ESKİŞEHİR TECHNICAL UNIVERSITY JOURNAL OF SCIENCE AND TECHNOLOGY
A- APPLIED SCIENCES AND ENGINEERING

2021, 22(3), pp. 290-298, DOI:10.18038/estubtda.911741

RESEARCH ARTICLE

TEMPERATURE-DRIVEN EVAPORATION ANALYSIS OVER BALLIKAYA CATCHMENT

Adnan ELAĞCA [1], Muhammet Ömer DİŞ [2, *]

[1,2] Department of Civil Engineering, Faculty of Engineering & Architecture, Kahramanmaras Sutcu Imam University, Kahramanmaras, Turkey

ABSTRACT

Hydrometeorological analysis such as terrain characteristics, flood forecasts and water potentials have become possible through computer models today in parallel with rapidly ever-evolving technology. While the surface-runoff during a storm has linearly and highly correlation with effective precipitation, it is inversely proportional to hydrological losses, including interception, infiltration, transpiration and evaporation. However, flood estimation analysis, in especially rural areas in Turkey, is still not widely and accurately usable, due to difficulties in accessing the necessary ground-based data records such as evaporation, which affects much of the rainfall. Although direct measurement of evaporation is not available now, indirect methods such as evaporation pans have been developed to give acceptable results. On the one hand, observation networks are built by Turkish State Meteorological Service for the estimation of evaporation from open water bodies; these measurements, on the other hand, are only obtained at large climatological stations such as city centers and generally for only six months of the year. In this sense, evaporation values, in order to apply rainfall-runoff analysis, were estimated by Kharrufa, Blaney-Criddle, and modified Blaney-Criddle methods to be used in Monthly Average models. While the highest underestimations were obtained in modified Blaney-Criddle method, Kharrufa method outperformed the other two Blaney-Criddle products. The results, confirmed by analysis of the temperature-based Kharrufa approach in two urban areas close to the study basin, show to be appliable for estimation of long-term hydrographs. The analyzed method can be applied over rural watersheds lacking in-situ evaporation measurements as well as enables more accurate rainfall-runoff simulations processes with calibrated and verified hydrological models.

Keywords: Ballikaya Basin, Pan-evaporation, Kharrufa, Monthly Average Model

1. INTRODUCTION

Rainfall-runoff estimations are one of the most important parts of hydrological structure designs. Therefore, precipitation driven flow simulations play a crucial role in both design and construction for roads, bridges, dams, culverts and all types of structures interacting with streams, rivers and lakes. Additionally, these models greatly support decision mechanisms for long-term water management and pumping stations [1, 2]. The accurate prediction ability and design potential runoff amounts are not only helpful in ensuring adequate drainage capacity of these structures, but also economically essential. When runoff volume estimates are excessive, this situation can cause unnecessary expenditures as a result of enormous design of the structure. On the other hand, insufficient predictions can result catastrophic damage to the structure and expensive repairs [3].

Numbers of methods have been developed to proper design such structures and to adequate estimate rainfall-runoff simulations. However, precipitation associated runoff procedure varies highly spatio-temporally and has a complex relationship. This relationship depends on enormous number of parameters such as evaporation, transpiration, land cover, land use, soil type, antecedent soil moisture, infiltration, precipitation distribution and/or rainfall duration, lag time, basin size and slope [4-7]. One of the first successful hydrological models, used digitally in the 1960s, is Stanford Watershed Model. It was developed by Norman Crawford and Ray Linsley at Stanford University, California. Later, many hydrological models were developed using different parameters and various degrees of complexity [8,

*Corresponding Author: momerdis@ksu.edu.tr
Received: 08.04.2021 Published:29.09.2021

9]. In recent years, both data collection and computational capabilities have enabled hydrologists to develop more sophisticated models within parallel today's technological developments. The number of hydrological models has increased along with the development of computer technologies in order to better simulate this complex relationship. For example, Yilmaz and Bulut analyzed the evapotranspiration values in Turkey with NOAH model using the spatio-temporal properties of the hydrological models [10].

