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Determining the most appropriate method of estimating the runoff in the aquifer basin of Central Iran

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ABSTRACT

Estimating the annual volume of the aquifer basin is of the main issues in designing the aquifer projects. Since the aquifer basin of central Iran covers half of country and a great number of the aquifer basins are situated in the arid and semi arid regions of the hydrometric stations, their watering figures are estimated by experimental models. The general structure of these models in some cases brings about considerable differences in the estimated and observed figures resulted from an incorrect selection of a model. This study has made use of 9 experimental formulas of Justin, Lisi, the world Meteorology Organization ratio, Agricultural Research Association of India, ICAR, Khosla, Turc, the Irrigation Department of India, and Inglis and De Souza for calculating the annual runoff in the water basin of Iran. Therefore for selecting the basins with the least annual natural and artificial Debi changes, the equal aquifer basins with an area less than 300 square kilometer which had no stank and vast agricultural lands which had little to middle degree of penetrability were firstly chosen. In selecting and determining the basin border two soft wares, Google earth, and ArcGIS were used, then the geological, climatological, and land applicability maps of the studied basin were prepared and their hydro climatologic statistics in the common 30-year-old time limit (1976- 2005) were extracted. At the end, the annual runoff altitude of the selected stations was determined using the aforementioned 9 ratios and these outcomes were compared with the observed data of the stations using four methods MAPE, RMSE, t distribution, and the unilateral analysis variance. The results show the superiority of Khosla to the other methods in the arid and semi arid regions. The estimated data in both arid and semi arid climates were studied separately, in both cases Khosla was selected as the most appropriate method.

Introduction

The recent developments in different fields as agriculture, industry, hygiene, and etc. resulted in an increase in water consumption per capita and abusing this magnificent resource of existence has brought shortage in it. This crisis and shortage is mainly seen in the countries where the dominant climate is arid and semi arid. The researches suggest that the rate of evaporation and distillate and runoff in the arid regions is respectively 70 and 29 percent and in the semi arid regions it is 50 and 30 percent respectively (Davie, 2008).

Knowing the annual estimation of the aquifer basin is one of the most important aspects in designing the aquifer projects which requires a serious allocation of the expertise. Although it is easily possible in the hydrometric stations, the aquifer projects are mainly suggested and performed in the regions where the land is intact and commonly empty of any hydrometric stations, therefore the experts have to proceed with the experimental models of determining the annual runoff. On the other hand, since these models are mostly prepared and qualified in the particular regions, they have the best efficiency in the same regions, in a way that utilizing two different models in the same region has brought considerable differences in the calculated runoff figures in some cases (Mahdavi, 2009). This study aims at assessing and comparing the most important experimental models of estimating the runoff in a comprehensive framework, and then it would introduce the most efficient ones in order to be used in the arid and semi arid regions about which there is no statistical information. In this way, the recorded research can be expressed as: Ghahraman and Hatamiyazd (2006) evaluated five common ratios of Justin, Uttar Pradesh Irrigation Department (UPID), Indian Agricultural Research Association (ICAR), Inglis and De Souza, and Khosla in the aquifer basins of Nahrein dam in Tabas. The results showed that two Justin and Uttar Pradesh Irrigation Department of India, amongst all, were relatively closer to the reality of the studied region.

Davoudirad (2007) calculated various experimental methods of estimating the runoff altitude in the rivers at 47 chosen hydrometric stations of the observed runoff altitude, aiming at evaluating the efficiency of the experimental equilibriums for estimating the runoff altitude and the possibility of reassessing and correcting them in Salt Lake aquifer basins. The results showed that ICAR, Cotagne, Justin, and Turc enjoyed more correctness and accuracy respectively. Then he got through reassessing the ratios and correcting their coefficients, and their creditability proved that the performed reassessment was acceptable and meaningful only for Khosla.

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Abdi et al (2009) compared the experimental methods of the runoff estimation in Sanich aquifer basin of Yazd as a case study in order to select a proper method for assessing the annual runoff. The results of testing various methods showed that Khosla was the most appropriate method in estimating the runoff.

Boshra Seghale and Afzali (2010) examined different methods of watering estimation in Maleh Mir aquifer basin. This was performed by the surface and pointed Debi, ratios and the experimental methods using 30- year- old statistics of Debi. The results showed that Khosla and Justin had calculated the watering rates as being more than the true figures, and ICAR had presented more acceptable results in comparison with others in the studying area.

Raghunath (1997) pointing to the studies by Khosla, examined this formula on a great number of basins in India. He mentioned that that method had brought good results in calculating the annual water balance sheet for being used in the preliminary studies.

Lilua & Shenglianego (1999) utilized a two-parametric model for the monthly water balance sheet in order to simulating the runoff in 70 sub basins in southern Chine. There, they found that the two-parametric model of the water balance sheet can give acceptable figures of the monthly runoff.

