Hydrological Analysis of Murat River Basin

Warvin Hussein FATTAH
Mehmet Ishak YUCE
Civil Engineering Department, University of Gaziantep
Turkey

Abstract

The overall objective of this study is to determine a practical rainfall-runoff relationship for the Murat River Basin by the linear method. The Murat River is the largest tributary of the Euphrates River situated within the borders of Turkey. The hydrologic characteristics of the basin were determined by employing the standard digital elevation model (DEM) and geographic information systems (GIS). The annual average discharge of the stream flow was acquired from seven flow measurement stations (FMS), while the annual total precipitation data was obtained from nineteen precipitation measurement stations (PMS) located within and in the vicinity of the basin. The rainfall-runoff coefficient for the whole basin was found to be around 0.6.

Key Words: Murat River Basin, Basin Delineation, Basin Characteristics, Rainfall-Runoff Coefficient, Linear Method, GIS.

1. Introduction

The assessment and management of water resources are vitally important, since it is essential for every form of life. Poorly managed resources can cause water scarcity or pollution, which may lead to social, economic and health crisis. The watershed based managements should include planning and conserving the available water resources. A watershed, which is also called drainage basin, drainage area, catchment, catchment area, catchment basin, river basin or water basin, can be defined as a delineated area from which the runoff drains into a single point on a stream at a lower elevation, generally the exit of the basin (Murthy, 2000; Bose et. al., 2012).

Delineating catchment areas by employing geographic information systems (GIS) and digital elevation model (DEM) is being preferred to manual techniques due to the improved accuracy, less duplication, easier map storage, flexibility, simplicity in data sharing, timeliness, greater efficiency and higher product complexity. GIS tools can be automated in implementation of various practical applications of watershed delineation. DEM is a 3-D representation of a landscape, which is widely utilized in hydrological analyses including delineation of watersheds. They are used in water resources projects to identify drainage features such as ridges, valley bottoms, channel networks and surface drainage patterns. Quantifying sub-catchments and stream channel properties such as size, length and slope can also be accomplished by employing DEM data. The accuracy of a topographic information is a function of both the quality and the resolution of the DEM, and of the DEM processing algorithms used to extract the necessary information. ArcGIS Hydrology tools could be used to describe the physical components of a surface by identifying sinks, calculating flow direction and accumulation, delineating watershed and creating stream network (William, 2000; Kang, 2008; Burrough and McDonnell, 1998; Yanmaz, 2006; Ogden et al., 2000; Garbrecht and Martz, 1999; Guertin et al., 2000; Beasely et al. 1980; Beven and Kirkby 1979; Fortin et al, 2001; Esri, 2012; O'Callaghan and Mark 1984; Quinn et al, 1991; Fairfield and Leymarie 1991; Costa-Cabral and Burges 1994; Tarboton, 1997).

The estimation of stream flows is essential for all water resources projects including construction of dams and hydroelectric power plants (HPP). The dimensions, thus the cost of these structures depend on the stream flow estimation and the reservoir capacity. The primary objectives of this study are to determine the rainfall-runoff coefficients of the sub-basins of the Murat River and estimate stream flow data for a dam site which is located on an ungauged river section within the studied watershed area.

2. Study Area and Data

The Euphrates River is the longest and one of the most historically important rivers of Western Asia in terms of catchment area and length. Although small portions of the basin are within the borders of Saudi Arabia and Kuwait, the Euphrates Basin lies primarily in three countries, namely; Turkey, Syria and Iraq. The total length of the river is approximately 2786 km. The river has a total catchment area of about 440 000 km^2, 28% of this total is situated in Turkey, about 123 000 km^2.

The Murat River, which is also known as the Eastern Euphrates, is the major source of the Euphrates. It originates about 3520 m above-sea-level (asl), in the mountainous region characterized by steep slopes, near Mount Ararat, north of Lake Van, Turkey, and flows westward for 720 km long through hilly areas with a catchment area of 40 000 km^2 (Figure 1). Prior to the construction of the Keban Dam the Murat River joined with the Karasu River about 10 km north of the current dam site and 13 km north of the town of Keban to form the upper Euphrates. The latitudes and the longitudes of the Murat River Basin are 40°04 - 40°02N and 38°53' - 43°46'E, respectively. The Murat River Basin is characterized by warm-dry summers and cold-wet winters. In the mountainous headwater areas, precipitation predominates in autumn, winter and spring with a mixture of rain and snowfall. The transition periods in spring and autumn are very short. Precipitation is concentrated during winter seasons, from November to April. The total annual precipitation in the Murat River Basin ranges from 350 to 1010 mm from location to location.