Evapotranspiration is the combination between evaporation from the open water bodies, rivers, seas, wet surfaces and transpiration from vegetation. However, since it is difficult and unnecessary to separate both water losses, they were combined under the term evapotranspiration [11]. While the effect of evaporation and evapotranspiration losses can be ignored in event based hydrological modelling, it becomes critical in the water budget when the simulation period rises by up to a year [12]. Although many studies show that there is regional variation in evaporation trends due to climate change, majority of the water (approximately 70-75% of total rainfall) that falls as precipitation on the earth surface returns to the atmosphere through evaporation and transpiration in continental areas [13-17]. According to Dingman [18], approximately 3% of total this is by evaporation from free water bodies while the rest of it is due to evapotranspiration from the land surfaces. Moreover, this hydrological component has also demanded importance in irrigation planning as well as water resource management [19, 20]. Both evaporation and evapotranspiration losses spatially vary along with latitude, longitude, altitude, soil type, vegetation cover, land use/cover, and environmental conditions [21]. Generally, assessment of these models, that is based on statistical relationship of evaporation by minimum, maximum or mean climatological factors, is experimental. Thus, performance of a model varies over different regions. That’s why hydrological simulations offer different options to include such meteorological losses. Each evaporation and evapotranspiration methodology includes different procedure limitations, various calibration parameter and different data requirements as well as advantages/disadvantages according to application. For instance, Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) offers including a physically-based energy balance model (Penman Monteith), a simplified physically-based model (Priestley Taylor), and a simple Monthly Average (MA) approach. The physically expressed energy balance model (Gridded Penman Monteith) applies the gridded ModClark conversion method, and numerous input parameters (i.e. wind speed, vapor pressure, temperature and etc.) should be used in this method. Contrarily, the MA method can be applied with the total monthly amount and the pan coefficient. As its name implies, data values are typically considered as the average evaporated water depth from each month, regardless of the data collection method [12].

While, in Turkey as well as in many other countries, the weather stations measure only the air temperature, unfortunately some of them are equipped with limited hydrological variables (i.e. solar radiation, relative humidity, wind speed, soil heat flux density and etc.), and these are scarce [20]. In this study, the MA approach is preferred for meteorological model due to the low data requirements. The EvaPorated (EP) water losses will be estimated occurring in the Ballikaya Catchment by empirical methods. In this aim, EP values will be derived based only on temperature data and will be predicted with Blaney-Criddle, modified Blaney-Criddle according to geography, seasons and plant species, and Kharrufa approaches. This paper is organized as follows: Material and Methods Section provides description of the study area, data, and the applied temperature-based EP methods. The results and evaluations are examined in the next section while conclusions and future research directions are discussed in Conclusions Section.

2. MATERIALS AND METHODS

2.1. Study Area and Data

The study area is located in Southeastern Anatolia, Turkey (Figure 1). Ballikaya Watershed is lying at 37º 04' 30" N and 37º 12' 00" N latitudes with 36° 50' 00" E and 37° 02' 30" E longitudes and is situated between Kahramanmaras-Gaziantep. The basin boundary lines were delineated applying Arc-GIS (Aeronautical Reconnaissance Coverage Geographic Information System) using the Digital Elevation Model (DEM) data. This model, which has 30x30m spatial resolution, obtained from the U. S. Geological Survey (USGS) [22]. The area of the region is approximately 78-km^2 and its altitude vary from 615 to 1416 M.S.L. (Abbreviation of Mean Sea Level). The highest peak is in the south-eastern corner, and the lowest point is in west with general elevation gradient accelerating from west to east (Figure 1). The study area is generally rural, settlement is scattered and scarce, while vegetation consists mainly of farmland and forests. In Figure 1, blue lines and red cross sign represent the river network and flow observation station (outlet point) in the delineated catchment, respectively. Flow measurements at the outlet point of the basin are maintained by the General Directorate of State Hydraulic Works (DSI).

