International Journal of Engineering and Advanced Research Technology (IJEART)
ISSN: 2454-9290, Volume-2, Issue-4, April 2016

Validation of the Kostiakov model to estimate cumulative infiltration in the arid regions of the southwestern Iran

Bijan Azad, Atefeh Fatahi, Negar Eyni, Marjan Noorolahi, Danial Dabiri

Abstract— **Infiltration is a complex physical process in time and space, which is difficult to characterize with precision under the intrinsic heterogeneous and dynamic soil conditions. The precise determination of the water infiltration in the soil helps to minimize the risks of degradation, especially with the processes of surface runof and flood. Dashte-Abbas is one of the most talented agricultural areas of the Ilam province and Iran country. measurement and classification of soil infiltration is essential to better manage water resources and the prevention of desertification in the Dashte-Abbas plain. Measurement of soil infiltration is time and cost consuming and but many models have been developed for infiltration estimate, which prevents of a lot of time and high costs consuming. Kostiakov is one of the models that is being used widely to estimate soil infiltration, which as the most widely used model in the planing of soil and water. The main objectives of this study were: to; 1) validate the Kostiakov model estimates with the measured cumulative infiltration and 2) to determine the coefficients of Kostiakov model. For this purpose, soil infiltration measured using the double-ring infiltrometer in 37 stations with 3 repetitions. Using the data obtained, Kostiakov model coefficients were determined. Mean values of a and c coefficients were 0.4275 and 0.7542, respectively. Results showed that the range of variation of coefficient of c was large, which demonstrated considerable spatial variability in the study area. The normalized root mean square error (NRMSE) indicates the total difference between the measured and modeled (estimated) values was NRMSE=0.15, and performance efficiency was EF= 0.74. Thus, it confirms that the Kostiakov model accurately estimates the cumulative infiltration in the Dashte-Abbas plain in southwestern Iran.**

Index Terms— **Valdation model, Soil infiltration, Kostiakov model, Double-ring infiltrometer, Dashte-Abbas plain.**

I. Introduction

Quantifying of soil infiltration as one of the major components in the hydrological cycle can be useful in the management of catchments. Soils with high restricts, infiltrate smaller amount of rainfall into soil and bring about produce of the more runoff and flood [1]. Inversly, with the increasing infiltrate of water into soil, decrease runoff and flood and to reduce the human and financial losses [2].

Soil infiltration is a key factor in the rainfall and runoff models [3] and an essential factor for increasing agricultural production, since an efficient application of water fundamentally depends on the infiltration capacity of the soil [4]. soil infiltration plays an important role in crop yield and leaching of soils in the agricultural aspects [5], [6]. Therefore, study and quantifying of soil infiltration is very importance to detemine the amount of available water for plant growth, additional water needed for leaching and design of irrigation systems [7], [8].

In order to estimate soil infiltration, many models such as Green-Ampt, Kostiakov, Horton and Philip have been developed for this purpose. Measurement of soil infiltration is time consuming and application of these models prevents of a lot of time and high costs consuming [9]. Specifically the Kostiakov is one of the models [10] that is being used widely to soil infiltration. This model is one of the best models because paying attention to all the conditions and factors affecting the soil infiltration process [11].

Kostiakov model:

The model of Kostiakov is defined as equation (1) [10], where i(t) is the cumulative infiltration (cm) as a function of time, **a** and **c** are the equation's coefficients (**a**> 0 and 0 <**c**< 1). Coefficients of **a** and **c** are different and they depond on many factors such as soil type, time, ancient moisture, hydraulic conductivity of soil and etc [12].

$$i(t) = ct^{a} \qquad (1)$$

Duan et al., (2011) [13] using six different models showed Kostiakov and Horton models provided the best predictions of cumulative infiltration and average infiltration rate, respectively. Zolfaghari et al (2012) [14] eveluation sevene infiltration models for estimate cumulative infiltration in the four diiferent claases of soil including loam-clayey, loam-silty, loam and loam-clay-silty textures through the use of ring double. Zolfaghari et al (2012) [14] reported that kostiakov and SCS models estimated cumulative infiltration properly and imprecise in all the soil classes, respectively. Mirzaee et al., (2014) [15] using some models in the different areas of Iran, reported that Kostiakov model among other models had been the best fitness with measured data.

