Comparative Analysis of Some Existing Models for Estimating the Time of Concentration for Watersheds in Anambra State, Nigeria

J. C. Agunwamba¹ and N. C. Mmonwuba²*

¹Department of Civil Engineering, University of Nigeria Nsukka, Enugu State, Nigeria.  
²Department of Civil Engineering, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.

Authors’ contributions

This work was carried out in collaboration between both authors. Author JCA designed the study while Author NCM wrote the introduction, managed the literature searches and performed the statistical analysis. Both authors read and approved the final manuscript.

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ABSTRACT

This study considered the estimation of the time of concentration (Tc) using 30 different watersheds in Anambra State, Nigeria. The study assessed the performance of some existing models for the estimation of time of concentration in the study area. Data for this research were collected from watersheds located at Awka-South Local Government in Anambra State. A measured time of concentration values was also obtained by using a tracer at the watershed divide and the time it took the tracer to get the outlet of the watershed was recorded. This was carried out on all the 30 watersheds at the same time. The length, slope and area of the 30 watersheds were also measured. Thereafter, the time of concentration was estimated using the 30 existing models. The extent of linear association between the observed and estimated time of concentration for the different models was determined. The outcome of the study revealed that the Ventura model (Tc12) developed in Italy recorded the highest correlation coefficient with a measure of 0.681, followed by DNOS model (Tc14) with a coefficient measure of 0.661 while the least performing model was...
Picking model (Tc13) with -0.423 correlation measure. There was also an obvious difference in the values of the time of concentration calculated using the different models. Therefore there is always a need to verify any model to be used for estimating the time of concentration in other to have a more robust design.

Keywords: Concentration; correlation; models; watershed; time.

1. INTRODUCTION

There are many definitions to time of concentration as well as for related estimation processes. It can be defined as the necessary time, used by the overland flow, to reach a balance. McCuen et al. [1] state that it is the necessary time taken by a water drop to superficially move from the most distant spot (within a hydraulic path) in the basin up to the outlet point. According to [2], the time of concentration is the time spent by a single raindrop to move from the most distant spot in the basin until its outlet point. The time of concentration can as well be viewed as the time spent by the overland flow to reach a balance [3]. In their contribution, [1] stated that it is the necessary time spent by a single water drop to superficially move from the most distant spot in the basin (in the hydraulic path) up to the outlet point.

Many researchers have developed empirical equations using experimental and analytic methods to estimate the time of concentration. Each equation resulted from studies performed in different fields. They were adjusted according to local physical and hydrologic features. However, such equations are useful tools to estimate time of concentration within watersheds. They are usually used in experiments that involve parameter settings; Fang et al. [4] suggested a method to identify the most effective equation to set time of concentration. The study by Fang et al. [4] found many differences among time of concentration that were estimated using different formulas using parameters of watersheds. The importance of a suitable model for estimating the concentration-time useful for accurately predicting flow rates from hypothetical storms becomes necessary in the study area [5,6]. This is because Anambra State has recently been hit by floods and the government is looking for ways to effectively manage and avoid subsequent devastation. A suitable model for predicting the concentration-time is expected to help engineers and hydrologists to accurately predict the reaction of a watershed to a particular rain event. This is usually important for infrastructure development, management and flood risk assessment.

2. LITERATURE REVIEW

Table 1 presents a review of twenty nine existing models for the estimation of time of concentration across the globe.

There are limitations associated with using some of the models for the estimation of the time of concentration. The study by Kirpich [9] recommended applying his adjustment curves only to rural basins that present area between 0.0040 and 0.8094 km². For small drainage basins that are dominated by channel flow, the Kirpich [9] equation can be used. Some authors use an adjustment factor for the Kirpich approach to correct for paved channels. Kirpich method yields very conservative or short times of concentration that result in high peak runoff rates, especially from the rational method. This method should only be used if the available data are limited to watershed length and slope (or) the method is specified by Kirpich.

A study conducted by [40] attempted to verify the application of the popular Kirpich Equation for determining the time of concentration using field data. Based on regression analysis, a modified Equation \( Tc = 331.43L^{1.7502}S^{-0.7692} \) was formulated. Results indicated no correlation between the measured and computed values of Tc. There were also marked variations between values obtained using the existing Equation and values obtained using the modified formula.

