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Presentation of Rain Water Saving Method in Rainy Regions Using ArcGIS and Regressional Analysis of Non-Dimensional Numbers (Case Study: Ziarat Basin, Golestan, Iran)

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Abstract: Rainfall runoff can be saved in the subsurface reservoirs in order to supply water to different rural and urban parts. Volume estimation and dimensional optimization depend on a lot of hydrological and physiological factors of the basin. In this study, the dam's usage to provide the drinkable water was investigated in the Ziarat district located in the Golestan province. For this purpose, the sub-basins and basin's runoff, flood potential of each sub-basin, DEM and their physiographic characteristics were determined by ArcGIS software. Then in determination of the reservoir's optimal volume in different return periods, the cost diagram was drawn according to the reservoir's building value and the water provision. The effective parameters in the study which include the reservoir's Capacity (C), annually water Demand (D), the area of each sub-basin (A_i), Rainfall (R), Reservation assurance degree (Re), stream Length (L), average slope of each Sub-basin (S) and Curve Number (CN) were used in non-dimensionalizing process and were used in order to determine the size of the reservoir. For this purpose, a mathematical model was presented using the exponential regression between π s and solving equations in MATLAB. Because of the lack of statistics in the hydrometric stations in the basin, the maximum flooding estimations were conducted, using the regional analysis. The instantly maximum discharge was defined as a function of basin area using the related code. By determining the initial volume and output, the modeling was conducted. Results show that these reservoirs can compensate the 11% water shortage which this province (Gorgan) faces each month with regard to 300 L sec^{-1} water shortage in this province.

Key words: Rainfall runoff, MATLAB, non-dimensional numbers, parameters, reservoirs

INTRODUCTION

Although, Golestan province is one of the pluvial provinces in the country, it faces some water shortages in drought periods. The changes arising from becoming a province and also the cultural and economic changes and increasing number of visitors to this location caused a great variation and intensification in the population of the province following a greater demand for water supplies. In the present conditions, Gorgan city faces a water shortage of 300 L sec^{-1}. Some of the province's water challenges include limited water reservoirs, dependence on underground water, disordering population increase and high capitation usage of 236 L day^{-1} for each person. Precipitation water is a valuable source which can be used. The main purpose of application of precipitation water in the reservoirs is to reserve drinkable water. The water from reservoirs can be used for non-drinking purposes like irrigation of agricultural lands during the drought periods in drinkable fields for decreasing the water shortage rate during the low precipitation periods. Crowe *et al*. (2005) state that there are two methods for dimensional analysis: step-by-step and exponential. They stated that some repetitive parameters should be determined in exponential method. The choosing method of these parameters are as follows: Moriyama *et al*. (2016) studied the smartening of underground rain water reservoirs and used the saving data to control the runoff and to measure the rainfall. The results of investigations were used operationally for sample of 110 tones and smaller home samples. Campisano and Modica (2014) studied the storage and confining amount of the water in underground reservoirs using a method called step-by-step time analysis and used a household prototype in his study. Raimondi and Becciu (2014) studied the two-section reservoirs used foe rain water accumulation. In that study, Campisano *et al.* (2014) investigated the application effect of rain water reservoirs

