Artificial Low Stream Flow Time Series Generation of Palaia Kavala Stream, Kavala City, NE Greece

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Abstract.

The present study generates synthetic low stream flow time series of an entire calendar year considering the stream flow data recorded during two certain interval periods of the years 2016 and 2017. We examined the goodness of fit tests of six theoretical probability distributions to low stream flow data acquired at the exit of the Perigiali stream, Kavala city, NE Greece watershed, during part of May, June, July, part of August, part of December 2016 and part of January 2017, using either a combination of a 3-inches U.S.G.S. modified portable Parshall flume in conjunction with a 3-inches Montana portable flume and a combination of a 3-inches conventional portable Parshall flume in conjunction with a 3-inches Montana portable flume and calculated the corresponding probability distributions parameters. The six specific probability distributions used in this study were the following: (1) Gumbel min (Minimum Extreme Value Type 1) distribution, (2) 3-Parameter Log-Normal distribution, (3) Pearson Type 5 distribution, (4) Pearson Type 6 distribution, (5) Two-Parameter Weibull distribution, (6) Kumaraswamy distribution and (7) Wakeby distribution. The Kolmogorov-Smirnov, Anderson-Darling and Chi-Squared, GOF tests were employed to show how well the probability distributions fitted the recorded data and the results were demonstrated through interactive tables providing us the ability to effectively decide which model best fits the observed data.

Keywords: time series, discrepancy ratio, goodness-of-fit tests low flow data, conventional and modified Parshall flumes

1. Introduction

Artificial stream flow time series generation is a means of paramount importance in hydrology and water resources management in order to handle efficiently precarious or doubtful situations, pertinent to a natural watercourse's flow regime, associated particularly to a short period of stream flow rate data acquisition. The increasing water demands worldwide, caused primarily by the global population increase and exacerbated by the water scarcity due to the climate change, especially in North-Eastern Europe, gives significant prominence to the wise use of the available water resources, showcasing stream flow rate monitoring as a factor of paramount importance with the view to design water storage reservoirs and other water resources management infrastructure works. Therefore, the necessity to minimize dubiety and ambivalence in estimating the flow regime of a natural watercourse constitutes a challenging task in the sector of hydrology and water resources management. This difficulty can only be adequately worked out employing artificial stream flow time series generation procedures and techniques, as a common process.

2. Literature review

Numerous studies and reviews have been carried out in the field of low flows, handling different subjects such as the fit of theoretical probability distribution functions on observed low stream flow rate data, surface runoff and groundwater exchange relationships, watershed drought management, hydrological low-flow and drought indices estimation, watershed water budget and balance compilation, evapotranspiration estimation, daily stream flow variation computations, in-stream environmental stream flows calculation etc. (Matalas, 1963; Beard, 1968; Singh and Stall, 1973; Singh, 1987; Vogel and Kroll, 1989; Ming-Ko and Kai, 1989; Vogel and Kroll, 1990; Vogel and Wilson, 1996; Wang, 1997; Smakhtin and Toulouse, 1998; Young *et al*., 2000; Smakhtin, 2001; Stahl, 2001; Spangler, 2001; Zaidman *et al*., 2002; Acreman and Dunbar, 2004; Laaha and Blöschl, 2005; Yongqin *et al*., 2006; Černohous and Šach, 2008; Tallaksen and Hewa, 2008; Gribovszki *et al*., 2008; Nalbantis, 2008; Gribovszki *et al*., 2010; Sen and Niedzielski 2010; Demirel *et al*., 2013; Orlowski *et al*., 2014; Wittenberg, 2015; Yürekli *et al*., 2005; Büyükkaraciğan, 2014; Papalaskaris and Panagiotidis, 2016).

3. Materials and methods

3.1. Study area

The stream flow rate gauging station, which was established at Palaia Kavala village area, in the proximity of Kavala city area, a coastal city, located at the north of the Aegean Sea, across the Thassos Island, and surrounded by the Lekani mountain series branches to the North and East and the Paggaion Mountain ramifications to the West,

Figure 1. 90^o V-Notch, Sharp Edged, Thomson Type, Portable Weir Plate gauging station, Palaia Kavala village area, Kavala city, Greece (Source: Authors' Google Earth compilation archive)

(established in the proximity of the city urban web center and at the western exit of the city as well), located at the specific co-ordinates 41o0'263" N and 24o24'766" E, Palaia Kavala village area, and operated continuously, spanning a time period from 17.08.2013 to 07.02.2014, as illustrated in Figure 1.

