Application of Two SIRMOD (SM) and SRFR (SF) Software in Simulation of Various Stages of Border Irrigation

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Abstract: Given lesser energy consumption and required equipments, surface irrigation systems have is largely wide in irrigated fields. However, the simulation process of these systems has some specific complexities which has led to the development of several models such as hydrodynamic, kinematic wave, zero inertia and volume balance for optimal designing and managing surface irrigation. The main purpose of this research is to evaluate the results obtained from simulation of models present in SIRMOD (SM) and SRFR (SF) software through field information. This research was done in a four-section in the experimental field of university of Agriculture and Natural resources of Ramin (Khuzestan Province) and it was irrigated five times. The results of evaluations indicated that the "wave "Kinematic model has provided more acceptable results for "advance stage" and "infiltration process" in SM software (with respectively 8 and 4% of relative error) and therefore, it can be recommended for the conditions of the studied area and the surface irrigation of the "open-end border" type. Also for the regression stage, although the SF-KW model has better results (4% of relative error in contrast with 14%), given the relative advantages of SM software, and importance of prediction of infiltration process and moisture distribution of water in soil, this expectation is negligible in the ultimate selection.
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1. Introduction

Surface irrigation systems form more than 95% of the world's irrigated lands (Jalili, 2006); thus, optimal designing and management of these systems, for increasing irrigation efficiency and reducing water losses, is an essential and unavoidable. On the other hand, most farmers implement surface irrigation with their previous experiences and traditional methods which unfortunately leads to severe water losses like runoffs and deep infiltration in many cases. In this respect, models of surface irrigations are tools with the help of which designing and management of irrigation projects can be done with higher efficiency. The primary intention of model is better understanding of internal relationships of processes and variables and therefore accurate evaluation of simplifications which are necessary for providing practical programs and projects. Background of the researches and studies on the subject of simulation models of surface irrigation goes back to nearly half a century ago. The basis of simulation of various stages of surface irrigation is the numerical resolve of "general equations of flow" or Saint-Venant's coupled differential equations (Mostafa Zadeh and Mousavi, 2006).

(1) Mass continuity

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} + I = 0$$

(2) Equation of momentum

$$\frac{1}{g}\frac{\partial v}{\partial t} + \frac{v}{g}\frac{\partial v}{\partial x} + \frac{\partial y}{\partial x} = S_o - S_f + \frac{vI}{2gA}$$

In these equations, Q is the flow intensity (m^3/s), x is the distance in the direction of flow (m), A is sectional area (m^2), t is time (s), I is infiltration intensity ($m^3/s/m$), g is acceleration of gravity (m/s^2), v is flow velocity (m/s), y is flow depth (m) S_o is bottom slope (m/m) and S_f is friction slope (m/m).

Given the applied hypotheses in these equations, numerical models are divided into four groups: hydrodynamic, zero inertia, kinematic-wave and volume balance models (Mostafa Zadeh and Mousavi). The "hydrodynamic HD" model is basically obtained from complete and simultaneous salvation of Saint-Venant's differential equations and infiltration of water to soil equation (Abbasi et al, 2009). In the "zero inertia ZI" model, given the low rate of velocity of water flow in the conditions of surface irrigation, the inertial sections and acceleration in the equation of momentum have been ignored and the momentum equation is obtained to be $\partial y / \partial x = S_0 - S_f$ (Mostafa Zadeh and Mousavi). In the "kinematic-wave KW" model, for simplicity and prevention of complexity, the momentum equation hasn't been considered and for this, the inertial sections and gradient of the depth of the flow are ignored (assumption of uniform flow): $(S_0 = S_f)$. In the "volume balance VB" model, by concentrating on the analectic salvation of flow issues, the momentum equation is totally ignored (Mostafa Zadeh and Mousavi). For facilitation in the mentioned models, several software packages have been used. SIRMOD and SRFR are the most common simulation software packages of water flow hydraulic in surface irrigation systems.