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in decreasing of maximum flood discharge at the basin's exit point. In the stated simulation, the precipitation data and the demand values were selected as inputs of the model and finally the reservoir's size and the usage pattern were introduced as most important factors in decreasing of maximum discharge. Matos *et al.* (2014) studied the determination of the optimal reservoir size for a commercial building. In order to achieve acceptable results, they studied different scenarios. Mashford and Maheepala (2015) accurately investigated the reservoir's recoverable volume. The rainfall-runoff distribution, demand distribution and the reservoir's ultimate capacity are the main effective factors in the study. Finally, a model was presented that could exactly calculate the amount of stored water and the total available volume in each time step. Imteaz *et al.* (2011) investigated the reliabitilty related to rain reservoirs under different scenarios including climate condition, roofs' area, rain reservoirs' capacity, household demand and the designated portion of the reservoirs for water provision. Analyses were based on three climates different in precipitation and everyday precipitation usage. At the end, the results were provided seperately based on parameters used in simulation. Campisano *et al.* (2014) studied the optimal size of the rain reservoirs for local usages in Sicily (Italy). They presented annual precipitation pattern using the non-dimensionalising method and the data from 17 rain stations. The optimal size of reservoir was presented based on the results of daily water equilibrium stimulation and usage of the precipitation data from the Sicily stations and also the cost minimizing criteria. Eroksuz and Rahman (2010) conducted a study on the water savings potential of rainwater tanks which were located in multi-storied residential buildings for three cities in Eastern Australia. They have concluded that rainwater tank of appropriate size in a multi-storied building is ideal in providing significant water savings even in dry years. They have also provided equations for predicting annual rainwater savings potentials for stataed cities. Khastagir and Jayasuriya (2010) analyzed reliability of rainwater tanks and calculated the reliability by usage of a daily water balance model. They have presented contours of optimum tank sizes for surrounding areas of Melbourne while considering the historical daily rainfall, the demand for rainwater, the roof area for a supply reliability of 90%. All of these analyses were based on daily rainfall data gained historically, making an average of cumulative historical savings and other variables. Through such analysis of averaged variables/parameters rainwater tank users do not get an actual range of expected results. With the consequents of climate change, such ranges of actual results are expected to be widen further. Additionally, design contours presented by Khastagir and Jayasuire (2010) are based on an expected reliability of 90%. In reality, different user may choose different reliability. So, the purpose of this study is to determine a regional model for determination of maximum flood by experimental method. Determine the subsurface reservoir optimal volume in every sub-basin of Ziarat with completely natural surfaces by dimensional analysis.

MATERIALS AND METHODS

Designated location: Ziarat basin in Gorgan, Iran is located between 54°, 13 min, 54° and 45 min East longitude and 36°, 31 min, 36° and 59 min North latitude in the South of Golestan Province. Ziarat basin is set in the south of Golestan province which abuts the Shast Kela basin from west and abuts the Chahar Bagh basin from east, from south it is adjacent to Lareh Kooh heights and from north it abuts the Ghareh Soo River. The area of this basin is 77.91 Km^2 which consists of three mountain basin, urban basin and plain basin. The Ziarat River in the mountain basin is consisted of two river branches named abshar river and tool baneh river that after converging of these two branches, the ziarat river is formed. According to the Naharkhoran meteorology station's statistics which is located in the basin, annual rainfall average is: 527.4 mm. The precipitation average in different seasons of the year (Spring 121.3 mm, Summer 80.5 mm, Fall 169.9, Winter 155.7mm). The season with the least precipitation is July with average precipitation of 20.5 mm and the season with the most precipitation is October with average precipitation of 60.0 mm and the annual precipitation days average is 101 day. Figure 1 displays the location of the Ziarat basin. According to the basin's geographical location with regard to Gorgan city and its effect on the water supply of different rural and urban regions, a model of basin was developed in the GIS Software. According to, Fig. 2 in this environment, the Ziarat basin was divided into 6 sub-basins and DEM of the basin was achieved using TIN. Then in the ArcGIS scene and using DEM of the basin, the required physiographic characteristics like weighted average slope, weighted average height, area, perimeter, etc. were determined for separated sub-basins. These characteristics are presented in Table 1 for Ziarat sub-basins.

Determination of regional model of the flood: Although, it is expected that discharge of the flood is a function of the other physiographic parameters of the basin, in this method some models are presented using the statistics of the stations and the characteristics of the basin which by