The present study is outstanding amongst the similar studies in the field since it is the first which makes a comprehensive comparison of all the common experimental methods in estimating the annual runoff in Iran. The next point is that the previous studies were mainly case studies performed in a limited region. The present study which is based on dividing the country into six-party aquifer basins, the central aquifer basins of Iran involving the main portion of the existed problems are evaluated. And finally, for making equal status, the basins containing a stank or from which there was considerable water usage for irrigation and etc. were identified and eliminated from the study.

Materials and methods

The aquifer basin of Central Iran is surrounded by the Alborz Mountains to the north, the Zagros Mountains and the eastern mountains of Iran to the west and south. All the rivers streamed in the basins are in approach to the lakes, swamps, and the internal bounded deserts as Salt Lake, Sirjan desert or Gavkhooni swamp. That basin with the extent of 830000 square kilometer covers more than a half of country land and is subdivided into smaller basins.

In order to choose the proper stations, studying the statistics of hydroclimatological stations in 18 provinces of country, the hydrometric stations within the limits were recognized and then the stations whose upper basin was less than 300 square kilometer were determined and the stations whose Debi parameter had been measured were recognized. In the next stage, using the soft wares Google earth and ArcGIS, the position of the basins was determined and every basin concerning its land applicability was evaluated using the satellite pictures and the basins excluding of any residential zones and the stank being empty of any widespread agricultural operations were selected. Then making use of the geological maps 1/250000, the basins with inscrutability or little penetrability were selected.

In the next stage, after drawing the existed hydroclimatological statistic barograph in the thirty-year-old statistical period (1976- 2005) including Debi, rainfall, and temperature, we engaged to quality controlling and reconstructing the statistical shortcomings. In that stage, because of the severe statistical poverty, one of the stations was extracted from the calculation process.

After reconstructing and completing the Debi statistics, temperature and rainfall of the remaining stations, the runoff and rainfall statistics of the basins were compared relatively and two other stations, Gachsar and Bandar Holakou, were omitted because of having the annual runoff more than the annual rainfall.

At the end, among the statistics of hydrometric stations of 343 studied basins in 18 provinces, respecting the considered criteria7 basins were selected. Fig. 1 shows the separation of the studied stations in that zone.

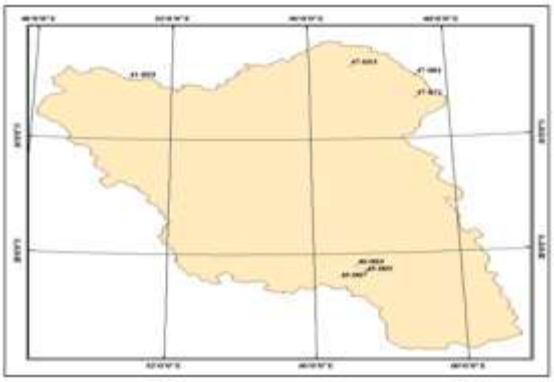

Fig. 1. Separation of the final stations water in the aquifer basin of Central Iran

Additionally, the climate of each sub basin using the climatic categorization method of du Marton was evaluated in the following stage.(Table 1)

Experimental formulas

The experimental models involve the ratios and the relations which have been determined through analyzing the limited data and the particularities of each zone; they are used for estimating the special probable parameters(2).

Turc ratio:

$$D = \frac{P}{\sqrt{0.9 + \left(\frac{P}{LT}\right)^2}} \quad (1)$$

$$LT = 300 + 25T + 0.05T^3 \quad (2)$$

$$R = P - D \quad (3)$$

in which P: the annual rainfall, D: the annual stream shortage, and R: the annual runoff, all based on centimeter, and T: the average annual temperature at °C. The ratios of the Indian Irrigation Department:

$$R = P - 1.17P^{0.86} \quad (4)$$

where P is rainfall and R is the annual runoff are both based on centimeter.

ICAR ratio:

$$R = \frac{1.511P^{1.44}}{T^{1.34}.A^{0.0613}} \quad (5)$$

where P and R are the annual rainfall and the runoff respectively based on centimeters. A: the aquifer basin based on square kilometers, T: the average temperature at °C.
Justin Relation:

$$R = K.Sh^{0.155}\frac{P^2}{(1.8T+32)} \quad (6)$$

$$Sh = \frac{\Delta H}{A^{0.5}} \quad (7)$$

Lisi ratio:

$$W = \frac{P}{1+\frac{304.8}{P}(\frac{F}{Z})} \quad (8)$$

in this ratio P and R are rainfall and the runoff altitude based on centimeter, F: the parameter related to the rainfall permanence, and Z: the coefficient of the physiographical particularities. The quantities related to F/Z are presented in Table 2.

