Assessment of the Fire Effect on Water Balance Components Under Different Land Uses, Central Zagros, Iran Case Study

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Assessment of the fire effect on water balance components under different land uses, Central Zagros, Iran case study

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Abstract

Background: Fire occurrence may lead to a significant impact in many terrestrial ecosystems. This study attempted to evaluate the effects of fire on the water balance components in the Central Zagros, Iran. The study used two modeling frameworks, including WetSpa-M and Bayesian Belief Networks to investigate the effect of fire on the amount of runoff, groundwater recharge and evapotranspiration. The first part of the study was a water balance simulation at a monthly scale. In addition, a Bayesian belief networks was applied to explore and understand key issues affect in the water balance after fire. Calibration and validation of the WetSpa-M model was performed without considering the effect of fire (2000-2014) and then the model was run again to with the fire scenario by reducing manning roughness coefficient and increasing the θ coefficient.

Results: Calibration and validation were performed before finalizing the simulation. A Nash-Sutcliffe coefficient of 0.61 and 0.58 was obtained during the calibration and validation respectively. The analysis of the water balance components results depicted that fire has increased the amount of runoff and it has reduced the amount of groundwater recharge and actual evaporation especially in the sparse forest and poor, medium and good rangelands.

Conclusions: Water balance components of each class, i.e. sparse forest, poor, medium and good rangelands were different under fire/non-fire scenarios. The percentage of change in the water balance components were used for comparison. The results of Bayesian model for post-fire

scenario showed a significant increase in runoff due to reduced vegetation in the area. Both simulated groundwater recharge and surface flow have showed a reduction rate in the fire occurrence scenario. A similar conclusion was obtained from probabilistic Bayesian model due to reducing vegetation cover and surface changes. Actual evapotranspiration component for the poor rangeland has dropped off significantly. Therefore, there is a need for monitoring hydrologic dynamics of the lands with a high risk of burning.

Keywords: Biomass burning, Water budget, water cycle dynamics, WetSpa-M model.

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1. Introduction

Fire is a major negative factor for the most natural ecosystems along with urban excessive development of agricultural lands (Yin *et al.*, 2005). It is also one of the most important physical factors that affect many environmental processes (Thomazet *et al.*, 2014). These impacts mostly lead to changes in land cover and soil characteristics (Shakesby, 2011). In the case of wild fires, they not only reduce the land cover of the natural ecosystems, but also result in damages soil damaged soil due leads to an increased rain droplet exposure. Therefore, it has an important effect on hydrological conditions that are vital to soil loss by increasing hydrophobicity of the soil. There are some reports where burning of land surface reduces permeability (Hemmatboland *et al.*, 2010). This influences soil water balance as it can reduce the amount of infiltrated water (Madsen *et al.*, 2012), increase the surface flow, intensify the surface flow rate and has a high impact on partitioning of water compared to pre-firing conditions (De Bano, 2000; Benavides-

43 Solario and MacDonald, 2001&2005; Kunze and Stednick, 2006; Shakesby and Doerr, 2006;
44 Moody et al., 2009). The degree of change in water balance components depend on the surface
45 response and intensity of soil disorder (Heydari *et al.*, 2012). Even stability of soil structure may
46 be reduced due to slights (Mataix-Solera and Doerr, 2004) while the stability of soil structure
47 after severe fires may be more likely to lead to increasing bulk density and blockage of soil pores
48 (Martin and Moody, 2001; Badia and Marti, 2003). Certain changes in soil chemical
49 characteristics and soil regime is expected after severe wildfire (Kavdir *et al.*, 2005). For many
50 natural ecosystems, wild fire may lead to the change in structure and function of the ecosystems
51 (Bond and Keeley, 2005; Bahlakeh *et al.*, 2017). Wild fires are mostly due to human activities,
52 however they may also occur naturally. For instance, they might occur due to lightning (Leone *et*
53 *al.* 2009; Papakosta and Straub 2011). Wildfires also considered as a key environmental concern
54 for plant ecosystems (Renard *et al.*, 2012), where as they annually destroy million hectares of
55 ecosystems (FAO, 2010). Iran is ranked fourth in terms of forest fires in the Middle East and
56 North Africa (Adab *et al.*, 2011). For citing an example case according to the Iran Statistic
57 Center report, during the period between 2014 and 2018, as many as 9962 cases of fire have been
58 recorded in Iran, which caused the burning of approximately 78000 hectares of natural
59 resources (National Agricultural Statistics, 2014-2018). In terms of future perspectives, due to
60 climate change and human activities on land use, it is expected that this trend will continue and/or
61 will even increase in the future (Eskandari and Chuvieco, 2015). However, the risk of fire is not
62 the same during the wet and dry periods. The results of Black *et al.* (2016) showed that fires
63 increase during the dry season and decrease in the wet season. Increased wildfires can lead to
64 strict decrease in hydrological processes.