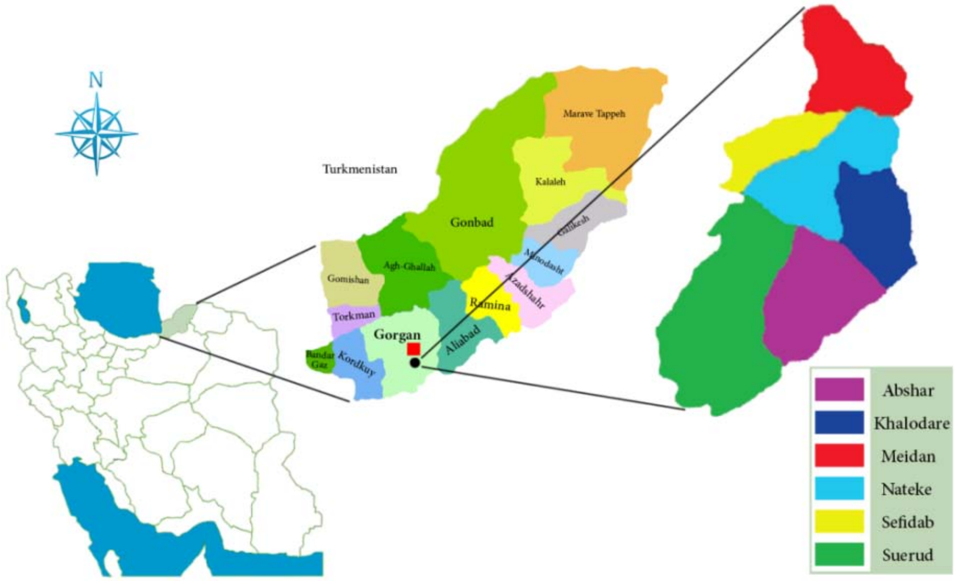

Fig. 1: Ziarat basin location map in Golestan province and Iran country

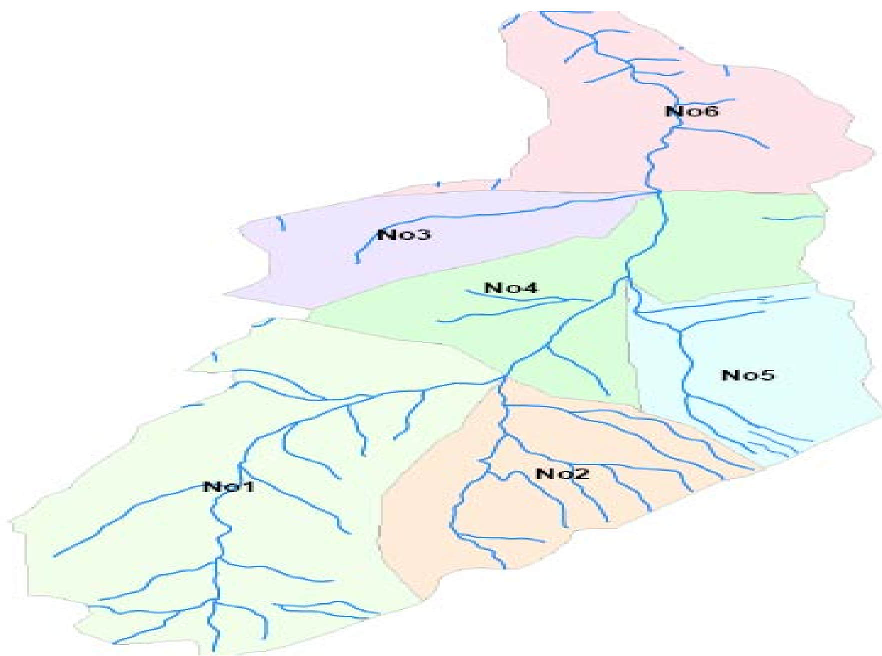

Fig. 2: Ziarat basin division

Table 1: Some physiographic characteristics of Ziarat basin

Regions	Values
Area (km^2)	77.91
Maximum height (m)	3300
Minimum height (m)	200
Weighted average height (m)	1915.45
Basin's weighted average slope (%)	54.47
Waterway's weighted average slope (%)	9.41
Main waterway length (km)	16.36
Curve number	65.46

the help of these models in every spot of the region that lacks some statistics and hydrometric data, the flood's discharge for different return periods will be acquired. Some current methods for estimation of periodic maximum flood are application of experimental formulas, composing of artificial hydrograph, simulation method, statistical estimation of periodic maximum flood, regional analysis and flood index method which every one of them are

Table 2: Maximum flood (Cubic meter per second) with different return rate and proper distribution

				Return period (year)					
Sub basin No.	Station name	Proper distribution	Area	2	5	10	25	50	100
1	Sooteh rood	Log pearson Type 3	19.83	1.6	4.3	7.8	15.5	25.1	39.5
2	Abshar	Log pearson Type 3	11.47	1.0	2.6	4.7	9.4	15.2	24.0
3	Sefidab	Log pearson Type 3	8.85	0.6	1.7	3.0	6.0	9.7	15.3
4	Natkeh	Log pearson Type 3	13.38	0.8	2.1	3.8	7.6	12.4	19.5
5	Khaloo dareh	Log pearson Type 3	10.72	0.3	0.8	1.4	2.8	4.5	7.1
6	Meydan	Log pearson Type 3	13.66	0.6	1.5	2.7	5.4	8.7	13.8