The world Meteorology Organization ratio:

This method is based on the studies performed in the arid and deserting zones of the United States of America and, according to the world Meteorology Organization, could be used in similar zones of the world.

$$LT = 10^{(0.027T+0.886)} \quad (9)$$

P and R: the annual rainfall and the runoff based on centimeters respectively, T: the average temperature at °C. In Table 3, using parameters P and T and calculating LT, the amount of the ratio P/LT can be obtained and regarding the existed numbers in the Table, R/LT can be calculated and finally the runoff altitude can be obtained.

The ratios of Inglis and De Souza:

These two scientists presented the following ratio as the results of their studies in the plains and mountains of Maharashtra located in India (Mutreja, 1986).
For mountain locations:

$$R = 0.85P - 30.5 \quad (10)$$

For plains:

$$R = \frac{(P-17.8)P}{254} \quad (11)$$

where P and R are the annual rainfall and the runoff respectively based on centimeters.
Cotagne ratio:

$$D = P - LT.P^2 \quad (12)$$

$$LT = \frac{1}{0.8+0.14T} \quad (13)$$

$$R = P - D \quad (14)$$

This formula is true when P is between $\frac{1}{8\lambda}$ to $\frac{1}{2\lambda}$. If P is less than $\frac{1}{8\lambda}$ then there would be no equal rainfall and the superficial stream shortage. On the contrary, if P is more than $\frac{1}{2\lambda}$ the stream shortage would be independent of P and would be calculated through the following formula:

$$D = 0.20 + 0.035T \quad (15)$$

P,R,D based of meters and T based of temperature at °C
Khosla ratio:

$$R = P - \frac{T}{3.74} \quad (16)$$

P and R are rainfall and the runoff altitude based on centimeter, and T temperature at °C.

After processing the required statistics and information, the necessities for Cotagne ratio in the studied basins were evaluated. As expressed in Table 4, this condition was not satisfied in most of the studied basins (except one), and therefore it was omitted from the related calculations.

In the next stage the runoff figures achieved from 8 remained ratios were assessed whose final results are mentioned in Table 5.

On the other hand, for determining the probable errors of the experimental ratios and the observed data of each station ANOVA method was firstly used which showed a meaningful difference in all the studied formulas. Then the results derived from the experimental relationships with all the stations were evaluated and suggested no meaningful difference between Khosla and the observed data. In order to compare the runoff altitude in the observed data and formulas derived from two reliable indexes MAPE and RMSE were used, the results of which shown in Table 6. As clear there, comparing with the rest, Khosla method devotes the least MAPE and RMSE to it and therefore considered as the most appropriate method in estimating the runoff.

In addition to that, for comparing the runoff altitude in two arid and semi arid climates, the results derived from two sub basins of these two climates were compared with each other using two reliable indexes MAPE and RMSE the results of which suggested that Khosla had the least difference with the observed data in both climates, and was therefore the most appropriate method for calculating the runoff in both climates whose results are presented in Table 7.

Results and Discussion

The present study, dealing with 9 ratios of Justin, ICAR, Lisi, the World Organization , Khosla, Turc, Cotagne, Inglis and De Souza, and the Irrigation Department of India in Khorasan Razavi province, chose Khosla as the closest method to the observed data whose results correspond with Davoudirad (2007), Abdi et al (2009), Boshra Seghale and Afzali (2010), Raghunath (1997), however the researches for comparing the Khosla ratio with the rests for determining the most appropriate runoff estimation method through the studies of Ghahraman and Hatamiyazd (2006) and Abdi et al (2009) led to different results. In the aforementioned studies, Ghahraman and Hatamiyazd introduced Justin and the Irrigation Department as the proper method while Abdi et al recognized Lisi as appropriate. Abdi et al (2009) performed in Banadek Sadat basin of Yazd province which is a part of central Iran basin, was evaluated; the results showed that Banadek Sadat basin statistically possessed no hydrometric station with long lasting data, and so being content with the present data for studying and generalizing it to the other parts requires more considerations. In the study by Ghahraman and Hatamiyazd, the studied basins involved the residential and agricultural lands and a stank, all of which were influential on the runoff altitude. In some studies as Kalantari and Bazrafshan (2003), Ghezavi and Abbasali (2003), Boshool (2004), Davoudirad (2006), Payervand (2007), Abdollahvand (2009), Ghafari et al (2010) Khosla has not been involved in the researching methods ,so their results could not be compared with the present study.

Of the most important characteristics of this ratio is the small number of required parameters which could easily calculate the runoff altitude in the areas excluding the statistics (Zare et al, 2008). Regarding the possibility of calculating the annual and seasonal rainfall as a subtraction from evaporation and distillate, and regarding the fact that the figures of evaporation and distillate depend largely on the temperature, usually the temperature in the relation of rainfall- runoff is considered as an important parameter. Although the temperature is changeable to time and place, the average temperature in each basin does not change annually to a large extent; based on the theory that the average temperature can change all the influential factors in destructions, Khosla analyzed the monthly rainfall in the various basins of India and America (Bajelan et al, 2005).