Figure1. General location of the Murat River Basin

The data used here is 30X30 m spatial resolution digital elevation model (DEM). The annual total precipitation data was obtained from nineteen precipitation measurement stations (PMS) situated within and in the vicinity of the Murat River Basin, while the annual average discharge data was acquired from seven flow measurement stations (FMS). The details of the PMS are given in Table 1 and the details of the FMS are shown in Table 2.

Table1. Precipitation measurement stations in the study area

Stations	Lon.	Lat.	Elev. (m)	Data Used	# of year Data Used
Ağrı	39.72	43.05	1640	1980 - 2005	25
Tunceli	39.11	39.55	1200	1985-1995	10
Bingöl	38.88	40.49	1158	1980 - 2005	25
Muş	38.75	41.51	1327	1975 - 2005	30
Siirt	37.93	41.49	893	1975 - 2005	30
Horasan	40.05	42.17	1561	1980 - 2005	25
Sarıkamış	40.34	42.57	2069	1980 - 2005	25
Doğubeyazit	39.55	44.08	1592	1980 - 2005	25
Mazgirt	39.02	39.61	1428	1985 - 1995	10
Hınıs	39.36	41.70	1712	1980 - 2005	25
Hozat	39.11	39.22	1562	1985 - 1995	10
Karakoçan	38.96	40.04	1094	1980 - 2005	25
Solhan	38.96	40.04	1392	1975 - 2005	30
Varto	39.17	41.46	1527	1975 - 2005	30
Malazgirt	39.14	42.54	1538	1975- 2005	30
Palu	38.69	39.93	871	1980 - 2005	25
Genç	38.75	40.56	1015	1980 - 2005	25
Erzincan	39.75	39.49	1215	1985 - 1995	10
Gemişgezek	39.06	38.91	963	1985 - 1995	10

Table2. Flow measurement stations in the study area

Catchment	Lon.	Lat.	Data used	Ann Ave. Disc. (m^3/s)
Palu	39,93	38,68	1980-2005	253,34
Tutak	42,78	39,53	1986-2002	49,27
Karaköprü	41,49	38,78	1975-2005	25,83
Çayağzı	40,55	38,80	1983-2001	39,53
Batman Köprüsü	39,56	39,10	1985-1995	32
Adivar	42,16	39,21	1985-2005	31,29
Abdurrahman Paşa	41,48	39,10	1980-2005	39,85

3. Delineation of the Murat River Basin

The DEM data was employed in the terrain pre-processing model of ArcGIS in order to satisfy the surface drainage pattern. Once it is pre-processed, the DEM and its derivatives can be used for effective watershed delineation. A pour point should be placed within an area of high flow accumulation since it is used to calculate the total contributing flow to that particular point. Figure 2 shows the catchment area of the part of the Euphrates located within the borders of Turkey, with its two major tributaries, namely; the Murat River and the Karasu River.