Table 3: Regression coefficients with different region return periods

Return period (year)									
Period	Different region								
T	2	5	10	25	50	100	200	500	1000
a	0.04480	0.09440	0.119200	0.153000	0.176400	0.198700	0.218200	0.242200	0.3000
b	52.2389	122.389	189.1558	297.5583	395.2803	507.5574	638.2047	839.8209	1017.4

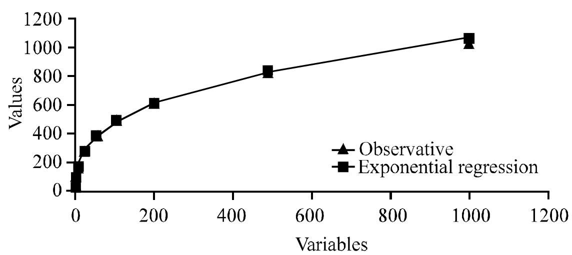

Fig. 3: Variations curve of (b) with return period (R^2 = 0.952)

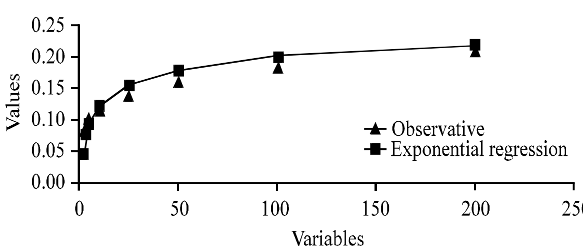

Fig. 4: Variations curve of (a) with return period (R^2 = 0.914)

applicable in specific conditions (Campolo *et al*., 1999). In the experimental equations method with area variable, the effect of other hydrological and territorial accounts is inserted in the equation as coefficients and symbols and three formations of these equations are (Eq. 1-3):

$$Q = CA^{n} \quad (1)$$

$$Q = CA^{m.A^{-n}} \quad (2)$$

$$Q = CA[(a+bA)^{-m}+d] \quad (3)$$

Where:

Q = The flood maximum discharge
A = The basin's area
a-d = The equation's coefficients and m, n are the equation's symbols

For this purpose, six hydrometer stations were selected. Then by selecting a 15 years index (2000 till 2014) the data were completed using the regression. Periodic flood statistics were completed and in the next level, floods with different return period till 10000 yeasr were calculated. Results with proper data and area distribution for each station are presented in Table 2. Using Table 2, the homogeneity relation between area and maximum floods with different return periods was formed. The flow-discharge equation was generally considered as Eq. 4:

$$Q = aA + b \quad (4)$$

The a, b amounts are written in Table 3. Also some samples of corresponding curves are shown in Fig. 3 and 4. By using Table 2, the regression relation between the values of a and b with different return periods was formed in the MATLAB software that the final relation is as follows (Eq. 5 and 6):

$$a = 0.0699T^{0.2114} \quad R^2 = 0.952 \quad (5)$$

$$b = 95.1014\ T^{0.3482} \qquad R^2 = 0.95 \tag{6}$$

Determination of optimal volume of precipitation subsurface reservoir: Designing criteria is not just contingent upon demand because the potential of each sub-basin in flood producing should be considered. Thus these two factors are considered in determination of the reservoir optimal size. It should be assured that there is enough water in the reservoir for demands (In other words an increase in credential). The level of water storage depends on the return period and the amount of forecasted precipitation. The water demand of the reservoir D_t depends on many different factors. A simple equilibrium equation is presented for the calculation of the rain water reservoir capacity. It is stated as Eq. 7:

$$S_{t+1} = S_t + Q_t - D_t \qquad 0 \leq S_{t+1} \leq C \tag{7}$$

Where:

S_{t-1} = The stored amount in the reservoir at the end of month t
s_t = The stored at the beginning of month
Q_t = The available runoff in each sub basin during the month
D_t = The total demand for water in month t and C is the capacity of the reservoir

Equation 3 is used at the end of each time stage for obtaining the water storage level. The credit capability of the reservoir is defined as the probability that reservoir has the enough certainty for demands and is calculated as Eq. 8:

$$Re = \frac{P}{N} \times 100 \tag{8}$$

Where:

Re = The credit of the reservoir, P is the number of days which the reservoir is not empty
N = Total days of the month

The size criteria of the reservoir is not only dependent on demands. Yet there are some other variables that directly and indirectly affect the decisions concerning the reservoir's size which include: the precipitation in the area, the basin's physiographic characteristics and hydrological parameters and the final application decided for the water. The non-dimensional sing makes way for expansion of a network to select a proper size for the rainfall water reservoir.