The next important point to be considered is that today it has been proved that regarding all the necessary notices in selecting a formula, the climate diversity would affect the dominant equations of the hydro system in a long run. The studies done in the United States and Canada would confirm this fact (Velayati, 1988; Smith 1987; Modi, 1988; Manning, 1997). Therefore, the factors affecting beyond the parameters of a formula should be regarded, especially in a long term.

Although the results of the present study show the superiority of Khosla in the arid and semi arid zones comparing with other methods considered in this research, the experimental formulas of estimating the water balance sheet had been managed in special zones and so showed the best efficiency in the same zones. Therefore utilizing these ratios in the arid and semi arid zones is just based on their use in the world or their simplicity, there might be great mistakes with the calculations when they had not been tried in one or more aquifer basins, this is of more importance in the arid and semi arid regions of country. It has been mentioned in the studies by D' Olivera & Mimoso in a research performed in 1978 in the rivers of Southern Mouzambique, Basu (1978) and Vandile et al (1992) had came to this conclusion that a model could not be selected as the appropriate for all the aquifer basins and they should be bounded in the zones whose coefficients had been calculated and possessed similar particularities.

It should also be implied that in the arid and semi arid zones, the requisites for utilizing the Cotagne method are not satisfied. On the other hand, concerning the resulted outcomes of the statistical analysis, we can infer that the Turc and Inglis and De Souza methods showed the greatest differences in the observed and estimated figures.

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Table 1 : The climate of studies sub basins

Station code	Drought Index	Climate
Darband	18.87	Semi arid
Senobar	14.13	Semi arid
Cheshmeh	14.86	Semi arid
Ali	8.20	Arid
Hatiteh	12.05	Semi arid
Jirefto	10.51	Semi arid
Khamrotak	9.76	Arid
Barehsoz		

Table 2 : The proposed coefficients of Lisi(F/Z)

The basin land types	Rainfall permanence		
	Short	Avrage	Long
Involving plateaus, flat plains with deep ground and proper vegetations	2	4	6
Relatively flat with semi deep ground and pasturing vegetations	0.83	1.67	2.5
Hills with a relatively shallow ground and a relatively weak vegetation	0.5	1	1.5
Sandy lands full of gravel with a severe slope in the heights	0.23	0.58	0.88
Stony lands with much height and slope and empty of vegetation	0.14	0.28	0.43

Table 3 : Estimated ratios in the world Meteorology Organization ratio

P/LT	0	1	2	3	4	5	6	7	8	10	12	14
R/LT	0.009	0.026	0.075	0.2	0.415	1	1.9	2.7	3.4	5	7	9

Table 4: Studing λ condition for every stations

Station name	Rainfall(meter)	$\frac{1}{8\lambda}$	$\frac{1}{2\lambda}$	condition
Senobar	0.332	0.0335	1.34	inacceptable
Hatiteh	0.20	0.37	1.48	inacceptable
Cheshmeh Ali	0.34	0.31	1.24	acceptable

Table 5: Estimated the runoff figures using experimental formulasin in different basins (based on centimeters)

Station name	the observed figures	Justin	ICAR	Lisi	the World Meteorology Organization	Khosla	Turc	Irrigation Department	Inglis and De Souza
Senobar	22.01	5.66	4.06	4.47	1.22	29.60	1.42	9.41	2.01
Hatiteh	17.42	2.10	1.71	1.87	0.56	16.80	0.00	4.94	0.26
Cheshmeh Ali	30.00	6.76	5.06	8.28	1.43	30.94	2.27	9.78	2.19

Table 6: Comparing experimental formulas with observed datas using 2 index MAPE and RMSE

Index	Justin	ICAR	Lisi	the World Meteorology Organization	Khosla	Turc	Irrigation Department	Inglis and De Souza
RMSE	16.41	17.80	17.13	18.19	**4.43**	22.34	15.53	22.12
MAPE	78.44	79.32	74.86	94.35	**13.73**	95.33	65.42	94.02

Table 7: Comparing Reasults of experimental formulas with observed datas using 2 index MAPE and RMSE separated in arid and semi arid regions

Method / Climate	Index	Justin	ICAR	Lisi	the World Meteorology Organization	Khosla	Turc	Irrigation Department	Inglis and De Souza
Semi arid	RMSE	14.12	15.76	15.16	18.56	**6.14**	17.83	12.14	21.35
	MAPE	53.03	54.18	50.61	66.78	**34.72**	66.23	39.83	92.91
Arid	RMSE	8.35	8.26	7.98	9.06	**0.25**	9.39	6.75	9.25
	MAPE	25.41	25.14	24.25	27.57	**0.67**	28.57	20.53	28.15