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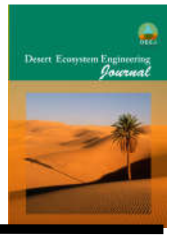

Assessment and Sensitivity Analysis of Effective Parameters involved in Estimating Coastal Urban Areas' Concentration Time: A Case Study of Bandar Abbass City, Iran

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Abstract

This study set out to introduce the quantitative analysis of open surface water systems located at Bandar Abbass in southern Iran, seeking to identify the best applicable formulas for urban catchment and determine the sensitivity index in each formula. To this end, the observed concentration-time was compared with twenty-two empirical formulas already developed for concentration time. Moreover, the sensitivity index was assessed for each variable involved in formulas regarding the concentration time. The study's results indicated that from among all methodologies used in Gorsozan estuary, the F.A.A. method best fitted the concentration-time with the N.S. and RMSE values reported as being 0.66 and 1.61, respectively, and the Henderson and Wooding method best suited the Seyed Kamel estuary, with the N.S. and RMSE values found to be 0.892 and 2.541, respectively. Furthermore, The Yen and Chow's method with the N.S. and RMSE values of 0.88 and 1.15, and the Duran &Rangan method with the N.S. and RMSE values of -0.42 and 31.72 were the best results found for the overland time in Gorsozan and Seyed Kamel estuaries. Also, the results for the sensitivity index indicated that any decline in variables such as length, slope, and N Manning had a significant impact on the concentration-time. In addition, changes of slope and N Manning values in all overland-flow formulas considerably affected the low-slope surfaces.

Keywords: Concentration Time, Overland Time, Sensitivity index, Urban Area, Bandar Abbass.

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1. Introduction

As an especially relevant factor for ungauged basins, the concentration-time (T.C.) continues to find application in recent hydrological models (USACE 2001, SWAT: Aronica and Candela 2007, Koutroulis and Tsanis 2010). Moreover, due to the intrinsic uncertainty involved in making assumptions, estimating the concentration-time for ungauged watersheds is always a challenging task to do (Álvarez & et al., 2020).

As found in the current literature on hydrology, T.C. has been defined variously by different scholars (McCuen et al. 1984; Perdikaris et al. 2018), and multiple empirical equations have been proposed for its estimation in different types of stormwater management and design of drainage structure manuals/guidelines (TxDOT, 2019). Increased surface runoff generated in urban areas due to a more significant proportion of impervious surfaces has, in many cases, exceeded the capacity of urban drainage systems (Zhou & et al., 2015), leading, in turn, to the increased risks of pluvial flooding in city regions undergoing fast urbanization, where vast urban constructions have generated growing impervious surfaces (Hejazi and Markus, 2009; Dearden and Price, 2012).

Abdul-Aziz and Al-Amin found Basin runoff and pollutant loads showed moderate sensitivities to the hydrologic and land cover parameters; imperviousness and roughness exhibited more dominant influence than slope. The quantified sensitivities can be useful for appropriate management of storm water quantity and quality in complex urban basins under a changing climate, land use/cover, and hydrology around the world.

The concentration-time of overland flow significantly contributes to the hydrological analysis of watersheds where the estimation of maximum discharge plays a substantial role. Being aware of the basin's behavior regarding concentration time helps prevent and/or minimize the consequences of natural disasters and punctual pollution of water resources.

Among all parameters involved in a watershed's response time, concentration time is the most commonly used parameter in this regard (McCuen et al. 1984; Wong 2009), which, according to Pavlovic and Moglen (2008), indicates how fast the watershed responds to rainfall events (de Almeida et al, 2016). Recognizing its significance, hydrologists have developed many empirical and semi-empirical methods for estimating the T.C. (Sharifi and Hosseini, 2011). However, scholars are usually confused by the number of T.C. estimation methods and formulas and often select a method without evaluating its accuracy and comparing it with other methods (McCuen et al. 1984; Wong 2009).

On the other hand, many researchers (for instance, Kirpich, 1940; Dooge 1956; Chow 1962) have developed empirical equations to estimate the concentration time, using experimental and analytic methods, adjusted based on local physical and hydrologic features. Therefore, it could be said that such equations are useful tools for estimating the watersheds' concentration-time (de Almeida et al, 2016), usually used in experiments that involve parameter settings (Kang et al. 2008; Upegui and Gutiérrez, 2011; Liang and Melching, 2012).

Overland flow, also known as sheet flow or overflow, is a gravity-driven flow on channelized surfaces. It is formed when rainfall or snowmelt does not infiltrate the soil or collect in surface depressions (i.e., channels or surface water bodies). As a significant part of rivers, streams, lakes, etc., the movement of overflow toward water bodies is accompanied by the transfer of pollutant elements and soil leaching (Zhang et al. 2016). Moreover, overland flow pathways may differ in terms of rainfall volume, humidity, or other climatic conditions. It should also be noted that shallow flow is significantly affected by the friction of the solid surface, the surface geological types, land usage types, cultivation, and other spatial variation factors (Zhang & et al., 2016).

As mentioned earlier, many scholars have so far attempted to develop reliable formulas for estimating the concentration-time. For instance, Sharifi and Hosseini (2011) suggested a method to identify the most effective equation for determining the concentration time, applying it to 72 watersheds and sub-watersheds. Fang et al. (2008) found many discrepancies among concentration times estimated through different formulas where watershed-related parameters have been used.

Mata-Lima et al. (2007) have subdivided the 20 methods already proposed to estimate concentration-time into two distinct categories: strictly empirical and semi-empirical methods. Silveira (2005) assessed the performance of 23 formulas for rural and urban basins, showing that such formulas outperformed in rural basins than the urban ones. De Almeida et al. (2016) argued that the watershed behaviors regarding the concentration-time are directly related to the prevention and mitigation of natural disaster consequences, and the source of water resources' pollution. They also proved that the changes in land use associated with urban development and that the replacement of permeable soil by impervious surfaces could affect runoff. Finally, Gwenzi and Nyamadzawo (2014) stated that urbanization alone reduced concentration time and increased peak discharge, runoff volumes, and velocity for the on-site and downstream hydrographs.

According to Konrad (2014), considering the urban basins' less water storage capacity and more rapid runoff, urban streams rise more quickly during storms and have higher peak discharge rates than the rural streams. Thus, the concentration-time in rural watersheds tends to be larger than the one in urban watersheds. Li and Chibber (2008) compared fourteen concentration-time models developed from overland flow and watershed data, using five laboratory plots with shallow slopes. Their study's results indicated that most of such empirical models underestimated overland flow time.