If the amount of whole demand is greater than the whole savable rainfall, the optimal size will be volume of the whole precipitation. It will not be acceptable with regard to the province's water potential that has precipitation in 9 months of the year. If two diagrams of supply and demand could be drawn, in that case the intersecting point of these two curves will determine the reservoir's optimal volume considering some limits. With so many restrictions for provision and demand diagrams with regard to different seasons and capitation usage, this task will be difficult. Thus by setting up an equation between amounts of πs with considering highly influential parameters on discharge exponentially we will reach a very practical relation. The parameters considered for determination of dimensionless numbers include: capacity of reservoir $C(L^3)$, annually water demand $D(L/t)$ Area of each sub-basin $A_i(L^2)$, Rainfall $R(L)$, (Re) Reservoir assurance degree, (L) Length of waterway, average slope of each Sub-basin (S), (CN) Curve Number of each sub-basin. Curve number is one of the most influential causes on the runoff. In this case, instead of considering the amount of runoff as a variable, curve number was taken into account. Also the estimated discharge with different return periods stated above was used for determination of the reservoir initial Capacity (C). With inserting discharge with different return periods in specification of C, the optimal estimation value of the reservoir can be specified but this is not economically and practically effectual. Thus in this study discharge with return period of 25 years was set as designing criteria for the reservoirs. Two repetitive parameters of stream length and demand of annually water were selected. By considering the π-Buckingham relation, 6 the dimensionless number was achieved (Table 4).

Table 4: Dimensionless numbers achieved from π-Buckingham method

Dimension	Formala
π_1	CN
π_2	S
π_3	Re
π_4	C/L^3
π_5	R/L
π_6	A/L^2

Because of the diversity in purposes and limits, the programming issue in water reservoirs is complicated and for investigation of systems, some appropriate mathematical models are needed. These models make the most important part of the programming procedure. Because the rainfall variations are exponentially connected with produced corresponding runoff for the determination of the reservoir's optimal size, in this case the presented formula was considered exponentially. The amount of Re parameter can be selected randomly and also by considering the relation mentioned before, shortage of water as 20 L sec^{-1} for the basin, considering Re = 90% is expected. Table 5-7 indicate the amount of dimensionless numbers π_4-π_6, achieved in MATLAB for each sub-basin.

Table 5: Amount of achieved dimensionless number π_4 for each sub-basin

π_4					
1	2	3	4	5	6
0.00159523	0.00174980	0.00174025	0.00206280	0.00165024	0.000996
0.00300000	0.00329068	0.00327273	0.00387931	0.00310345	0.001874
0.00311000	0.00341133	0.00339273	0.00402155	0.00321724	0.001942
0.00083333	0.00091408	0.00090909	0.00107759	0.00086207	0.000520
0.00173610	0.00190431	0.00189393	0.00224496	0.00179597	0.001084
0.00160000	0.00175503	0.00174545	0.00206897	0.00165517	0.000999
0.00196667	0.00215722	0.00214545	0.00254310	0.00203448	0.001228
0.00295000	0.00323583	0.00321818	0.00381466	0.00305172	0.001842
0.00108333	0.00118830	0.00118182	0.00140086	0.00112069	0.000677
0.00265000	0.00290676	0.00289091	0.00342672	0.00274138	0.001655
0.00173833	0.00190676	0.00189636	0.00224784	0.00179828	0.001086
0.00391667	0.00429616	0.00427273	0.00506466	0.00405172	0.002446

Table 6: Amount of achieved dimensionless number π_6 for each sub-basin

π_5					
1	2	3	4	5	6
0.000784	0.002123	0.002467	0.001642	0.001636	0.000620
2.49E-05	8.62E-05	0.000130	2.97E-05	6.49E-05	3.75E-07
0.000398	0.000973	0.001007	0.001021	0.000860	0.000617
0.000317	0.000839	0.000943	0.000687	0.000715	0.000270
0.001281	0.003471	0.004042	0.002688	0.002923	0.001035
0.000572	0.001542	0.001783	0.001208	0.001302	0.000467
0.001371	0.003673	0.004235	0.002952	0.003109	0.001241
0.000810	0.002089	0.002333	0.001918	0.001799	0.001057
0.001128	0.003010	0.003424	0.002408	0.002554	0.000920
0.000825	0.002131	0.002371	0.001924	0.001834	0.000999
0.000794	0.002127	0.002446	0.001702	0.001801	0.000694
0.000723	0.001685	0.001627	0.001977	0.001527	0.001291

