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Full Length Research Paper

Utilizing the KINFIL model for investigation of deforestation on the runoff- peak (Case study: Sepidroud catchment)

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Abstract: 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. The results show when the observed discharge peak was 2.25 m^3/s, the computed discharge by the KINFIL model predicted 2.4 m^3/s (about 7% errors) and when the observed discharge peak was 1.9 m^3/s, the computed discharge by the KINFIL model predicted 1.8 m^3/s (about 5% errors) .also, the KINFIL model may be used for the catchment management, including the investigation of deforestation on predict flood runoff assessment with a significant precision. The results showed when deforestation reaches 10% of total primitive areas in Sepidroud basin; the runoff-peak may increase more than 14.5 times.

Keywords: KINFIL model, design discharge peak, runoff, GIS, deforestation

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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 P. et al 2002). These N-year design discharges caused by the design rainfalls play a significant role in the new investments (Beven K.J. 2006). 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 (Tani M. and Abe T. 1987). 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 V. and Lovar P.2009). The direct runoff simulation has been computed using the kinematics wave sub-model (i.e. KINFIL model) respecting the catchment topography (Kovar P. 1992). 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 (U.S. SCS 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 (*K*S) and sorptivity (*S*f), 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 J.S. and Robinson M. 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 approach (Harder F. and Kovart P.1994). The second basic component of the KINFIL model is the simulation of the runoff. This process is based on a kinematics wave approximation of the model (Swank W.T. and Crossley D.A.1988). In the cases of high rainfall intensities as it is always in the design floods when those are often higher that 2 mm/min and their depth is over 50 mm, the conditions for using a kinematics wave are mostly feasible (Morel-Seytoux H.J.1982). 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, *K*S and *S*f, 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 V. and Lovar P. 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. This model was used for the Sepidroud catchment data. Table 1 shows the land use in this catchment.

Table 1. Land use in the Sepidrod catchment

Land use	Area (km2)	Percentage (%)
Coniferous forest	2.81	26.06
Deciduous forest	1.64	15.18
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

The spatial properties of the Sepidroud catchment are characterized in the raster maps based on the topographical maps 1:25 000(Figure 1).

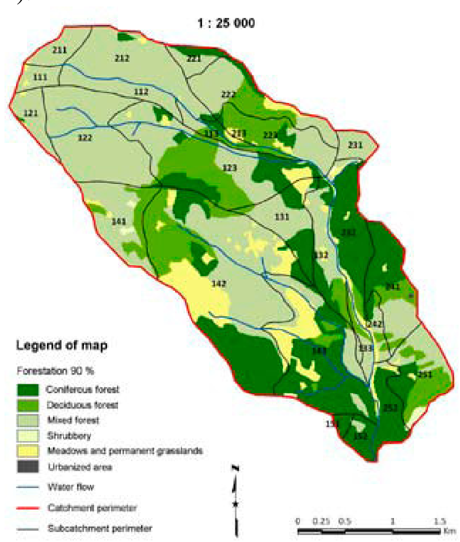

Figure 1. Land use in the Sepidroud catchment

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 paper, were used. All these characteristics are given in Table 2. Average yearly temperatures vary between 6 degrees(c) and 33 degrees(c). Average yearly precipitations amount to 857 mm and 1320 mm.

RESULTS AND DISCUSSIONS

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, 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).

Table 2. Basic characteristics of experimental Sepidroud catchment

Catchment area (km2)	Sp	10.80
Forested catchment area (km2)	SL	9.84
Forestation (%)	l	90.14
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	1458
Min. catchment altitude (a.s.l.)	H min	569
Average catchment altitude (a.s.l.)	H ave	909.86
Average width catchment (km)	Bp	1.580
Average river slope (%)	It	15.75
Average talweg slope (%)	Iú	12.34
Average catchment slope (%)	Is	31.15

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 (m3/s)	2.۲۵	1.8
Total depth of causal rainfall (mm)	81.10	18.60
Total depth of effective rainfall (mm)	8.13	9.05

The AMC I to III are classified according to the U.S. Soil Conservation Service Method (U.S. SCS 1986) to distinguish between the levels of saturation with precipitation depths during five previous days (AI to 36 mm, AII from 36 to 53 mm, and AIII more than 53 mm). These sudden intensive rainfalls caused floods which, with their peaks of 2.25 m3/s and 1.8 m3/s, 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).The total rainfall and effective rainfall of the recorded gauge have been submitted in Figure 2 and 3 for the precipitation of (16. 09. 2005 18:00 ----17. 09. 2005 06:00).