Taking what has already been mentioned into account, it could be said that the concentration-time is estimated through the following methodologies: (a) direct estimation based on the observed rainfall-runoff data set via computational definitions; (b) estimation through empirical formulas; and (c) calibration performance which is evaluated by the Root-mean-square error (RMSE), the Nash Sutcliffe Efficiency (NSE), Pearson correlation coefficient (r), and Coefficient of Determination (R^2).

The coastal city of Bandar Abbas (the study area of this research) is usually inundated by heavy floods in rainy conditions due to the following factors: 1) an increase in impervious surfaces (Heydarzadeh et al. 2017); 2) Lack of sufficient green spaces (Heydarzadeh et al. 2017); 3) Influence of runoff outside the urban area; 4) Inadequate size of canals in some areas (Nohegar et al. 2019); 5) Accumulation of garbage in urban canals in most months.

Considering the residential and commercial usages of most sub-areas of the Bandar Abbas city, it is necessary to determine the exact concentration and the overland-flow time in urban planning. Unfortunately, in March 2014, due to the lack of accurate information regarding the concentration and daily flow time, extensive flooding occurred in all urban areas, canals, and estuaries of the study area. This study, therefore, sought to identify and propose the best possible formula for urban catchment, evaluate the impervious and pervious catchment area, and develop a reliable concentration-time equation for urban areas. To this end, the relevant effective parameters were determined by the sensitivity index.

2. Materials and Methods

2.1. Study area

The case study is part of Bandar Abbass city (Fig.1) with 0.0252 km2 and 23 urban sub-catchments, located in the center of Hormozgan province, Iran, (27^ 10' 30"_ 27^ 12' 30"N; 56^ 15' 30"_18' 30"E) that is fully served by a combined open channel system (entire catchment shown in Fig.1). It is predominantly a residential area accommodating single-family houses and some larger multi-story apartment blocks. The terrain varies between 1.05 and 44.58 m above sea level, with a mean slope of approximately 5.547 %. The area also includes two main channels called Seyed Kamel and Gorsozan Estuaries, each of which are divided into segments based on the input current. Table 1 illustrates the features of the area's estuary.

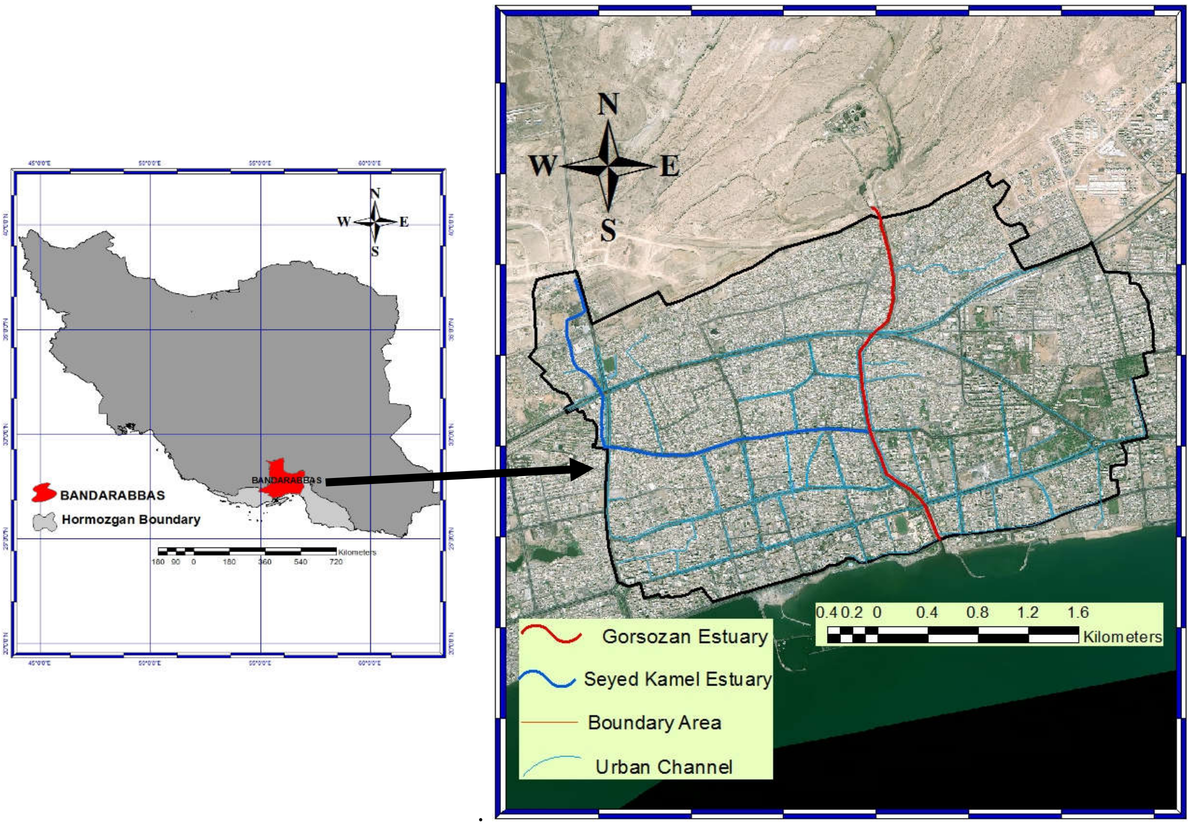

Figure1: Location of the Bnabar Abbasa city in Hormozgan province of Iran. The planned surface water system in Bandar Abbass city. The channel network, Seyed Kamel and Gorsozan Estuaries are shown with light blue, dark blue and red

2.2. Methods

This study compared the observed concentration-time with twenty-two empirical formulas already proposed for the estimation of concentration-time in each section of both estuaries. The list of methodologies selected for the current study and their respective descriptions are presented in Table 2. The basin's boundary was determined using 1:2000-scale urban topographic maps (including streets, avenues, gardens, urban blocks, etc.) Urban catchments' features such as channel slope, surface slope, length, and the basin's area and perimeter were estimated by ArcGIS10.3 software. Moreover, the mean weight of main channel's slope and Manning's roughness coefficient were measured via field operation. As for channels, first, each one was divided into inflow sections, and then, their Manning roughness coefficient was measured based on field visits, manual books, and expert opinions.

Furthermore, the movement of water in each channel was determined through field operations. The runoff data were also measured by the current meter in two main Bandar Abbass channels. To this end, the speed parameters were calculated by the current meter at the end of each section, whose results were calibrated according to the relevant speed equation. Therefore, based on the values identified for slope, roughness coefficient, and the channel's length, the concentration time was calculated. The percentage of the impervious surface was also estimated by the AutoCAD software based on the sub-catchment land use.