Table 7: Amount of achieved dimensionless number π_6 for each sub-basin

π_6					
1	2	3	4	5	6
0.35	0.49	0.37	0.53	0.42	0.34

Table 8: Achieved values of c and d for sub-basins 2, 4, 5

Sub-basin	π_6	c	d
5	0.42	-5.9649	-0.1022
2	0.49	-6.0007	-0.0940
4	0.53	-6.0818	-0.1264

Table 9: Achieved values of c and d for sub-basins 1, 3, 6

Sub-basin	π_6	C	d
1	0.35	-6.5403	-0.5803
3	0.37	-5.7516	-0.2351
6	0.34	-6.4703	2.3178

Because the relation between the runoff and its corresponding rainfall is exponentially connected and the volume of the reservoir is dependent on the amount of runoff, so the relation between, was considered exponentially (Eq. 9):

$$\pi_5 = ce^{d\pi_2\pi_3\pi_4\pi_6} \quad (9)$$

Amounts of c and d were achieved by the regression between π_4 ,π_5 of each sub-basin. Because of the low homogeneity coefficient between achieved amounts of c and also d, setting up a general formula for all sub-basins will yield amounts with high rates of error. But for the sub-basins 2, 4, 5 and 6, 3, 1. The homogeneity coefficients for amounts c and d were achieved approximately 90% which with this account, two formulas for this basin as shown in Table 8 and 9 are presented as:

$$c = -0.002\pi_6+0.003 \quad R^2 = 0.9 \quad (10)$$

$$d = -0.18\pi_6-0.020 \quad R^2 = 0.4 \quad (11)$$

$$c = 0.064\pi_6+0.02 \quad R^2 = 0.9 \quad (12)$$

$$c = -70.17\pi_6+25.26 \quad R^2 = 0.4 \quad (13)$$

RESULTS AND DISCUSSION

Regional analysis methodology has a widespread usage in measuring the flood discharge accompanying specific returns period, using geometrical features of catchment basin and providing appropriate multi-variable models. Table 2 indicates that adaptable statistic distribution is log pearson type 3. Also, Fig. 5 and 6 show that there is a good correlation between basins area and maximum discharge with various return periods up

Table 10: The formula for each sub-basin, the number of tanks and their optimum size

The formula for each sub-basin	No. of sub-basin	No. of tanks	Optimum size (m)
$\pi_5 = (-0.02\ \pi_6+0..003)$	2	3	25×25×5
$e(-0.18\ \pi_6-0.020)\pi_2\pi_3\pi_4\pi_6$	4	4	35×35×5
	5	1	25×25×5
$\pi_5 = (-0.02\ \pi_6+0..003)$	1	6	65×65×5
$e(-70.17\pi_6-25.26)\pi_2\pi_3\pi_4\pi_6$	3	4	35×35×5
	6	4	40×40×5

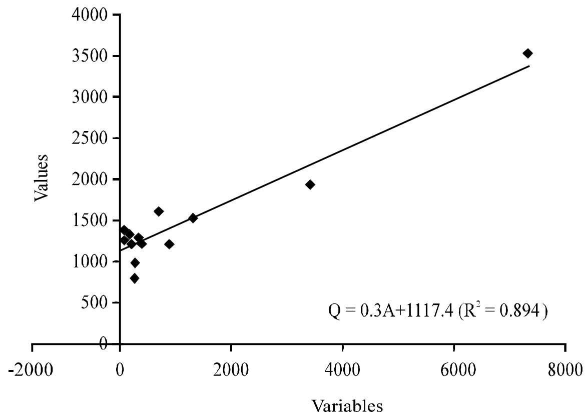

Fig. 5: The graph of relationship between floodwater areas with 1000 years return period