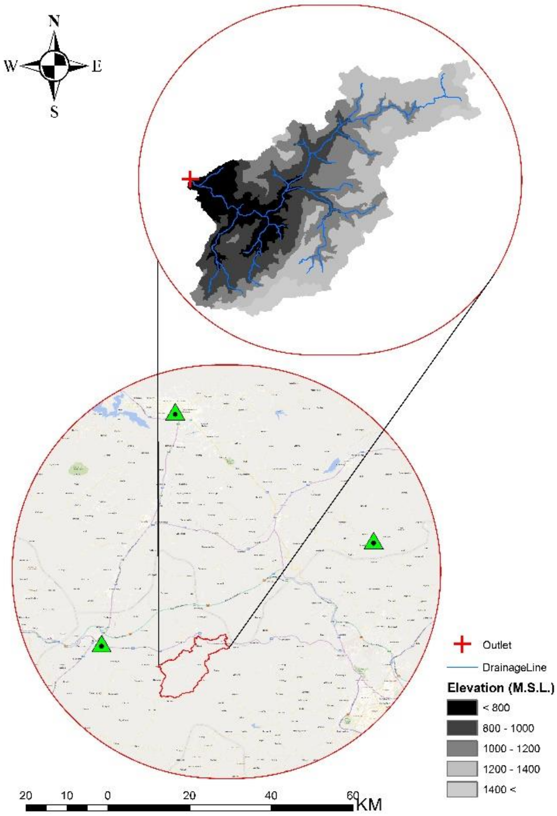

Figure 1. Study Area and Climatological Stations

As it can be seen from the Figure 1, meteorological datasets (i.e. temperature, pan-evaporation and precipitation) are recorded at western side, northern, and north-eastern of the region by the Turkish State Meteorological Service (MGM). These stations are symbolized by green triangles and named with their numbers. These are namely: Nurdagi 18151 (in Asi Basin), Kahramanmaras 17255 (in Ceyhan Basin), Gaziantep 17261 (in Firat-Dicle Basins). Daily temperature data from Nurdag 18151 station (located west of the study area) is acquired for the period 2013-2018 to perform EP estimations over the area due to the scarcity of the observations. In addition, daily temperature and pan-evaporation measurements at the nearest neighboring stations (Gaziantep 17261 and Kahramanmaras 17255) are obtained for the period 2006-2016 from also MGM in order to investigate the applicability of methods in the region. The aforementioned temperature datasets were used to force different EP methods for the study area and resulting EP estimations were evaluated at daily time resolution.

2.2. Temperature based Evaporation Methods

Due to the lack of both pan-evaporation measurement and calculated evapotranspiration data at Nurdag 18151 station, EP estimation methods, requiring temperature as input variable is used in this study. Temperature-based EP methods are one of the simplest and oldest methods that have low data requirements [23, 24]. The methods applied in this study can be listed as Blaney-Criddle, modified Blaney-Criddle according to geography, seasons and plant species, and Kharrufa methods.

The Blaney-Criddle method can be considered one of the most widespread evaporation approaches especially in the Western USA and expanded all over the world [24-26]. According to this method, the measured climate variable input is air temperature, and the equation is as follows (Equation 1).

$$EP = p(0{,}46 * T_m + 8) \quad (1)$$

Here, T_m is the average daily temperature of the month, and p is the average daily percentage of annual daylight hours for the calculated month. This method was modified as Equation 2 depending on geography, season and plant type. k is expressed as the monthly consumption coefficient and the average value is 0,85 and may require local calibration [27].

$$EP = k * p(0{,}46 * T_m + 8{,}13) \quad (2)$$

The relationship between temperature and average daily percentage of annual daylight hours expressed by Kharrufa as Equation 3 [28].