3.2. Sample collection and data used in this study

A total number of 174 individual stream flow rate (discharge) measurements were performed within 174 consecutive days, between 17.08.2013 and 07.02.2014, during which a thorough presentation of the methodology and procedure followed up was analytically supplied, whereas, all of them were recorded and uploaded on the first author's personal Youtube platform web-site, namely, "Thomas Papalaskaris". The first stream flow rate (discharge) measurement (17.08.2013) lasted 42':18", and the last one (07.02.2014), respectively, 01:00':00" sharp. In accordance with the recorded observations of the only available private meteorological station located at Dexameni area, Kavala city, Greece, Kavala city received total monthly rainfalls as following: 56.80 during May 2016, 14.00 mm during June 2016, 1.60 mm during July 2016 and 10.40 mm during August 2016 (82.80 mm in total respecting the four months) respectively. The recorded stream flow rate (discharge) (denoted by the blue-colored continuous line) and the observed rainfall (denoted by the red-colored vertical bars) during the time period 14.05.2016 and 29.08.2016 are simultaneously illustrated within Figure 2.

3.3 Sample analysis and checking the goodness of fit

Mathwave EasyFit and StatAssist software packages was employed to estimate the best probability distribution (based on the Anderson-Darling, Chi-Squared and Kolmogorov-Smirnov goodness-of-fit criteria tests), together with the associated parameters, fitting the daily lowest stream flow data, as well as the goodness-of-fit of all the other candidate probability distributions. Moreover, after having calculated the parameters of the examined probability distributions, we generated a sequence of high quality random numbers for each individual candidate probability distribution with the same parameter values to the origina calculated ones. The Kolmogorov-Smirnov test (KS-test) tries to determine if two datasets differ significantly, whilst, it has the advantage of making no assumption about the distribution of the data (technically speaking it is non-parametric and distribution free). MS Excel software is employed in order to plot the real observed (recorded) against the artificial (generated, forecasted) low stream flow rate (discharge) data. The calculation of six examined candidate probability distribution estimates are of paramount importance as they enable us, by assigning different specified scores, according to their goodness of fit performance, to evaluate which is the most appropriate one simulating the recorded stream flow rate values. The goodness of fit tests are performed in order to evaluate which distribution fits to the low stream flow rate (discharge) data series in the best possible way. The values of Anderson-Darling statistics, Chi-square (χ^2), Kolmogorov-Smirnov (D) respectively are computed and illustrated within Table 2, for the entire low