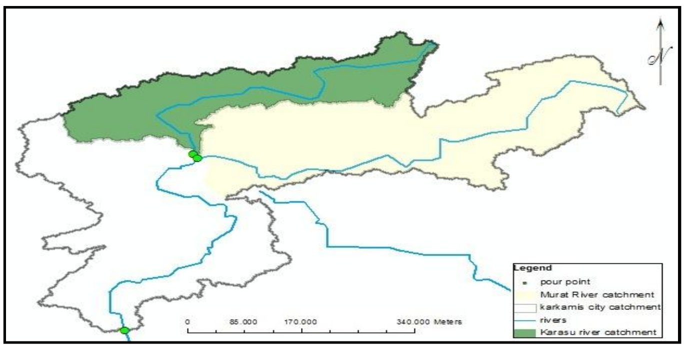


Figure2. Euphrates River Catchment

The region covered by the DEM data should cover a landscape larger than the study area for an accurate calculation by the GIS techniques. Figure 3 illustrates the DEM which covers an area larger than the Murat River Basin. All of the procedures of the pre-processing model must be finalised before the watershed processing functions are used. The DEM data may include pits or bulges, which characterises errors arising from interpolation. These errors must be removed by fill and sink function, before it is being utilised in the hydrological modelling (Ashe, 2003). (Figure 4) presents the fill and sinks procedure applied DEM data of the Murat Basin. The flow direction map is determined by calculating the steepest slope and by encoding it into each cell for possible eight flow directions toward the surrounding cells (Hammouri and El Naqa, 2007) (Figure 5). The flow accumulation is generated by addressing each cell of the DEM which counts how many upstream cells contribute to flow through the given cell (Figure 6). Watershed slope reflects the rate of change of elevation with respect to the distance along the principal flow path, expressed in degrees or as a percentage. The slope function in ArcGIS calculates the maximum rate of change between each cell and its eight neighbouring cells. (Figure 7) demonstrates the slope model the study area.

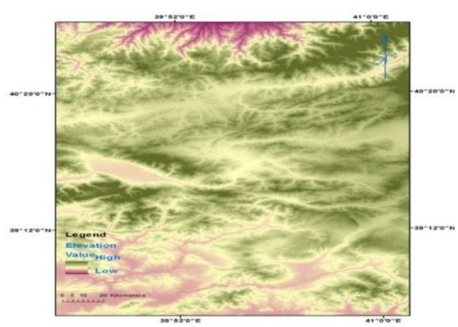


Figure 3. Terrain DEM lager than study area

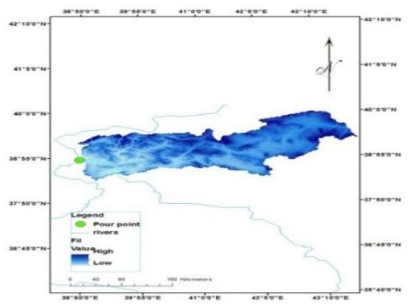
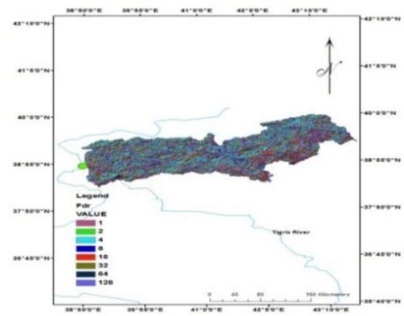


Figure 4. Fill sinks computation



Figurer 5. Flow direction

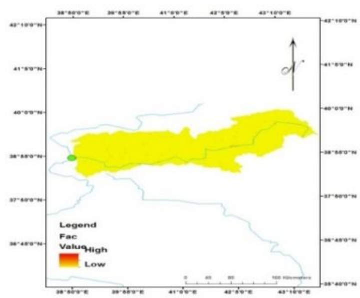


Figure 6. Flow accumulation

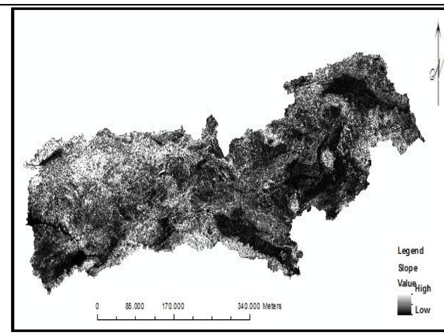


Figure 7. Slope Model

The hydrological analysis of the Murat River Basin was conducted by employing seven flow measurement stations (FMS) situated on the stream and nineteen precipitation measurement stations (PMS) located within and in the surrounding areas. As these FMSs are chosen to be the pour points, seven sub-basins of the Murat River are determined. The PMSs, FMSs and the seven sub-basins of the catchment are illustrated in Figure 8. The mean total annual areal rainfall distribution of the Murat Basin was obtained by utilising the kriging method. Kriging is an advanced geostatistical procedure that generates an estimated surface from a set of scattered points with total annual precipitations measured at 19 meteorological stations in and around the basin. Figure 9 demonstrates the mean total annual areal rainfall distribution of the basin. The spatial distribution shows a significant variation in the total annual precipitation.