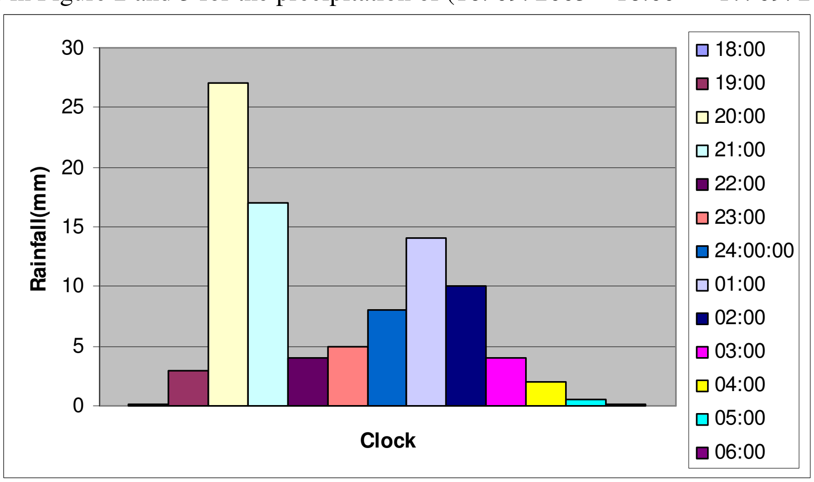

Figure 2. Total rainfall (16. 09. 2005)

Table 4. Scheme of the Sepidroud catchment (according to Figure 1)

Cascade	Area (km2)	Plane No.	Area (km2)	Average width (km)	Length (km)	Slope (–)%
DP 1	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
DP 2	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
DP 3	0.831	131	0.377	2.426	0.155	0.286
		132	0.362		0.149	0.254
		133	0.092		0.038	0.337
DP 4	3.600	141	0.474	3.938	0.120	0.348
		142	2.081		0.528	0.317
		143	1.045		0.265	0.278
DP 5	0.146	151	0.036	0.418	0.086	0.276
		152	0.110		0.263	0.363
		----	----		----	----
DP 6	0.811	211	0.153	2.733	0.056	0.280
		212	0.618		0.226	0.377
		213	0.040		0.015	0.172
DP 7	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
DP 8	0.598	231	0.115	1.794	0.064	0.344
		232	0.483		0.269	0.288
		----	----		----	----
DP 9	0.569	241	0.455	0.379	1.200	0.161
		242	0.114		0.301	0.364
		----	----		----	----
DP 10	0.680	251	0.438	1.127	0.389	0.179
		252	0.242		0.215	0.320
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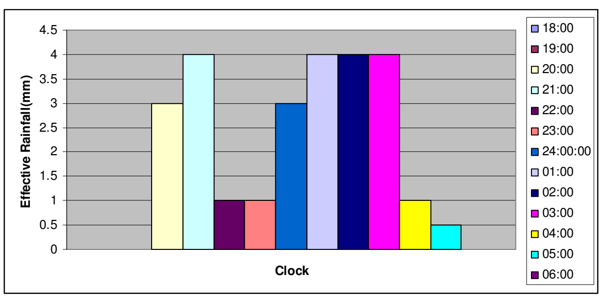

Figure 3. Effective rainfall (16. 09. 2005)

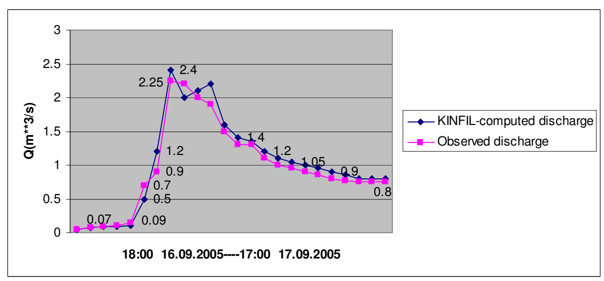

Figure 4. Measured and computed discharges of the KINFIL model (16. 09. 2005 18:00 ------17. 09. 2005 06:00)

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

According to figure 4, the computed peak of discharge by KINFIL model reached to 2.4 m3/s and the observed peak of discharge reached to 2.25 m3/s.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 figure 5 and 6 for the precipitation of (11. 10. 2006 15:00 ----12. 10. 2006 03:00).

The computed discharge by KINFIL model and observed discharge are compared in figure 7. According to Figure 7, the computed peak of discharge by KINFIL model reached to 1.9 m3/s and the observed peak of discharge reached to 1.8 m3/s.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.

