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Investigation of Deforestation on the Runoff-Peak by KINFIL Model

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Abstract: Problem statement: In present study the KINFIL model was used for the catchment management, including the investigation of deforestation on predict flood runoff assessment with a significant precision. **Approach:** The KINFIL rainfall-runoff model has been used for the reconstruction of the rainfall runoff events in agricultural land use. The implementation of the KINFIL model supported by GIS proved to be a proper method for the flood runoff assessment on Sepidroud catchments (north of Iran), during which different scenarios of the rainfall events. **Results:** The results show when the observed discharge peak was 2.25 m^3 sec^{-1}, the computed discharge by the KINFIL model predicted 2.4 m^3 sec^{-1} (about 7% errors) and when the observed discharge peak was 1.9 m^3 sec^{-1}, the computed discharge by the KINFIL model predicted 1.8 m^3 sec^{-1} (about 5% errors). Also, the results showed when deforestation reaches 10% of total primitive areas in Sepidroud basin; the runoff-peak may increase more than 14.5 times. **Conclusion/Recommendations:** It can be stated that utilizing KINFIL model for determining the peak of discharge in agricultural land use, is a hydrological model, which has the good convergence with observed data.

Key words: KINFIL, design discharge peak, runoff, GIS, deforestation

INTRODUCTION

Recent development in hydrological modeling provides modern methods of runoff forecasting and techniques for the prediction of design discharges impacted by human activities (Kovar *et al*., 2002). These N-year design discharges caused by the design rainfalls play a significant role in the new investments (Beven, 2004). The catchment management, including the land use, plays an important role in the rainfall-runoff relationships. The implementation of hydrological models allows a better analysis of the flood situations in agricultural lands. The reliability of these data varies and one possible way to improve it is the use of hydrological models. One of these models, simulating the direct runoff from ungauged catchments is the KINFIL model (Kaldec and Lovar, 2009). The direct runoff simulation has been computed using the kinematics wave sub-model (i.e., KINFIL model) respecting the catchment topography. Topographical characteristics of the Sepidroud catchment were processed by the ARC/INFO system. The reliability of these modern methods of hydrological modeling and their GIS interface is relevant for an adequate mathematical description of the rainfall-runoff process.

MATERIALS AND METHODS

The KINFIL model uses the Curve Number method (Cronshey, 1986) but suppresses its weak theoretical background by substituting the physically-based infiltration theory for a common empirical CN approach. The correspondence between CN values and soil parameters, such as the saturated hydraulic conductivity (KS) and sorptivity (Sf), was derived through a correlation technique of these parameters with the design rainfalls. The infiltration part of the model is based on the Morel-Seytoux equations (McCulloch and Robinson, 1993), based on the Green-Ampt concept, distinguishing the pre- and post-ponding infiltrations from the constant or variable rainfalls. It is always disputable if the Green-Ampt approximation is adequate to simulate the infiltration process on forested mountainous catchments. The KINFIL model uses this approximation in combination with the SCS Curve Number method based on the Morel-Seytoux (1982) approach. The second basic component of the KINFIL model is the simulation of the runoff.

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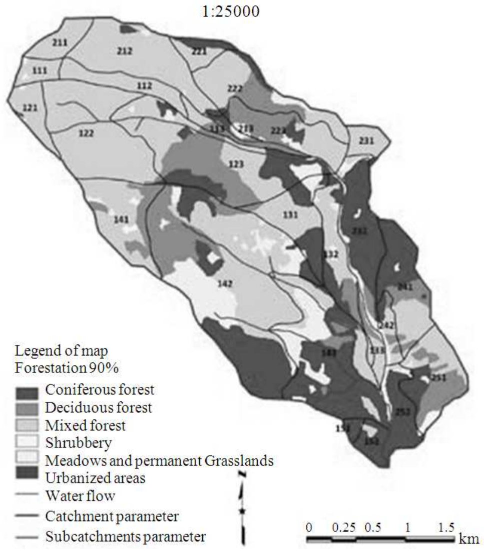