Fire has a significant effect on water budget. The study conducted by Flerchinger and Clark (2003) indicate the first year after the fire had less evaporation, more permeability in some areas, and runoff is left without significant changes as opposed to non-fires. Gonzalez-Pelayo *et al.* (2010) examined hydrological processes such as runoff and penetration from July 2002 to July 2004 on a plot scale in Spain. Their study showed that in the post-fire period, runoff was increased by 20% and water penetration to soil was reduced by 18%.

Gholami-Gohareh *et al.* (2012) have discussed the forest fire in the Mazandaran province of Iran caused an increase of 118 and 152 percent in both runoff and sedimentation, while they have reported while this has resulted in a 101.4 percent reduction of 18 percent in.

Results by Heydari *et al.* (2014) in the semi-steppe pastures of the Karsanak Basin in the Chaharmahal-Bakhtiari province in the western parts of Iran, demonstrated that fire caused a decrease of the soil organic in surface samples for the first and second years after the fire and reduced the mineralization of soil carbon in the surface layer, one year after the fire. They also stated the negative effects of fire land cover on soil properties in the first year after the fire were more considerable than the second or third years.

The aim of the current study is to investigate the relationship between fire and simulated water balance components using the WetSpa-M in the Karebas Basin, a high land located in the Central Zagros geographically. The applied model is a kind of distributed model that calculates the overall water balance for each cell from the independent sub-pixel water budget for each land cover including bare soil, water reservoirs and impermeable land. This means the model takes advantage of a heterogeneous land use for each cell instead of assuming a uniform area for each pixel (Batelaan and De Smedt, 2001). WetSpa-M was widely used for the change assessment in studies related to investigation of the impacts of land use changes on the groundwater systems,

simulation of water balance components (Paul, 2006;Pan *et al.*, 2011), investigation of the climate change effects on water resources (Woldeamlak *et al.*,2007; Wang *et al.*, 2015; Shrestha *et al.*, 2016; Kajewska-Szkudlarek *et al.*, 2017), assessment of the impacts of urbanization on water balance (Zhang *et al.*, 2017; Graf and Jawgiel, 2018),and studies related to the interaction between ground water and water balance components (Al Kuisi and El-Naqa, 2013; Gebreyohannes *et al.* 2013; Graf and Przybylek, 2014; Pandian *et al.*, 2014; Zarei *et al.*, 2016;Soleimani-Motlagh, 2017).

The occurrence of the fire phenomenon is a frequent event in the central Zagros region of Iran. Similar to other parts of the world, this destructive phenomenon has caused severe after effects to the environment and land cover of natural ecosystems in the region (Naghipour *et al.*, 2016).In the central Zagros region, especially within the Karebas region, the occurrence of fires in these habitats becomes more frequent during drought periods with the reduction in rainfall. This study attempts to investigate the cause and its impact of biomass burning on water balance components in the area of interest.

2. Materials and Methods

2.1. Study area

The Karebas Basin is located between 55° 26' - 56° 04' E longitude and 37° 25' -37° 47' N latitude with 2,825 km² area. This transboundary area is geographically situated between Chaharmahal-Bakhtiari and Esfahan provinces in the western part of Iran (Fig. 1). The basin is a mountainous region located in the center of the Zagros mountains with an elevation range of 1,760 m to 3,794 m. The area west of the basin is mostly mountainous with high altitude and the eastern parts consist of low-slopes and flat areas. The land cover of this study consist of poor

rangeland, moderate rangeland, and good rangeland with sparse forests that cover 25, 20, 4, and 26 percent of the basin area, respectively. According to the information released by of the Forest, Rangeland and Watershed Organization of the Iran, the canopy density in sparse forests and poor rangeland is 5 to 25 percent while the canopy density in the moderate rangeland varies in rang of 25 to 50 percent. For the good rangeland, this value is more than 50 percent.

Our field investigation indicates that for most fire cases, the cause is due to human factors. Previous reports also noted that the impact of human factors could possibly be related to the economic and social problems of the central Zagros region. There are several researches highlighting strong dependence of the resident people on the natural resources (*Bashari et al., 2016*).

Fig. 1.The location map of the Karebas basin in Iran.

2.2. WetSpass-M Model description

124 The WetSpass¹ model was developed by the Hydrological and Hydraulic Institute of the
 125 University of Brussels to predict the transfer of water and energy between soil, plant, and
 126 atmosphere in a quasi-steady state. The first version of this model was based on time and
 127 dependent on the spatial distribution model of the WetSpa water balance (Wang *et al.*, 1997)
 128 which is used to predict hydrological processes in a distributed methodology. The original model
 129 was scripted in ArcView software and based on annual and seasonal time scales (Al Kuisi and El-
 130 Naqa, 2013). A newer model version was developed by Abdollahi *et al.* (2012) named
 131 WetSpass-M with the ability of simulating interception, runoff, evapotranspiration, soil water
 132 balance, and groundwater recharge at a monthly time scale. The recent version of the model is
 133 independent of the ArcView software. While the original model was designed for temperate
 134 regions, WetSpass-M has been developed to simulate water balance in arid and semi-arid
 135 regions. The model is capable of simulating the long-term temporal and spatial variations of
 136 water balance components, including runoff, actual evapotranspiration, and groundwater
 137 recharge (Wang *et al.*, 2015). One of the capabilities of this model is to study the effect of land
 138 use and climate change on groundwater recharge systems, investigating the effect of climate
 139 change on the spatial and temporal patterns of water resources by estimating the components of
 140 water balance. In this methodology, the overall water balance for a grid cell is calculated from
 141 water budget for vegetated area, bare soil, open water/reservoirs, and impervious surface of each
 142 cell (Batelaan and De Smedt, 2001):