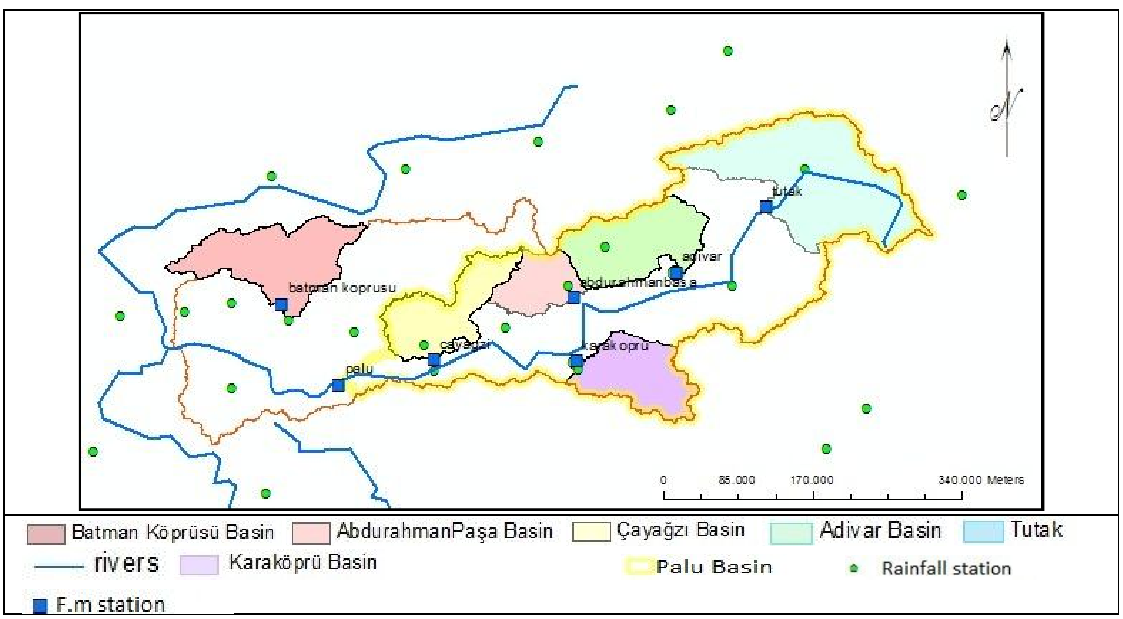


Figure8. Sub-basins of the Murat River

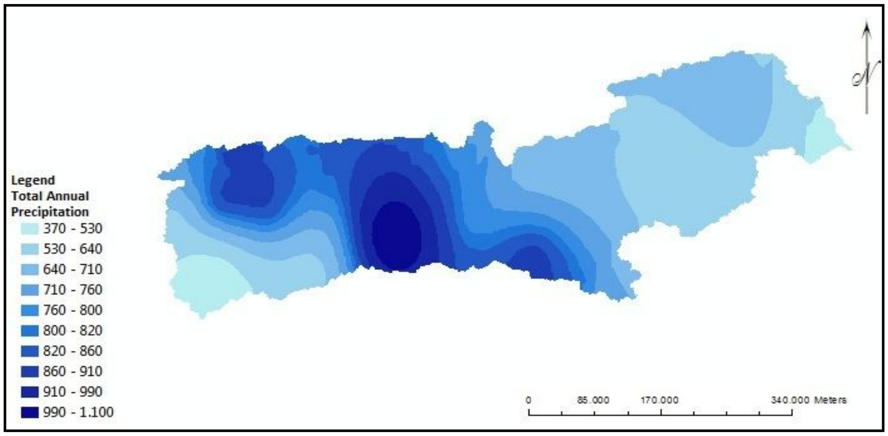


Figure9. Annual Areal Rainfall Distribution

4. Rainfall-Runoff Relationship

As the rain falls on the surface of the earth, the water infiltrates into the soil primarily by gravitational forces. When the rainfall intensity exceeds the infiltration capacity of the soil then the surface flow is generated, which is called the runoff. The relationship between the rainfall and the runoff is determined by a dimensionless coefficient known as the runoff coefficient. It has a large value for areas with low permeability. In order to determine the annual runoff coefficient of a basin, the total annual stream flow is plotted against the total annual precipitation. The slope of the regression line is accepted to be the runoff coefficient. This coefficient, which is a function of vegetation cover, degree of urbanization, climatologically features and geological setting of the catchment area, plays a major role in the planning, design and operation of water resources projects in a catchment (Kadioglu and Şen, 2001; Sen and Altunkaynak, 2006; La Torre Torres, et al., 2011; Raji, et al., 2011).