Fig. 1: Land use in the sepidroud catchment

This process is based on a kinematics wave approximation of the model (Brakensiek and Rawls, 1982). In the cases of high rainfall intensities as it is always in the design floods when those are often higher that 2 mm min^{-1} and their depth is over 50 mm, the conditions for using a kinematics wave are mostly feasible. For the numerical solution, the explicit Lax-Wendroff finite difference scheme was implemented. It should also be stated that the infiltration part of the KINFIL model has two parameters, KS and Sf, strictly dependent on the CN values which are not subjected to a change through calibration. However, each of these partial areas has its own CN-value characterizing the rainfall excess conditions (Kaldec and Lovar, 2009). The routing part of the model has two groups of parameters-geometrical parameters of partial sub-catchments (at least the width and length of rectangles, or segment parameters) that have to be used and the Manning roughness (Overton and Meadows, 1976; Wannawong *et al*., 2010). This model was used for the Sepidroud catchment data. Table 1 shows the land use in this catchment. The spatial properties of the Sepidroud catchment are characterized in the raster maps based on the topographical maps 1:25 000 (Fig. 1). Graphical inputs/ outputs were made in GIS ArcView and ArcGIS (version 9.0). GIS tools for catchment identification in the form of DTM including the topographical characteristics, soil groups, land use and water drainage pattern in this study, were used. All these characteristics are given in Table 2 (Swank and Crossley, 1988).

Average yearly temperatures vary between 6 degrees(c) and 33 degrees(c). Average yearly precipitations amount to 857 and 1320 mm.

Table 1: Land use in the Sepidrod catchment

Land use	Area (km^2)	Percentage
Coniferous forest	2.81	26.06
Deciduous forest	15.18	1.64
Mixed forest	5.24	48.56
Shrubbery	0.06	0.50
Meadows and permanent Grasslands	0.91	8.47
Urbanized areas	0.01	0.03
Road network	0.13	1.20

Table 2: Basic characteristics of experimental Sepidroud catchment

Catchm catchment area (km^2)	Sp	10.8
Forested catchment area (km2)	SL	9.840
Forestation (%)	l	90.140
Length of river (km)	L	6.438
Length of inflows (km)	ΣLpi	9.263
Catchment perimeter (km)	O	14.905
Length of talweg (km)	Lu	6.834
Max. Catchment altitude (a.s.l.)	H max	1158.000
Min. catchment altitude (a.s.l.)	H min	569.000
Average catchment altitude (a.s.l.)	H ave	909.860
Average width catchment (km)	Bp	1.580
Average river slope (%)	It	15.750
Average talweg slope (%)	Iú	12.340
Average catchment slope (%)	Is	31.150

RESULTS

When the first flood (Wave 1) came, the catchment had been moderately saturated with the previous precipitations to the level of antecedent moisture conditions AMC II (Tani and Abe, 1987), during the second wave (Wave 2) the catchment was extremely saturated (level AMC III), as a consequence of which the culmination inflow was higher, even though the precipitation was much lower in this case (Table 3).

The AMC I to III are classified according to the U.S. Soil Conservation Service Method to distinguish between the levels of saturation with precipitation depths during five previous days (AI to 36 mm, AII from 36-53 mm and AIII more than 53 mm) (Kaldec and Lovar, 2009; Cronshey, 1986). These sudden intensive rainfalls caused floods which, with their peaks of 2.25 and 1.8 m^3 sec^{-1}, may be classified in the category of the recurrence time N = 2 years. Each sub-catchment was differentiated mainly according to the parameters of the slope inclination and the soil and land use. The cascades were determined with 2-3 elements with the help of GIS. In total, 10 basic sub-catchments were identified in the runoff processes. All sub-catchments were reoriented towards rectangular elements of the cascade in the same area. This procedure is schematically represented in and Table 4. The simulation was undertaken of the scenarios of the flood runoff from N-year design rainfall exceedence probability and return period p = 0.01 (N = 100 years).

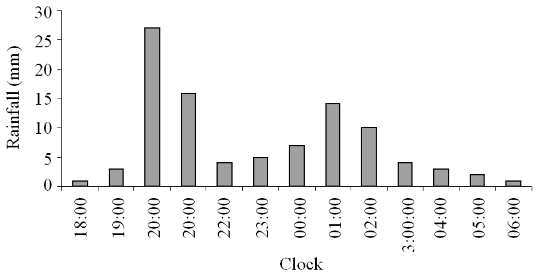

Fig. 2: Total rainfall (16. 09. 2005)

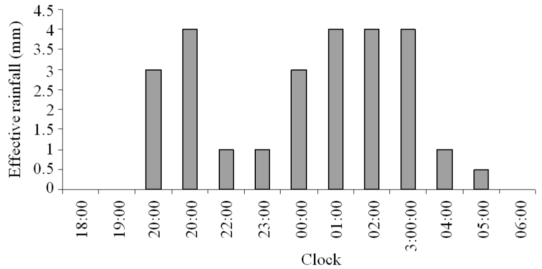

Fig. 3: Effective rainfall (16. 09. 2005)