Overland flow roughness is another factor that affects the volume and velocity of surface runoff, flood peaks, and the scouring capability of flow (Lumbroso and Gaume, 2012). Classifying different flow types into pipe flow, open channel flow, and overland flow, Smith et al. (2007) argued that roughness plays an essential role in overland flow and that its influence changes when it affects other flow types. Cea et al. (2014) considered the role of the terrain's micro-roughness characteristics in reproducing the flow hydrodynamics correctly. Shit and Maiti (2012) used some tests to prove that the flow velocity is influenced by the hydraulic roughness coefficient rather than the rill gradient.

Therefore, as the effect of roughness is homogenized in the process of flow concentration in a large-scale watershed, it is advisable to construct an outside experimental watershed or an indoor small catchment model in order to observe the flow velocity in practice. It should be noted that small experimental catchments can be precisely divided into grid cells, with their discrete boundaries and joints of water channel systems being located by G.P.S. (Mügler & et al., 2011). Finally, the roughness values of all sub-basins were measured via field visits, manual books, and prior studies.

Table (1): The study area's Physiographic features and parameters

Sub-catchment	section Length(m)	N manning* (channel)	Area sub catchment (km^2)	Current length-m	Slop surface (m/m)	N manning* (surface)
1	224	0.017	0.0389	357.104	2.402	0.015
2	130	0.017	0.00833	154.493	4.094	0.015
3	23	0.02	0.01218	205.451	2.474	0.015
4	187	0.02	0.00593	233.636	1.817	0.015
5	201	0.02	0.00548	234.947	2.482	0.015
6	223	0.02	0.00624	588.508	2.189	0.015
7	213	0.02	0.00692	283.019	2.222	0.015
8	521	0.02	0.01091	501.401	1.776	0.0168
9	235	0.02	0.01959	326.049	2.959	0.0160
10	381	0.02	0.03608	443.590	2.294	0.015
11	544	0.017	0.15639	955.151	4.132	0.015
12	186	0.017	0.01766	226.090	2.881	0.015
13	613	0.02	0.21947	664.395	2.980	0.018
14	495	0.015	0.1279	1184.060	4.771	0.015
15	50	0.017	0.00111	52.401	1.851	0.015
16	480	0.017	0.04548	641.748	3.515	0.015
17	30	0.017	0.04548	641.748	3.515	0.015
18	447	0.017	0.04489	891.987	2.130	0.015
19	290	0.017	0.0183	389.136	4.313	0.015
20	316	0.017	0.0446	731.202	2.022	0.015
21	334	0.017	0.03231	525.972	1.916	0.015
22	110	0.017	0.01134	252.907	2.1923	0.015
23	203	0.017	0.03025	362.733	2.787	0.015
24	253	0.017	0.049	470.265	2.195	0.015

Table (2): List of methodologies used for estimating concentration time

Name	Equation	Comments	References
Kirpich	TC=$0.0078L^{0.77}S^{-0.385}$ tc = Time of concentration (min) L = length of channel/ditch from headwater to outlet, ft S = average watershed, ft/ft	Developed for small drainage basins in Tennessee and Pennsylvania, With basin areas from 1 to 112 acres (0.40 to 45.3 ha).	Kirpich (1940); Li and Chibber (2008); Taghvaye Salimi et al. (2016)
F.A.A.	$tc = 1.8(1.1 - C) L^{0.5}S^{-0.333}$ tc = Time of concentration (min) C = rational method runoff coefficient L = length of overland flow, ft S = surface slope, ft/ft	Obtained from airfield drainage data assembled by the U.S Corps of Engineers.	Circular on Airport Drainage (1970); Li and Chibber (2008); De Almeida et al. (2016); Taghvaye Salimi et al. (2016)
TxDOT	$tc = 0.702(1.1 - C) L^{0.5} S^{-0.333}$ tc = Time of concentration (min) C = rational method runoff coefficient L = length of overland flow, m S = surface slope, m/m	Modified from F.A.A.	Circular on Airport Drainage, (1970); Hydraulic Design Manual (1994); Li and Chibber (2008); Taghvaye Salimi et al. (2016)
Papadakis and Kazan	$tc = 0.66L^{0.5}n^{0.52}S^{-0.31}i^{-0.38}$ tc = Time of concentration (min) L = length of the flow path, ft n = roughness coefficient S = average slope of the flow path, ft/ft I = rainfall intensity, in./h	Obtained from USDA Agricultural Research Service data of 84 small rural watersheds from 22 states.	Papadakis & Kazan (1986); Loukas & Quick (1996); Li and Chibber, (2008); USDA.NRCS (2010); De Almeida et al. (2016); Taghvaye Salimi et al. (2016)
Henderson and Wooding	$tc = 0.94(Ln)^{0.6} S^{-0.3}i^{-0.4}$ tc = Time of concentration (min) L = length of overland flow, ft N = Manning's roughness coefficient S = overland flow plane slope, ft/ft I = rainfall intensity, in./h	Based on kinematic wave theory for flow on an overland area.	Henderson and Wooding, (1964); Li and Chibber (2008); Taghvaye Salimi et al. (2016)
California Culvert Practice	$tc = 60(11.9L^3/H)^{0.385}$ tc = Time of concentration (min) L = length of the longest watercourse, mi H = elevation difference between divide and outlet, ft If expressed as $Tc = kL^a n^b S^{-y} i^{-z}$ format: $tc = KL^{0.77}S^{-0.385}$	Essentially the Kirpich formula; developed for small mountainous Basins in California.	California Culvert Practice (1955); Li and Chibber (2008); Taghvaye Salimi et al. (2016)
U.S. Soil Conservation Service	$tc = (1/60) \sum(L/V)$ tc = Time of concentration (min) L = length of the flow path, ft V = average velocity in ft/s for various surfaces (The exponent of S, if converted from Manning's equation, will be –0.5)	Developed as the sum of individual travel times. V can be calculated Using Manning's equation.	U.S. Soil Conservation Service, (1975, 1986); Li and Chibber (2008); Taghvaye Salimi et al. (2016)
Natural Resources Conservation Service	$tc = 0.0526[(1000/C.N.) - 9] L^{0.8} S^{-0.5}$ tc = Time of concentration (min) $C.N.$ = curve number L = flow length, ft S = average watershed slope, %	For small rural watersheds.	Natural Resources Conservation Service (1997); Li and Chibber (2008)
Carter	$Tc = 0.0015476L^{0.6} S^{-0.3}$ tc = Time of concentration (hr) L = flow length, ft S = average watershed slope(ft/mi)	Developed for urban watersheds. The site's area less than 20:7199049 km2 (8 mi2). Channel length less than 11.265408 km (7 mi)	Carter (1961); Sharifi and Hoseini (2011); Taghvaye Salimi et al. (2016)

