrometric station is on the Dez River. Fig. 12 shows the relation between sub-basins and the Modeling process.

3.7.1. Modeling results (2-10000 years' floodwater)

The hydrograph of 2-10000 years' floodwater is the result of the model shown in Fig. 13. Table 4 also presents the values of 2 - 10000 years' floodwater calculated in this study and the values reported by the two consultants of the present study contract, Ghods-Niroo and Pöyry consulting engineers, and their percentage differences.

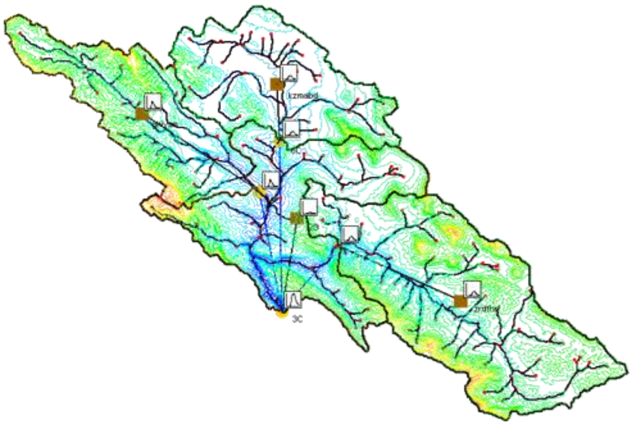

Fig. 12. The results of running the hydrological model

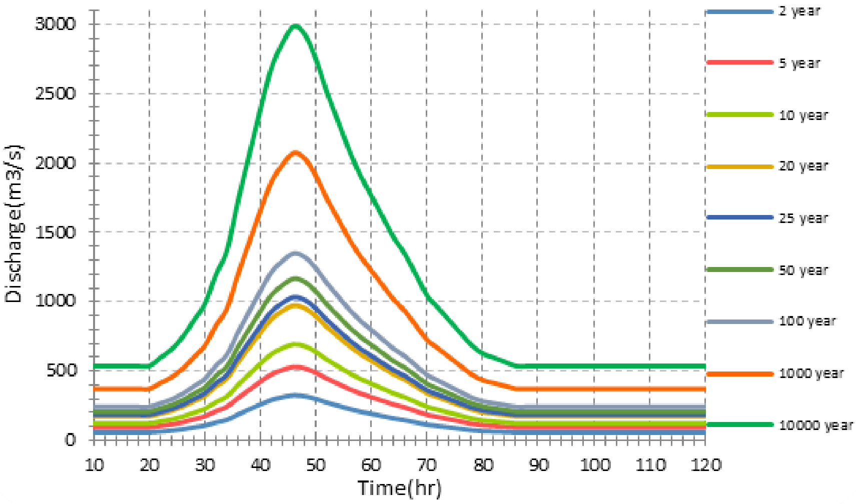

Fig. 13. 2-10000 years floodwater hydrograph in Rudbar Dam location

Table 4. Comparison of 2-10,000 years' floodwater discharge results modeled and reported by Ghods-Niroo and Pöyry

	2	5	10	20	25	50	100	1000	10000
Model Results	326	531	694	974	1034	1167	1349	2073	2986
Ghods-Niroo	315	516	662	812	860	1016	1186	1916	2808
Pöyry	307	560	748	944	1009	1219	1442	2292	3342
Difference of results with Ghods-Niroo (%)	3.49	2.91	4.83	19.95	20.23	14.86	13.74	8.19	6.34
Difference of results with Pöyry(%)	6.19	-5.18	-7.22	3.18	2.48	-4.27	-6.45	-9.55	-10.65