1.1.SIRMOD

SIRMOD software's (with the symbol SM in this article) was developed by Walker in Utah state university in 1989 and it includes three numerical models: hydrodynamic, zero inertia and Kinematic-wave. In this software, the Kostiakov-Lewis equation has been used as follows:

$$Z = k\ t^{a} + f_{\circ} t \tag{3}$$

In which, Z is cumulative infiltration (m^3m^{-1}), t is the time of infiltration (min), k and a are the constant coefficient obtained from fitting, f_o is the velocity of ultimate infiltration ($m^3min^{-1}m^{-1}$). This equation is extracted through the two-point method and by application of Advance data in SM software.

1.2.SRFR

SRFR software's (with the symbol SF in this article) was also developed by Strelkoff and Clemmens in 1999 in America's water conservation laboratory and it includes two numerical models: zero inertia and kinematic-wave. In this software, in order to describe the specifications of infiltration, the Kostiakov-Lewis infiltration equation has been used together with c constant rate (equal to the preliminary depth of the water required for filling the fractures caused by crust).

$$Z = kt^{a} + f_{o}t + c \tag{4}$$

Softwares SM and SF can be run in all of the surface irrigation systems (furrow, border and basin) and they are able to apply irrigation management about wave flows, reduction of flow and irrigation with open-end and closed-end. By using these softwares, effective variables in irrigation performance shall be selected in a way that the efficiency of water application is maximized.

In this field, numerous researchers have evaluated simulation models of surface irrigation by using field data. Boroumand Nassab et al (2002), in a research that they did in the farms of Fars province, studied the efficiency of SM and SF softwares in furrow irrigation. The results showed that the predicted rates of Advance is less than reality in all of the models used in two softwares and the minimum relative error in this stage was associated with the kinematic-wave model of SM software. In the regression stage, the SM software has predicted some rates more than reality and SF software has predicted them to be less than reality. Also there is not a difference between Advance and regression in the two models zero inertia and hydrodynamic models of SM software. In terms of infiltration stage, all of the models predicted some rates more than reality. But SF software showed better results in this stage. In terms of the runoff stage, the models kinematic-wave and zero inertia models of the SM software had the minimum rate of error. In this study, by considering the overall results of the stages of zero inertia model of the software SM and the kinematic-wave model of SF software have been recommended for the required regional conditions. Behbahani and Babazadeh (2005) evaluated the function of SM software in a farm with clay soil located in study farms of Tehran University and about furrow irrigation. The results of the studies indicated that the velocity of Advance and the rate of infiltration have been less than their reality in all three hydrodynamic, zero inertia and kinematic-wave models and yet the rate of Advance rate is closer to the observed values in the hydrodynamic model. And also in terms of runoffs of all models, they showed an estimation which was higher than the observed values. Jalili (2006) reviewed the efficiency of the two SM and SF softwares in the border irrigation of hay farm located in Hamedan province. The results showed that all of the models predicted rates more than reality for the time of Advance and rate of infiltration and a rate lesser than reality for runoff. In the regression stage, predictions of models of SM software was more than reality and for models of SF software, they were less than reality. In total, by considering the weak results of SF software in the Advance stage, the SM software was prioritized in the experimented region.

Bahrami (2008), in a research in the study farm of Shahid Chamran University of Ahvaz, studied the efficiency of the Muskingum-Cunge model and available models in the SM software in border irrigation and showed that the hydrodynamic and zero inertia models of the SM software predict the Advance stage well. Majd Zadeh et al (2008), in a research in the farm of agricultural department of Karaj, studied efficiency of SM and SF softwares for reviewing the function of irrigation with a constant and wave flow. The results showed that SF software calculates the irrigation stages better in constant irrigation and in wave irrigation; SM software calculates the irrigation stages better.

In the present research, the hydrodynamic models, the zero inertia and kinematic-wave in the

SM software and zero inertia and kinematic-wave models in SF software, for surface irrigation of the "open-end type", have been evaluated and compared with farm data.