$$ET_{raster} = a_v ET_v + a_s ET_s + a_o ET_o + a_i ET_i \quad \text{Eq. 1}$$

$$S_{raster} = a_v S_v + a_s S_s + a_o S_o + a_i S_i \quad \text{Eq. 2}$$

$$R_{raster} = a_v R_v + a_s R + a_o R_o + a_i R_i \quad \text{Eq. 3}$$

¹Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-steady state

143

144 Where ET_{raster} , S_{raster} and R_{raster} values are evapotranspiration, surface runoff, and groundwater
 145 recharge respectively (all units expressed in millimeters), a_v , a_s , a_o and a_i are related to areas of
 146 vegetated cover, bare soil, open water/reservoirs and impervious surface of the grid the cell
 147 respectively. The water balance in this model is defined as:

$$P = I + S_v + T_v + R_v \quad \text{Eq. 4}$$

148

149 Where P , I , S_v , T_v , and R_v are precipitation, interception, surface runoff, evapotranspiration and
 150 groundwater recharge respectively (all in millimeters) (Abdollahi *et al.*, 2017). The amount of
 151 runoff in this model is calculated via Equation 5:

$$SR_m = C_{sr} C_h (P_m - I_m) \quad \text{Eq. 5}$$

$$C_h = P_m / LP (P_m^\alpha + ET_m^\alpha)^{1/\alpha} \quad \text{Eq. 6}$$

$$C_{sr} = C_{wp} \bar{P}_{24} / C_{wp} \bar{P}_{24} - RCD \times C_{wp} + RCD \quad \text{Eq. 7}$$

$$C_{wp} = (1 - A_{Imp}/100) C_{per} + (A_{Imp}/100) C_{Imp} \quad \text{Eq. 8}$$

$$C_{per} = W1(0.02/n) + W2(\theta_w/(1 - \theta_w)) + W3(S_p/(10 + S_p)) \quad \text{Eq. 9}$$

$$C_{Imp} = 0.9 e^{0.024 A_{Imp}} \quad \text{Eq. 10}$$

152

153 Where SR_m , P_m , and I_m are the amount of surface runoff, precipitation and monthly interception
 154 respectively (all in millimeters). C_h is a descriptive coefficient of soil moisture content
 155 (dimensionless) that is calculated from equation 6; when the potential evapotranspiration is
 156 greater than the monthly precipitation, otherwise the value of C_h is equal to 1.

ET_m , LP , as well as α are potential evapotranspiration (in mm/month), the dimensionless calibration coefficient of effect of evapotranspiration on surface runoff and evapotranspiration coefficient respectively.

C_{sr} , C_{wp} , RCD , A_{Imp} , C_{per} , C_{Imp} , n , and S_{pare} also the actual runoff coefficient (dimensionless), potential runoff coefficient, average daily precipitation (millimeter per day in month), level of regional consecutive dryness (in millimeters), permeable area, runoff coefficient of permeable areas, runoff coefficient of impermeable areas, Manning roughness coefficient, volumetric moisture content of soil at the wilting point, and the gradient of the land's surface in percent, respectively. W_1 , W_2 and W_3 represent three constituent weights for C_{per} , namely the slope factor, land use factor, and soil texture factor (Abdollahi, 2015). In order to give more importance to the land surface characteristics in the fire processes, the values of 0.2, 0.4 and 0.4 coefficients, were selected for these weights, respectively.

Groundwater recharge, R_m was obtained as the residual of the water balance in WetSpass-M (Eq. 11). Monthly base-flow for each cell based on the previous month's storage and groundwater recharge in the current month are calculated via equation 12 (Abdollahi *et al.*, 2017):

$$R_m = P_m - SR_m - ET_m \quad \text{Eq. 11}$$

$$Q_{b(t)} = \beta Q_{b(t-1)} + 0.001 N_m (1 - \beta) \emptyset R_m \quad \text{Eq. 12}$$

Where β is the storage parameter (between zero and one), $Q_{b(t-1)}$ is the previous month's base-flow (in cubic meter per month), N_m the number of days per month and $\emptyset$ the contributing parameter in recharge for the current base-flow in square meters per day (Arnold And Allen, 1999).