The long-term annual average discharge of the stream flow of seven flow measurement stations and the total annual precipitations measured at nineteen hydro-meteorological stations within and around the Murat River Basin were used here in order to determine the rainfall-runoff coefficients of the seven pre-determined sub-basins. Thiessen polygon method was employed in order to find out the influence area of each meteorological station (Figure 10). The linear equation method was employed in the analyses. The observed total stream flow volume and the total annual precipitation were utilized to define the runoff coefficients of the sub-basins and the whole basin. The relationship between the rainfall and the runoff for Abdurrahman Paşa, Adıvar, Karaköprü, Batman Köprüsü, Çayağzı, Tutak and Palu sub-basins are presented in Figure 11. Table 3 illustrates the sub-basins and their runoff coefficients.

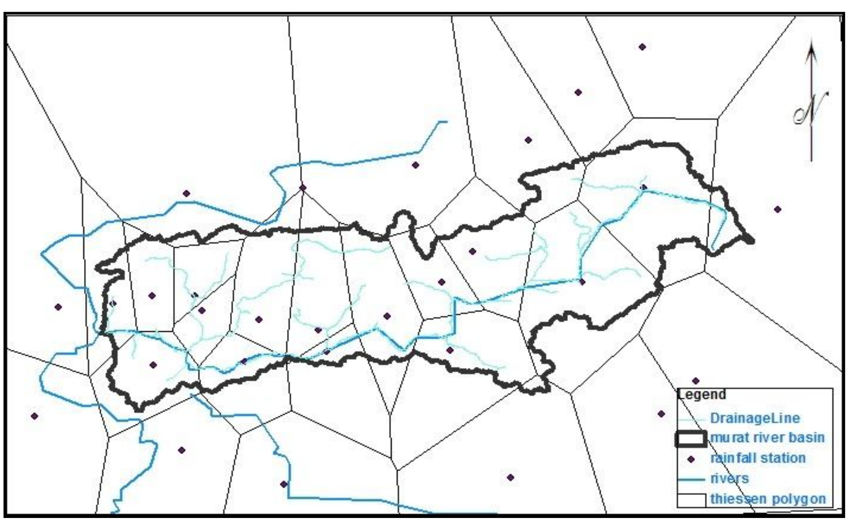
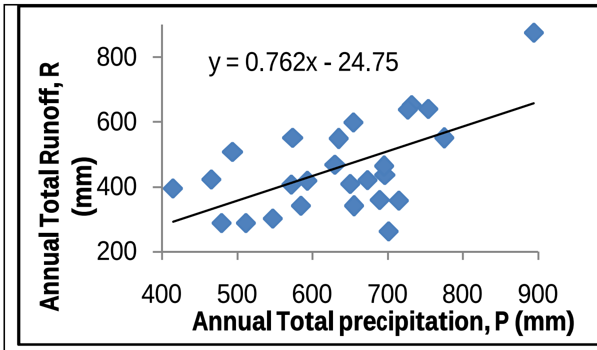
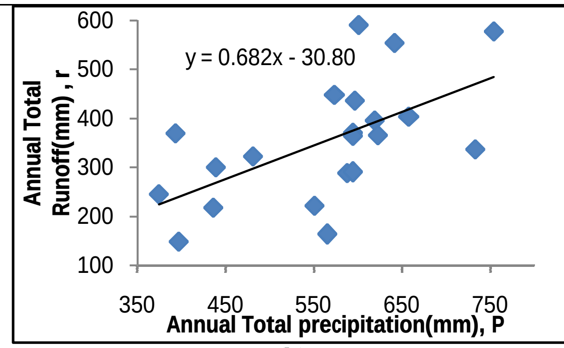