2. Materials and methods

This research has been done in the summer of 2008 in the experimental farm of university of agriculture and natural resources of Ramin (Mollasani) located in 35km northeast of the city Ahvaz of Khuzestan province (48º-53' geographical longitude and 31º-35' geographical latitude). According to the 23-year statistics of meteorological station of Ramin University, the average annual rainfall is 234mm and annual evaporation is 1647mm and the average of annual temperature is also 22.9ºC. In this experiment, the plant "Sorghum" was cultivated in four sections of border with a length of 60 meters and an approximate width of 6 meters and it was irrigated for five times with the method of "open-end border irrigation". In this research, by considering how water is accessed, a seven-day irrigation period was used and due to the impact of the preliminary moisture of soil on the velocity of soil's preliminary infiltration (Alizadeh, 2002), irrigations were done with a similar moisture condition as much as possible. Soil texture of the farm was obtained to be silt – clay to the 30cm depth and of the clay type from 30 to 60cm.

In order to extract the infiltration equation, the method of input-output flow was used in which, in order to control most of the intensity of input flow, some overflows were used which had been installed in the primary and secondary stream (Alizadeh, 2002). Intensity of the flow used in this experiment was between 7 and 9 liter per second in proportion with the accessible flow rate in this experiment. The rate of the manning roughness coefficient in the cultivation conditions of Sorghum has been mentioned to be 0.15 to 0.2 in various references (Garcia Navarro et al, 2004; Amin Alizadeh, 2002), but in order to be more sure, these rates were calculated by measuring the variables of the manning equation in the farm.

2.1.Evaluation indexes of the models

In order to evaluate the capabilities of the models used for application in farm conditions, the following three statistical indexes were used in this research:

2.1.1. Index of determination coefficient (R^2) and slope of fitting line (λ)

Index of determination coefficient determines the proportion of the fitting of a linear equation on a series of data and it shows that which proportion of "changes" of all data are justified with linear relationship. For the initial evaluation of the mentioned models, the linear relationship obtained from the fitting of the "rates simulated by the model" is extracted in comparison with the "observed data":

$$\mathrm{X}p = \lambda \times \mathrm{X}o \quad (5)$$

In this equation, X_o is the observed values, X_p is the rates simulated by the model, and λ is the slope of the best fitting line which passes the center of coordinates. Closeness of determination coefficient (R^2) to "one" shows the good correlation between observed and predicted rates and the closeness of the slope of equation (λ) to "one" is indicative of the proper simulation of the model. The mode λ <1 shows that prediction has been less than reality and the mode λ >1 expresses a prediction which is more than reality (Esfandiari and Mahshavari, 2001).

2.1.2. Average of model error (e_r)

The average of the model error in the prediction of the real rates is obtained from the following equation:

$$e_r = |1 - \lambda| \times 100 \quad (6)$$

In which, λ is the slope of fitting line. This index shows the "overall process of error" in data and when the rate of determination coefficient R^2 obtained from the fitted equation is closer to "one", it is indicative of "real rate off error" (Esfandiari and Mahshavari, 2001).

2.1.3. Average of model's relative error (e_a)

The criterion of the average of model's relative error is defined as follows:

$$e_a = \frac{100}{n} \sum_{i=1}^{N} \frac{|Xo_i - Xp_i|}{Xo_i} \quad (7)$$

In this equation, n is the number of compared data. The rate e_a = 0 shows that the model has estimated the variables without any errors and the more the rate of e_a is, the more the relative error in model's simulation will be. The criterion of the average of model's relative error has brought a general perspective of "function of a model" by measuring the "rate of closeness" of the prediction rates to the observed rates and it is the reason why the ultimate conclusion is more accurate and precise in terms of model's capabilities.

3. Results and discussion

Among the main purposes of application of surface irrigation models, there is simulation or prediction, designing and evaluation of various stages of irrigation and obtaining the optimal rate of irrigation efficiency. Thus, in this research, after the completion of the desert operations, by using the required input data of the models, the observed and simulated results were evaluated and compared. The results of various stages are as follows:

3.1. Advance stage

The results obtained from the evaluation of models in the Advance stage for all irrigations have been provided in table 1. By considering the five irrigations in four borders and measurement in 6 spots of the length of the border, the number of all of the evaluation data was 120.

