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A comparison of the applicability of the theoretical VART, Gaussian, and ADZ models for pollution source identification in the rivers

Jafar Chabokpour[1]

[1] Assiatant Professor of Hydraulic Structures, Faculty of Engineering, University of Maragheh, Maragheh, Iran

ABSTRACT: A series of experimental data and two series of field data which have been extracted by USGS in the MONOCACY River and ANTIETAM creek have been utilized to compare source identification accuracy of the Gaussian, ADZ, and VART models. To achieve the object of the study, the theoretical solution of the VART model for sudden release, and the second-order central moment equation of the Gaussian and ADZ models have been operated For all of the experimental and field data series, firstly, all of the model parameters have been computed and then by operation of the extracted parameters and the mentioned relationships, the accuracy of them have been calculated. The results showed that the accuracy of the VART model for experimental and field data is 25% and 4.8% respectively. Also, the average relative errors of the Gaussian and ADZ models are 1.65% and 14%, respectively, which confirms the desirable accuracy of the Gaussian model. The results of the present study have been revealed that the Gaussian model in both of the model parameter numbers and the calculation accuracy is superior to the others. Also, to assess the goodness of fit between experimental and field data series and the theoretical Breakthrough curves, the average Nash-Sutcliffe parameters have been calculated about 0.97, which exhibits the favorable goodness in the fits.

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1. INTRODUCTION

Identification of the pollution source is one of the most critical problems in environmental engineering issues. After recognition of the pollutions in the flow, in the next step, it is important to find the type, magnitude, and source of the pollutions. Therefore, the arrangement of the researches in this area can be helpful [1, 2, 3].

Previously, different methods of source identification have been developed and presented based on the probability analysis, biological methods, and numerical solutions [4].

Study of the previous researches has been revealed that accurate identification is needed for the experimental or field data series of the breakthrough curves. Also, different theoretical transport models should be examined to find the best of them. Additionally, these pollute graphs can be operated by the application of the temporal or spatial moments. Therefore, to achieve the objectives of the current study, three theoretical models of the ADE (advection-dispersion equation), ADZ (aggregated dead zone), and VART have been used.

2. METHODOLOGY

2.1.VART model

By considering the injection of the conservative pollution in the steady-state, spatially constant free surface flows, the VART model equations can be written according to Eqs. 1-3 [5].

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}=k_s\frac{\partial^2 C}{\partial x^2}+\frac{A_{adv}+A_{dif}}{A}\times\frac{1}{T_V}\left(C_s-C\right) \quad (1)$$

$$\frac{\partial C_s}{\partial t}=\frac{1}{T_V}\left(C-C_s\right) \quad (2)$$

$$A_{dif}=4\pi D_S t_s \quad (3)$$

In which, C is the main flow concentration, C_s is the storage flow concentration, x is the distance from injection point, t is the time origin, T_V is the real residence time of the pollution, A is main flow area, A_{adv} is the area of the advection in the storage zone, A_{dif} is the dispersion area in the storage zone, k_s is the Fickian dispersion coefficient, D_s is the effective dispersion coefficient in the storage zone, and t_s is the time origin from the moment of pollution entrance through the storage zone.

By imposing the sudden release mass (M) as an initial conditions, the theoretical solution has been derived as Eq. 4 [5].

*Corresponding author's email: email

$$C(x,t)=\frac{M}{A\sqrt{4\pi k_s t}}\times\exp\left[\frac{ux}{2k_s}-\left(\frac{u^2}{4k_s}+\frac{4\pi D_s}{A}\right)t-\frac{x^2}{4k_s t}\right] \quad (4)$$

2.2.ADE model

Similar to the mentioned conditions for the VART model, the theoretical Equation of the ADE model for instantaneous mass injection is according to Eq. 5.

$$C(x,t)=\frac{M}{A\sqrt{4\pi Dt}}\exp\left(-\frac{(x-ut)^2}{4Dt}\right) \quad (5)$$

In which, M is the tracer mass, A is the flow area, D is the longitudinal dispersion coefficient, and u is the average flow velocity.