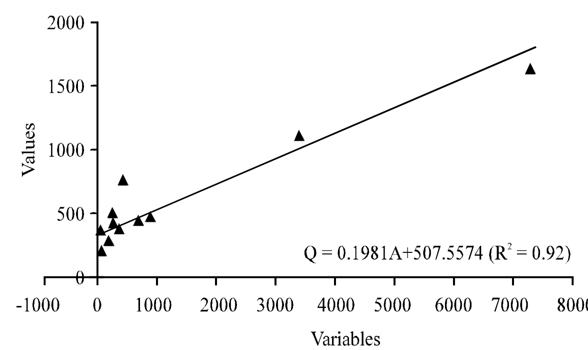

Fig. 6: The graph of relationship between floodwater areas with 100 years return period

1000 years. However, as there is a good distribution with area, an appropriate circulation with return period was created too. Table 3 indicates correlation coefficient changes along with various return periods. Although, regression analysis is generally more on the low return periods but is no special changes for which a specific equation could be considered. The best coherent equation established is exponential equation which is shown in Fig. 3 and 4. As it can be seen and shown in the Eq. 5, there is a good correlation coefficient. Therefore ,the final calculated equation of discharge of maximum floodwater with various return periods in the MATLAB Software is as follows Eq. 14:

$$Q = 0.0699T^{0.2114}\ A + 95.1014T^{0.3482} \quad (14)$$

A is basin area (km^2) and Q is discharge of maximum floodwater (m^3/sec) and T is return period based on the year. So the equation of region obtained in the all Ziarat basins can be used for >10,000 km^2 areas and return periods up to 1000 years.

The amount of obtained runoff shows that how much is each sub-basin capability for producing surface waters and how much should be considered for the initial estimated of reservoir capacity. Water caused by precipitation for each sub-basin may contain sediment, dust, leaves, etc. which is affiliated to lesions in the periphery area.

It is essential that a fixed contribution of occurred rainfall be wasted to improve water quality. By creating a stilling basin before the tank, it can prevent water entering with low quality. This operation for creating appropriate water quality is called initial siphon. Yaziz *et al*. (1989) Jenkins and Pearson (1978) examined what portion of created runoff should be allotted to initial siphon. However, due to different views on the initial siphon to ensure water quality, a reduction factor (0.8) was selected in this study for computing runoff.

Consequently, the formulas were obtained for each sub-basin, the number of tanks in each sub-basin and their optimum size in MATLAB Software (Table 10). The goal in the equation above is to obtain $\pi_4$in order to measure the optimum volume of reservoir when the π_4 value be positive, it is acceptable. Because the numbers used in some cases are close to zero, the numbers obtained are sometimes negative. Then the negative numbers which obtained for sub-basin (2, 4, 5) should be multiplied by (-0.57139) and for sub-basin (1, 3, 6) should be multiplied by (-0.3665). These numbers are correction factors which are obtained from average of the ratio of observational to computational.

CONCLUSION

Precipitation and runoff can be used for utilization of urban non- potable or potable water in the rural areas in most of sub-basins. Therefore, application of subsurface reservoirs is necessary in order to prevent the demolition of villages, agricultural lands, buildings, etc., due to occasional flooding and surface erosion and continuously landslides caused by intense rainfalls. Designing criteria of reservoirs size is not only based on demand because hydrological factors are also directly effective.

So, the ability of each sub-basin on runoff production should be examined. In the first step sub-basin and basin runoff, DEM and their physiographic characteristics were determined in GIS Software. In order to avoid a large number of hydrological parameters developments in determining the optimal volume of reservoirs in different return periods, it was decided that dimensional analysis should be used to reduce the number of independent variables. Basin hydrological stations had shortage of data required for maximum instantaneous discharge and reservoirs initial estimate was difficult due to lack of flood return periods. Due to using geometric features of basin the estimation of flood discharge with regular return periods was done from regional analysis with presenting of appropriate multivariate models. This discharge regional model defined instantaneous as a function of basin area. Achieved discharge showed the ability of basin and each sub-basin to produce surface water. Thus, the initial estimate of reservoir volume for optimization and then determination of the reservoirs optimal volume was done using characteristics of the basin and non-dimensionalizing them using dimensional analysis in MATLAB. To ensure water quality, a reduction factor of 0.8 was considered for initial Siphon. For each sub-basin a separate formula was obtained. But in this study by determining the same sub-basin (because the same changes c and d) two general formulas were prepared for the whole basin which are applicable for all similar sub-basins in terms of their hydrological factors and physiographic. In This formula, duplicate parameters were considered as length of the channel and demand rate. The present strategy in this study can compensate 11% of Gorgan city's water deficit per month due to lack of 300 L sec^{-1}.

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