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Research Article

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Genetic Algorithm for Determining Optimal Unit Hydrograph for Harpeth River Watershed, Tennessee

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Keywords

Unit Hydrograph,
Optimization,
Genetic Algorithm,
Flood.

Abstract

The unit hydrograph for a watershed plays a significant role in predicting the flood hydrographs of any duration precipitation event, which can be used to calculate the peak flow for designing hydraulic structure to save the area from flooding. The main objective of this study was to obtain an optimal unit hydrograph from twenty field data-based unit hydrographs for the Harpeth River watershed. To attain this objective, field flow data for three years was collected, and twenty random events were drawn to get the flood hydrographs. The flood hydrographs were converted into direct runoff hydrographs and then unit hydrographs. The gamma distribution function was used to get the optimal unit hydrograph through the genetic algorithm for getting optimized values of shift and scale parameters of the distribution. Applying the genetic algorithm, the obtained values of these parameters were 6.86 and 4.03, using the objective function to minimize the root mean square error of peak flow values between filed data-based unit hydrographs and optimal unit hydrographs. To sum up, heuristic optimization, like a genetic algorithm (GA), can be used to optimize gamma distribution parameters due to the difficulty in optimizing it using traditional methods like maximum likelihood and method of moments.

1. Introduction

Forecast of flow hydrographs is vital for water crisis actions and control procedures [1]. A considerable number of techniques have been presented for flow projection. The unit hydrograph (UH) is a widely used technique proposed by Sherman et al. [2], particularly in developing nations. It is a direct runoff hydrograph from one unit (one inch or one cm) of steady uniform precipitation over the whole basin [3]. The unit hydrograph idea proposed for evaluating the runoff hydrograph at the weather station compares to a precipitation hyetograph. This was one of the foremost implements known to the hydrologic society to choose the complete form of the hydrographs rather than the extreme flow simply [4, 5]. Moreover, Sherman et al. [2] paved the path to expanding watershed rainfall-runoff research with his UH approach. He created hypotheses that are the motivation of current hydrology. These assumptions can be rephrased: The hydrologic method is linear and time-invariant. In contrast, it fails to describe the runoff distribution accurately because of its limitations. Furthermore, the UH clarifies the basin response features to all the precipitation events [6]. Many studies were conducted using a unit hydrograph for the estimation of a flood. [7]used the unit hydrograph to calculate overflow hydrographs for ungauged urban watersheds. Sorman et al. [8] used the unit hydrograph for the prediction of the peak flood for the ungauged station. Jain et al. [9] used the unit hydrograph for a complex drainage system examination for the Himalayan River to spotlight its importance in the overflow control schedule. Khaleghi et al. [10] used several models, including the unit hydrograph, to specify the formation and measurements of outlet runoff

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hydrographs for a selected Basin. Sule et al. [11] used the unit hydrograph method for a basin. They found that this approach can provide valuable information on runoff, such as height discharge velocities and duration of the height flow. Eizeldin et al. [12]used the unit hydrograph integrated with the basin's geomorphological characteristics and kinematic-wave equations to predict the rainfall-runoff hydrograph within ungauged arid drainage basin used the unit hydrograph model to forecast the surface runoff in hillslopes. They revealed that the model predicted the subsurface flow accurately, and they verified the results based on the laboratory data. Pratama et al. [13] used the unit hydrograph to estimate flood volume and peak flow and showed that the results were accurate [14]. Wang et al.[15] used an improved unit hodograph to estimate flood for an area with fewer data. They demonstrated that the model is applicable for estimating the spatial distribution of flow, and the results can be used for stream network discharge concentration. Bahrami et al. [16] used a unit hydrograph approach to estimate flood hydrograph for a basin located in the mountains. They showed that the model predicts the flood hydrograph precisely. Shatnawi et al. [17] employed the synthetic unit hydrograph method to predict the flood from a hurricane event for an ungauged area. They indicated that the unit hydrograph model could be an efficient approach for estimating floods. The UH, acquired from a separate thunderstorm occurrence, can be distinguishable for a basin [18]. Hence, it is essential to specify the variables of optimal UH, which can decrease the mistakes in the calculation of UHs. Many methods can be used to get an optimal UH from numerous thunderstorm events for a typical basin [19]. Moreover, researchers have used the probability distribution procedure to specify the unit hydrograph by assuming that the number of unexplored parameters is equivalent to the number of probability distribution variables.