Due to low rainfall (220 mm y^{-1}) and its poor distribution in the country, Iran is considered among the arid countries which faced with water shortage [16]. Around 70% of Iran's agricultural lands are located in arid and semi-arid regions of the country. Dashte-Abbas plain with the mean annual rainfall 235 mm is a arid region of Iran that almost 85% of its agricultural lands have suitable capable for irrigation. Also given the important role of soil infiltration in the prevent loss of water during irrigation, measuring and quantifying soil infiltration to better manage water resources and rising irrigation efficiency is essential in this plain. The main purpose of this study were: to; 1) validate the Kostiakov model estimates with the measured cumulative infiltration and 2) to determine the coefficients of Kostiakov model as the most widely used model in the planing of soil and water, in the Dashtabass plain in southwest of Iran.

II. MATERIALS AND METHODS

a. Study area

The Dashte-Abbas plain located about 67km of Dehloran, (32’27”N, 47’ 25”E) Ilam province, in southwestern Iran (Fig. I).

Based on data obtained from the meteorological station in Dehloran city (southwest Iran), the total annual precipitation is 235 mm, the mean annual temperature is 26°C, and the total annual open pan evaporation rate in the area are 4300 mm, respectively. The climate type is classified as arid region according to the De-martonne classification, with a distinct dry season during summers and relatively humid during the winters. The Dashte-Abbas plain contain Piedmont Alluvial Plains soil properties and lies within a relatively flat basin physiography. Soils are mainly Entisols based on soil [17] with sandy textures (75.7% of sand). Croplands are current dominant vegetation type in the plain. The most croplands including corn, wheat and barley in this plain. Also almost 85% of its agricultural lands have suitable capable for irrigation (Fig. II).