Also in another study conducted by Adaba et al. [24] to determine the adequacy of drainage channels in a small urban watershed in Nigeria a new time of concentration model was proposed for channel flow \( Tc = 0.076L^{0.354}S^{-0.71} \). SCS Lag suits small rural basins of rural basins with \( A < 8km^2 \) in which the superficial flow is prevalent. The parameters reflect the behaviour of medium-sized basins as well as the prevailing flows in the canals. SCS Lag method did not take into consideration the total area of land contributing...
to the total runoff but rather the nature of the surface watersheds. Gian
dotti’s equation is commonly used in Europe, mainly in Italy for A
between 170 km2 - 70,000 km2 for a small agricultural watershed. Thus, diverse authors
have been getting coherent results by applying the methodology to Italian basins. Radice et al.
[19] highlight that the use of Giandotti’s equation is mainly appropriate to mountainous basins
considering the weather conditions.

Table 1. Some existing Models for estimating the Time of Concentration (Tc)

| S/N | Name of Model        | Models                                                                 | Applications                                                                                      | References                          |
|-----|----------------------|------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|-------------------------------------|
| 1   | Kerby-Hathaway       | Tc = 0.606 IN^{0.474} L^{0.247} S^{0.234}                              | Analysis of overland Flow in experimental surface (L<0.37 km²)
A<0.0404685642 km² (10 acres), slope <1% N< 0.8 | (Kerby[7]; McCuen et al.[1])                       |
| 2   | Watt and Chow        | Tc = 0.0014(Lc/\sqrt{Sc})^1.17                                        |          | Watt and Chow [8]                          |
| 3   | Kirpich              | Tc = 0.078L^{0.577} S^{0.385}                                          | Data of rural basin (0.004 - 0.453 km²) and (0.03<S<0.1) chow 3% to 10% | Kirpich [9]                         |
| 4   | FAA                  | Tc = 0.3788(1.1-c) L^{0.9} S^{0.332}                                   | Valid for small water sheet where sheet flow and overland Data of aero ports flow dominates drainage | Chow et al. [10]; Silveira [11]     |
| 5   | SCS Lag              | Tc = 0.857(1000/CN^{0.667})                                          | Data of rural basins (A<8km²)                                                                  | Folmar et al. [12]                   |
| 6   | Simas-Hawkins        | Tc = 0.322A^{0.542} L^{0.313} S^{0.12}                                 | Analysis of overland flow for (A=0.001-14 km²)                                                 | Simas – Hawkins [13]; Fang et al.[4] |
| 7   | Vente-Chow           | Tc = 0.1602 L^{0.65} S^{0.32}                                          | Area = (0.01-18.5 km²) & (0.0051<S<0.09)                                                       | Chow [14]; Silveria [11]            |
| 8   | Dooge                | Tc = 0.365A^{0.47} L^{0.2} S^{0.17}                                     | Area (145-948)km²                                                                             | Dooge [15]; Silveria [11]           |
| 9   | Johnstone-Cross      | Tc = 0.4623L^{-0.23} S^{0.23}                                          | Rural basin A≤12.000 km²                                                                       | Johnstone and Cross [16]; Silveria [11] |
| 10  | Giandotti            | Tc = 0.419K^{1.0} A^{0.2} L^{0.2} S^{0.2}                               | Rural basin (A<0.45 km²)&(0.03<S<0.1)                                                          | Giandotti [17]; Preti et al. [18]; Radice et al. [19] |
| 11  | Pasini               | Tc = 0.108A^{0.5} L^{0.3} S^{0.17}                                     | Applied for rural basins in Italy                                                               | Pasini [20]; Greppi [21]            |
| 12  | Ventura              | Tc = 0.322A^{0.2} L^{0.3} S^{0.17}                                     | Rural basins                                                                                   | Mata-Lima et al. [21]               |
| 13  | Picking              | Tc = 0.0883L^{0.65} S^{0.332}                                           | Data of rural basins                                                                          | Mata-Lima et al. [22] Silveria [9] |
| 14  | DNOS                 | Tc = 0.419K^{1.0} A^{0.2} L^{0.2} S^{0.2}                               | Rural basin (A<0.45 km²)&(0.03<S<0.1)                                                          | Silveria [9]                        |
| 15  | George Ribeiro       | Tc = 0.267(1.05-0.2p)^{1.0} L^{-0.385}                                  | Applied to data of 7 rural basins in the USA and a rural basin in India (A < 19000km²) and (0.03<S<0.1) | Ribeiro [23]                        |
| 16  | Dept. of Public      | Tc = 60(1.19L^{0.2})^{0.066} H^{-0.6}                                  | Applied to a rural basin                                                                       | Adaba and Agunwamba [24]            |
| 17  | Carter               | Tc = 0.0977L^{0.12} S^{0.2}                                            | A<20.72 km²& (S<0.005) Developed from urban                                                    | Carter [25]; Sharrifi and Hosseini [26] |
| S/N | Name of Model | Models | Applications | References |
|-----|--------------|--------|--------------|------------|
| 18  | Temez        | $T_c=0.3(L/S^{0.25})^{0.74}$ | Natural basins | Temez [27], Mata-lima et al. [22] |
| 19  | Pickering    | $T_c=0.871L^2/H$ | Equivalent to Kirpich's | Mata-lima et al. [22] |
| 20  | California curvet practice (CHPW) | $T_c=0.95(L/7H)^{0.227}$ | For small mountain basins | Chow et al. [26], Sharifi & Hosseini [26] |
| 21  | Bransby Williams | $T_c=0.605L/(100S)^{0.12}$ | Specially recommended for rural basins | MOTH [29], ASDOT [30] |
| 22  | Epsey        | $T_c=0.95(L/4A)^{0.38}$ | Applied for a rural basins | Hotchkiss and McCallum [31], Mata-lima et al. [22] |
| 23  | Mata-Lima et al. [22] | $T_c = 4xA^{0.5} x Lw^{0.5} x Hm^{0.2}$ | Data of basins in India (A ≤128,5km²) | Williams [32], Fang et al. [4] |
| 24  | Williams     | $T_c = (0.272 x LA^{0.5}) / DS^{0.5}$ | Data of basins in India (A ≤128,5km²) | Williams [32], Fang et al. [4] |
| 25  | Yen and Chow's | $T_c=1.2(nL/S)^{0.8}$ | Based on the theory of kinematic wave | Yen and Chow's [33], Wong [34] |
| 26  | Haktanir and Sezen (1990) | $T_c=0.7473L^{0.341}$ | $A=11.9667km^2$ | Haktanir and Sezen [35], Fang et al. [4] |
| 27  | Fed. Aviation Admin (FAA) | $T_c = 18 (1.1 c) x L^{0.77}/S^{0.33}$ | | Joo-Hyon et al. [36] |
| 28  | Corps engineers | $T_c=0.191L^{0.25} S^{0.79}$ | $A≤12.000km^2$ | Linsley [37], Silveria [11] |
| 29  | Arizona DOT  | $T_c=0.00956A^{0.5}(1000[L])^{0.22}$ | Agricultural basins modified from FAA | Arizona DOT [38] |