177

178 **2.3. Water balance model data requirements**

179 The input data requirements for the water balance model include soil texture maps, land use,
180 slope, elevation digital model, evaporation from the pan, precipitation, number of rainy days,
181 groundwater depth, temperature, wind speed at a height of two meters, and the depth of
182 groundwater. The data in this research were collected from the Ministry of Energy, the Natural
183 Resources and Watershed Management office and the regional water company of Chaharmahal-
184 Bakhtiari province, the Regional Water Organization of Isfahan, and the Meteorological
185 Organization of Iran. Then monthly maps were rasterized using the Kriging interpolation
186 method. The number of rainy days and degree day were also calculated as a spatial average. The
187 time series of leaf area index and snow maps are also were used in the modeling. The snow cover
188 maps were collected using the temperature index method and the leaf area index collected from
189 the MODIS website as ASCII raster maps.

190 The volumetric values of surface water discharge were used to compare simulated results with its
191 observational values. The gauge station discharge values were separated into surface and base-
192 flow (Willems, 2009) using a recursive digital filter method (WHAT software) which the
193 equation of this method is presented in the following equation (Eckhardt, 2008).

$$q_t = (1 - BFI_{max})\alpha \times q_{t-1} + (1 - \alpha)BFI_{max}Q_t / 1 - \alpha BFI_{max} \quad \text{Eq. 13}$$

194

195 Where q_t is the filtered base-flow at time t , q_{t-1} is the filtered base-flow at time $t-1$ and Q_t is the
196 total flow at time t (all in m^3/s), α the constant recession curve and BFI_{max} is the maximum value
197 of the base-flow index. The filter considers both the hydrological characteristics of the flow and

the basin (Eckhardt, 2008). The method requires the determination of two parameters; the fixed recession curve for the catchment area and the maximum value of the base-flow index. In this study, α and BFI_{max} are 0.75 and 0.36 respectively.

Fig. 2. A schematic view of the input maps.

2.4. Field sampling

In different parts of the region, both intentional and non-intentional fires have occurred throughout the past several years. Since variation of the land cover are affected by fire sites in each study, land use including good, medium and poor rangelands, as well as forest (total 12 sites) were visited for one-year fire. The term one-year fire refers to a location that fire has occurred over one year before the sampling. For each fire occurrence area, appear no fire area (control) was identified adjacent to the sampling area. Figures 3 and 4, show images of different land cover in the control and fire areas respectively. The stratified random sampling method was used after preliminary identification and determination of study sites. In each sampling site, 20

plots of 4 square meters were installed which 10 plots in the fire area and 10 plots in the control area. The canopy cover percentage of each plant species was recorded.

Fig. 3.An example of the land cover in the control area.

Fig. 4. An example of the land cover in the fire area.

2.5.Modeling Method

As previously explained, WetSpass-M methodology was adopted to simulate monthly water balance. The period of calibration and validation was for 2004-2014 and 2000-2003, respectively.

After parameterization of the water balance model, two scenarios were used to perform modeling

the water balance. The first scenario was the modeling of water balance under non-fire conditions, which the model applied using the prepared maps with no consideration of fire and the second scenario was related to water balance modeling considering the occurrence of fire. Since fire has a significant impact on land surface features, two time series of LAI monthly maps were used, in order to consider the effect of fire on land cover on the base field collected fire/no fire data. The land cover percentage was adopted based on the control and fire areas and decreasing coefficients were used to capture leaf area index values for land cover after the fire in the sparse forests, poor, medium and good rangelands. Literature review of Stoof *et al.* (2015) showed that the fire reduced the Manning soil roughness coefficient. Manning's roughness decreased by 56% in this study, which was applied for modeling water balance in the second scenario. A similar procedure was used for the soil parameter of θ , where the land cover was sparse forests, poor, medium, and good rangelands. Lastly, the simulated values for water balance components in both scenarios were compared.

2.6. Evaluation of water balance model efficiency

The model outputs included runoff maps, actual evapotranspiration and groundwater recharge, along with average values of these outputs. In this study, the performance of the model was evaluated by using the Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970) which was calculated as follows:

$$ENS = 1 - \Sigma(Q_{obs} - Q_{sim})^2 / \Sigma(Q_{obs} - \overline{Q_{obs}})^2 \quad \text{Eq. 14}$$

Where Q_{obs} is the observed flow, Q_{sim} is the estimated flow, $\overline{Q_{obs}}$ is the average of the observed flow, and $\overline{Q_{sim}}$ is the average of the estimated flow.

2.7. Bayesian belief networks modeling

In order to assess the fire effect on water balance components, a Bayesian Belief Networks (BBN) methodology was applied. Bayes' rule provides an underpinning for the inferential mechanisms for prediction and diagnosis describing both positive and negative impacts of fire on the water balance components using BBNs. Netica software version 5.15 (Norsys Software Corporation 2014) was used for this purpose. BBNs are mathematical and visual models that provide a better understanding of cause-and-effect relationships among the contributing variables. In a BBN, each variable is represented by a node, in order that the number of nodes indicates the number of variables involved in the modeling. Each node contains a discrete set of states and the information about the meaningful relationships as a set of conditional probability. For each node, a set of states may be specified. The graphical representation of BBN contains a number of variables/nodes and their directed edges/causal relationships. If no edge exists between two nodes, then this implies the state is conditionally independent. After factorizing the joint probability distribution for interconnected variables, a directed acyclic graph (DAG) was established. By structuring the available information and expert opinion a network diagram was created.