Table 1 – average of models' evaluation variables in the Advance stage

Software	Model	Number of data n	Determination coefficient R^2	Slope of fitting line λ	Model's error e_r (%)	Relative error e_a (%)
SM	**HD**	120	0.912	0.807	19.28	31.68
	ZI	120	0.912	0.807	19.28	31.68
	KW	120	0.968	0.948	5.20	7.86
SF	**ZI**	120	0.902	1.316	31.56	47.82
	KW	120	0.905	1.361	36.11	43.11

According to the obtained results, the rates of determination coefficient of the fitting equations (R^2) were in the range of 0.90 to 0.97 and are indicative of a high linear correlation between predicted and observed data that the slope of fitting lines are reflective of "models' acceptable efficiency" in simulation of the Advance stage by considering the rates close to one. Nevertheless, the slope of the fitting lines is indicative of this matter that the rates predicted by the SM software are less than the observed rates (λ<1) and the rates predicted by the SF software are more than the observed rates (λ>1). Among this, the kinematic-wave model in SM software (SM-KW) is preferred compared to other models due to high rates of determination coefficient and the rates of slope of fitting line which are closer to "one".

Reviewing the rate of prediction errors of SM and SF softwares (Table 1) shows that except for SM-KW model with the mean of 5% of error, the other models have had about 20 to 40 percent of error. The rate of average relative error of the models for water's Advance process has fluctuated in the borders as well (between 30 to 40%), but the minimum relative error is associated with the SM-KW model and it is less than 8%.

These results show that the SM-KW model have a considerably relative excellence in terms of the overall process of error and the rate of closeness of the predicted rates to the observed ones.

3.2. Regression stage

Similar to the Advance stage, in the Advance stage, the statistical indexes were calculated in order to evaluate the models for all irrigations as well and the mean of them has been provided in Table 2.

Table 2 – average of model's evaluation variables in the regression stage

Software	Model	Number of data n	Determination coefficient R^2	Slope of fitting line λ	Model's error e_r (%)	Relative error e_a (%)
SM	**HD**	120	0.885	0.832	16.80	14.88
	ZI	120	0.885	0.832	16.80	14.88
	KW	120	0.957	0.835	16.50	13.88
SF	**ZI**	120	0.998	1.089	8.99	11.52
	KW	120	0.999	1.027	2.72	3.65

The results show that the correlation of the predicted data compared to observed data is also close to one in the regression stage and by considering the rates of the slope of fitting line in all cases; models' prediction will be acceptable. However, the predicted rates of the regression stage in SM software are less than observed rates (λ<1) and they are more than the observed rate (λ >1) in SF software. Generally, the mean of the rates of the indexes of the slope of fitting line λ and determination coefficient R^2 – respectively 1.03 and 0.999 – shows that SF-KW model is more proper for predicting the regression process of the flow.

The results obtained from the indexes of model's error and relative error also show that for the regression stage, the model SF-KW has had lower errors (about 3%) compared to the other models and this difference has been dramatic (in comparison with 10% and 15% errors of other models).

3.3. Infiltration process

In the infiltration process, by considering the input and output discharge statistics and also statistic of Advance and regression in the borders, also by having an equation of infiltration of water in soil, the rate of real infiltration of water in soil was specified. The rate of infiltration of water in soil was estimated by considering the infiltration equation obtained in the initial stages and Advance – regression information in borders. Comparison and evaluation of these rates together with model's prediction have been briefly provided in Table 3.

Table 3– average of model's evaluation variables in the infiltration process

Software	**Model**	**Number of data n**	**Determination coefficient R^2**	**Slope of fitting line λ**	**Model's error e_r (%)**	**Relative error e_a (%)**
	HD	120	0.925	0.957	4.30	8.95
SM	**ZI**	120	0.925	0.957	4.30	8.95
	KW	120	0.952	0.950	5.00	3.96
SF	**ZI**	120	0.802	0.853	14.70	19.72
	KW	120	0.815	0.910	9.00	21.26

The results of comparing determination coefficient and slope of fitting line in the table above indicates that although simulation of the infiltration process is acceptable, all models have predicted a rate less than reality for infiltration of water in soil (λ<1). However, SM software has provided more acceptable results compared to SF software for simulation of infiltration process.