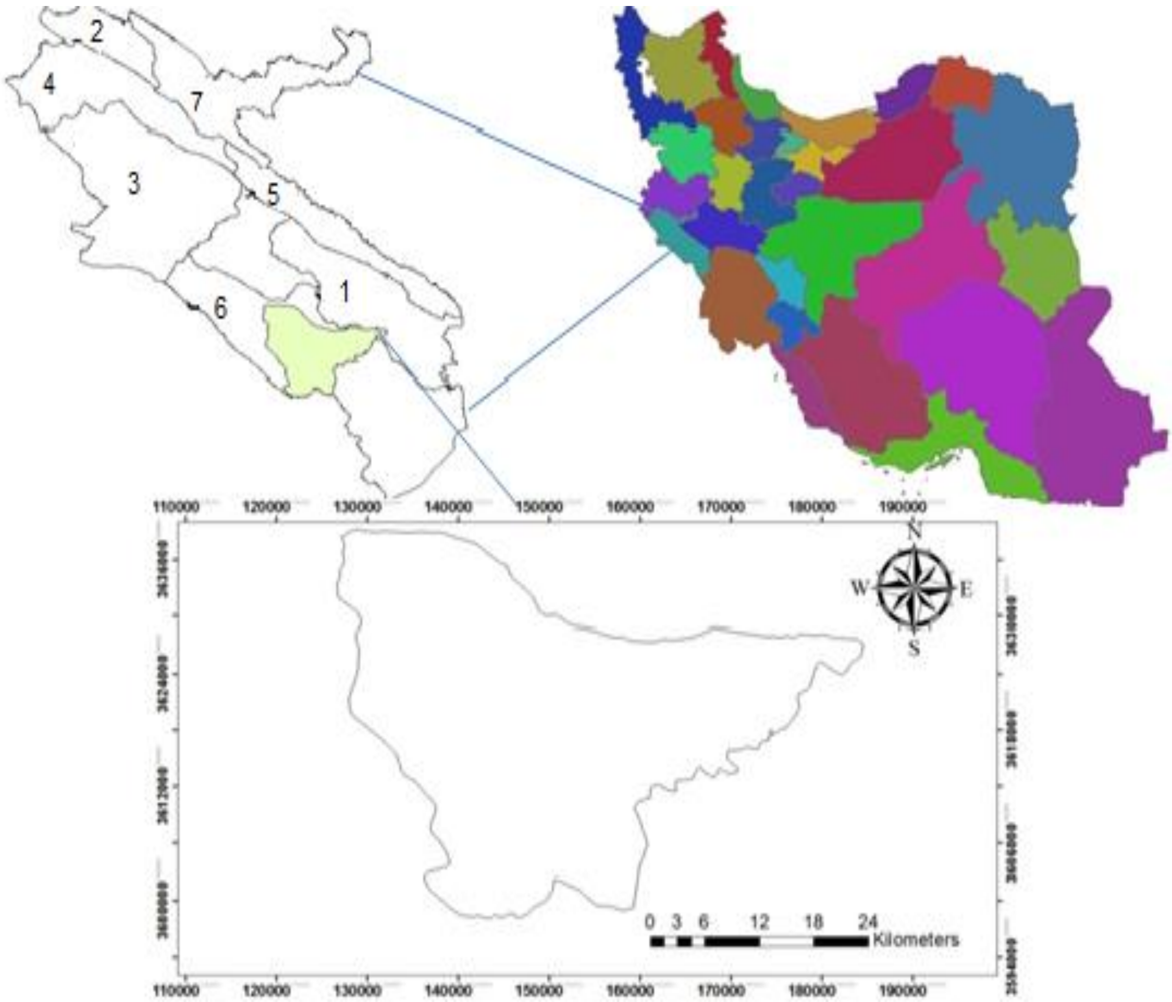

Fig. I. Location map of the Dashte Abbas plain in the southwestern Iran.

b. Field measurments

Infiltration was measured using a double-ring infiltrometer [18], [19] in the Dashte-Abbas plain. Double-ring infiltrometers had been 30 and 60 cm internal and external diameter, respectively, and height of 50 cm. Infiltration tests were carried out at time intervals of 1, 2, 4, 6, 11, 16, 26, 36, 56, 76, 106, 136, 166 and 196 min and often have been measureds continously untill infiltration rate arrived to a level of reletaively constan. determined cumulative infiltration of soil in 37 stations with 3 repetitions and alltogether 111 soil samples were measured.