**Definition of parameters presented in Table 1**

- $T_c$ (hr) = time of concentration;
- $A$ (Km²) = area of the watershed;
- $C$ = overland flow coefficient of the rational method;
- $CN$ = Curve-number parameter of the SCS method;
- $D$ (Km) = equivalent diameter of the watershed;
- $H$ (m) = height difference between the ends of the main water line;
- $H_m$ (m) = mean altitude in the basin (it is the mean elevation starting from the mouth);
- $I$ (mm/h) = rainfall intensity;
- $K$ = coefficient of the type of surface;
- $L$ (Km) = length of the main water line;
- $L_{ca}$ (m) = mean length starting from the concentration spot along the L up to the spot where L is perpendicular to the centroid of the basin (Arizona DOT);
- $N$ = retardance coefficient;
- $n$ (m⁻¹⋅s) = Manning’s roughness = relation coefficient; between the vegetation cover and $p$ the total area of the basin;

Greppi [21] have suggested that Pasini’s equation must be applied to basins presenting smooth steepness where the basin data were collected. According to Mata-lima et al. [22], Temez’s methodology suits natural basins presenting area as large as 3000 Km².

The Bransby Williams’s method was mainly recommended to natural basins Arizona DOT is a modified form of FAA. It was developed from data from agricultural watersheds. In regards to ASCE, even though it is recommended only to length less than 0.09 km basins, Kang et al. (2008) proved its good performance in studies on big basins based on the topographical area. Yen and Chow’s (1983) had proposed simplifying the ASCE. Williams (1922) developed the equation after performing a study on flood flow in India only. Haktanir and Sezen [35] developed their methodology using a regression analysis using data from basins located in Turkey. Kerby [7] Method can be used for small drainage basins that are dominated by channel flow. Some authors use an adjustment factor for the Kerby approach to correct for paved channels. The Kerby method is limited to the watershed with a drainage area of about 200 acres. The study by [41] evaluated the daily electricity flow forecasts.
using two simple conceptual models and one complex model for four large water catchment areas of the Tana Lake Basin (15,114 km²) in Ethiopia, which is a source of the Blue Nile Basin. The study compared the capabilities of the model to reproduce the observed current flow in the time and quantile domains. The model comparison based on several criteria shows that the simple conceptual models performed best in smaller catchment areas for reproducing the observed current flow in the time domain while the complex model performed best for the largest catchment area. The result showed that to reproduce the observed current flow in the quantile range, the simple conceptual models are best suited for the simulation of high, humid, medium and dry rivers in the Gilgelabay watershed; of dry and low rivers in the Gummera and Megech catchment areas and high rivers in the Ribb watershed. The results of the analysis show that the distributed models are particularly suitable for the complex watershed due to their physical heterogeneity. In general, the integration of these three models can be useful for assessing water resources.

3. MATERIALS AND METHODS

Estimations and derivation of time of concentration was done using data from catchment areas in Awka-South Local Government Area. Awka is a large city and the capital of Anambra State in Nigeria. Its population is about 300,000 people. The latitude of Awka, Nigeria is 6.210528, and the longitude is 7.072277. Awka, is located at Nigeria country in the Cities place category with the Global Positioning System (GPS) coordinates of 6° 12’ 37.9008” N and 7° 4’ 20.1972” E. Awka, Nigeria elevation is 105 meters height, that is equal to 344 feet.

A topographic map of the area was used to locate the watersheds, drainage network, locate and mark the downstream outlets of the watershed. Using the map, the possible watersheds were delineated and the areas of the perimeter of the watershed were be mapped out. After the delineation of the watersheds, the following parameters will be measured; the area of the watersheds, the flow length of the tributaries, the slope of the watershed. And also the time of concentration was measured.

3.1 The Watershed Area A,

Watershed areas are the land and water areas that contributes to the runoff or an area that drains all the streams and rainfall to a common outlet.

3.2 Flow Length L

the overflow length of the watershed which is the distance measured along the main channel from the watershed outlet to the basin divide was gotten by using a measuring tape to get the total length along that channel.

3.3 Watershed Slope S

Watershed slop reflects the rate of change of elevation with respect to distance along the principal flow path.

![Fig 1. Map of the Study Area](Source: www.google.com/map)
The slope was measured using the following steps;

A. located the catchment area of interest using the topographic map
B. get the highest and the lowest elevation on the map
C. subtracted the elevation of the lowest contour from the highest contour
D. measured the distance from that topmost height to the lowest height of the catchment area
E. divided this height by the difference in elevation to get the slope of the catchment area.

4. RESULTS AND DISCUSSION

The data presented in Table 2 shows the values of the watershed parameters which were gotten from the 30 selected watersheds in Awka-South.

Where,

\[ W_1, \ldots, W_{30} \]: watershed 1 to watershed 30
\[ T_c \]: Time of concentration

The data presented in Table 2 was employed to estimate the time of concentration of the selected watersheds using the 30 time of concentration models.

The result presented in Table 3 represents the time of concentration values which were estimated using the existing Tc models with the Awka-south watershed parameters. There were significant variations amongst the Tc values. These significant differences may be due to different contributing factors. Firstly, the input variables used for the development of these models are different; secondly, the empirical coefficients (constants or exponential coefficients) of the Tc models are different because each of them was calibrated for a specific region with their range of input parameters different from the values of other catchments. Therefore, due to these limitations, it is relatively not possible to get the same Tc values when calculating the time of concentration of a particular watershed area using a Tc model developed from a different watershed data.

| S/N | Length(M) | Average width (M) | Area(M²) | %Slope | Measured Tcs(S) |
|-----|-----------|-------------------|----------|--------|----------------|
### Table 3. Summary result of time of Concentration for the selected Watersheds