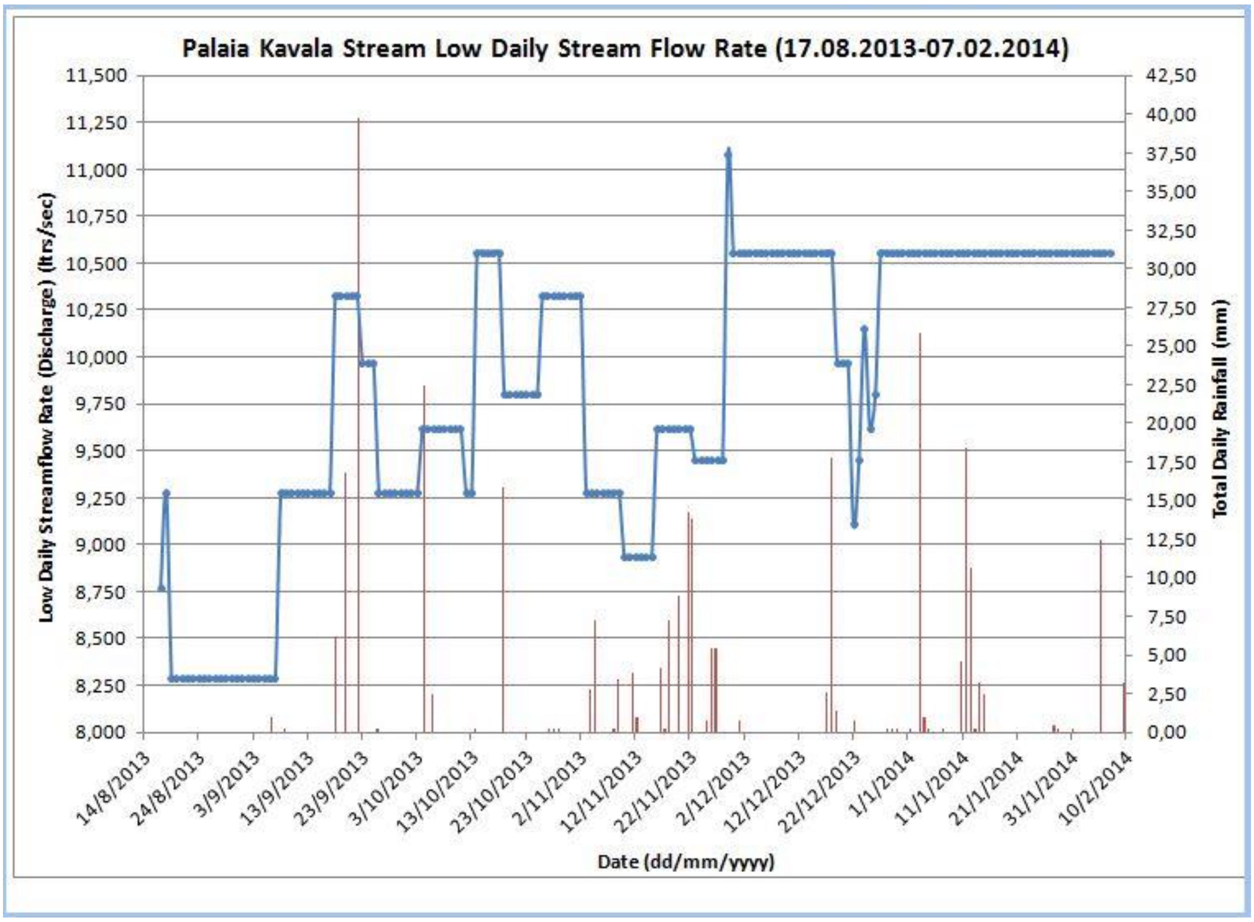

Figure 2. Recorded stream flow rate at Palaia Kavala village area, 90^{o} V-Notch, Sharp Edged, Thomson Type, Portable Weir Plate, gauging station vs. observed rainfall at Dexameni area station, Kavala city, Greece (Source: First author's personal plot compilation archive and https://www.meteokav.gr)

Table 1. Goodness of fit tests results for the 90^{o} V-Notch, Sharp Edged, Thomson Type, Portable Weir Plate, Palaia Kavala village area, Kavala city Greece, gauging station, data series,(Source: EasyFit, Goodness Of Fit)

Probability distribution	Anderson - Darling	Chi-Squared	Kolmogorov-Smirnov	Highest final goodness of fit score obtained
Gumbel min (2P)	10.262	45.349^{3}	0.24022	1
Log-Normal (3P)	9.7803^{2}	17.511^{1}	0.21644	5
Pearson type 5 (3P)	10.138^{3}	66.152	0.21743	1
Pearson type 6 (3P)	38.517	147.45	0.42896	0
Weibull (2P)	8.2174^{1}	33.427^{2}	0.20688^{3}	6
Kumaraswamy (4P)	32.245	N/A	0.19169^{1}	3
Wakeby (5P)	11.503	N/A	0.19579^{2}	2

stream flow rate (discharge) time series data. It should be underlined that, employing an improvised scoring system, the superscript number makes reference to the order ranking of the probability distribution which best fits the low-flow time series data, ranging from 1 (the best one) to 3 (the worst one).Further, the ranking score values of numbers 3, 2, and 1, are, inversely assigned to the already given, (as above mentioned followed procedure), ranking scores 1, 2, and 3 correspondingly, in order to assess the highest final goodness of fit score obtained for each candidate individual probability distribution, determining, as an outcome, the best one which best fits the observed