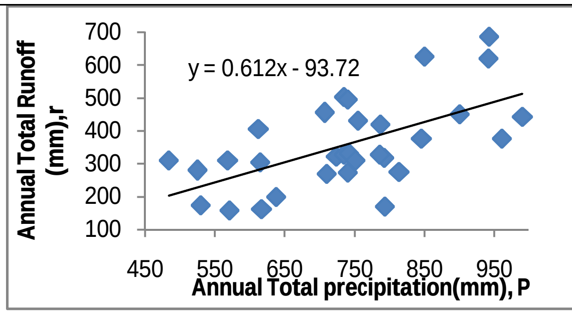
Figure10. Theissen polygon Model



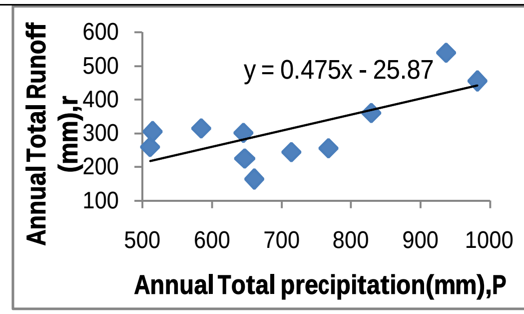
(a)



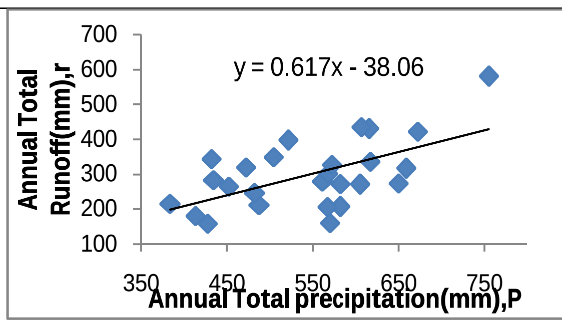
(b)



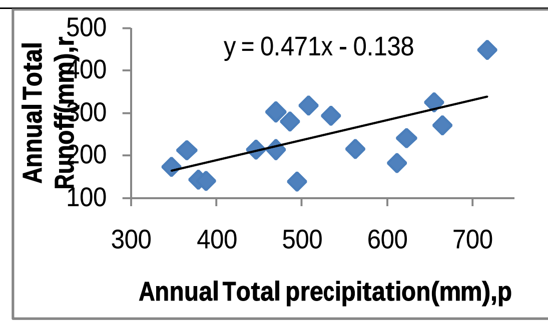
(c)



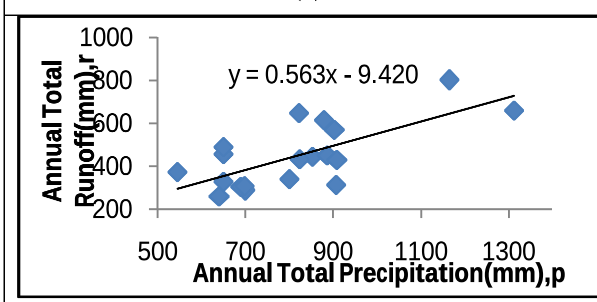
(d)



(e)



(f)



(g)

Figure 11. Runoff-Rainfall relationship for

a) Abdurrahman Paşa sub- basin
b) Adivar sub-basin
c) Karaköprü sub- basin
d) Batman Köprüsü sub- basin
e) Palu sub- basin
f) Tutak sub- basin
g) Çayağzı sub- basin

Table3. Runoff Coefficients of the Murat River Sub-basins

Basin	Rainfall Station	Polygon Area (km^2)	Annual Rainfall (mm)	Mean Ann. Areal Rainfall (mm)	Mean Ann. Discharge (m^3/s)	Runoff Coefficient
Tutak	Ağrı	4584.37	592.61	545.06	49.27	0.47
	Horasan	598.36	424.11			
	Sarıkamıs	30.92	636.10			
	Doğubayazit	703.55	334.15			
Adivar	Hınıs	1951.59	608.22	584.97	31.29	0.6
	Varto	241.86	603.15			
	Malazgirt	513.94	509.90			
	Horasan	70.37	426.34			
Abdurraham	Varto	850	648.51	669.96	39.85	0.7
	Solhan	444.51	710.99			
Karaköprü	Mus	1822	804.31	763	25.83	0.6
	Siirt	139	726.99			
	Malazgrt	232	466.73			
Cayağzı	karakocan	77	689.95	886.58	39.53	0.56
	bingol	1263	1007.3			
	solhan	841	727.37			
	genc	42	920.37			
	Varto	22	666.54			
Batman Köprüsü	Tunceli	1391	865.67	779.07	32	0.47
	Mazgrt	130	823.41			
	Karakocan	248	733.22			
	Erzincan	376.88	440.27			
	Hozat	721.37	841.79			
	Cemisgezek	211.34	625.72			
Palu	Karakocan	188.66	673.64	616	253.3	0.6
	Genc	667.85	897.43			
	Bingol	1464.02	994.20			
	Solhan	2795.96	710.99			
	Varto	1746.29	598.98			
	Mus	2881.26	798.38			
	Hinis	2799.49	606.86			
	Malazgirt	5598.54	483.85			
	Siirt	141.07	732.36			
	Horasan	1091.83	417.58			
	Ağri	5335.26	555.46			
	Doğubeyazıt	705.68	333.93			
	Sarıkamıs	30.95	620.90			
	Palu	230.01	552.80			