| S/N | Tc 1  | Tc 2  | Tc 3  | Tc 4  | Tc 5  | Tc 6  | Tc 7  | Tc 8  | Tc 9  | Tc 10 | Tc 11 |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| W1  | 3.75  | 0.1302| 54.0  | 4.600 | 11.382| 957.78| 6.301 | 0.582 | 15.038| 652.32| 2.15  |
| W2  | 4.44  | 0.178 | 74.59 | 5.265 | 18.883| 98371.21| 8.119 | 0.327 | 22.551| 3278.54| 48.577|
| W3  | 4.765 | 0.2005| 83.757| 6.449 | 6.413 | 37676.79| 8.940 | 0.552 | 11.276| 2025.04| 35.63 |
| W4  | 3.3364| 0.110 | 46.7  | 3.805 | 17.392| 54307.20| 5.507 | 6.416 | 19.256| 1673.58| 13.56 |
| W5  | 4.684 | 0.145 | 81.77 | 6.344 | 6.314 | 40812.23| 8.764 | 0.267 | 11.102| 15406.57| 12.507|
| W6  | 2.846 | 0.084 | 36.084| 3.285 | 11.783| 24438.11| 4.440 | 0.206 | 14.073| 1060.15| 12.56 |
| W7  | 1.689 | 0.035 | 15.336| 2.009 | 4.971 | 22428.23| 2.182 | 0.412 | 6.567 | 1519.66| 19.75 |
| W8  | 3.609 | 0.126 | 53.189| 4.505 | 11.146| 50314.38| 6.131 | 0.350 | 14.717| 2745.2 | 55.77 |
| W9  | 6.251 | 0.3178| 131.908| 8.630 | 8.582 | 101197.73| 12.978| 0.478 | 15.090| 3554.71| 48.20 |
| W10 | 5.840 | ∞     | 117.385| 0     | 0     | 11.836 | 0.432 | 13.326| 0     | 16.34 |
| W11 | 3.360 | 0.111 | 47.291| 3.828 | 17.509| 75920.32| 5.560 | 0.283 | 19.415| 1749.77| 53.89 |
| W12 | 4.474 | 0.182 | 75.563| 5.313 | 19.057| 108748.06| 8.215 | 0.494 | 22.759| 3417.71| 15.57 |
| W13 | 3.414 | 0.115 | 48.519| 3.985 | 14.292| 51206.05| 5.680 | 0.542 | 17.748| 1564.89| 8.219 |
| W14 | 2.286 | 0.050 | 25.18 | 2.542 | 11.626| 2198.45 | 3.288 | 0.416 | 12.982| 996.59 | 7.08  |
| W15 | 2.074 | 0.050 | 21.442| 2.345 | 8.412 | 12524.74| 2.884 | 0.369 | 10.046| 910.31 | 9.688 |
| W16 | 2.536 | 0.070 | 29.623| 2.905 | 10.419| 16065.86| 3.793 | 0.275 | 12.444| 1642.39| 15.94 |
| W17 | 3.161 | 0.097 | 41.492| 3.834 | 9.486 | 35988.81| 4.990 | 0.469 | 12.533| 1635.91| 13.93 |
| W18 | 2.907 | 0.087 | 37.295| 3.233 | 17.302| 69860.97| 4.563 | 0.373 | 18.323| 2448.86| 36.78 |
| W19 | 5.423 | 0     | 103.966| 0     | 0     | 10.700 | 0.578 | 12.316| 2308.43| 14.35 |
| W20 | 2.973 | 0.0984| 38.763| 3.953 | 15.379| 60068.79| 4.712 | 0.262 | 17.048| 2158.33| 12.13 |
| W21 | 2.576 | 0.071 | 30.451| 2.953 | 10.593| 32793.24| 3.874 | 0.452 | 12.651| 1635.76| 9.18  |
| W22 | 2.033 | 0.048 | 20.785| 2.447 | 6.055 | 12803.18 | 2.809 | 0.434 | 2.241 | 734.63 | 16.75 |
| W23 | 2.893 | 0.087 | 37.039| 3.561 | 8.812 | 35238.88 | 4.538 | 0.462 | 11.642| 1496.84| 24.7  |
| W24 | 4.502 | 0.1825| 76.392| 5.233 | 23.893| 159512.52| 8.282 | 0.226 | 26.467| 4082.13| 51.45 |
| W25 | 4.200 | 0.162 | 67.833| 4.968 | 17.819| 109124.41| 7.532 | 0.369 | 21.282| 5018.46| 22.97 |
| W26 | 3.899 | 0.143 | 60.425| 4.891 | 12.101| 6601.73  | 6.815 | 0.435 | 15.989| 3699.33| 43.85 |
| W27 | 3.835 | 0.1394| 58.708| 4.510 | 16.176| 82095.87 | 6.616 | 0.275 | 19.319| 4199.94| 43.44 |
| W28 | 3.544 | 0.122 | 51.587| 4.147 | 13.137| 74102.88 | 5.977 | 0.327 | 17.761| 3264.43| 41.44 |
| W29 | 4.223 | 0.164 | 68.834| 5.326 | 13.178| 71678.17 | 7.597 | 0.269 | 17.411| 4130.19| 24.053|
| W30 | 4.196 | 0.1199| 50.705| 4.367 | 10.805| 59880.22 | 5.892 | 0.296 | 14.276| 3247.32| 21.753|