The unit hydrographs obtained using various rainfall events are different. Thus, it was crucial to select the most suitable unit hydrograph that anticipates the real precipitation events with insignificant mistakes. The optimization methods like genetic algorithms can convert the different unit hydrographs to an optimal unit hydrograph using the probability distribution. Therefore, the aim of this study was to obtain the optimal unit hydrograph for the watershed using a gamma distribution.

2. Study Area, Climate, and Significance

2.1. Study Area

Harpeth watershed is in Middle Tennessee, US. It drains its water into the Harpeth River. This watershed consists of many sub-watersheds. For this study, a sub-watershed of this big watershed was considered, which drains its water in Harpeth River at Bellevue, located at 36°03'13.7" N, and 86°55'43.7" W. The area of this watershed is approximately 430 square miles.

2.2. Climate

The study area has an average annual precipitation of 4.6 inches. However, the temperature was varied. For example, January is the coldest month with a low temperature of 26 degrees, while July and August are the hottest months, with temperatures reaching 89 degrees.

2.3. Significance

The purpose of using this watershed for the study was its significance because due to the urban development of this watershed, the response to each precipitation event may be different and will cause flooding. So, it was essential to optimize the unit hydrograph study to better understand and predict the flows for future development projects and structures design.

3. Methodology

The following steps were followed to obtain the optimized unit hydrograph for the watershed.

3.1. Data Acquisition

The flow in cubic feet per second (cfs) and precipitation in inches (in) data of the study area were obtained from U.S. Geological Survey (USGS). The data length was from January 01, 2018, to December 31, 2021. There were many flood hydrographs from various precipitation events. Twenty events were selected randomly to represent the watershed's response after a precipitation event.

3.2. Flood Hydrograph to Unit hydrograph

The flood hydrographs for these twenty events were drawn. Then, the base flow for each event was selected as the minimum flow value before the rising limb of the flood hydrograph. Next, the base flow was separated from each event to get the direct runoff hydrograph. Finally, the direct runoff hydrographs were converted to the unit hydrographs using the watershed area and effective unit precipitation. The obtained unit hydrograph from direct runoff and flood hydrographs of the event 14 is shown in Figure 1.

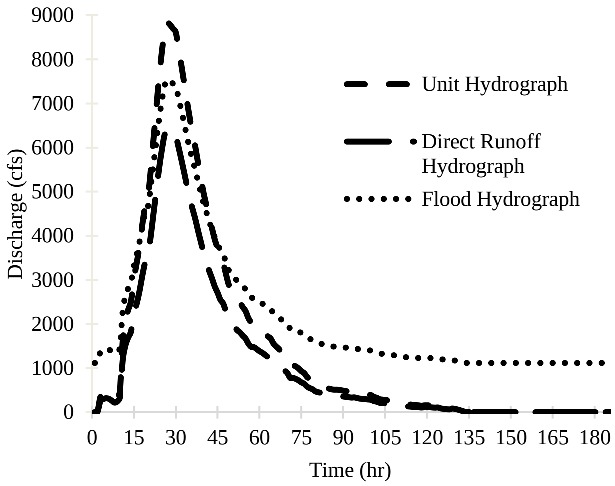

Figure 1. Conversion of flood hydrograph to unit hydrograph

The unit hydrographs for all the twenty events obtained from field data are shown in the figure given below.

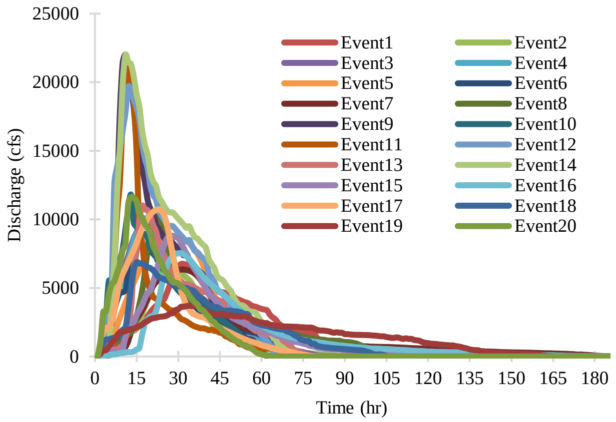

Figure 2. Unit hydrographs obtained from flood hydrographs of twenty events

3.3. Gamma Distribution

The gamma distribution benefits from holding solely positive outcomes in hydrology since hydrological parameters like precipitation are consistently positive, more significant, or equivalent to 0 as a lower boundary [20]. The gamma distribution is a particular subject of the Pearson Type III distribution where the locus variable is 0. Fisher [21] was the first who gave the maximum likelihood approach for this distribution; nevertheless, the formula did not conveniently handle a frequent assessment. Besides, the gamma distribution is a two-variables commonness distribution presented as Eqs. (1) and (2) [22].