$$EP = 0{,}34 * p * T_m^{1{,}3} \quad (3)$$

3. RESULTS AND DISCUSSIONS

The monthly average EP values were obtained for neighboring stations in order to assess the applicability of the three empirical equations in the study area over the time period 2006-2016.Then, temperature-derived EP against the pan-evaporation measurements values were presented over the districts in Gaziantep 17261 (Figure 2) and Kahramanmaras 17255 (Figure 3). In both figures, blue lines indicate in-situ measurements while orange, light gray, and yellow lines represent Kharrufa, Blaney-Criddle, and modified Blaney-Criddle temperature-driven estimations, respectively.

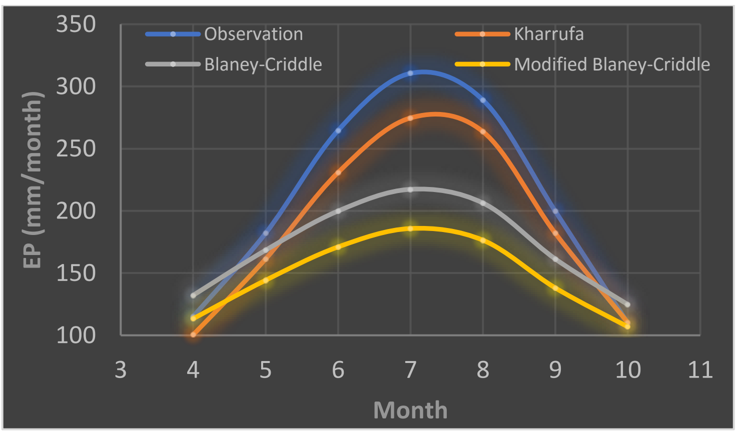

Figure 2. Evaporation Curves Derived from Different Methods and Reference for Gaziantep 17261 Station.

As can be seen from Figure 2 and Figure 3, the skill of capturing temperature-derived monthly based EP fluctuations for all the methods overlapped at two observation stations while this circumstance is generally more dominant during cold season. However, the magnitude of the underestimation was the strongest for three methods during summer months. The highest underestimations were retrieved in modified Blaney-Criddle method. Blaney-Criddle exhibited better consistency than the modified Blaney-Criddle formula. These biases in observed values were almost twice comparing to obtained using Equations 1 and 2 in two stations during summer months regardless of original and modified one. On the other hand, temperature-driven EP values via Kharrufa method outperformed the other Blaney-Criddle products at both stations.

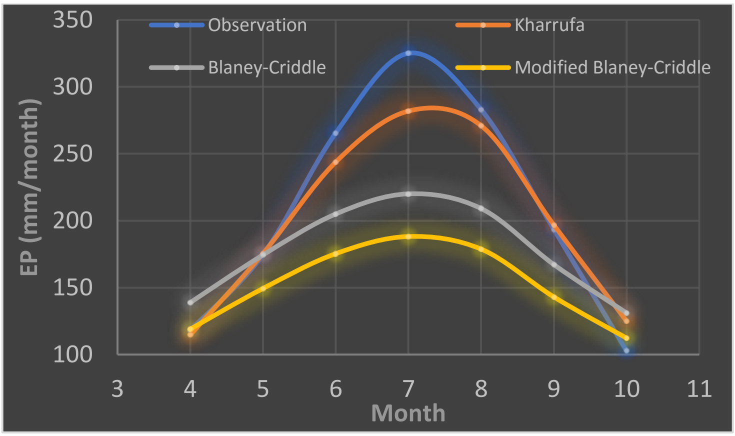

Figure 3. Evaporation Curves Derived from Different Methods and Reference for Kahramanmaras 17255 Station.