4. Conclusion

The results of the Kan basin simulation show very good agreement between the measured and computational results. However, as noted above, the key to deriving concordant results is how to apply the coefficients and initial settings. In fact, these settings should be within a reasonable range, since in the case of observation basins, the coefficients can be adjusted very well, as Fig. 5 confirms. This is the case in all studies based on numerical simulations. In the present study and WMS model, the parameters mentioned are limited to the parameters of precipitation distribution and basin soil conditions. In fact, if the input data of precipitation temporal distribution in the form of rainfall hyetograph and soil moisture status were included in the calculation of infiltration, the above discussion would have no place in simulating rainfall-runoff with the WMS model used. In the two experimental cases used, the Kan Basin and Walnut Gulch Basin had a rainfall hyetograph and were applied to the model but no information on soil moisture status was available and Investigation of model behaviour in parameter variation is the approach used in the simulation of two simulated experimental cases in the simulation of Rudbar Lorestan dam basin.

It should also be noted that the differences in observational and computational hydrographs of the Walnut catchment. It seems that the high number of hydrometric stations has led to the capture of all fluctuations in the output hydrograph, which, again, a lack of knowledge of the distribution of soil moisture status has resulted in the model's inability to cover the above changes. In fact, it can be concluded that with increasing accuracy of the output hydrograph recording, the input data weakness becomes more pronounced.

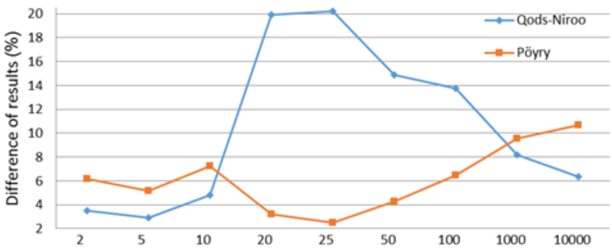

Fig. 14. Difference of results with Ghods-Niroo and Pöyry

Finally, in the simulation results of the Rudbar Lorestan catchment, Table 4 presents the quantities of floods and the difference between the results of the present study and the studies carried out by the two consultants Ghods-Niroo and Pöyry. As can be seen in all of the floodwaters with different return periods (except the floodwater with a 2-year return period) results of Ghods-Niroo were below the results of Pöyry. This difference increases up to 20% at 25 years return period, due to noticeable basin area, the mentioned difference leads to a difference in flow rate of 174 m3/sec. It is noteworthy that these studies are older than Pöyry. However in the case of Pöyry, the results are different, and in some periods, the estimates of floods are higher than in the present study and, in some cases, lower. The difference near 10% between the results of the present research and the mentioned studies indicates relative approval of those studies. But the noticeable point is that the maximum and the minimum difference between the previous study and the present research occurred at 25-year return period. The results of studies of Ghods-Niroo by a difference of 20.23% indicate the most difference between present research and the results of Pöyry, with a difference of 2.48% showing the less difference. Due to the lack of details in the mentioned studies, a definitive assessment cannot be done about this confluence. Actually, according to Fig 14 absolute value of the difference in results, it indicates a complete antonym trend in the two studies. Therefore, according to statistical methods and the same sources for both consultants, the significant differences between the presented results are because of disability in these methods, and the effect of personal analysis and experience. However, statistical methods have not been used in the present study, and there is no need to use statistical data and no dependence on such data, which is accurate in their preparation and has many uncertainties and error rates that have always been a subject of research. More importantly, that personal opinion has no effect on the results.

The deficiencies of the current research are the lack of observational data for the investigated basin, with the possibility of accessing the mentioned data, it is possible to make a better judgment about the obtained results, but the degree of agreement of the results in two representative basins that have reliable data (especially the Walnut Gulch basin) They are showing the correct simulation process in the model.

5. Disclosure statement

No potential conflict of interest was reported by the authors.

6. References

Beck, M. B., Kleissen, F. M., & Wheater, H. S. (1990). Identifying flow paths in models of surface water acidification. *Reviews of Geophysics*, *28*(2), 207-229. doi: 10.1029/RG028i002p00207.

Clark, C. O. (1945). Storage and the unit hydrograph. *Transactions of the American Society of Civil Engineers*, *110*(1), 1419-1446. doi: 10.1061/taceat.0005800.