$$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}(x)^{\alpha-1}e^{-\frac{x}{\beta}}, \quad x \geq 0 \tag{1}$$

$$\Gamma(\alpha) = \int_{0}^{\infty}(x)^{\alpha-1}e^{-x}\,dx \tag{2}$$

where x is the randomly distributed variable, α is the shift parameter, β is the scale parameter, and f(x) is the standard gamma function.

3.4. Genetic Algorithm

Recently metaheuristic algorithms and machine learning models have been employed to fix complicated concerns originating from various domains [23-30]. Most metaheuristic algorithms are introduced by natural growth, swarm manners, and physics[31]. A genetic algorithm is an investigation heuristic motivated by Charles Darwin's idea of biological development. This algorithm images the natural preference approach, where the best someone is chosen for duplication to create descendants for the following era [32]. For example, if parents have more good wellness, their descendants will be more promising and have a reasonable chance of enduring. This methodology maintains repeating, then a generation with the most qualified people's willpower is discovered.

The steps of the genetic algorithm (GA) are as follows. First, a sample (Y) of chromosomes is created unsystematically. Then, the wellness of separate chromosomes in 'Y' is calculated. According to the wellness value, two chromosomes, 'C1' and 'C2', are chosen from the sample. Then, the crossover operator with crossover likelihood (Cp) is involved with 'C1' and 'C2' to create descendants, assuming it is O'. After that, a constant modification operator is used to create descendants (O) with modification possibility (Mp) to develop 'O'. Finally, the new descendant's "O" is recognized in the latest sample. The choice, crossover, and modification procedures will be replicated on the existing sample until the recent sample is done [32].

Besides, the crossover formula is defined as Eq.(3) [34]

$$R = \frac{(G+2\sqrt{g})}{3G} \tag{3}$$

where 'G' is the number of generations and 'g' is the whole number of developed generations set by sample.

3.5. Optimization of Unit Hydrograph

Using gamma distribution, the primary goal was to locate the optimal weight of shape parameter 'α' and shift parameter 'β' for the most suitable unit hydrograph solution with gamma distribution. Besides, the optimized peak unit hydrograph and required duration for peak and time to peak were compared to the field unit hydrographs obtained straight from precipitation events [35-36]. Finally, the objective function with constraints and decision variables was defined as follows which is root mean square error (RMSE). As shown in Eqs. (4)-(7)

$$Min\sqrt{\frac{1}{n}\sum_{i=1}^{n}(gamma\ distribution\ peak - UH\ peak)^2} \tag{4}$$

$$G(a) \geq L(a) \tag{5}$$

$$G(b) \geq L(b) \tag{6}$$

$$G\ (time\ to\ peak) = L\ (time\ to\ peak) \tag{7}$$

Decision variables G(a) and G(b) are the 'α' the shift parameter, and 'β' is the scale parameter for the gamma distribution process that can be described as the function of the unit hydrograph. Index 'I' describes the number of various unit hydrographs utilized for optimization and 'n' is the total number per basin, and 'UH peak' is the maximum value of the UH obtained from the optimized 'α' and 'β' of the gamma distribution approach. L(a) and L(b) is the lower boundaries of G(a) and G(b) for each of the unit hydrographs obtained from field data. In the genetic algorithm, 2 genes, 6 chromosomes, 25% of the population for crossover rate, two as mutation rate, and 5% of the population as elitism size in each generation were used.

4. Results and Discussion

The shift and scale parameters of the gamma distribution were optimized using the genetic algorithm by minimizing the root mean square error defined as the objective function. After 633 Generations, the genetic algorithm found the optimal values of the scale and shift parameters of the gamma distribution which are 6.86 and 4.03. The corresponding lowest mean square error was 1213.93. These values were used to get the unit hydrograph which represents the optimized response of the watershed considering the twenty events of the field data. The plot for fitness vs. generation is given in Figure 3.