Table (2): List of methodologies used for estimating concentration time

McCuen et al.	$Tc=2.2535i^{-0.7164}L^{0.5552}S^{-0.2070}$ Tc= time of concentration(hr) L = length of the main water line (Km) S = mean steepness (ratio between the mean fall and the L length of the course), m/m i = rainfall intensity, mm./h	Starting from data of 48 urban basins in the USA ((0,4 -16 km2) and (0,0007<S<0,03)	McCuen et al. (1984); Fang et al. (2008); De Almeida et al. (2016)
Kinematic wave	$Tc=7.35n^{0.6}i^{-0.4}L^{0.6}S^{-0.3}$ Tc= time of concentration(hr) L = length of the main water line (Km) n =Manning roughness coefficient S = mean steepness (ratio between the mean fall and the L length of the course), m/m i = rainfall intensity, mm./h	Analysis of overland flow in experimental surfaces (L <0,03 km)	Kibler (1982); Sharifi & Hosseini (2011); De Almeida et al. (2016)
NRCS Lag Method	$Tc= 1.67(Tlag)$ $Tlag= L^{0.8} (s+1)^{0.7}/1900y^{0.5}$ S=1000/CN (inc) Tc= time of concentration(hr) L = length of the main water line (ft) CN = curve number *y* = surface slope, %		Akan & Houghatalen (2011)
Rational Hydrograph	$Tc= M\left[\frac{L}{\sqrt{S}}\right]^{0.66}$ tc = Time of concentration (min) *L* = flow length, m *S* = watershed slope(m/m) M= is a constant equal to 0.026 in U.S. customary units and 0.057 in S.I. units.		
Ventura	$Tc = 7.62\ (A/S)^{0.5}$ T = time of concentration, min A = surface of the basin, km2 S = average slope of the hydraulic way, m/m		Guermond (2008); Quaro (2011); Taghvaye Salimi et al. (2016)
Chen and Wong	$Tc=0.595 * (3.15)^{0.33*k} * c^{0.33k} * l^{0.33*(2-k)} * s^{-0.33} * i^{-0.33*(1+k)}$ For water at 26C C, k = constants (for smooth surfaces, C =□3, k=□0.5. For grass, C = 1, k =0) Tc= Time of Concentration (min) L = length of overland plane, m S = slope of overland plane, m/m; i =□net rainfall intensity, mm/h	Overland flow on test plots 1 m wide by 25 m long. Slopes of 2% and 5%.	Chen and Wong (1993); Wong (2009) Li and Chibber (2008)
Ragan & Duru	$Tc= 6.94(L\ n)^{0.6} / I^{0.4}\ S^{0.3}$ Tc= overland flow travel time (min) L = flow path length (m) n* = surface roughness; I = rainfall intensity (mm/h); S = slope (m/m)		Goyen et al. (2014)
Kerby Method	$Tc=1.45[N_k L_0/S^{0.5}]^{0.467}$ Tc = Time of overland flow (min), N= Kerby roughness parameter (dimensionless) L_o = Length of overland plane(m) S= overland flow slope (dimensionless).		Abustan et al. (2008)
Yen and Chow's Simplified Formula	$Tc=1.2[nL_0/S^{0.5}]^{0.6}$ Tc=Time of overland flow (min) n = Manning's resistance coefficient for the overland surface. Lo = length of the overland plane (m) So = Overland slope (m/m)		Yen & Chow's (1983); Wong (2009); Abustan et al. (2008)

Table (2): List of methodologies used for estimating concentration time

Bransby-Williams Formula	$Tc=58\ L/A^{0.1}\ S^{0.2}$ Tc=Time of overland flow (min) L = Mainstream length (km) S = Overland slope (m/km) A = Catchment area (km2)		Abustan et al. (2008); Department of Transport and Main Roads (2010); Taghvaye Salimi et al. (2016)
Morgali and Linsley, Aron and Erborge	$tc = 0.94L^{0.6}\ n^{0.6}S^{-0.3}i^{-0.4}$ Tc=Time of overland flow (min) L = length of overland flow, ft n = Manning roughness coefficient S = average overland slope, ft/ft i = rainfall intensity, in./h	Overland flow equation from kinematic wave analysis of runoff From developed areas.	Morgali and Linsley (1965); Aron and Erborge (1973); Li and Chibber (2008);(Taghvaye Salimi et al. (2016)
National Association of Australian State Road Authorities	$Tc= 107nL^{0.333}/S^{0.2}$ tc = overland flow travel time (min) L = flow path length (m) n = Horton's roughness value for the surface. (QUDM ,2007) S = slope of surface (%)	for Steep Slope (>10%), L ≤ 50 m for Moderate Slope (<5%), L ≤ 100 m for Mild Slope (<1%), L ≤ 200 m	Goyen et al. (2014)
SCS Method (NRCS Method)	T=To+Ts+Tc T = time of concentration, hours Tc = overland flow travel time, hours Tc = travel time of shallow concentrated flow, hours Tc = travel time for open channel flow, hours $To=C_f * (n * L)^{0.8}/P_2^{0.5} * S_0^{0.4}$ To = Time of overland flow (h) n = Manning's coefficient for overland surface. L = Length of overland plane (m) So= Overland slope (m/m) P2 = rainfall 24-hour, 2-year Cf= is a constant equal to 1.49 in U.S. customary units and 1.0 in S.I. units. Ts=L/3600*V T=travel time of shallow concentrated flow, hours L=flow length, ft V=average velocity, ft/s $V=K/n*R^{2/3}*S^{1/2}$ V= velocity of the channel, m/s R= Hydraulic radius. m/m k= is a constant equal to 1.49 in U.S. customary units and 1 in S.I. units. S= channel slope m/m. n= Manning's resistance coefficient for the channel.		USDA, (2013); Akan & Houghatalen (2011)

Thus, observing the overland flow's velocity in practice is of great importance. The statistical indicators used for evaluating the model's performance include the Root-Mean-Square error (RMSE), the Nash-Sutcliffe Efficiency (NSE), Pearson correlation coefficient (r), and the Coefficient of Determination (R^2). However, hypothesis testing, confidence intervals, and test of the underlying structure are some other statistical approaches that can be used for the same purpose (Geberemariam, 2015). RMSE is a commonly used error-index statistical indicator (Eq.1) (Chu and Shirmohammadi 2004; Singh et al. 2004; Vasquez-Amábile and Engel 2005).