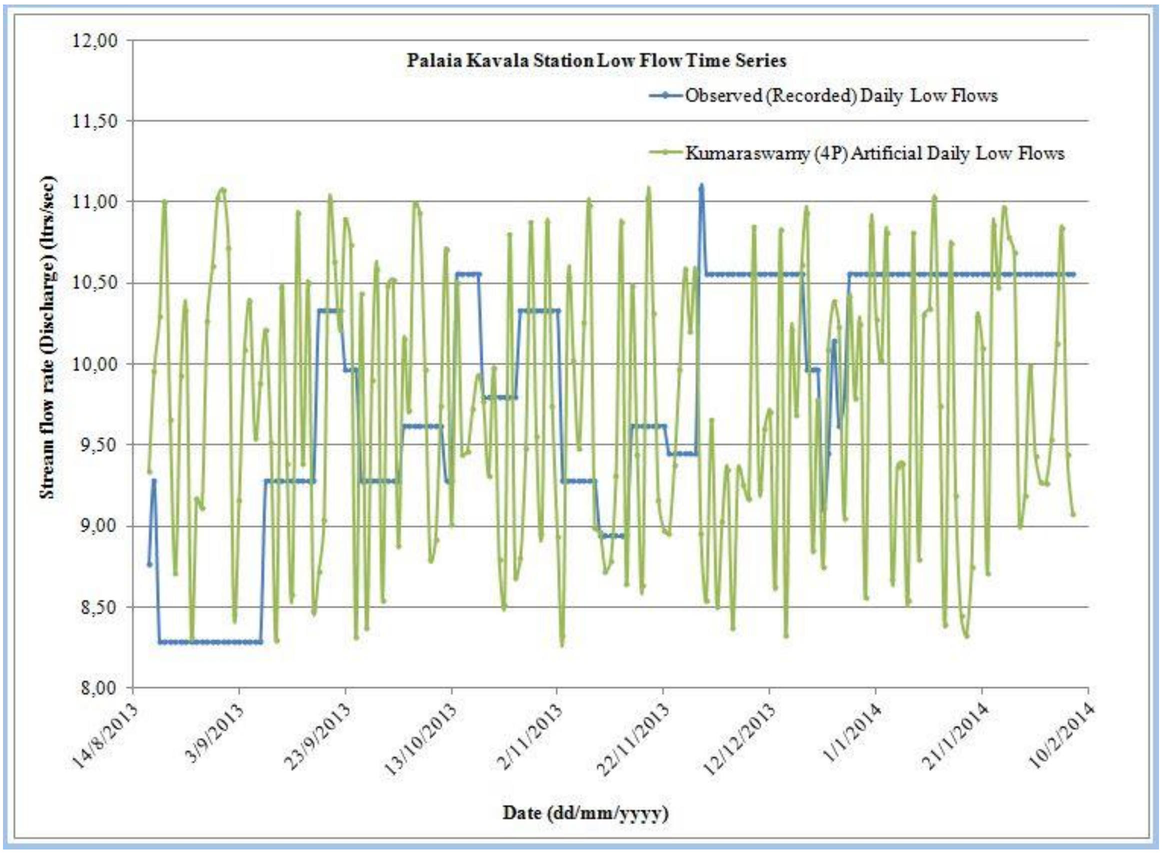

Figure 3. Plot of observed against artificial low stream flow rate time series data at Palaia Kavala village area, 90^o V-Notch, Sharp Edged, Thomson Type, Portable Weir Plate gauging station, Kavala city, Greece (Source: Authors' plot compilation archive)

low stream flow rate (discharge) time series data.It can be identified from Table 1, that all the examined probability distribution functions can be accepted to fit to the low stream flow rate (discharge) time series data at the significant level α of 0.05, except Kumaraswamy and Wakeby (5P) probability distribution functions, based on the Chi-squared goodness of fit test, whilst, at the same time, based on all three individual goodness of fit tests, Weibull (2P) obtained the highest score of six. Still, the probability density function of Kumaraswamy (4P) probability distribution (which obtained the highest score based on the Kolmogorov - Smirnov goodness of fit test) is finally chosen in order to produce artificial low flow time series data. Visually inspecting the Figure 3, where the real observed (recorded) low stream flow rate (discharge) time series data are plotted against the artificial ones, for the same time period (17.08.2013-07.02.2014) we can identify that both, by first sight, coincide (for the most of the paired values) remarkably well.