Mutual information analysis method was used to rank the degree of individual and conjoint influence of each input on output. Mutual information is a measure that determines to what extent one variable can express to the other one. In Bayesian models, this is a useful indicator to find the variables that strongly affect the behavior of the system or the variables where the system is not very sensitive to their change. Through sensitivity analysis of developed BBN, the most critical factors in the soil water balance were determined. Using this framework, the state of water balance components considering with/without the effect of fire on vegetation and soil was

investigated. Table 1 shows the sources information and independent variables used in the model. The containing variables in this table are based on the variables used in WetSpas-M.

Table 1. Description of independent variables and their sources used in the BBN model

Variable	Type	States (classes)
Water Balance in Soil	Discrete	Very Dry, Dry, Normal, Wet, Very Wet
Mean Annual Temperature	Continuous	Low (<12°C), Medium (12-16°C), High (>16°C)
Potential evaporation	Continuous	Low (<1500 mm), Medium (1500-3000 mm), High (>3000 mm)
Mean Annual Precipitation	Continuous	Low (<250 mm), Medium (250-500 mm), High (>500 mm)
Wind Speed	Continuous	Low (<6 nut), Medium (6-16 nut), High (>16 nut)
Slope	Continuous	Gentle (<5°), Moderate (5-15°), Steep (>15°)
Percentage of vegetation	Continuous	Low (<25 %), Medium (25-50 %), High (>50 %)
Elevation	Continuous	Low (<1000 m), Medium (1000-2000 m), High (>2000 m)
Manning coefficient	Continuous	Low (<0.05), Medium (0.05-0.1), High (>0.1)
Soil texture	Discrete	Sand, Loam, Clay
Landuse	Discrete	Dense range, Moderately dense range, Sparse range, Cultivated land, Bare rock water urban, Forest
Interception	Continuous	Low (<10 mm/day), Medium (10-20 mm/day), High (>20 mm/day)
Runoff	Continuous	Low, Medium, High
Actual evaporation	Continuous	Low (<10% Mean Annual Precipitation), Medium (±10%

		Mean Annual Precipitation), High (>10% Mean Annual Precipitation)
Infiltration	Continuous	Low, Medium, High

3. Results and discussion

The graph of the base-flow separation from the daily total flow for measured discharges over the period of 2000-2014 at the Karebas Hydrometric Station is shown in Fig.5. By means of a trial and error method, the initial calibration process of the water balance model was carried out manually. The optimized parameters for calibration are presented in Table 2. For these optimal values, the Nash–Sutcliffe efficiency coefficient and the determination coefficient were used to evaluate the model's performance in a direct runoff simulation. The baseline flow and total flow of the studied basin in the calibration and validation periods are presented in Table 3. The value of Nash-Sutcliff coefficient for the flow of the entire basin for calibration and validation period were 0.61 and 0.58, respectively. According to the table, simulated flow is reliable (based on Gitau and Chaubey, 2010).

Fig. 5. The separation hydrograph of the base-flow from total flow from studied watershed.

Table 2. The optimal parameters of water balance model at calibration stage.

Parameter	Parameter characteristic	Optimum value
Interception	a	2.5
Evapotranspiration	α	0.8
Surface runoff	LP	2.8
Snow melting Factor	MF	0.02
Surface runoff	X	0.7
Base-flow	β	0.63
Nutrition Participant	$\emptyset$	0.149

Table3. The results of statistical criteria for calibration and validation periods.

Period	Parameter	ENS	R ²
Calibration	Direct runoff	0.62	0.64
	Base-flow	0.6	0.62

		Total flow	0.61	0.65
		Direct runoff	0.51	0.52
Validation		Base-flow	0.67	0.7
		Total flow	0.58	0.59

292

293 3.1. Surface and sub-surface flow simulation

294 Fig. 6 shows the observed and simulated hydrograph of the Karebas watershed. The missing part
295 in the graph is related to unavailability of discharge data of Karebas Hydrometric Station. As the
296 figure also shows, in wet months the simulated flow rate are greater than the observational
297 values. Although there is a difference between observation and simulation flows, in some peak
298 flow in the hydrograph, in some other cases the model has captured the peak well
299 (simulated hydrograph in February 2006). On average, the highest simulation errors belong to
300 March and April, when the simulated discharge is typically less than the observational values. In
301 these months, a combination of rainfall and the air warming leads to quick snow melt. This
302 means the degree-day snow melt has shown a functional limitation over this period of
303 simulation. The lowest flow simulation error belongs to September, which the model has
304 simulated the flow of the basin with slight differences. In general, the simulated flow of the
305 model has followed the trend of observational flow changes at Karebas watershed outlet.