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| S/N | Tc 12 | Tc 13 | Tc 14 | Tc 15 | Tc 16 | Tc 17 | Tc 18 | Tc 19 | Tc 20 | Tc 21 | Tc 22 |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| W1  | 5476.44 | 4.063 | 4.494 | 0     | 156423.23 | 3.454 | 19.179 | 5761.12 | 985.11 | 2.637 | 5433  |
| W2  | 2004.78 | 5.295 | 17.778 | 315.69 | 461988.7 | 4.566 | 12.825 | 9632.97 | 2909.55 | 0.004 | 62.708 |
| W3  | 113380.71 | 5.840 | 25.648 | 607.33 | 234787.62 | 4.285 | 4.731 | 4891.29 | 609.34 | 0.005 | 66.263 |
| W4  | 104892.20 | 3.535 | 12.679 | 0     | 184317.5 | 3.266 | 9.32 | 12614.64 | 1098.68 | 0.004 | 50.374 |
| W5  | 77654.70 | 5.720 | 26.344 | 0     | 101709.7 | 4.206 | 4.623 | 3347.57 | 640.54 | 0.004 | 65.524 |
| W6  | 36535.48 | 2.823 | 11.126 | 202.61 | 1011829.1 | 2.593 | 6.382 | 2154.28 | 641.29 | 0.005 | 44.655 |
| W7  | 46067.67 | 1.345 | 12.994 | 249.96 | 42880.01 | 1.277 | 5.628 | 567.31 | 270.04 | 0.005 | 29.919 |
| W8  | 59013.19 | 3.951 | 17.056 | 0     | 247903.6 | 3.368 | 18.594 | 1082.22 | 1561.23 | 0.003 | 53.512 |
| W9  | 304489.70 | 8.614 | 35.771 | 1252.47 | 460159.0 | 6.0782 | 14.125 | 10811.51 | 1194.24 | 0.003 | 81.726 |
| W10 | 147904.90 | 0     | 0     | 0     | 366765.16 | 0     | 6218.64 | 2309.80 | 0      | 0      |       |
| W11 | 116350.28 | 3.570 | 14.196 | 226.60 | 135439.7 | 3.296 | 2.694 | 4614.12 | 852.96 | 0.002 | 50.659 |
| W12 | 178815.05 | 5.360 | 18.391 | 2413.47 | 489547.6 | 4.616 | 13.001 | 8441.63 | 3083.02 | 0.002 | 63.124 |
| W13 | 101945.88 | 3.652 | 14.273 | 534.86 | 147709.7 | 63.268 | 8.493 | 4591.48 | 930.24 | 0.004 | 51.314 |
| W14 | 49842.28 | 2.068 | 9.379 | 0     | 72889.794 | 2.017 | 1.469 | 2070.09 | 499.04 | 0.004 | 37.725 |
| W15 | 21656.854 | 1.800 | 5.081 | 0     | 74025.75 | 1.730 | 3.876 | 1019.93 | 466.19 | 0.005 | 35.034 |
| W16 | 32036.29 | 2.396 | 10.714 | 141.37 | 132273.42 | 2.236 | 5.265 | 1576.06 | 833.02 | 0.004 | 40.872 |
| W17 | 111049.00 | 3.186 | 23.978 | 400.04 | 134089.52 | 2.775 | 14.464 | 2512.43 | 844.46 | 0.003 | 47.646 |
| W18 | 47179.93 | 2.907 | 12.775 | 173.16 | 244307.0 | 2.792 | 1.996 | 2511.67 | 1538.59 | 0.001 | 45.364 |
| W19 | 64704.42 | 0     | 0     | 0     | 366765.16 | 0     | 6218.64 | 2309.80 | 0      | 0      |       |
| W20 | 26944.43 | 3.00 | 13.115 | 228.97 | 221320.46 | 2.822 | 2.226 | 1986.53 | 1501.73 | 0.002 | 46.144 |
| W21 | 60419.50 | 2.499 | 12.283 | 0     | 144654.48 | 2.563 | 5.452 | 2161.97 | 911.00 | 0.002 | 41.360 |
| W22 | 283571.86 | 1.751 | 19.762 | 90.065 | 41765.92 | 1.819 | 7.534 | 851.76 | 263.03 | 0.003 | 34.488 |
| W23 | 173755.69 | 2.888 | 15.128 | 0     | 101236.16 | 2.539 | 13.132 | 1961.48 | 637.96 | 0.002 | 45.183 |
| W24 | 283571.86 | 1.162 | 17.605 | 1201.38 | 611786.51 | 4.788 | 4.273 | 1161.69 | 3852.89 | 0.002 | 63.367 |
| W25 | 173755.69 | 4.901 | 18.412 | 1572.10 | 666435.99 | 4.259 | 11.771 | 7069.45 | 4197.06 | 0.003 | 60.146 |
| W26 | 111519.76 | 4.409 | 18.683 | 223.79 | 197004.77 | 3.717 | 2.000 | 4347.92 | 3219.21 | 0.003 | 56.775 |