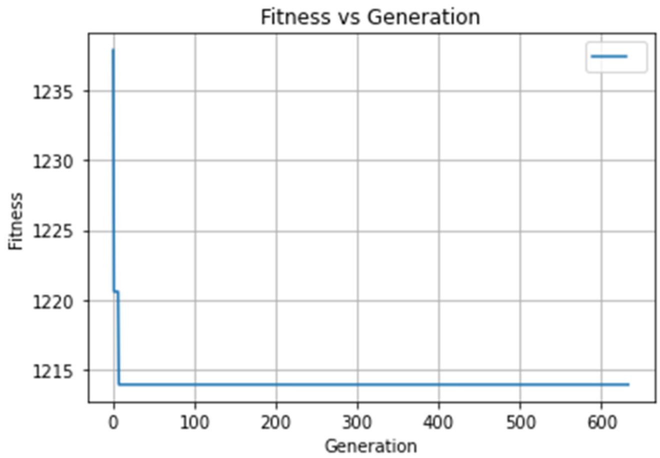

Figure 3. Fitness vs. generation plot obtained through genetic algorithm.

After this fitness, the resultant values of scale and shift parameters of the gamma distribution were used in the gamma distribution function to get the optimal unit hydrograph which is presented as follows:

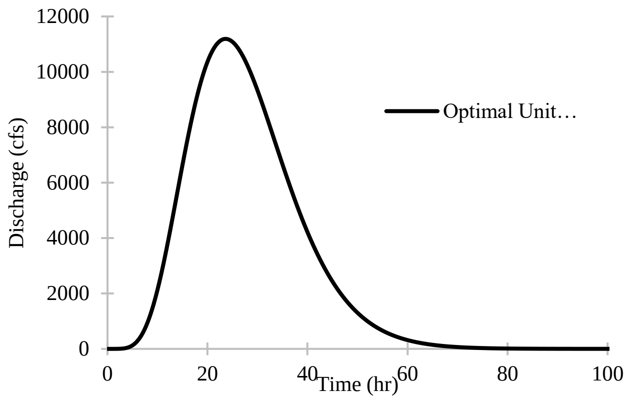

Figure 4. Optimal unit hydrograph obtained through genetic algorithm.

The optimal unit hydrograph showed the peak flow value of around 11000 cfs, which is well optimized between the lowest and highest flow values of the twenty events about 3000 and 22000 cfs, respectively. Similarly, another important parameter of the unit of the hydrograph is time to peak, around 25 hours which is in the range of unit hydrographs of all the twenty events. The following figure gives the comparison of the optimal unit hydrograph with the twenty field data unit hydrographs.

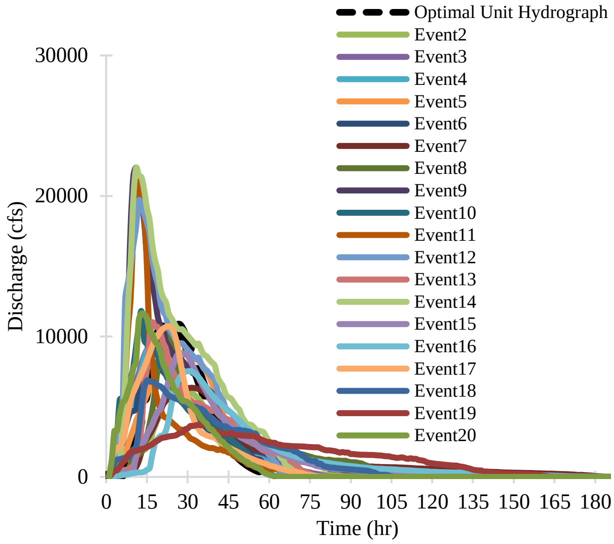

Figure 5 Comparison of optimal unit hydrograph with field data-based unit hydrographs.

5. Conclusions

The conclusion drawn from this study is presented below.

- The conversion of field flood hydrographs into the unit hydrographs resulted in various unit hydrographs instead of one hydrograph, which may be due to the variations of precipitation intensity over the area and some climatic factors.
- The gamma distribution was influential in getting the optimal unit hydrograph using the genetic algorithm from twenty events of unit hydrographs obtained from the field flow data.
- The optimal unit hydrograph showed a good, optimized agreement with the field data-based unit hydrographs with a mean square error was 1213.93. This calculated unit hydrograph had a better relationship with the minimum and peak flow values and the time to reach the peak flow with the twenty events of the field unit hydrographs.
- Generally, maximum likelihood and method of moments are used for the parameter estimation of distributions in statistical theory. Both of these methods are very difficult due to the density operation form of the gamma distribution [37]. Hence, in this study, we are showing the capability of heuristic optimization like genetic algorithm can be used to optimize gamma distribution parameters.