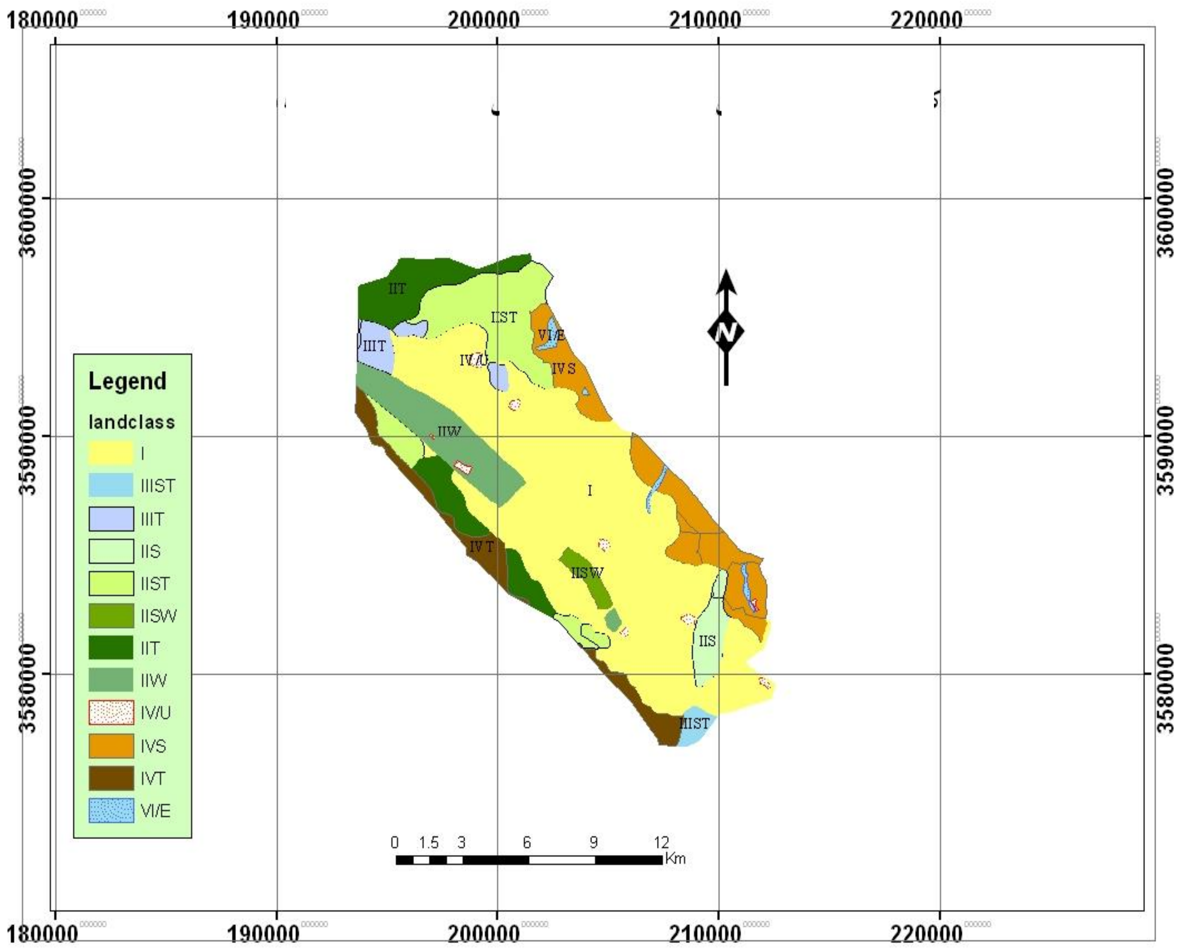

Fig. II. Classification of lands for surface irrigatin in the Dashte-Abbas plain (I class is sutaible for irrigation and VI class is not sutaible).

c. Fitness of Kostiakov model to measured data

After determined cumulative infiltration in 37 stations (each with 3 repetitions) in the Dashte-Abbas plain, we used these data to determine coefficients of Kostiakov model. In the first defined goal function as equation (2) [20]. Where I(m)j and I(p)j are measured data and estimated cumulative infiltration by Kostiakov model at j^{nd} time as well as n is the number of the paired values, and SSE is sum of square error (cm^2). For determine coefficients of Kostiakov model, SSE minimum amount chosen to the best fit between measured and estimated to be created.

$$SSE = \sum_{i=1}^{n} \left(I(m)_j - I(p)_j\right)^2 \qquad (2)$$

d. Validation of Kostiakov model

Using the cumulative infiltration data obtained from the this study the Kostiakov model was validated. Some statistical comparisons between the estimated and measured data including determination factor (R^2), correlation coefficient (r), normalized root mean square error (NRMSE) (Eq. 2) and the performance efficiency (EF) were used for model validation (Eq. 3). As described the smallest value for NRMSE is zero, indicating that there is no difference between measured and estimted values. The model's best performance is at EF=1. Where I(m)j and I(p)j are measured data and estimated cumulative infiltration by Kostiakov model at jnd time as well as I(mean) is mean measured cumulative infiltration and n is the number of the paired values.

$$NRMSE = \frac{\sqrt{\frac{\sum_{i=1}^{n}\left(I(m)_j - I(p)_j\right)^2}{n}}}{I(mean)} \qquad (3)$$

$$EF = \frac{\sum_{i=1}^{n}\left(I(m)_j - I(mean)\right)^2 - \sum_{i=1}^{n}\left(I(p)_j - I(m)_j\right)^2}{\sum_{i=1}^{n}\left(I(m)_j - I(mean)\right)^2} \qquad (4)$$

III. RESULTS

a. Determine of coefficients for Kostiakov model in the Dashte Abbas plain

Table I shows the range of variation coefficients of Kostiakov model in the Dashte Abbas plain. Mean values of **a** and **c** coefficients were 0.4275 and 0.7542, respectively (See table I) which approximately mean values of coefficients of Kostiakov model are high in this plain. Coefficients of **c** and **a** should be bigger than zero and between zero and one, respectively which in this study coefficients were in the range mentioned (See table I). precent of coefficient variation (CV%) were 31.57 and 51.6 for coefficients of **a** and **c**, respectively which demonstrated the range of variation of **c** and **a** coefficients were large in the Dashte-Abbas plain. (See table I). Finally, general form of Kostiakov model in the Dashte-Abbas plain is as equation (5), which farmers and manegers can use it to determine the infiltration in this area.

$$i(t) = 0.7641t^{0.4275} \quad (5)$$

b. Validation of Kostiakov model in the Dashta Abbas plain

A significant linear relationship (R^2= 0.98) was found between the measured cumulative infiltration data and the estimated lines (Fig. III). Also correlation coefficient (r) was 0.99. A comparison of modeled (estimated) vs. measured cumulative infiltration in the Dashte-Abbas allows an overview on Kostiakov's performance in estimating cumulative infiltration (Fig. III). Also as shown (Fig. III), the measured and modeled (estimated) cumulative infiltration values were found near distribution lines. The normalized root mean square error (NRMSE) indicates the total difference between the measured and modeled (estimated) values was NRMSE=0.15, and performance efficiency was EF= 0.74 (See table II).