5. Estimating Hydroelectric Power Potential at Ungauged Sites

Estimating the annual average discharge as well as discharge variation within certain periods of time is crucially important in planning phase of a water resources project. Most of the time, these types of projects are carried out at the sections of rivers where flow measurements do not exist or they may not be observed for a long enough period. The discharge observations of the closed flow measurement station are carried to that particular cross-section by a number of statistical methods. When the project is a dam the discharge data will be used in determining the design flow of the spillway, the volume of the reservoir (thus the height of the dam), and the amount of the energy can be generated. The location of the dam is the point at which water flows out of a particular sub-basin. The contributing area or the sub-catchment which supply water to the project location is delineated from a raster data of flow direction by using watershed function in ArcGIS. The selected project location in the cross-section which has been proposed for a dam project is located upstream of the Tutak flow measurement station and named as Cecen I **(**Figure 12). In order to determine the stream flow at the dam site, the amount of the precipitation should be multiplied by the runoff coefficient of the Tutak sub-basin, since the drainage area of the dam reservoir is located completely within that basin area.

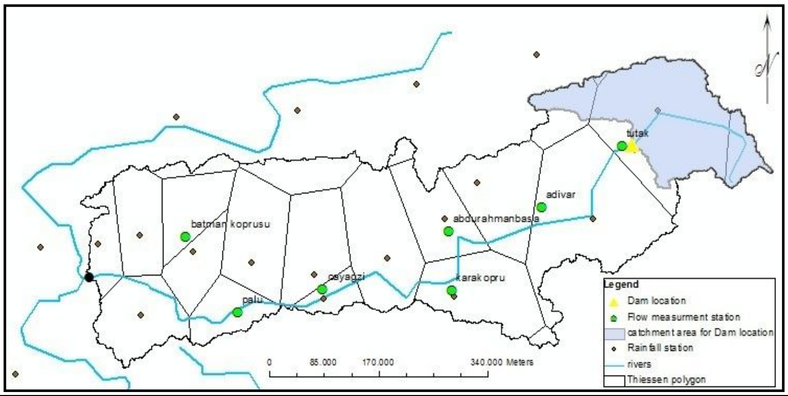


Figure 12. Dam location

6. Conclusion

In this Study, a rainfall-runoff relationship for the Murat River Basin, which is the largest tributary of the Euphrates, was determined by employing the linear method. The digital elevation model (DEM) and geographic information systems (GIS) were utilized in the hydrological analyses of the basin. The annual average discharge of the stream flow was acquired from seven flow measurement stations (FMS) along the river, while the annual total precipitation data was obtained from nineteen meteorological stations located within and in the surrounding of the basin. The rainfall-runoff coefficients were estimated to be 0.47, 0.6, 0.6, 0.47, 0.6, 0.56 and 0.7 for Tutak, Palu, Adivar, Batman Köprüsü, Karaköprü, Çayağzı and Abdurhamanpaşa sub-basins, respectively. The runoff coefficient was calculated to be around 0.6 for the whole Murat River Basin.

References

Ashe R (2003) Investigating runoff sources area for an irrigation drain system using archydro tools. In: Proceedings of the twenty-third annual esri user conference, San Diego

Beven, K. J, Kirkby, M. J. (1979). A physically based, variable contributing area model of basin hydrology. *Hydrological Sciences Bulletin, **24**(1), 43-69.*

Beasely, D. B., Huggins, L. F., and Monke, E. J. (1980). A model for watershed planning, *Transactions of the American Society of Agricultural Engineers*, **23**(4), 938-944.

Burrough P.A., McDonnell R. A., (1998). Principles of Geographical Information Systems**,** Oxford University Press, England, ISBN: 0-19-823365-5.