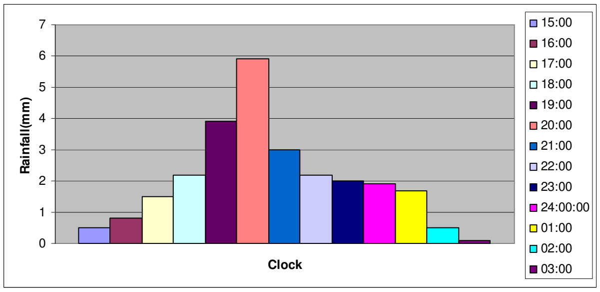

Figure 5. Total rainfall (11. 10. 2006)

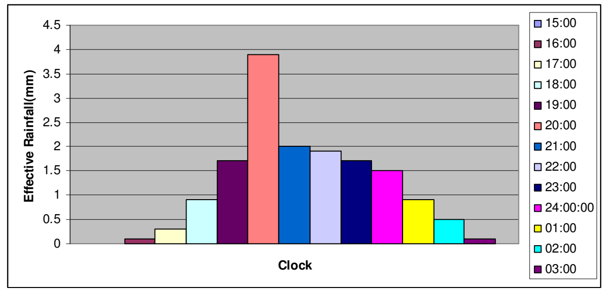

Figure 6. Effective rainfall (11. 10. 2006)

The KINFIL computation results, showed, the increase in design discharges (m3/s) 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 (Figure 8-10 and Table 5).

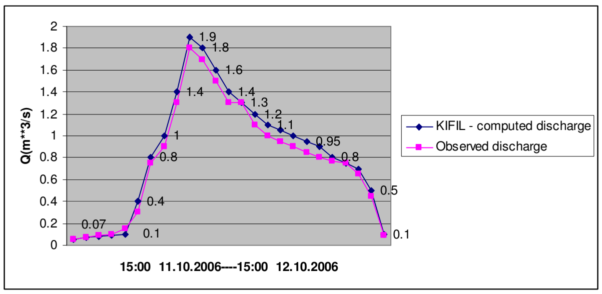

Figure 7. Measured and computed discharges of the KINFIL model (11. 10. 2006 15:00 ------11. 10. 2006 15:00)

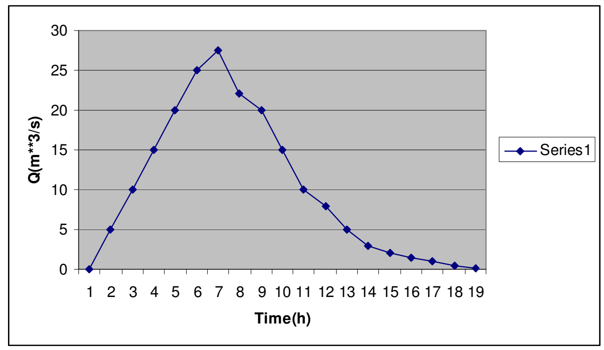

Figure 8. Computed discharges of the KINFIL model for deforestation 10% and td = 30min

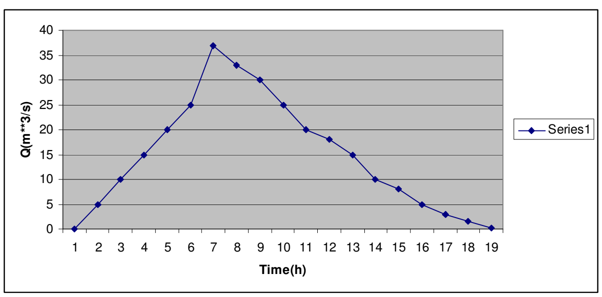

Figure 9. Computed discharges of the KINFIL model for deforestation 10% and td = 60min

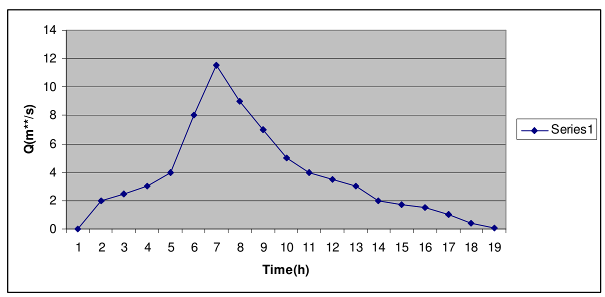

Figure 10. Computed discharges of the KINFIL model for deforestation 10% and td = 300min

Table 5. Design discharges (m3/s) in the Sepidroud catchment, return period of 100 years

	t_d= 30(min)	t_d= 60(min)	t_d= 300(min)
Runoff (m^3/s)	Q(m^3/s)	Q(m^3/s)	Q(m^3/s)
Forestation (10%)	27.5	37.8	11.65
Forestation (50%)	22.1	31.5	8.3
Forestation (90%)	18.5	20.5	6.4

CONCLUSIONS

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), the computed peak of discharge by KINFIL model reached to 2.4 m3/s and the observed peak of discharge reached to 2.25 m3/s.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), the computed peak of discharge by KINFIL model reached to 1.9 m3/s and the observed peak of discharge reached to 1.8 m3/s. 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 (m3/s) to 2.4(m3/s)(more than 14.5 times)with an event duration of td = 60 min, return period of 100 years.

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