Table 3: Basic information on rainfall-runoff events in the Sepidroud catchment

Sepidroud Catchment	Wave1	Wave2
Beginning of causal Rainfall	16.09.2005 18:00	11.10.2006 15:00
End of causal rainfall	17.09.2005 06:00	12.10.2006 01:00
Peak flow ($m^3 sec^{-1}$)	2.25	1.8
Total depth of causal rainfall (mm)	81.10	18.60
Total depth of effective rainfall (mm)	8.13	9.05

The total rainfall and effective rainfall of the recorded gauge have been submitted in Fig. 2 and 3 for the precipitation of (16. 09. 2005 18:00 ----17. 09. 2005 06:00).

DISCUSSION

The computed discharge by KINFIL model and observed discharge are compared in Fig. 4.

According to Fig. 4, the computed peak of discharge by KINFIL model reached to 2.4 $m^3 sec^{-1}$ and the observed peak of discharge reached to 2.25 $m^3 sec^{-1}$. So, the precision of the computed discharge by KINFIL model is 7% approximately. Also the total rainfall and effective rainfall of the recorded gauge have been submitted in Fig. 5 and 6 for the precipitation of (11. 10. 2006 15:00 ----12. 10. 2006 03:00).

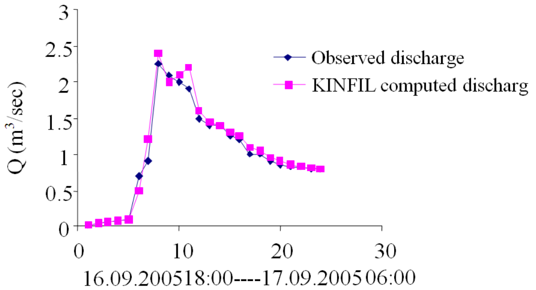

Fig. 4: Measured and computed discharges of the KINFIL model (16. 09. 2005 18:00 ------17. 09. 200 06:00)

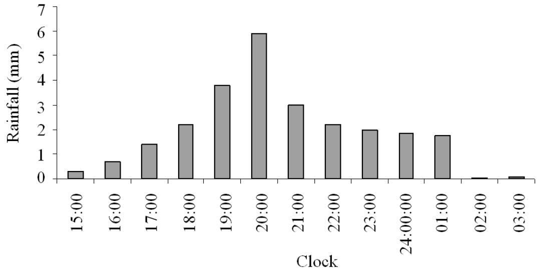

Fig. 5: Total rainfall (11. 10. 2006)

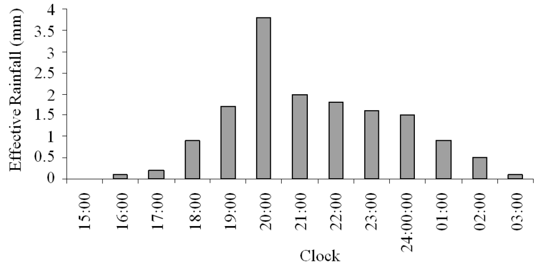

Fig. 6: Effective rainfall (11. 10. 2006)

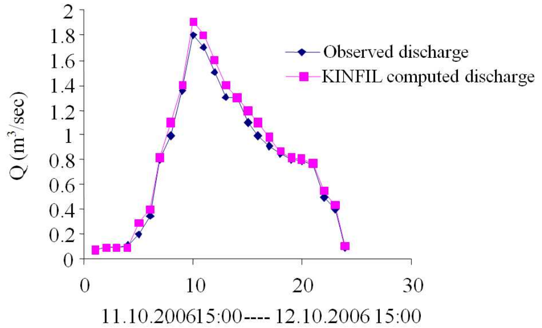

Fig. 7: Measured and computed discharges of the KINFIL model (11. 10. 2006 15:00------11. 10. 2006 15:00)

Table 4: Scheme of the Sepidroud catchment (According to Fig. 1)