In this study, the Goodness-of-fit measures approaches are discussed according to the following equation:

$$RMSE=\sqrt{\frac{1}{N}\sum_{i=1}^{n}(Y_i - X_i)^2} \qquad (1)$$

where Y_i and X_i represent the average values of the observed and simulated measurements found at a space-time point (N), calculated from all available data (obtained from observation and multiple simulation tests). The Nash–Sutcliffe efficiency coefficient model (NSE) (Nash and Sutcliffe, 1970; Wong 2009; Abustan et al. 2008; Pluntke et al. 2014; Geberemariam 2015; de Almeida et al. 2016; Li & et al., 2018; Álvarez & et al., 2020) is a normalized measure (-∞ to 1.0) that compares the mean squared error of a particular model with the variance of an observed variable (Eq.2).

$$NS = 1 - \frac{\sum_{i=1}^{n}\{y_i - x_i\}^2}{\sum_{i=1}^{n}\{x_i - \bar{x}\}^2} \quad (2)$$

where yi=observed overland time of concentration, Xi = estimated overland time of concentration, and $\bar{x}$= mean of all observed times of concentration. In this equation, if the NSE falls between 0.65 and 0.75 (0.65<NSE ≤ 0.75), the model's performance is interpreted as being good, and if it is greater than 0.75 (i.e., NSE>0.75), the model's performance would be described as very good (Pluntke et al. 2014).

Correlation Coefficient is the degree of relationship between two variables (for instance, x and y) whose value varies from -1 to +1, where -1 means that they are in perfect opposite with each other, and +1 indicates a perfect correlation between them.

The Pearson linear correlation coefficient (r), shown in (Eq.3), describes the linear correlation between two random variables (x, y), which do not depend on the measurement unit.

$$r= \frac{n \sum_{i=1}^{n} x_i\, y_i - \sum_{i=1}^{n} y_i}{\sqrt{[n \sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2] * [n \sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2]}} \quad (3)$$

As this coefficient approaches 1 or −1, correlations in the observed data grow stronger. A zero correlation indicates the absence of a linear relationship between variables (de Almeida & et al., 2016). Table.3 shows other degrees of correlation between variables.

Table (3): Degrees of correlation between variables according to the Pearson coefficient

Pearson correlation coefficient	Degree of correlation
0.90 < r ≤ 0.99	Very strong
0.70 < r ≤ 0.90	Strong
0.30 < r ≤ 0.70	Moderate
0 < r ≤ 0.30	Weak

2.2.1 The sensitivity coefficient

In hydrological studies and ecological applications, several sensitivity coefficients have been defined based on the purpose of the analyses (Hou & et al., 2013). However, in most cases, a mathematically defined sensitivity coefficient is used to characterize sensitivity (Hupet and Vanclooster 2001; Rana and Katerji 1998). In multivariable models (e.g., the FAO56-PM model), variables have different dimensions and ranges of values, making it difficult to compare the sensitivity by partial derivatives (Hou & et al., 2013). Nearing et al. (1989a) normalized the input and output concerning their mean values to produce an average linear sensitivity index, measured based on the following equation:

$$ALS= \frac{\frac{(Tc_2 - Tc_1)}{Tc}}{\frac{(I_2 - I_1)}{I}} \quad (4)$$

Where A.L.S. represents the average linear sensitivity coefficient, I stands for the intended variable, I_1 = baseline value for the input parameter, I_2 = input parameter whose changes vary within the range of ±50%, T_{c1} =output response when all input parameters are set to baseline values, and T_{C2} =output response when one input parameter is different.

"N-dimensional average linear sensitivity coefficient" was first adopted by McCuen and is now widely used in hydrology studies (Ascough & et al., 2013). A variable's positive/ negative sensitivity coefficient indicates that T.C. will increase/decrease with an increase or decrease in the variable. The larger the sensitivity coefficient is, the greater the effect of a given variable would be on the T.C.

3. Results and discussion

In this study, equations with the following characteristics were used: a) their variables are measurable and sufficiently accurate, b) There is a diversity in parameters whose effects are to be determined on the time of concentration, c) they are generally accepted by the designers and specialists of hydrology.

The time of concentration for the Bandar Abbass catchment was measured via two different methods. In the first method, the runoff velocity was measured directly, and in the second method, four empirical formulas were used to calculate the T.C. Finally, the results of both methods were compared with each other. Moreover, to estimate the T.C, twenty-two empirical formulas were randomly selected from each sub-catchment, using the second method, the results of which are presented in Table 4. As shown in Table 4, from among the 22 formulas used to estimate the T.C, only 11 formulas produced significant N.A.S. and RMSE values. Values N.A.S. and RMSE coefficients selective highlighted in table 4. Furthermore, eight equations, including F.A.A., Henderson and Wooding, Natural Resources Conservation Service, Kinematic wave, Duran & Rangan, Yen and Chow's, National Association of Australian State Road Authorities, and S.C.S produced the best results for Gorsozan Estuary, and eight equations including the F.A.A., TxDOT, Papadakis and Kazan, Henderson and Wooding, Natural Resources Conservation Service, Kinematic wave, Rational hydrograph, and Duran & Rangan performed well for the Seyed Kamel Estuary.

The results of the application of the formulas for estimating the T.C in Gorsozan Estuary showed that the N.S. and RMSE values produced by Yen and Chow's formula were 0.88 and 1.15, and the ones produced by Duran and Rangan were 0.79 and 1.57, indicating "a very good performance" of the model according to Pluntke et al. (2014). Moreover, significant coefficients were found between time of concentration with N.S. and RMSE values of 0.66 and 1.61 and NAASA method with N.S. and RMSE values of 0.69 and 1.88; F.A.A. with N.S. and RMSE values of 0.66 and 1.61, and S.C.S. with N.S. and RMSE values of 0.66 and 1.98, indicating a good model performance according to Pluntke et al. (2014).

In Seyed Kamel Estuary, Henderson and Wooding were found to be the best applicable formulas, with their N.S. and RMSE values being 0.892 and 2.541, respectively. In addition, there was an acceptable agreement between Kinematic wave with N.S. and RMSE values of 0.86 and 2.881; NRCS with N.S. and RMSE values of 0.76 and 3.776, and F.A.A. formula with N.S. and RMSE values of 0.75 and 3.86957, suggesting a very good model performance according to Pluntke et al. 2014. These are the nearest N.S. values to unity, indicating an excellent estimation of the Tc. Furthermore, in all selected formulas, the Pearson linear correlation coefficient (r) was reported to be either very strong or strong, indicating a very high correlation between observations and the estimated time of concentration (de Almeida & et al., 2016).