Fig. 6. Simulated and observed flow hydrograph in Karebas Hydrometric Station.

3.2. The effect of fire on the components of water balance

The results of the percentage changes for fire/non-fire scenarios in runoff, groundwater recharge and evaporation in millimeters were shown in Table 4. According to the results, by applying the fire scenario, the average amount of runoff in the basin increased by 13.5% and the actual evapotranspiration and groundwater recharge decreased by 4.45% and 52.2% respectively. Fig. 7 also shows the percentage of changes in the water balance components after applying the fire effects. Under this condition, the amount of actual evaporation and groundwater recharge in all land use classes (poor, moderate, and good rangelands and sparse forest) were decreased while the amount of runoff was increased. The highest percentage of variation can be seen in the amount of actual evaporation. This result is in agreement with the study of Black *et al.* (2016) that post-fire evapotranspiration was significantly reduced in all three types of land cover, including grasslands, savanna, and croplands. As shown in Fig. 7, the greatest reduction in actual evapotranspiration belongs to poor, moderate, good rangelands and sparse forest. The reason for this sharp change can be related to the type of land cover and its coverage characteristics. In poor

rangelands, it may lose the most of vegetal cover and a major reduction in evaporation and interception may be seen after fire occurrence. In contrast, for forest lands, unless the intensity of the fire is extensive due to stronger land cover, remaining materials and renewed coverage increase after fire occurrence. The type of land utilization also has a great impact. For example, poor and medium rangelands are exposed to severe and moderate grazing respectively, whereas in good rangelands, grazing is usually light. This is why the restoration of land cover may be accelerated in good rangelands while this takes a much longer time in poor rangelands. After the degradation of land cover, due to the formation of an impermeable layer, the amount of infiltrated water into the soil decreases, thus the runoff increases. Letey (2001) and Shakesby and Doerr (2006) reported transmissibility as the responsible cause of reduction of infiltration. Gholami-Gohareh *et al.* (2012) stated an increment in fine particles like residual ash may be responsible to filling the pores and reduction in permeability of the burnt soil under the bush cover. Reduction of permeability due to mild and severe fire is reported in some other studies as well (interested readers refer to Robichaud (2000), Martin and Moody (2001), Gonzalez-Pelayo *et al.* (2010), and Robichaud *et al.* (2016)). There was also little difference in the percentage of groundwater recharge. Jafarian and Sepehri (2018), stated that the intensity of the fire affects the amount of final infiltration of the soil. Infiltration after the mild and control fire was no different. This may be because of what little remains on the surface of the soil acts like land cover in the treatment without fire. However, in the severe fire, the entire land cover is greatly impacted resulting in more water contributing to runoff instead of infiltration.

Table 4. Long-term values and their percentage change for water balance components under fire/none-fire scenarios.

Water balance components	Evapotranspiration	Runoff	Recharge
	(mm)	(mm)	(mm)
Before fire	1357.09	1202.88	4074.61
After fire	1296.72	1365.24	3971.89
Percentage of changes	-4.45%	13.5%	-2.52%

Fig.7. The variation of water balance components in different uses after the fire in the study basin.

3.3. The results of BBN modeling

The graphical representation of BNN modeling for the first and second scenarios are shown in Fig. 8 and Fig.9. The bar graph in Fig. 10 shows the probability distribution of each node changing according to its conditional probability. For the first scenario where (no fire) with a high percentage of vegetation and manning coefficient, the soil water reaches to 58.3% under the wet and very humid states (Fig. 8). For the second scenario where the fire reduces both percentage of vegetation cover and Manning coefficient, soil water dropped to 46.7% (dry

condition) (Fig. 9). The reason for this reduction is less flow resistance due to reducing the surface roughness coefficient. This leads to an increased runoff coefficient and a reduced infiltration into the soil. The sensitivity analysis of the Bayesian model showed that runoff acts as the major affecting factor on soil water balance (50.36%) followed by land use (10.49%), and infiltration (10.12%). Therefore, after the fire occurrence, vegetation cover decreases and runoff coefficient increases significantly. As seen from the changes in the simulated water balance components under two scenarios by WetSpss-M, the highest percentage of change in water balance components belongs to the surface runoff 13.5% (Table 4).

Fig. 8. Soil water balance BBN model for no-fire scenario

Fig.9. Soil water balance BBN model for the fire scenario

Fig. 10. The results of sensitivity analysis of the factors sorted in descending order

4. Conclusion

373 Comparison of the observed and simulated hydrographs by water balance model showed that the
374 model was able to simulate streamflow components of Karebas watershed with satisfactory
375 accuracy. The greatest difference between observed and simulated flow rates is related to high
376 flows occurring in March and April. A possible explanation for this might be because the basin is
377 relatively mountainous and, during cold months, precipitation mostly falls in the form of snow.
378 With increasing temperature during spring, snowmelt could be intensified. It seems that the
379 internal degree-day module of WetSpa-M may not be able to capture intensified snowmelt runoff.