Table I. Range of coefficients of Kostiakov model in the Dashte-Abbas plain.

coefficient	mean	Standard deviation (%)	coefficient variation (%)
a	0.4275	0.135	31.57
c	0.7641	0.395	51.6

Table II. Quantitative statistical analysis of between measured and modelled (estimated) cumulative infiltration.

r	EF	NRMSE	R^2
0.99	0.74	0.15	0.981

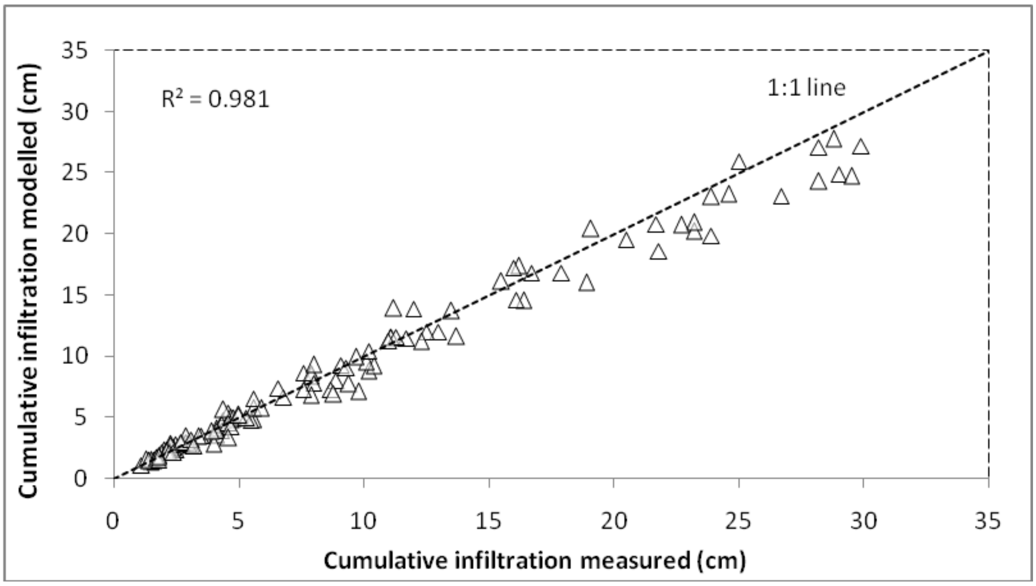

Fig. III. Measured and modelled (estimated) cumulative infiltration in the Dashte Abbas plain compare with 1:1 line.

IV. Discussion

Result showed that values of coefficients of Kostiakov model are high (See table I), which probably due to high levels of sand (75.7%) in the Dashte-Abbas plain. Also results showed that the range of variation of coefficient of c was large (See table I), which demonstrated considerable spatial variability in the study area. Measured data were well correlated with estimated values obtained from the Kostiakov model (See table II and Fig. II). Thus, it confirms that the Kostiakov model accurately estimates the cumulative infiltration in the Dashte-Abbas plain in southwestern Iran. These results have been consistent with studies of [13], [14], [15].

REFERENCES

[1] Mandal, U. K., Bhardwaj, A., Warrington, D., Goldstein, D., Tal, A. B., and Levy, G. Changes in soil hydraulic conductivity, runoff, and soil loss due to irrigation with different types of saline–sodic water. *Geoderma*, (2008). 144, 509-516.

[2] Talavori A. Hydrologic models in a simple word. Forest and rangeland research institute. First edition, (1996). 118p.

[3] Chahinian, N., Moussa, R., Andrieux, P., and Voltz, M. Comparison of infiltration models to simulate flood events at the field scale. *Journal of Hydrology*, (2005). 306, 191-214.