| W27 | 10126.707 | 4.307 | 16.725 | 229.73 | 622989.64 | 3.791 | 10.200 | 4478.98 | 3923.45 | 0.003 | 56.098 |
| W28 | 101041.76 | 3.851 | 16.161 | 195.69 | 392955.37 | 3.427 | 9.008 | 3934.33 | 2474.74 | 0.002 | 52.807 |
| W29 | 84019.03 | 4.139 | 19.217 | 282.53 | 532412.66 | 4.117 | 23.823 | 4035.41 | 3353.01 | 0.003 | 60.367 |
| W30 | 149171.02 | 3.791 | 18.085 | 157.34 | 336613.60 | 2.986 | 17.759 | 4453.49 | 2119.91 | 0.002 | 52.329 |
| S/N | Tc 23 | Tc 24 | Tc 25 | Tc 26 | Tc 27 | Tc 28 | Tc 29 | Tc 30 |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|
| W1  | 531.53| 243.42| 24.728| 148.41| 6.517 | 22.97 | 18.831 | 170.05|
| W2  | 40414.85| 272.02.68| 31.41 | 13991.31| 8.005 | 27.09 | 27.523 | 506.39|
| W3  | 22962.77| 4558.99| 34.434| 4269.84| 6.485 | 33.21 | 23.105 | 256.56|
| W4  | 14396.21| 720.33 | 21.804| 3290.89 | 6.841 | 19.47 | 18.324 | 256.79|
| W5  | 8591.89 | 26442.31| 33.797| 25651.43| 6.416 | 32.67 | 22.565 | 399.78|
| W6  | 7242.35 | 18142.79| 17.837| 9331.37 | 5.804 | 16.89 | 13.441 | 274.67|
| W7  | 1681014.48| 1712.05| 9.150 | 1049.33 | 3.704 | 19.63 | 18.544 | 382.48|
| W8  | 521735.85| 17610.18| 48.842| 17081.88| 7.909 | 44.45 | 35.974 | 225.78|
| W9  | 39136.15| 0.00 | 0 | 0 | 0 | 0 | 0 | 0 |
| W10 | 11,991.94| 22780.29| 22.010| 10175.19| 6.877 | 19.63 | 18.544 | 425.65|
| W11 | 46292.08| 11035.17| 31.759| 5659.17 | 8.056 | 27.29 | 27.911 | 518.78|
| W12 | 12271.44| 542.73 | 22.488| 1964.01 | 6.621 | 20.84 | 18.026 | 363.01|
| W13 | 6779.29 | 2435.52 | 13.466| 1112.68 | 5.202 | 13.03 | 9.952 | 249.41|
| W14 | 7489.70 | 1928.82 | 11.903| 992.56 | 4.612 | 12.05 | 8.053 | 187.43|
| W15 | 13424.55| 7312.10 | 15.390| 3733.05 | 5.337 | 14.95 | 10.732 | 244.28|
| W16 | 15908.14| 3765.27 | 19.872| 513.71 | 5.756 | 19.15 | 14.277 | 270.65|
| W17 | 58658.19| 9215.25 | 18.312| 3933.71 | 6.397 | 16.59 | 15.323 | 399.42|
| W18 | 26041.13| 0 | 0 | 0 | 7.010 | 0 | 0 | 0 |
| W19 | 28367.84| 19863.09| 18.839| 8926.26 | 6.245 | 17.24 | 15.227 | 268.91|
| W20 | 20081.25| 3501.49 | 15.698| 1796.80 | 5.397 | 15.19 | 11.433 | 265.05|
| W21 | 5610.51 | 1552.75 | 11.596| 104.87 | 4.238 | 12.21 | 9.216 | 158.62|
| W22 | 7691.98 | 3515.06 | 18.189| 2932.38 | 5.473 | 17.76 | 12.793 | 254.24|
| W23 | 64556.24| 72875.05| 31.962| 43850.66| 8.501 | 26.78 | 29.744 | 618.53|
| W24 | 84962.23| 20559.58| 29.301| 10496.36| 7.695 | 25.56 | 25.203 | 491.99|
| W25 | 72402.44| 9104.02 | 26.615| 5524.26 | 6.795 | 24.42 | 20.670 | 364.19|
| W26 | 81,790.81| 30206.51| 26.088| 15412.26| 7.204 | 23.20 | 21.757 | 433.99|
| W27 | 52939.63| 17000.67| 23.588| 8681.45 | 6.803 | 21.33 | 19.149 | 398.86|
| W28 | 63073.09| 33314.79| 29.480| 15923.01| 7.202 | 26.60 | 23.524 | 398.38|
| W29 | 54212.72| 18616.603| 23.233| 8028.73 | 6.289 | 22.23 | 17.404 | 327.22|
Table 4. Summary of Rank Analysis of the performance of the models based on the degree of linear relationship with the Actual/observed time of Concentration of the study area