Conflict of Interest Statement

The authors declare no conflict of interest.

References

[1] S. Ebrahimi, M. Khorram, Variability effect of hydrological regime on river quality pattern and its uncertainties: case study of Zarjoob River in Iran, Journal of Hydroinformatics 23(5) (2021) 1146-1164.

[2] L.K. Sherman, Streamflow from rainfall by the unit-graph method, Eng. News Record 108 (1932) 501-505.

[3] M.A. Ghorbani, V.P. Singh, B. Sivakumar, M. H Kashani, A.A. Atre, H. Asadi, Probability distribution functions for unit hydrographs with optimization using genetic algorithm, Applied Water Science 7(2) (2017) 663-676.

[4] P. Bhunya, S. Panda, M. Goel, Synthetic unit hydrograph methods: a critical review, The Open Hydrology Journal 5(1) (2011).
[5] M. S. Alasta, A. S. A. Ali, S. Ebrahimi, M. M. Ashiq, A. S. Dheyab, A. AlMasri, A. Alqatanani, M. Khorram, Modeling of Local Scour Depth Around Bridge Pier Using FLOW 3D, Environ Eng, 8(2022)1–9.
[6] P. Singh, S.K. Mishra, M.K. Jain, A review of the synthetic unit hydrograph: from the empirical UH to advanced geomorphological methods, Hydrological Sciences Journal 59(2) (2014) 239-261.
[7] V. Stricker, V.B. Sauer, Techniques for estimating flood hydrographs for ungaged urban watersheds, Geological Survey, Doraville, GA (USA). Water Resources Div., 1982.
[8] A. Sorman, M. Abdulrazzak, Flood hydrograph estimation for ungaged wadis in Saudi Arabia, Journal of Water Resources Planning and Management 119(1) (1993) 45-63.
[9] V. Jain, R. Sinha, Derivation of unit hydrograph from GIUH analysis for a Himalayan river, Water Resources Management 17(5) (2003) 355-376.
[10] M. Khaleghi, V. Gholami, J. Ghodusi, H. Hosseini, Efficiency of the geomorphologic instantaneous unit hydrograph method in flood hydrograph simulation, Catena 87(2) (2011) 163-171.
[11] B. Sule, S. Alabi, Application of synthetic unit hydrograph methods to construct storm hydrographs, International Journal of Water Resources and Environmental Engineering 5(11) (2013) 639-647.
[12] M.A. Eizeldin, O. Almasalmeh, Flash Flood Modelling of Ungagged Watershed based on Geomorphology and Kinematic Wave: Case Study of Billi Drainage Basin, Egypt, (2019).
[13] M. Pratama, F. Rohmat, M. Farid, M. Adityawan, A. Kuntoro, I. Moe, Flood hydrograph simulation to estimate peak discharge in Ciliwung river basin, IOP Conference Series: Earth and Environmental Science, IOP Publishing, 2021, p. 012028.
[14] H. Babaali, T. Sabzevari, S. Ghafari, Development of the Nash instantaneous unit hydrograph to predict subsurface flow in catchments, Acta Geophysica 69(5) (2021) 1877-1886.
[15] W.-c. Wang, Y.-w. Zhao, K.-w. Chau, D.-m. Xu, C.-j. Liu, Improved flood forecasting using geomorphic unit hydrograph based on spatially distributed velocity field, Journal of Hydroinformatics 23(4) (2021) 724-739.
[16] E. Bahrami, M. Salarijazi, S. Nejatian, Estimation of flood hydrographs in the ungauged mountainous watershed with Gray synthetic unit hydrograph model, Arabian Journal of Geosciences 15(8) (2022) 1-10.
[17] A. Shatnawi, M. Ibrahim, Derivation of flood hydrographs using SCS synthetic unit hydrograph technique for Housha catchment area, Water Supply 22(5) (2022) 4888-4901.
[18] M. M. Ashiq, H. ur Rehman, N. M. Khan, Impact of large diameter recharge wells for reducing groundwater depletion rates in an urban area of Lahore, Pakistan, Environmental Earth Sciences 79 (2020) 1–14.
[19] M. Diskin, A. Boneh, Determination of an optimal IUH for linear, time invariant systems from multi-storm records, Journal of Hydrology 24(1-2) (1975) 57-76.