Also in association with the error of models, the results show that SM software has been more efficient in simulation of infiltration process with a more considerable difference with the SF software. Among models of SM software, although the slope of the fitting line is slightly less for KW model and thus it has led to the enhancement of the model's error, but the more difference of the relative error in this model is considerably less than the other two models and therefore the more compliance of the simulated rates with the observed rates are reflected in this mode. In order to come to a conclusion with the results and properly analyze them, the comparative graphs of the evaluation indexes of the models have been provided in Figure 1.

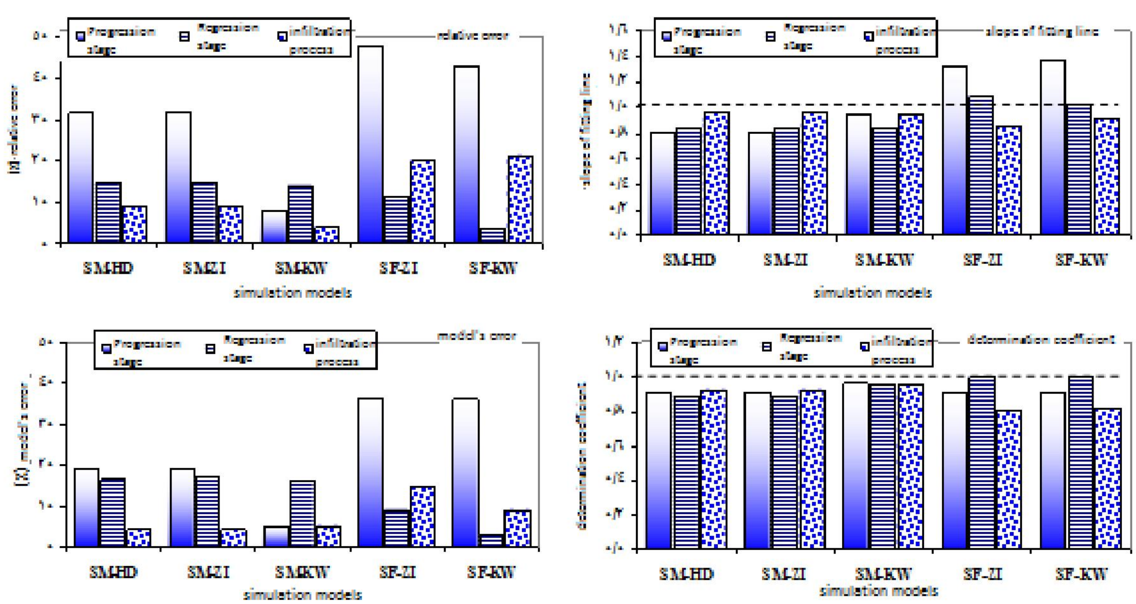

Figure 1 – comparison of evaluative indexes of the used models

1. As it is seen in the graphs, the dominant situation of the indexes is indicative of the more ability of SM software versus SF for simulation of "Advance stage" and "infiltration process". This relative superiority is considerable and diversely it is also seen the superiority of SF software versus SM for simulation of "regression stage". By considering the major difference of these two softwares in terms of the type of infiltration equation, it can be deducted from the results that adding a constant rate to the infiltration equation (the equation used in the SF software) has led to the reduction of efficiency of the simulation models.

2. The results show that "infiltration process", in comparison with Advance and regression, has been predicted by SM software with better efficiency and a more dramatic difference. This superiority can be regarded to be associated to the type of infiltration equation and the quality of its extraction from the farm conditions. In the expression of this issue, considering the rates of fitting slope (λ) about Advance and regression stages shows that since both predictions together are less than the observed rates (λ<1), thus in calculation and rate of infiltration, "infiltration opportunity" of the impact of these errors hasn't been aggregated.

3. Among the mentioned models, the kinematic-wave KW is prior to other modes in both softwares in which it is assumed $(S_0 = S_f)$. However, the SM software with one exception in the field of regression stage has a considerable superiority. The overall comparison of results and considerable errors of SF software in simulation of Advance and infiltration stages lead to the inefficiency of this exception in the ultimate selection of the proper software in the conditions of this research. Nonetheless, it seems that the acceptable results of model KW are associated with the assumption of uniformity of the flow which is provided in sloped borders and furrows with free drainage.