Between June and August, in the region, the most important hydrometeorological parameter is undoubtedly EP with considered the effect of temperature due to the non-occurrences of precipitation. Therefore, at Nurdag 18151 station, located between Kahramanmaras 17255 and Gaziantep 17261 stations, six-year (2013-2018) EP data was estimated using the Kharrufa method (Figure 4). In Table 1, the distribution of calculated EP values via Kharrufa model for the period from 2013 to 2018 is shown as mm/day for each month for The Ballikaya Basin, while Figure 4 shows the temperature-driven EP values during this period as mm/month by averaging of long time period over the area. As can be seen from the figure and table, the EP values in January and December were very low as expected while they increased in the summer and peaked in July.

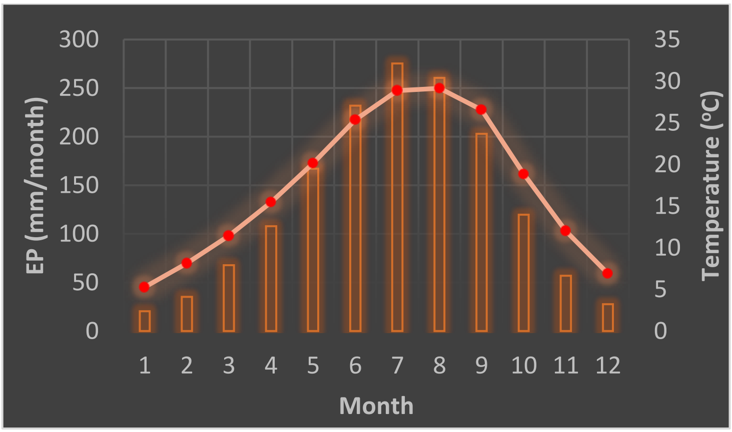

Figure 4. Kharrufa-Driven Monthly Average EP and Temperature Distribution for Nurdag 18151 Station During the Time Period of 2013-2018

For the MA Method to be used rainfall-runoff simulations, two important values are required as input parameter to the model: evaporation and pan coefficient. The pan coefficient that used as input criteria in a hydrological model when calculating EP is defined as the ratio of evaporation from the pan to evaporation from the surface of free water. Observed pan values are generally higher than actual losses (with the effected heat energy of the container) from deep water. Thus, the observed values that require adjustment coefficient is smaller than the value of one. The annual average of the coefficient in the United States is 0,7 and this is usually taken as 0,7 in Turkey as well occasionally the value can be required regional calibration [18, 29-30]. By obtaining the last two columns in Table 1, evaporation values with associated pan coefficients in the region required for continuous simulation and completed for all months of the year were acquired. The obtained results enable to simulate meteorological losses via MA method in rainfall-runoff hydrological models.

Table 1. Variation of Kharrufa-Driven EP Values throughout 2013-2018 for Nurdag 18151 (mm/day) and pan coefficient

Month	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*Daily Mean*	*Coeff.*
January	0,63	1,04	0,51	0,43	0,40	0,95	0,66	0,7
February	1,32	1,22	1	1,65	0,91	1,405	1,25	0,7
March	1,87	2,33	1,87	2,26	2,15	2,625	2,12	0,7
April	3,66	3,69	2,90	4,16	3,24	3,93	3,60	0,7
May	5,86	5,39	5,26	5,28	4,96	5,59	5,39	0,7
June	7,73	7,56	7,26	8,24	7,88	7,72	7,73	0,7
July	8,65	8,60	8,77	9,12	9,51	8,67	8,89	0,7
August	8,25	8,43	8,40	8,72	8,33	8,31	8,41	0,7
September	6	7,79	7,06	6,02	6,94	6,77	6,76	0,7
October	3,24	3,62	4,20	4,15	3,88	4,10	3,86	0,7
November	2,32	1,62	2,10	1,57	1,86	1,92	1,90	0,7
December	0,52	1,24	0,93	0,46	1,13	1,11	0,90	0,7

4. CONCLUSIONS

Land uses and vegetation cover vary with time and this creates anomalies on rainfall-driven runoff phenomena. The trigger of the runoff is undoubtedly precipitation while majority of this rainfall (i.e. 75%) returns back to the atmosphere with evaporation and evapotranspiration. Although simulations of hydrological cycle in a computer environment with today's technological developments are possible and convenient, importance of meteorological measurements increases for satisfied rainfall-runoff modelling. However, due to the expensive maintenance, calibration and other technical requirements of measurements, the availability of evaporation and evapotranspiration records is generally limited especially in rural areas.