2.3.ADZ model

Aggregated dead zone (ADZ) model is one of the cell-based conventional models in the transport modelling of the tracer. In this model, each river reach has been separated to the f-number of the interconnected units. Each unit is still is subdivided to double cells. In the first cell, the advection action has been completed, and in the second cell, the dispersion activities have been operated. The theoretical solution for such a system is according to the Eq. 6. [6].

$$C(t)=\frac{\text{Heviside}(t-\alpha)\gamma^{f-1}(t-\alpha)^{f-1}}{(f-1)!}\times\frac{M}{V}\times\exp\left(-\gamma(t-\alpha)\right) \quad (6)$$

Where, Heviside is the step function such that $\text{Heviside}(t-\alpha)=0$ for $(t-\alpha)$ less than zero, α is the residence time in the advection cell, f is the number of units, V is the cell volume, γ is the inverse of the cell residence time $\gamma=\frac{1}{T}$, and $T=\frac{V}{Q}$

2.4.Data Series

2.4.1.Experimental data

During the current study, a series of experimental data has been acquired in the laboratory flume with (length×width×depth) of (12×1.2×0.8) m. The sodium chloride solution has been used as a non-reactive tracer and injected through the width of the flume. Four EC sensors were installed in different lengths of the river model, and the EC data has been recorded with 4 seconds interval (Fig. 1).

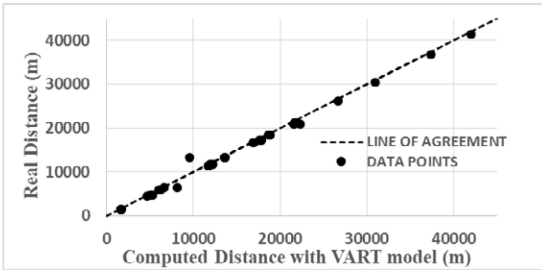
Fig. 1. Depiction of the laboratory river model

2.4.2.Field data

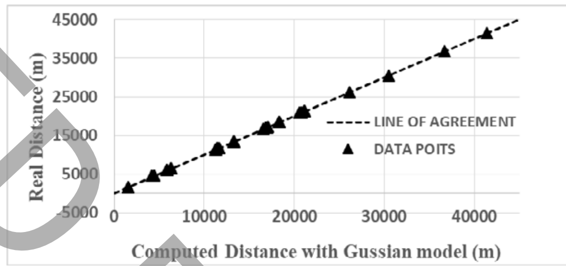
The published transport data for two rivers of the ANTIETAM and MONOCACY by the USGS which has been tested during years of (1968-1970) is used as field tracer data. The number of the recording locations for MONOCACY river was four and for ANTIETAM creek was 4 and 8. During these tests, Rhodamine has been used as a conservative tracer .

3. RESULTS AND DISCUSSION

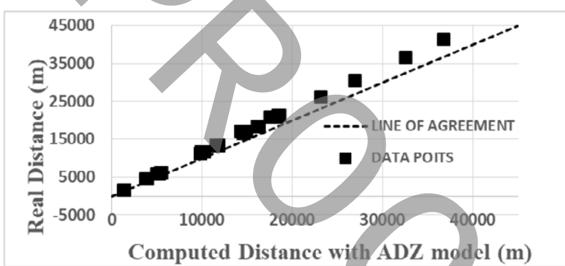
Temporal moments of the mentioned three theoretical models have been used in the reverse form to calculate



(a)



(b)



(c)

Fig. 2. (a) Computed values of the source position versus observed ones using VART model, (b) Computed values of the source position versus observed ones using ADE model, (a) Computed values of the source position versus observed ones using ADZ model

the source position. Analysis has been operated to the experimental and field data separately. It was found that the average error of the ADE, VART, and ADZ models is 1.65, 4.8, and 14 %, respectively. In Fig. 2, the computed distances have been depicted versus observed ones using mentioned theories.

As is found, it is evident that contrary to the developed concept of VART model in comparison with the others, the accuracy of simpler ADE model is higher than it. Another crucial issue in source determination is the estimation of the model parameters. In the current study, the parameters of all operated models, have been determined using least square curve fitting method. Therefore, it can be said that the accuracy of the estimated parameters would affect the identified source location. Furthermore, it is noteworthy to mention that obtained accuracies of other models are somewhat reliable, and the operation of them is not denied ultimately.

In addition to the main objectives of the study, complementary parameters of models have been calculated and evaluated. More excavation about them showed that any systematic error in the determination process has existed.

Moreover, analysis of the Skewness coefficient of the breakthrough curves revealed that the mass distribution in the rising and falling limbs of BC curve is not uniform but, with increasing of the distances, it becomes uniform which exhibits the Symmetry of BC curve.

4. CONCLUSION

Operation of the central temporal moment equations of the three theoretical moments of ADE, VART, and ADZ has been revealed that all of them can be operated in the pollution source identification process in the rivers but, the ADE model is superior. The number of the model parameters for this model is also lower than the others. It is also found that source identification using these models are very sensitive to the accuracy of the estimated parameters.

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