3.4. Hydrodynamic methods and equipment for sample data collection and analysis

Due to the extremely shallow waters, in conjunction with the extremely low water stream flow velocity prevailing at the gauging station, it is impossible to implement the area-velocity method in order to assess the stream flow rate (discharge), using a current meter mounted on a wading rod, owing to the fact that there isn't available depth to submerge the current meter as well as the extremely low water stream flow velocity is not sufficient enough to trigger the operation of a current meter; Under those particular circumstances the only alternatives are the use of either a small-sized flume or a small-sized portable weir plate which, eventually, was our final selected option, more specifically, a "90^o V-Notch, Sharp-Edged, U.S.G.S., Thomson Type, Portable Weir Plate", constructed by means of galvanized steel-sheet, with hexagon galvanized nuts, permanently welded along its top, in order to easily secure the weir plate's vertical stabilization by means of stainless steel wire ropes anchoring those hexagon nuts with steel pegs rammed into the stream bed upstream the stream flow rate gauging point (Rantz, 1982).

4. Comparison between calculated and site-measured low stream flow rate (discharge) values

The comparison between calculated and site-measured values of low stream flow rates (discharges) is made on the basis of several statistical criteria such as, root mean squared error (R.M.S.E.), relative error (R.E.), efficiency coefficient (E.C.), linear correlation coefficient (r), determination coefficient (r^2) and discrepancy ratio (D.C.) (Nash and Sutcliffe, 1970; Krause *et al*., 2005), as depicted within Table 2. The plot depicted within Figure 4 represents the discrepancy ratio concerning Palaia Kavala Stream, Kavala city, North-Eastern Greece, during the time period between 17.08.2013 and 07.02.2014. At this point, it should be noted that both coordinate axes are in logarithmic scale; therefore, the equations y=x, y=0.5x and y=2.0x are represented graphically by parallel straight lines.

Table 2. Statistical criteria values of 90^o V-Notch, Sharp Edged, Thomson Type, Portable Weir Plate gauging station, Palaia Kavala Stream, Kavala city, Greece, (17.08.2013-07.02.2014) (Source: Authors' table compilation archive)

Number of paired values	RMSE [kg/(m s)]	RE (%)	EC	r	r^2	Discrepancy ratio
175	1.1629	0.0047	-1.2594	-0.0443	0.0020	1.0000