In this study, temperature-based EP estimations were made to supply over the Ballikaya Basin lacking adequate in-situ measurements and results were verified in two nearby urbanized measurement stations. Meteorological data such as temperature and pan-evaporation used in the study were acquired from the Turkish State Meteorological Service. The EP values to apply in the MA model were derived using Blaney-Criddle, modified Blaney-Criddle and Kharrufa methods. The results show that analysis obtained by the Kharrufa method captures EP records over the two urbanized stations while temperature-driven EP values using Blaney-Criddle underestimates during the summer months regardless of the modified and original one.

Results from this study, combined with a calibrated and validated hydrometeorological model in the region, can motivate future studies on analyzing more accurate flood damage prediction and can be used as a better decision support tool for floodplain management as well as potential water resources management. Additionally, in future studies, it is possible to compare the performance of temperature-based EP methods with remote sensing products.

ACKNOWLEDGEMENTS

The authors extend their thanks to The Turkish State Meteorological Service for sharing hydrological data and Mehmet Keçik from the General Directorate of State Hydraulic Works (DSI) for sharing his valuable knowledge and experience over the study area.

CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

REFERENCES

[1] Nickman A, Lyon SW, Jansson PE, Olofsson B. Simulating the impact of roads on hydrological responses: examples from Swedish terrain. Hydrol Res J, 2016; 47(4): 767-781.

[2] Wicher K. Rainfall Runoff Modeling in Kävlinge River Basin with HEC-HMS. MSc, Division of Water Resources Engineering, Department of Building and Environmental Technology, Lund University, 2017.

[3] Hawkins RH, Van Mullem JA, Ward TJ, Woodward DE. ASCE/EWRI Task Committee Report on the State of the Practice in Curve Number Hydrology. Draft report to the American Society of Civil Engineers, 2006.

[4] Critchley W, Siegert K, Chapman C. Water Harvesting, A manual guide for the design and construction of water harvesting schemes for plant production, FAO, Rome, 1991.

[5] Solomatine DP, Dulal KN. Model trees as an alternative to neural networks in rainfall-runoff modelling. Hydrolog Sci J, 2003; 48(3): 399–411.

[6] Isik S, Kalin L, Schoonover JE, Srivastava P, Graeme Lockaby B. Modeling effects of changing land use/cover on daily streamflow: An artificial neural network and curve number based hybrid approach. J Hydrol 2013; 485: 103–112.

[7] Dis MO, Anagnostou E, Mei Y. Using High-Resolution Satellite Precipitation for Flood Frequency Analysis: Case Study over the Connecticut River Basin. J Flood Risk Manag, 2018; 11: 514-526.

[8] Beven K. Rainfall-runoff modelling. the Primer: Chichester, John Wiley & Sons Ltd., 355 pp, 2001.

[9] Redfearn HD. Rainfall-runoff changes due to urbanization: a comparison of different spatial resolutions for lumped surface water hydrology models using HEC-HMS. University of North Texas, USA, 2005.

[10] Yılmaz MT, Bulut B. Türkiye'deki 2000-2015 yılları arasındaki buharlaşma ve terlemenin NOAH hidrolojik modeli ile incelenmesi. Dicle Üniversitesi Mühendislik Fakültesi Özel Sayısı VIII. Ulusal Hidroloji Kongresi, 2016; 7(2): 225-236.