[20] H. Aksoy, Use of gamma distribution in hydrological analysis, Turkish Journal of Engineering and Environmental Sciences 24(6) (2000) 419-428.
[21] R.A. Fisher, On the mathematical foundations of theoretical statistics, Philosophical transactions of the Royal Society of London. Series A, containing papers of a mathematical or physical character 222(594-604) (1922) 309-368.
[22] H.C. Thom, A note on the gamma distribution, Monthly weather review 86(4) (1958) 117-122.
[23] A.R. Kashani, M. Akhani, C.V. Camp, A.H. Gandomi, A neural network to predict spectral acceleration, Basics of Computational Geophysics, Elsevier2021, pp. 335-349.
[24] A.S.A. Ali, M. Günal, Artificial Neural Network for Estimation of Local Scour Depth Around Bridge Piers, Archives of Hydro-Engineering and Environmental Mechanics 68(2) (2021) 87-101. https://doi.org/doi:10.2478/heem-2021-0005.
[25] A. S. A. Ali, S. Ebrahimi, M. M. Ashiq, M. S. Alasta, B. Azari, CNN-Bi LSTM neural network for simulating groundwater level, Environ Eng, 8 (2022) 1–7.
[26] B. Azari, K. Hassan, J. Pierce, S. Ebrahimi, Evaluation of Machine Learning Methods Application in Temperature Prediction, Environmental Engineering 8 (2022) 1-12.
[27] M. Akhani, S. Pezeshk, Using metaheuristic algorithms to optimize a mixed model-based ground-motion prediction model and associated variance components, Journal of Seismology (2022) 1-16.
[28] K. Azizi, A.R. Kashani, S. Ebrahimi, F. Jazaei, Application of a multi-objective optimization model for the design of piano key weirs with a fixed dam height, Canadian Journal of Civil Engineering (ja) (2022).
[29] M.M. Hamed, A. Al-Masri, Z.M. Dalala, R.J. AlSaleh, Modeling the Time Duration Until the Adoption of Residential Rooftop Solar Photovoltaic Systems, Journal of Energy Resources Technology 144(4) (2021). https://doi.org/10.1115/1.4051572.
[30] A.Ali, U. bin Waheed, M.. Ashiq, M.S. Alasta, M.khorram. Machine Learning Model for Estimation of Local Scour Depth around Cylindrical Bridge Piers. Iraqi Journal of Civil Engineering, 16(2) (2022), 1-13. doi: 10.37650/ijce.2022.160201
[31] A.R. Kashani, C.V. Camp, M. Rostamian, K. Azizi, A.H. Gandomi, Population-based optimization in structural engineering: a review, Artif. Intell. Rev. 55(1) (2022) 345–452. https://doi.org/10.1007/s10462-021-10036-w.
[32] M. Gandomi, A.R. Kashani, A. Farhadi, M. Akhani, A.H. Gandomi, Spectral acceleration prediction using genetic programming based approaches, Appl. Soft Comput. 106(C) (2021) 13. https://doi.org/10.1016/j.asoc.2021.107326.
[33] S. Katoch, S.S. Chauhan, V. Kumar, A review on genetic algorithm: past, present, and future, Multimedia Tools and Applications 80(5) (2021) 8091-8126.
[34] D. Liu, Mathematical modeling analysis of genetic algorithms under schema theorem, Journal of Computational Methods in Sciences and Engineering 19(S1) (2019) 131-137.
[35] F. Dell'Aira, T.J Chy, T.H Goebel, C.I Meier, Inferring Hydrological Properties of the Rainfall-Runoff Conversion Process through Artificial Neural Network Modeling. In World Environmental and Water Resources Congress (2022) 1264-1278).
[36] K. Hasan, S. Paul, T.J Chy, A Antipova. Analysis of groundwater table variability and trend using ordinary kriging: the case study of Sylhet, Bangladesh. Applied Water Science, 11(7) (2021) 1-12.
[37] V.S. Özsoy, M.G. Ünsal, H. H. Örkcü. Use of the heuristic optimization in the parameter estimation of generalized gamma distribution: comparison of GA, DE, PSO and SA methods. Computational Statistics, 35(4)(2020), 1895-1925.