Costa-Cabral, M. C., and Burges, S. J. (1994). Digital elevation model networks (DEMON): A model of flowover hill slopes for computation of contributing and dispersal area. *Water Resources Research*, **Vol**. **30**, (6), p. 1681–1692.

Chandra Bose A.S, Viswanadh, G.K and Giridhar, M.V.S.S (2012). Computation of watershed parameters using Geoinformatics,*International Journal Of Geomatics And Geosciences*, Volume 2, No 3,0976-4380 Esri. (2012) GIS for water resources [Online]. Available:
http://www.esri.com/industries/water_resources[Accessed13/05/2012.]

Fortin, J. P., Turcotte, R., Massicotte, S., Moussa, R., Fitzback, J., and Villeneuve, J. P. (2001). A distributed watershed model compatible with remote sensing and GIS Data, I: Description of model. *Journal of Hydrologic Engineering, 6(2), 91-99. [doi:10.1061/(ASCE)1084-0699(2001)6:2(91)]*

Fairfield, J., Leymarie, P. (1991). Drainage networks from grid elevation models. *Water Resources Research,* **Vol**. **27**(5), 709-717.

Guertin, D.P., S.N., Miller, D.C. Goodrich. (2000). Emerging tools and technologies in watershed management, In USDA Forest Service Proceedings RMRS-P-13: 194-204.

Garbrecht, J., and L. W. Martz. 1999.Digital elevation model Issues in water Resources Modeling. In 1999 ESRI *international User conference Proceedings* (paper 1 in this book), Environmental systems Research Institute, Inc., Redlands,California.

Hammouri, N., & El-Naqa, A. (2007). Hydrological modeling of ungauged wadis in arid environments using GIS: a case study of Wadi Madoneh in Jordan. *Revista Mexicana de Ciencias Geológicas*, *24*(2), 185-196.

Kang, H. (2008). Introduction to Geographic Information Systems, 4th Ed., McGraw-Hill International Edition.

Kadioglu, M. and Şen, Z. (2001) Monthly precipitation-runoff polygons and mean runoff coefficients, Hydrological Sciences Journal, 46:1, 3-11, DOI: 10.1080/02626660109492796

La Torre Torres, I. B., Amatya, D. M., Sun, G. and Callahan, T. J. (2011) Seasonal rainfall–runoff relationships in a lowland forested watershed in the southeastern USA, *Hydrological Processes 25,* DOI: 10.1002/hyp.7955

Murthy, J.V.S., (2000). A Text book of Watershed management in India, Wiley Eastern Limited.

Ogden, F.L., Garbrecht, J., DeBarry, P.A., and Johnson, L.E. (2001). "GIS and distributed watershed models. II: Modules, interfaces and models." *J. Hydrologic Engineering*, ASCE, 6(6), 515-523.

O'Callaghan , J. and D. Mark (1984). "The Extraction of Digital Elevation Networks from Digital Elevation Data ." Computer Vision, Graphics, and Image Processing. 28: 323-344.

Quinn, P, Beven, K. J., Chevalier, P., and Planchon, O. (1991). The prediction of hillslope flow paths for distributed hydrological modelling using digital terrain models. *Hydrological Processes, 5(1), 59-79. [doi:10.1002/hyp.3360050106]*

Raji, P., Uma, E. and Shyla, J. (2011) Rainfall-Runoff Analysis of a compacted area, *Agricultural Engineering International: the CIGR Journal*. Vol.13, No.1, pp. 1-7.

Sen, Z. and Altunkaynak, A. (2006). A comparative fuzzy logic approach to runoff coefficient and runoff estimation, *Hydrol. Process*. 20, 1993–2009, DOI: 10.1002/hyp.5992

Tarboton, D. G. (1997). A new method for the determination of flow directions and upslope areas in grid digital elevation models. *Water Resources Research*, **Vol 33**(2), pp. 309-319.

William, N. 2000. Agricultural and Small Watershed Hydrology: Watershed Characteristic. College of Engineering, Michigan State University. Available at: *http://www.egr.msu.edu/~northco2/BE481/WshedChar.htm (assessed Mac 2010)*

Yanmaz, A.M. (2006). Applied Water Resources Engineering. 3rd Ed. METU Press, Ankara. *ISB.*