Crawford, N. H., & Linsley, R. K. (1966). Digital Simulation in Hydrology'Stanford Watershed Model 4.

Farahani, S. V., Hejazi, S. M., & Boroomand, M. R. (2021). Torsional Alfvén wave cascade and shocks evolving in solar jets. *The Astrophysical Journal*, *906*(2), 70. doi: 10.3847/1538-4357/abca8

Freeze, R. A., & Harlan, R. L. (1969). Blueprint for a physically-based, digitally-simulated hydrologic response model. *Journal of hydrology*, *9*(3), 237-258. doi: 10.1016/0022-1694(69)90020-1.

Hromadka, T. V., & Whitley, R. J. (1994). The rational method for peak flow rate estimation 1. *JAWRA Journal of the American Water Resources Association*, *30*(6), 1001-1009. doi: 10.1111/j.1752-1688.1994.tb03348.x.

Kokkonen, T. S., & Jakeman, A. J. (2001). A comparison of metric and conceptual approaches in rainfall-runoff modeling and its implications. *Water Resources Research*, *37*(9), 2345-2352. doi: 10.1029/2001WR000299.

Vidyarthi, V. K., & Jain, A. (2023). Development of simple semi-distributed approaches for modelling complex rainfall–runoff process. *Hydrological Sciences Journal*, 1-18. doi: 10.1080/02626667.2023.2197117.

Lee, K. K. F., Ling, L., & Yusop, Z. (2023). The Revised Curve Number Rainfall–Runoff Methodology for an Improved Runoff Prediction. *Water*, *15*(3), 491.

Milly, P. C. D., & Eagleson, P. S. (1988). Effect of storm scale on surface runoff volume. *Water Resources Research*, *24*(4), 620-624. doi: 10.1029/WR024i004p00620.

Namin, M. M., & Boroomand, M. R. (2012). A time splitting algorithm for numerical solution of Richard’s equation. *Journal of Hydrology*, *444*, 10-21. doi: 10.1016/j.jhydrol.2012.03.029

Mulvaney, T. J. (1851). On the use of self-registering rain and flood gauges in making observations of the relations of rainfall and flood discharges in a given catchment. *Proceedings of the institution of Civil Engineers of Ireland*, *4*(2), 18-33.

Rezaie-Balf, M., Zahmatkesh, Z., & Kim, S. (2017). Soft computing techniques for rainfall-runoff simulation: local non–parametric paradigm vs. model classification methods. *Water Resources Management*, *31*, 3843-3865. doi: 10.1007/S11269-017-1711-9.

Shah, S. M. S., O'connell, P. E., & Hosking, J. R. M. (1996). Modelling the effects of spatial variability in rainfall on catchment response. 2. Experiments with distributed and lumped models. *Journal of Hydrology*, *175*(1-4), 89-111. doi: 10.1016/S0022-1694(96)80007-2.

Sherman, L. K. (1932). Streamflow from rainfall by the unit-graph method. *Eng. News Record*, *108*, 501-505. http://ci.nii.ac.jp/naid/10023998652/en/

Singh, V. P. (Ed.). (1995). *Computer models of watershed hydrology* (Vol. 1130). Highlands Ranch, CO: Water resources publications.

Stephenson, G. R., & Freeze, R. A. (1974). Mathematical simulation of subsurface flow contributions to snowmelt runoff, Reynolds Creek Watershed, Idaho. *Water Resources Research*, *10*(2), 284-294. doi: 10.1029/WR010i002p00284.

Strapazan, C., Irimuș, I. A., Șerban, G., Man, T. C., & Sassebes, L. (2023). Determination of Runoff Curve Numbers for the Growing Season Based on the Rainfall–Runoff Relationship from Small Watersheds in the Middle Mountainous Area of Romania. *Water*, *15*(8), 1452. doi: 10.3390/W15081452.