As shown in Table 4, the Sensitivity coefficients were calculated for all the variables included in the selected formulas. Initially, as shown in Table 5, values for each variable were changed in limited range of ±50%, Then the corresponding values of the time of concentration were obtained. The average time of concentration sensitivity coefficients were obtained by averaging variable values (WRSPM 2005). Figures 2 and 4 show the results obtained through the process carried out for measuring Sensitivity coefficients. Due to the slope of the North-southern Bandar Abbass city, all channels and estuaries' runoffs are discharged into the Persian Gulf. An overview of Bandar Abbass city and Gorsozan and Seyed Kamel Estuaries shows that there are two important channels for the passage of urban runoff from the upstream to the downstream. The Persian Gulf is the final destination of Bandar Abbas's urban runoff. Gorsozan estuary is surrounded by residential areas, commercial centers, and hotels. The levels of impervious and pervious surfaces surrounding the estuary are 94.494% and 5.506%, respectively. Therefore, the existence of low impervious areas around the estuary reduces the time of concentration and production of floods, a finding which is consistent with the results found by Abustan et al. (2008).

Table (4): Values of the Selected Goodness-of-Fit of Methods

Modified Method	Gorsozan Estuary				Seyed Kamel Estuary			
time of concentration	R	R2	NAS	RMSE	R	R2	NAS	RMSE
Kirpich	0.94	0.88	-7.01	4.115	0.91	0.82	-0.247	8.647
FAA	**0.83**	0.68	**0.66**	**1.61**	0.56	0.314	**0.750**	**3.869**
TxDOT	**0.83**	0.68	-3.31	20.34	0.56	0.314	**0.467**	**5.654**
Papadakis and Kazan	**0.84**	0.71	-3.044	19.09	0.59	0.35	**0.5122**	**5.408**
Henderson and Wooding-	**0.85**	0.73	**0.33**	**3.182**	0.62	0.38	**0.892**	**2.541**
California Culvert	0.84	0.71	-14.38	72.58	0.78	0.611	-0.883	10.624
U.S. Soil Conservation	0.84	0.70	-6.88	37.182	0.58	0.332	-0.103	8.1313
NRCS*	**0.92**	0.85	**0.471**	**2.497**	0.85	0.721	**0.76**	**3.7759**
carter	0.94	0.88	-29.70	144.92	0.91	0.83	-1.926	13.244
McCuen & et al.	0.95	0.89	-24.54	120.55	0.921	0.841	-1.51	12.27
Kinematic wave	**0.92**	0.84	**0.280**	**3.398**	0.91	0.83	**0.86**	**2.881**
NRCS Lag method	0.88	0.78	-58.13	279.13	0.88	0.77	-9.034	24.527
Rational hydrograph	**0.85**	0.7	-4.485	25.893	0.59	0.35	**0.309**	**6.438**
Ventura	0.53	0.29	-6.89	37.244	0.51	0.26	-0.09	8.096
SCS method	0.52	0.28	-107.05	34.463	0.61	0.38	-7.271	22.267
Time of overland flow								
Duran&Rangan	**0.71**	0.50	**0.79**	**1.57**	0.66	0.44	**-0.42**	**31.72**
Kerby Method	0.81	0.65	-1.09	4.90	0.62	0.39	-4.93	132.18
Yen and Chow’s	**0.84**	0.71	**0.88**	**1.15**	0.64	0.41	-5.10	135.91
Bransby-Williams	0.97	0.94	-21.54	16.10	0.89	0.78	-3.87	108.57
Morgali and Linsley	0.84	0.71	-0.23	3.76	0.66	0.44	-5.30	140.45
NAASA**	**0.80**	0.64	**0.69**	**1.88**	0.61	0.37	-2.37	75.08
SCS Method	**0.70**	0.48	**0.66**	**1.98**	0.63	0.40	-4.38	119.83

* Natural Resources Conservation Service

**National Association of Australian State Road Authorities

Roughness coefficient plays a significant role in the time of concentration. In the process of the flood's time of concentration along the slope, the flow is distributed downstream and increases the water depth there. There is a close relationship between roughness and the flow's Time of concentration because an increase in the roughness coefficient values has a significant impact on reducing the time of concentration. In all cases, a decrease in the roughness coefficient has a positive impact on the time of concentration, as seen in Fig 2 and 4. The changes pf roughness coefficient was very significant in the +10% _ -10% range. This range is very sensitive in terms of roughness coefficient, which could be seen in all selected formulas.

In fact, the roughness coefficient shows the type of catchment and the land use characteristics (e.g., the extent of impervious surfaces). In some parts of the estuary, household wastes and plants' growth inside the channel has increased the roughness coefficient, as shown in figure 3. It also indicates that an increase in length has a negligible effect on the time of concentration and that the decrease in length has positively correlated with the time of concentration. As for the Gorsozan estuary, all formulas experienced a significant decrease within the -10% _ -40% range, except the NRCS formula. In both estuaries, a decrease in the curve number (C.N.) is very influential. The curve number (C.N.) model is based on the assumption that there is a unique relationship between average moisture content and C.N. for all hydrologic response units and that the moisture distribution is similar in each runoff occurrence (Jiang & et al., 2015).

The results indicated that the increase in slope was insignificant in terms of the time of concentration, except for the NRCS method. In other formulas, the decrease in slope proved to be significant. These findings, which are illustrated in Fig 2 and 4, are consistent with those found by Abustan et al. (2008). Out of all methods applied in Gorsozan estuary, Duran and Rangan and S.C.S. were found to be more similar to each other than the other ones. Moreover, in the Seyed Kamel estuary, the Papadakis, Kazan, and TxDOT methods showed the highest similarity to each other. The results also suggested that from among all formulas applied to Gorsozan estuary, there were significant correlations between F.A.A., Henderson, and Wooding and the length variable, between NRCS and C.N, and between Kinematic wave and all studied variables. Moreover, in overland flows, it was found that there was a significant correlation between Duran and Rangan, Yen and Chow's, and S.C.S. methods and slop and N Manning coefficient. On the other hand, in terms of methodologies used for Seyed Kamel estuary, significant correlations were found between F.A.A. and TxDOT methods and slope, between Papadakis, Kazan, and Henderson and Wooding and slope and N Manning, between NRCS and C.N., and between Kinematic wave and all variables. Also, in Duran and Rangan formulas, significant correlations were found between overland flow, slope, and N Manning, and between rational hydrograph and slope, significantly affecting each other. Therefore, great care is recommended for measuring parameters such as channel length, slope, N Manning, and curve number when using these formulas. Any change in these variables, especially in slope and N Manning, affect the time of concentration. It should be noted that the slope and N Manning variables change when used in all overland formulas, and they are very influential in very low-slope surfaces.