[4] Machiwal, D., Jha, M. K., and Mal, B. Modelling infiltration and quantifying spatial soil variability in a wasteland of Kharagpur, India. *Biosystems Engineering* , (2006). 95, 569-582.

[5] Falstad, J. Soil Condition. Transplant Status in Burger Draw. Billings Gazette. Prepared by DG Steward Page. Burger Draw Comments and Recommendations, (2000).

[6] Warrence, N., Pearson, J. E., Krista, J. and Bauder, W. The basics of salinity and sod- icity effects on soil physical properties, (2003). [Online]. Available at http://waterquality.monta na.edu /docs/methane

[7] Rawls, W., Ahuja, L., Brakensiek, D., and Shirmohammadi, A. Infiltration and Soil Water Movement, Chapter 5 in Maidment, DR (Ed.) Handbook of Hydrology. McGraw-Hill, New York, NY, (1993).

[8] Bagarello, V., and Iovino, M. Field testing parameter sensitivity of the two-term infiltration equation using differentiated linearization. *Vadose Zone Journal* , (2003). 2, 358-367.

[9] Haghighi-Fashi F, Sharifi F, Kamali K. Modelling infiltration and geostatistical analysis of spatial variability of sorptivity and transmissivity in a flood spreading area. Spanish Journal of Agricultural Research, (2014). 12(1): 277-288.

[10] Kostiakov, A. N. On the dynamics of the coefficient of water-percolation in soils and on the necessity for studying it from a dynamic point of view for purposes of amelioration. *Trans*, (1932). 6, 17-21.

[11] Vghefi, M, Movahedza M. Evaluation and comparison of Infiltration Methods in the Catchment Area of Mond River – Dashti Township by Use Double Ring Tests. Quaterly of water and irrigation engineering, (2014). 4, 15.

[12] Harteli, E. Comparison of infiltration models. *Soil Science Society of America Journal*, (1992). 25, 103-114.

[13] Duan, R., Fedler, C. B., and Borrelli, J. Field evaluation of infiltration models in lawn soils. *Irrigation Science*, (2011). 29, 379-389.

[14] Zolfaghari, A., Mirzaee, S., and Gorji, M. Comparison of different models for estimating cumulative infiltration. *Int J Soil Sci*, (2012). 7, 108-115.

[15] Mirzaee, S., Zolfaghari, A. A., Gorji, M., Dyck, M., and Ghorbani Dashtaki, S. Evaluation of infiltration models with different numbers of fitting parameters in different soil texture classes. *Archives of Agronomy and Soil Science*, (2014). 60, 681-693.

[16] Zargar A. The effect of rainfall and land management on total runoff in watershed. Forest and rangeland research institute. (1995). 48p.

[17] Soil Survey Staff. Keys to soil taxonomy. United States Department of Agriculture, Natural Resources Conservation Service. English edition, (1998). P. 326.

[18] Bouwer H, Back JT, Oliver JM. Predicting infiltration and ground-water mounds for artificial recharge. J Hydrol Eng, (1999.) 4(4): 350-357.

[19] ASTM. D3385-03 Standard test method for infiltration rate in field using double-ring infiltrometer, (2003). Annual Book of ASTM Standards 04, 08. *American Society for Testing and Materials*, West Conshohocken, PA.

[20] Ghorbani Dashtaki, Sh, Homaee, M, Mahdian M M. Effect of Land Use Change on Spatial Variability of Infiltration Parameters. Iranian Journal of Irrigation and drainage, (2010). 2, 4, 206-221

First Author Faculty of Natural Resource and Environmental Engineering, School of Agriculture, Shiraz University, Shiraz, Iran, **correcponding author** (bijanazad70@gmail.com)

Second Author M.Sc. Graduate Student of Combat Desertification, Faculty of Desert Studies, Semnan University, Semnan, Iran.

Third Author M.Sc. Graduate of Combat Desertification, Faculty of Agriculture, Ilam University, Ilam, Iran.

Fourth Author M.Sc. Graduate of Desert Region Management, Department of Natural Resources and Environmental Engineering, Faculty of Agriculture, Shiraz University, Shiraz, Iran.

Fifth Author M.Sc. Graduate of Watershed Management, Department of Natural Resources and Environmental Engineering, Agricultural and Natural Resources University of Sari, Sari, Iran.