4. The results show that there is no difference between the predictions estimated by SM-HD and SM-ZI models (similar to the results of Jalili 2006). This indicates that the simplification of the hydrodynamic model by ignoring inertial sections and acceleration in the momentum equation (assumption of zero-inertia model) in farm conditions and the type of the used irrigation (open-end border irrigation) has been assumed in this. Thus, in similar conditions, instead of using the complicated model of HD, a simpler model of ZI can be used.

4. Conclusion

Ultimately, by considering that the SM-KW model has provided more acceptable results in the Advance and infiltration sections, for the conditions of the studied area, "open-end border" surface irrigation can be recommended. Also for the regression stage, although the SF-KW model has better results, given the relative advantages of SM software and importance of prediction of infiltration process and moisture distribution of water in soil, this expectation is negligible in the ultimate selection. On the other hand, one of the required outputs of the simulation models of surface irrigation is moisture distribution of water in soil, thus the preference of the SM software in predicting the infiltration process can naturally be considerable.

Also, in the conditions of this research, all of the models available in the SM software have predicted rates which are less than reality for simulation of various stages of flow (a slope between 0.80 and 0.95 in fitting lines), which shall be considered in exploiting the results.

References

1. Abrishami, J and Hossein, M, 1994; Hydraulic of open canals, Imam Reza University, Mashhad, 501 pages.
2. Boroomand Nasab, S, Behzad, M and Farvardin, N, 2002; evaluation of furrow irrigation with farm conditions in the region Zarghan of Fars, Scientific journal of agriculture, volume 26, issue 1:1-12.
3. Behbani, M, and Babazadeh, H, 2005; farm evaluation of surface irrigation model (SIRMOD) (case study), journal agricultural sciences and natural resources of Gorgan, 12th year, issue 2: 11-25.
4. Bahrami, M, 2008; comparing Muskingum-Cunge hydrologic model with models of SIRMOD software in furrow irrigation project in farms of Shahid Chamran University, master's thesis, Shahid Chamran University of Ahvaz, 129 pages.
5. Jalili , S, 2006; Evaluation of surface irrigation models in border irrigation of border of hay farm located in Hamedan, master's thesis, Chamran University of Ahvaz, 106 pages.
6. Abbasi, F, 1994; application of mathematic models in furrow irrigation project, , master's thesis, Tarbiat Moderras, 167 pages.
7. Alizadeh, A, 2002; designing irrigation systems, Astan-e Qods Razavi publications, 4th edition, 655 pages.
8. Majdzadeh, b, Ghobadi Nia, M, Sohrabi, T, and Abbasi, F, 2008; evaluation of the two SIRMOD and SRFR models for reviewing the

performance consistent and wave irrigation, Second seminar on improvement and reformation strategies of surface irrigation systems, Karaj, publication number 129, p 335 – 344.

9. Mostafazadeh, B, and Mousavi, F, 1996; surface irrigation (theory and practice), industrial university of Isfahan, Farhang-e Jame publications, 489 pages.
10. Abbasi F. Mahmodian S. M. and Feyen J. 2003. Evaluation of various surface irrigation numerical simulation models, J. Irrig. Drain. Eng. 129(3): 208-213.
11. Clemmens A. J. and Strelkoff T. 1999, SRFR. Version 4.06. U.S. Water Conservation Laboratory. Agricultural Research Service. Phoenix.
12. Esfandiari M. and Maheshwari B. L. 2001. Field evaluation of furrow irrigation models. J. Agric. Eng. Res 79(4):459-479.
13. Garcia-Navarro P. Sanchez A. Clavero N. and Playan E. 2004. Simulation model for level furrows. II: Description. Validation and Application. J. Irrig. Drain. Eng 130(2): 113-121.
14. Strelkoff T. and Katopodes N. D. 1977. Border irrigation hydraulics with zero-inertia. J. Irrig. Drain. Div 103(3): 325-342.
15. SIRMOD: surface Irrigation Simulation software. 1989. Irrigation software Engineering Div. Department of Agricultural and Irrigation Engineering, Utah State Univ. Loghan. Utah: 84322-4105. USA.

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