| Models | Correlation coefficient (r) | Rank |
|--------|-----------------------------|------|
| TC12   | 0.681                       | 1    |
| TC14   | 0.661                       | 2    |
| TC21   | 0.433                       | 3    |
| TC15   | 0.394                       | 4    |
| TC26   | 0.34                        | 5    |
| TC24   | 0.337                       | 6    |
| TC19   | 0.267                       | 7    |
| TC6    | 0.227                       | 8    |
| TC5    | 0.195                       | 9    |
| TC11   | 0.165                       | 10   |
| TC16   | 0.147                       | 11   |
| TC20   | 0.099                       | 12   |
| TC29   | 0.092                       | 13   |
| TC2    | 0.048                       | 14   |
| TC3    | 0.044                       | 15   |
| TC27   | 0.027                       | 16   |
| TC17   | 0.025                       | 17   |
| TC7    | 0.018                       | 18   |
| TC25   | 0.009                       | 19   |
| TC10   | -0.009                      | 20   |
| TC22   | -0.041                      | 21   |
| TC28   | -0.049                      | 22   |
| TC4    | -0.051                      | 23   |
| TC1    | -0.079                      | 24   |
| TC9    | -0.097                      | 25   |
| TC18   | -0.205                      | 26   |
| TC8    | -0.228                      | 27   |
| TC23   | -0.303                      | 28   |
| TC30   | -0.364                      | 29   |
| TC13   | -0.423                      | 30   |