Table (5): input parameters and values for sensitivity analysis

	parameter	max	min	Range of Test
F.A.A.	length of overland flow, ft	3882.165	506.54	±50%
	surface slope, ft/ft	15.64	5.82	±50%
TxDOT	length of overland flow, m	1184.06	154	±50%
	surface slope, m/m	4.77	1.78	±50%
Papadakis and Kazan	length of the flow path, ft	3882.17	506.54	±50%
	□roughness coefficient	0.0184	0.015	±50%
	slope of flow path, ft/ft	15.64	5.82	±50%
Henderson and Wooding	length of the flow path, ft	3882.17	506.54	±50%
	□roughness coefficient	0.0184	0.015	±50%
	slope of flow path, ft/ft	25176.52	9372.31	±50%
Natural Resources Conservation Service	□curve number	96	89	±50%
	flow length, ft	1796.7	62.29	±50%
	average watershed slope, %	8.29	3.089	±50%
Kinematic wave	Mainstream length (km)	0.544	0.019	±50%
	Overland slope (m/m)	4.77	1.78	±50%
	roughness coefficient	0.0184	0.015	±50%
Duran&Rangan	flow path length (m)	1184.06	154	±50%
	surface roughness	0.0184	0.015	±50%
	slope of flow path (m/m)	4.77	1.78	±50%
Yen and Chow's	flow path length (m)	1184.06	154	±50%
	surface roughness	0.0184	0.015	±50%
	slope of flow path (m/m)	4.77	1.78	±50%
National Association of Australian State Road Authorities	flow path length (m)	1184.06	154	±50%
	Surface slope (%)	8.29	3.089	±50%
Rational hydrograph	flow path length (m)	1184.06	154	±50%
	slope of flow path (m/m)	4.77	1.78	±50%
SCS Method	length of flow path, (m)	1184.06	154	±50%
	slope of flow path (m/m)	4.77	1.78	±50%
	Manning's coefficient	0.0184	0.015	±50%

4. Conclusions

Estimating the design rainfall and its associated runoff values for a given return period in ungauged watersheds can become daunting as it depends on various assumptions, such as the Tc estimation

based on a large array of available empirical equations that produce different results, requiring the best engineering judgment, which involves an assessment of equations. Hydrologic and hydraulic (H&H) analysis for storm water management such as dam-breach analyses; flood-prone area delineation and flood risk analyses; stream restoration; erosion, sediment, and contaminant load estimation, and conventional and sustainable drainage system design must be as accurate as possible when estimating all variables (Perdikaris et al. 2018; Duan et al. 2016; Hoogestraat. 2011; Duan et al. 2013; FEMA, 2019). Having said that, the results of this study shed light on the followings:

1) the fact that selecting a given equation cannot be taken as a random process in a hydrological analysis, which implies being aware of the equation's background and limitations (Álvarez et al. 2020); 2) the identification of suitable equations for the area of study to start ruling out those that definitely do not perform well, 3) the need to implement, in any given location, a robust network of flow and rain gauges so as to have a better understanding of the local hydrology, which should include the derivation of local Tc equations for urban areas given that none of the equations utilized in this study performed well in all of the twenty-four selected watersheds (Perdikaris et al. 2018); and 4) conduct these types of studies in urban areas given the different hydrological and hydraulic behavior of their watersheds and watercourses. Finally, the best method for estimating time of concentration in Bandar Abbass coastal urban catchment was determined by comparing the observation time and estimating the time of concentration. Among all methodologies used in Gorsozan estuary, F.A.A. method with N.S. and RMSE values of 0.66 and 1.61 showed the best agreement with the time of concentration. Moreover, in Seyed Kamel estuary, Henderson and Wooding method with N.S. and RMSE values of 0.892 and 2.541 were perfectly consistent with time of concentration. Also, Yen and Chow's method with N.S. and RMSE values of 0.88 and 1.15, and Duran and Rangan method with N.S. and RMSE values of 0.42 and 31.72 showed the best agreement with the for time of overland in Gorsozan and Seyed Kamel estuaries. After measuring the sensitivity index for each variable involved in formulas regarding the time of concentration, the two variables with the highest sensitivity index, i.e., slope and N Manning were selected to be used in developing a method for estimating the time of concentration, which is consistent with the results found by Taghvaye Salimi et al (2017), and (Shin and Choi 2018). Therefore, the sensitivity analysis confirmed the significant role of the main channel’s slope parameter, channel roughness, and the main channel’s length in estimating Tc, proving the fact that no matter what estimation method is selected, these parameters should be determined first. In general, it could be argued that choosing an appropriate method for carefully analyzing the sensitivity index requires using a large amount of experimental calculation models. It should also be noted that in this study, the sensitivity index analysis was performed in Excel software. Moreover, for convenience and time-saving purposes in using sensitivity analysis models under specific conditions, the application of computer programming is suggested.