[11] Şarlak N, Bağçacı SÇ. The Assessment of Empirical Potential Evapotranspiration Methods: A Case Study of Konya Closed Basin, Technical Journal of Turkish Chamber of Civil Engineers, 2020: 31(1); 9755-9772.

[12] HEC-USACE: Hydrologic Modeling System. HEC-HMS User's Manual Version 4.3, US Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA, USA, 2018.

[13] Aydın F, Topaloğlu F. Türkiye Buharlaşma Verilerinin Gidiş Analizi. Ç.Ü. Fen Bil. Ens. Dergisi, 2010; 22-2.

[14] Bacanlı ÜG, Tanrıkulu A. Ege Bölgesinde Buharlaşma Verilerinin Trend Analizi. AKU J. Sci. Eng, 2017; 17:980-987

[15] Çitakoğlu H, Demir V, Geyikli MS. Ege bölgesine ait açık yüzey buharlaşma verilerine gidiş analizi. IX. Ulusal Hidroloji Kongresi, Diyarbakır, Türkiye, 4-6 Ekim 2017.

[16] Özfidaner M, Şapolyo D, Topaloğlu F. Antalya Ortalama Sıcaklık Verisinde Gidişlerin Yeni Bir Gidiş Analiz Yöntemi İle Belirlenmesi. Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi, 1. Uluslararası Tarımsal Yapılar ve Sulama Kongresi Özel Sayısı 2018: 223-228.

[17] The Turkish State Meteorological Service Web. https://www.mgm.gov.tr/genel/buharlasma.aspx?s=3, (Accessed Date: 12 March 2021).

[18] Dingman SL. Physical Hydrology. 2nd Edition. Upper Saddle River, New Jersey: Prentice Hall, 2002.

[19] Tabari H, Grismer ME, Trajkovic S. Comparative analysis of 31 reference evapotranspiration methods under humid conditions. Irrigation Sci, 2013; 31: 107–117.

[20] Cobaner M, Citakoglu H, Haktanir T, Kisi O. Modifying Hargreaves-Samani equation with meteorological variables for estimation of reference evapotranspiration in Turkey. Hydrol Res, 2017; 48 (2): 480-497.

[21] Abtew W, Melesse A. Evaporation and evapotranspiration: measurements and estimations, Springer, New York, USA, doi: 10.1007/978-94-007-4737-1, 2012.

[22] Geographic (GIS) data website. URL: http://www.earthexplorer.usgs.gov/ (Accessed Date: 03 September 2020).

[23] Jensen ME, Burman RD, Allen RG. Evapotranspiration and Irrigation Water Requirements. American Society of Civil Engineers, New York, USA, 1990.

[24] Xu CY, Singh VP. Evaluation and generalization of temperature- based methods for calculating evaporation. Hydrol Process, 2001; 15 (2): 305-319.

[25] Blaney HF, Criddle WD. Determining Water Requirements in Irrigated Areas from Climatological Irrigation Data, Technical Paper No:96, US Department of Agriculture, Soil Conservation Service, Washington, D.C., 1959. 48 pp.

[26] Singh VP. Hydrologic Systems, Vol II, Watershed Modelling. Englewood Cliffs, New Jersey, USA: Prentice Hall, 1989.

[27] Poyen FB, Kundu P, Ghosh AK. Temperature based ET Method Selection for Burdwan District in WB, INDIA. Int J Appl Eng Res, 2018; 13(16): 12753-12763.

[28] Kharrufa NS. Simplified Equation for Evapotranspiration in Arid Regions, Beitr Hyd, Sonderheft 1985; 5(1): 339-347.

[29] Dis MO. Hydrological Analysis of an Urban Basin in Sub-Tropical Environment. MSc, University of Connecticut, USA, 2011.

[30] Usul N. Mühendislik Hidrolojisi. 2nd Ed. ODTÜ Yayıncılık, Ankara, 2013.