The result obtained in Table 4 represents Correlation Coefficient values for the Tc models. The performance of the models with regards to linear association showed that the model with the highest correlation coefficient was Ventura model (TC12) with correlation coefficient value of 0.681, followed by the DNOS model (TC14) with correlation coefficient value of 0.661 while the least performing model was the Picking model (TC13) with -0.423 measure. The Ventura model was developed by Mata-Lima et al. [22] using data collected from the rural basin in California. However, the TC27 due to having the lowest overall ranking may not result in a reasonable estimation. This may be because; the model depends on only one parameter which is the length.

5. CONCLUSION

This study compared the performance of some selected watershed model for estimating the time of concentration for a watershed situation in Anambra State. The findings of the study revealed the estimated time of concentration for the Ventura model has a better linear association than the other model considered in the present study. The findings are in line with the outcome of the study by [39] where the authors stated that among the analyzed methodologies in their study, the Pasini and Ventura are the models with a higher similarity with the Observed. The outcome of this study also generated serious questions on the application of any empirical formula in the environment different from the locations where these equations were derived. Based on the findings of the present study, the need for the verification and validation of any time of concentration model with the data from another environment before application in the estimation of time of concentration is strongly recommended until further studies prove otherwise. Also, the need for this to avoid underestimation or overestimation of the time of concentration for a better design of hydraulic structures.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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