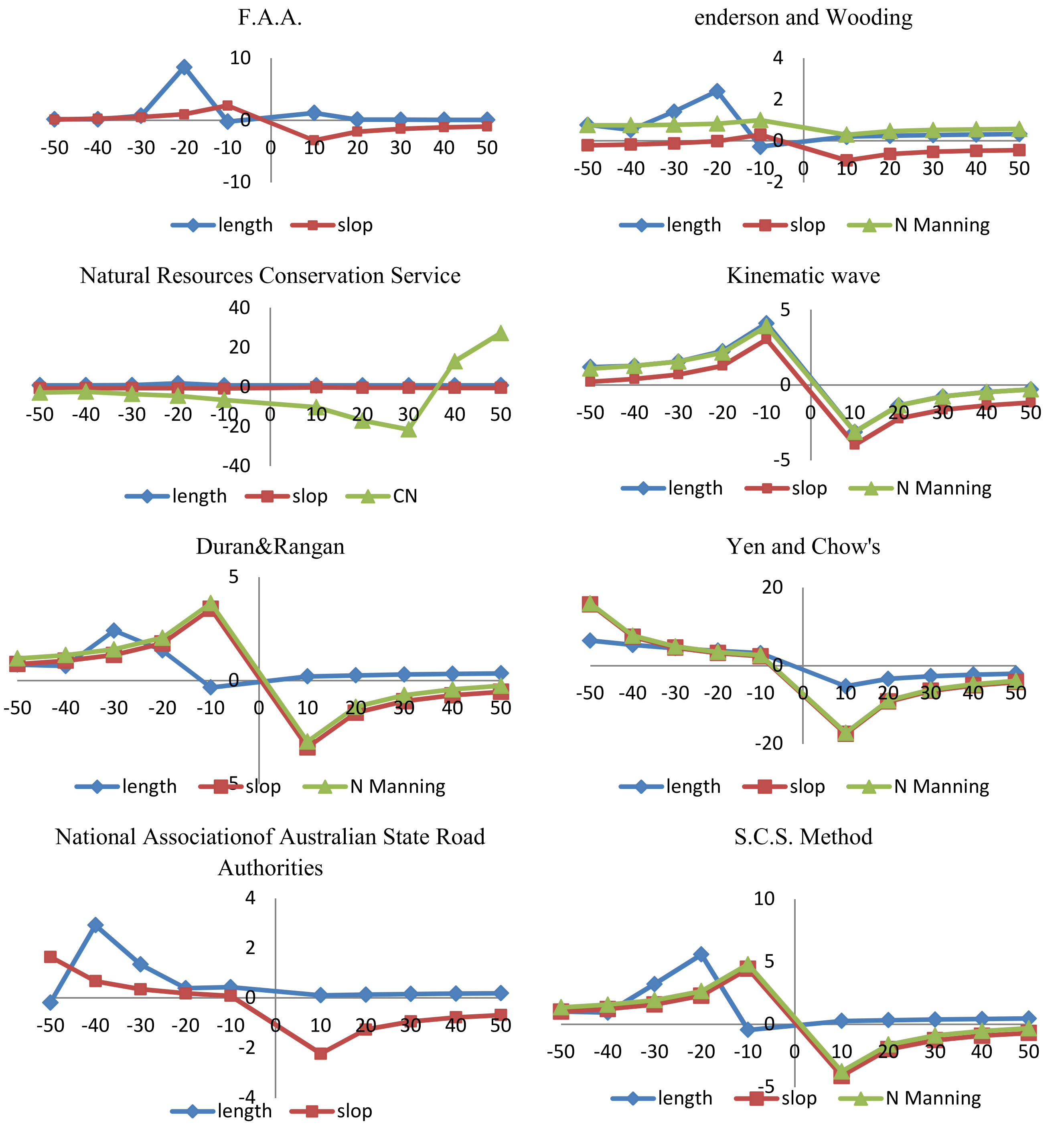

Figure (2): Sensitivity index between model output time of concentration and variations in each of the parameters in Gorsozan Estuary

Figure (3): View of situation N Manning in Gorsozan Estuary

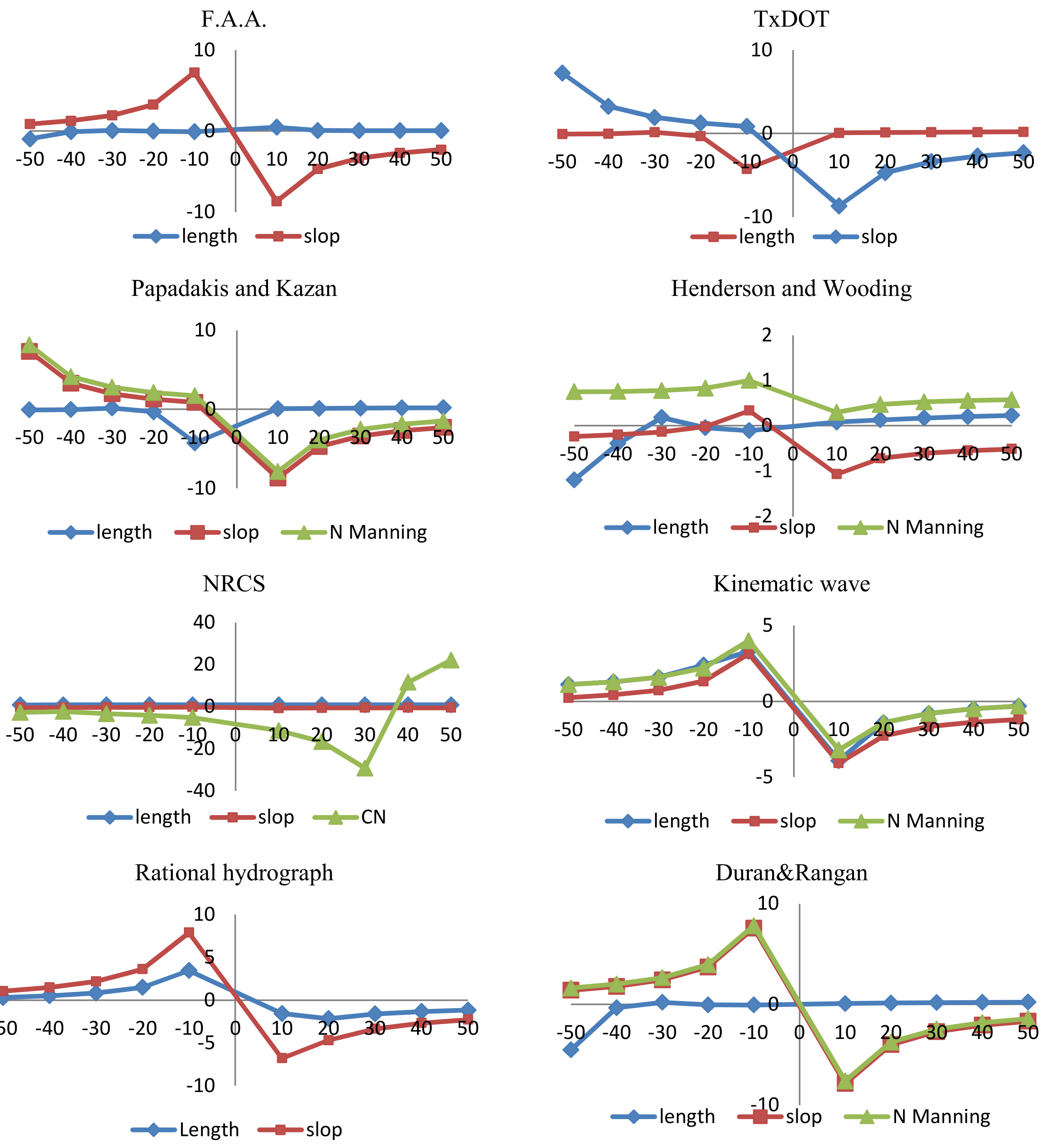

Figure 4: Sensitivity index between model output time of concentration and variations in each of the parameters in Seyed Kamel Estuary

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