Cascade	Area (km^2)	Plane No.	Area v	Average width (Km)	Length (Km)	slope (–) %
DP1	0.418	111	0.102	3.248	0.031	0.320
		112	0.216		0.067	0.360
		113	0.100		0.031	0.195
DP2	2.148	121	0.170	2.961	0.057	0.304
		122	0.863		0.291	0.434
		123	1.115		0.376	0.316
DP3	0.831	131	0.377	2.426	0.155	0.286
		132	0.362		0.149	0.254
		133	0.092		0.038	0.377
DP4	3.600	141	0.474	3.938	0.120	0.348
		142	2.081		0.538	0.317
		143	1.045		0.265	0.278
DP5	0.146	151	0.036	0.418	0.086	0.266
		152	0.110		0.263	0.363
DP6	0.811	211	0.153	2.733	0.056	0.380
		212	0.618		0.226	0.377
		213	0.040		0.015	0.172
DP7	0.994	221	0.126	0.821	0.153	0.218
		222	0.479		0.583	0.350
		223	0.389		0.474	0.329
DP8	0.689	231	0.115	1.794	0.064	0.344
		232	0.483		0.269	0.310
DP9	0.569	241	0.455	0.379	1.200	1.610
		242	0.114		0.301	0.363
DP10	0.680	251	0.438	1.127	0.389	0.178
		252	0.242		0.215	0.320

Table 5: Design discharges (m^3 sec^{-1}) in the Sepidroud catchment, return period of 100 years

		Td= 60(min)	
	Td = 30 (min)	Runoff (m^3/sec)	Td= 300(min)
Forestation (10%)	27.5	37.8	11.65
Forestation (50%)	22.1	31.5	8.30
Forestation (90%)	18.5	20.5	6.40

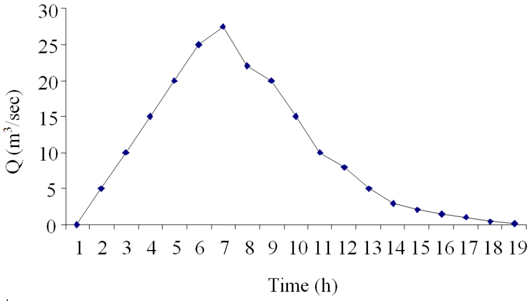

Fig. 8: Computed discharges of the KINFIL model for deforestation 10% and td = 30 min

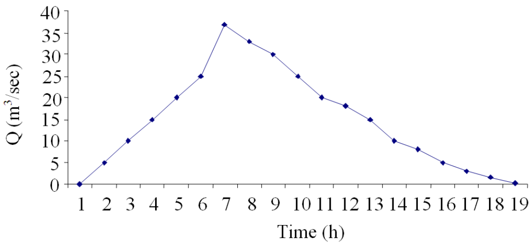

Fig. 9: Computed discharges of the KINFIL model for deforestation 10% and td = 60 min

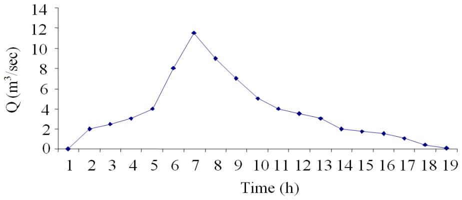

Fig. 10: Computed discharges of the KINFIL model for deforestation 10% and td = 300 min

Also, the computed discharge by KINFIL model and observed discharge are compared in Fig. 7. According to Fig. 7, the computed peak of discharge by KINFIL model reached to 1.9 m^3 sec^{-1} and the observed peak of discharge reached to 1.8 m^3 sec^{-1}. So, the precision of the computed discharge by KINFIL model is 5% approximately. Also deforestation Scenario simulations in Sepidroud basin area when the forested areas, which cover almost 90% of the catchment area, were replaced with permanent grass, which means the reduction of the forested area to 90, 50 and 10%, respectively.

The KINFIL computation results, showed, the increase in design discharges (m^3 sec^{-1}) more than 14.5 times with an event duration of td = 30, 60, 300 min, return period of 100 years and scenario changes of forestation (Fig. 8-10 and Table 5).

CONCLUSION

It can be stated that utilizing KINFIL model for determining the peak of discharge in agricultural land use, is a hydrological model, which has the good convergence with observed data. According to the obtained results, when the precipitation had high intensity (more than 25 mm h^{-1}), the computed peak of discharge by KINFIL model reached to 2.4 m^3 sec^{-1} and the observed peak of discharge reached to 2.25 m^3 sec^{-1}. So, the precision of the computed discharge by KINFIL model is 7% approximately. Also, when the precipitation had low intensity (less than 6 mm h^{-1}), the computed peak of discharge by KINFIL model reached to 1.9 m^3 sec^{-1} and the observed peak of discharge reached to 1.8 m^3 sec^{-1}. So, the precision of the computed discharge by KINFIL model is 5% approximately. Also The KINFIL computation results, showed, the increase in design discharges37.8-2.4 m^3 sec^{-1} (more than 14.5 times) with an event duration of td = 60 min, return period of 100 years.

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