380 The results of the analysis of water balance components according to two scenarios showed that
381 the fire has a reduced groundwater recharge (Groundwater recharge, soil moisture and subsurface
382 flow). A similar conclusion also was concluded from Bayesian analysis. The BBN model also
383 produced a significant increase in runoff by reducing vegetation cover and roughness coefficients
384 comparing non-fire scenario with fire scenarios. Analysis of water balance components of
385 different land use classes shows that actual evapotranspiration (interception, transpiration from
386 plants and soil evaporation) has been decreased remarkably in the poor rangeland. The reason for
387 this effect is that the removal of vegetated cover has caused minimal plant transpiration.

388 Seeing that sparse forest class contains less vegetated coverage, it is expected to lose less biomass
389 after the occurrence of a fire, unless the intensity of the fire be very extensive. One of the reasons
390 for reducing groundwater recharge and increasing runoff in the basin after the fire occurrence
391 could be the removal of the land cover factor. Land cover has a direct relationship with infiltration
392 and permeability of the soil, hence it decreases the runoff rate. The results of this study were not
393 able to find a great difference among the percentage of runoff and groundwater recharge
394 variations in different land uses. A possible reason for this might be due to the different intensity
395 of fire in different land uses.

396

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400 **References**

- 401 1. Abdollahi, K., Bashir, I. and Batelaan, O., 2012. WetSpass graphical user interface.
402 Cartography of Higher Swiss Education. Version 31-05-2012. Vrije Universiteit Brussel.
403 Department of Hydrology and Hydraulic Engineering. Belgium. 10p.
- 404 2. Abdollahi, K., 2015. Basin scale water balance modeling for variable hydrological regimes
405 and temporal scales. Ph.D. Vrije Universiteit Brussel, Belgium.
- 406 3. Abdollahi, K., Bashir, I., Verbeiren, B., Harouna, M.R., Van Griensven, A., Huysmans, M.
407 and Batelaan, O., 2017. A distributed monthly water balance model: formulation and
408 application on Black Volta Basin. Environ Earth Sci. 76 (198), 1-18.
409 <https://doi.org/10.1007/s12665-017-6512-1>.
- 410 4. Adab, H., Kanniah, D. and Solaimani, K., 2011. GIS-based probability assessment of fire
411 risk in grassland and forested landscapes of Golestan Province, Iran. In International
412 conference on environmental and computer science IPCBEE. Singapore. 19, 170-175.
- 413 5. Al Kuisi, M. and El-Naqa, A., 2013. GIS based spatial groundwater recharge estimation in
414 the Jafr basin, Jordan-application of WetSpass models for arid regions. Rev Mex Cinc
415 Geol. 30(1), 96-109.
- 416 6. Arnold, J.G. and Allen, P.M., 1999. Automated methods for estimating baseflow and
417 ground water recharge from streamflow records 1. J Am Water Resour As. 35(2), 411-
418 424.<https://doi.org/10.1111/j.1752-1688.1999.tb03599.x>.

7. Badia, D. and Marti, C., 2003. Plant ash and heat intensity effects on chemical and physical properties of two contrasting soils. *Arid Land Res Manag.* 17(1), 23-41. <https://doi.org/10.1080/15324980301595>.
8. Bahlakeh, K., Abedi, M. and Dianati Tilaki, G., 2017. Competition effects of *Onobrychis cornuta* changes between exposures and fire (Case Study Golestan Natural Park). *Rangeland J.* 11(3), 342-352. (In Persian).
9. Bashari, H., Naghipour, A.A., Khajeddin, S.J., Sangoony, H. and Tahmasebi, P., 2016. Risk of fire occurrence in arid and semi-arid ecosystems of Iran: an investigation using Bayesian belief networks. *Environ Monit Assess.* 188(9), 531. <https://doi.org/10.1007/s10661-016-5532-8>.
10. Batelaan, O. and De Smedt, F.L.O.R.I.M.O.N.D., 2001. WetSpa: a flexible, GIS based, distributed recharge methodology for regional groundwater modelling. *IAHS Publication.* 269, 11-18.
11. Benavides-Solorio, J. and MacDonald, L.H., 2001. Post-fire runoff and erosion from simulated rainfall on small plots, Colorado Front Range. *Hydrol Process.* 15(15), 2931-2952. <https://doi.org/10.1002/hyp.383>.
12. Benavides-Solorio, J.D. and MacDonald, L.H., 2005. Measurement and prediction of post-fire erosion at the hillslope scale, Colorado Front Range. *Int J Wildland Fire.* 14(4), 457-474. <https://doi.org/10.1071/WF05042>.
13. Binam. 2014-2018. Agricultural Statistics, ICT Center, Ministry of Agricultural Jihad.
14. Black, F.W., Lee, J., Ellison, L., Gupta, M., Bolten, J.D., Gatebe, C.K., and Ichoku, C.M. 2016. Biomass burning and its relationship with water cycle dynamics of the Chari-Logone catchment of Lake Chad Basin. In AGU Fall Meeting Abstract.