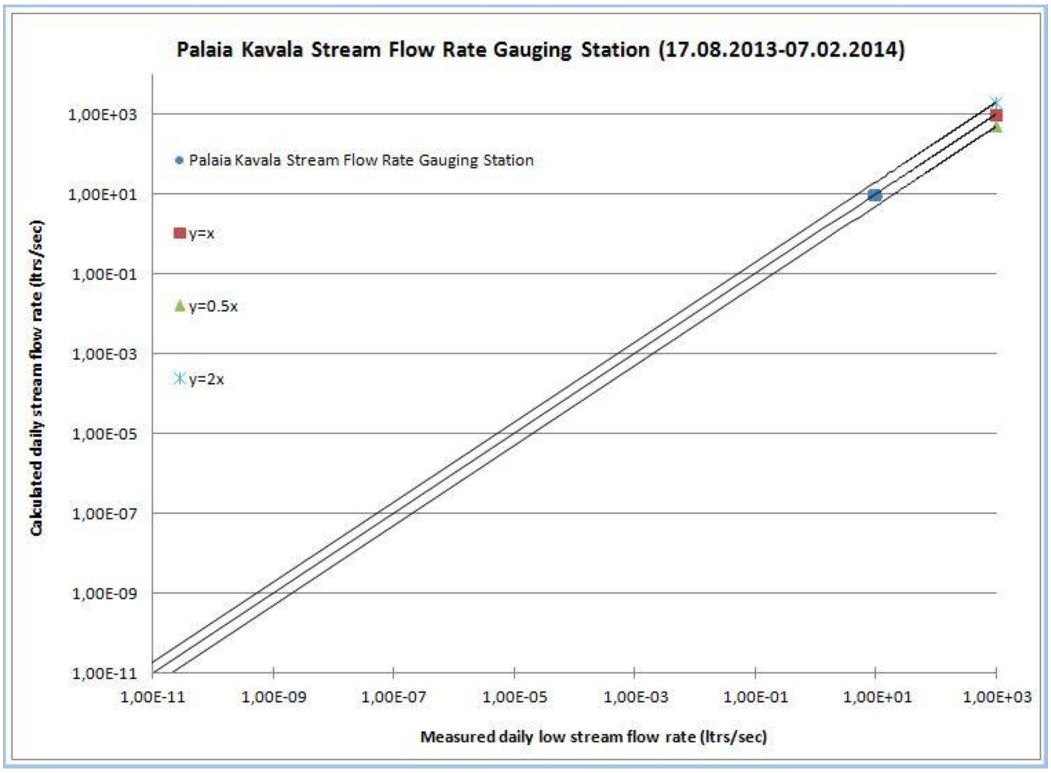

Figure 4. Discrepancy ratio plot of observed against artificial low stream flow rate time series data

In general, the obtained values of the statistical criteria R.M.S.E., R.E., E.C. for Palaia Kavala Stream "90^o V-Notch, Sharp-Edged, U.S.G.S., Thomson Type, Portable Weir Plate" gauging station can be considered fairly satisfactory considering the low stream flow rate numerical values. Additionally, the degree of linear dependence between calculated and measured bed load transport rate is very weak, implying that more iterations should be carried out until an artificial low stream flow rate time series data which best fits (by the perspective of the overall achieved statistical efficiency criteria) the observed low stream flow rate time series data is generated. The above mentioned statistical criteria values concerning Palaia Kavala Stream, Kavala city, North-Eastern Greece, are listed within Table 4. It is noted that the relative error value depicted within Table 4 represents the average value of the relative errors calculated for each pair of calculated and measured bed load values.

5. Results and discussion

A total number of 175 individual stream flow rate (discharge) measurements were performed within 175 consecutive days, between 17.08.2013 and 07.02.2014, at the Palaia Kavala village area, Kavala city, north eastern Greece, at the particular section of the homonymous watershed and main stream channel by means of a "90^o V-Notch, Sharp-Edged, U.S.G.S., Thomson Type, Portable Weir Plate". The daily lowest flows were undergone a probability distribution analysis and seven candidate probability distribution functions were fitted to the low stream flow rate time series data proving that the Weibull (2P) probability distribution function best fitted the data based on three different goodness of fit tests. As normally anticipated the stream flow rate (discharge) observed early in the morning, late in the evening and during the night patrols were (due to decreased evapotranspiration rate, stemming from the relatively lower temperature, solar radiation and dry wind intensity values hitting, in turn, the entire Palaia Kavala village area watershed) relatively higher that those performed around mid-day hours and early in the evening.

6. Conclusions and further research

Palaia Kavala watershed and main stream channel can sustain extremely low flow conditions which are essential for low flow studies in order to compile an as much consistent watershed and drought management plan and bridge the research and knowledge pertinent to the south eastern part of Europe were, as generally admitted, only a few stream flow rate (discharge) measurement gauging stations exist and transfer the acquired knowledge to ungauged watersheds as well, in accordance to the suggestions of the Braunschweig Declaration. Furthermore, Palaia Kavala Mediterranean watershed could be proposed to be incorporated within the global network of long-term small hydrological scientific research basins network the importance of which has been worldwide acknowledged. More future stream flow measurements would contribute to the production of extended stream flow rate (discharge) time series data which are of paramount importance in hydrology in order to compile accurate, consistent and sustainable watershed balance and budget computation and drought management plans compilation.

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