15. Bond, W.J. and Keeley, J.E., 2005. Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. *Trends Ecol Evol.* 20(7), 387-394. <https://doi.org/10.1016/j.tree.2005.04.025>.
16. DeBano, L.F., 2000. The role of fire and soil heating on water repellency in wildland environments: a review. *J Hydrol.* 231, 195-206. [https://doi.org/10.1016/S0022-1694\(00\)00194-3](https://doi.org/10.1016/S0022-1694(00)00194-3).
17. Eckhardt, K., 2008. A comparison of baseflow indices, which were calculated with seven different baseflow separation methods. *J Hydrol.* 352(1-2), 168-173. <https://doi.org/10.1016/j.jhydrol.2008.01.005>.
18. Eskandari, S. and Chuvieco, E., 2015. Fire danger assessment in Iran based on geospatial information. *Int J Appl Earth Obs.* 42, 57-64. <https://doi.org/10.1016/j.jag.2015.05.006>.
19. Flerchinger, G.N. and Clark, P.E., 2003. Potential hydrologic response to a prescribed fire on a small mountainous watershed. In *First Interagency Conference on Research in the Watersheds-2003 ASAE Annual Meeting* (pp. 631-636).
20. Food and Agriculture Organization of the United Nations. Forestry Department (Rome), 2010. *Global forest resources assessment 2010: Main report*. Food and Agriculture Organization of the United Nations.
21. Gebreyohannes, T., De Smedt, F., Walraevens, K., Gebresilassie, S., Hussien, A., Hagos, M., Amare, K., Deckers, J. and Gebrehiwot, K., 2013. Application of a spatially distributed water balance model for assessing surface water and groundwater resources in the Geba basin, Tigray, Ethiopia. *J Hydrol.* 499, 110-123. <https://doi.org/10.1016/j.jhydrol.2013.06.026>.

22. Gholami-Gohareh, R., Sadeghi, H. And Mirna, Kh., 2012. The effect of mild fires on penetration, runoff and sediment yield of pasture in Kadir area. *Iranian Journal of Watershed Management Sciences and Engineering*. 5(17), 23 to 32.
23. Gitau, M.W. and Chaubey, I., 2010. Regionalization of SWAT model parameters for use in ungauged watersheds. *Water*. 2(4), 849-871. <https://doi.org/10.3390/w2040849>.
24. Gonzalez-Pelayo, O., Andreu, V., Gimeno-Garcia, E., Campo, J. and Rubio, J.L., 2010. Effects of fire and vegetation cover on hydrological characteristics of a Mediterranean shrubland soil. *Hydrol Process*. 24(11), 1504-1513. <https://doi.org/10.1002/hyp.7612>.
25. Graf, R. and Przybyłek, J., 2014. Estimation of shallow groundwater recharge using a GIS-based distributed water balance model. *Quaestiones Geographicae*. 33(3), 27-37. <https://doi.org/10.2478/quageo-2014-0027>.
26. Graf, R. and Jawgiel, K., 2018. The Impact of the Parameterisation of Physiographic Features of Urbanised Catchment Areas on the Spatial Distribution of Components of the Water Balance Using the WetSpa Model. *ISPRS Int J Geo-Inf*. 7(7), 278. <https://doi.org/10.3390/ijgi7070278>.
27. Hemmatboland, I., Akbarinia, M. and Shafiei, A.B., 2010. The effect of fire on some soil chemical properties of oak forests in Marivan region. *Iran J For Pop Res*. 18(2), 205-218.
28. Heydari, J., GHORBANI, D.S., Raiesi, F. and Tahmasebi, P., 2014. Effect of rangeland fire on soil physical properties and water infiltration parameters using principle component analysis. *Journal of Water and Soil*. 28(5), 964-975. (In Persian).
29. Heydari, M., Salehi, A., Mahdavi, A. and Adibnejad, M., 2012. Effects of different fire severity levels on soil chemical and physical properties in Zagros forests of western Iran. *Folia Forestalia Polonica*. 54 (4), 241-250.

30. Jafarian, Z. and Sepehri, Z., 2018. The Effect of Fire Severity on Soil Permeability Components in Different Seasons (Case Study: Cherat Rangeland Watershed of Mazandaran Province). *Watershed Management Research*. 9(17), 206-215. (In Persian).
31. Kajewska-Szkudlarek, J., Kubicz, J., Kajewski, I. and Dąbek, P., 2017. Ocena zasobów odnawialnych wód podziemnych Pomorza Zachodniego na podstawie modelu symulacyjnego WetSpa. *Przegląd Geologiczny*. 65(11/1), 1080-1084.
32. Kavdir, Y., Ekin, H.U.S.E.Y.I.N., Yuksel, O. and Mermut, A.R., 2005. Soil aggregate stability and ¹³C CP/MAS-NMR assessment of organic matter in soils influenced by forest wildfires in Canakkale, Turkey. *Geoderma*. 129(3-4), 219-229. <https://doi.org/10.1016/j.geoderma.2005.01.013>.
33. Kunze, M.D. and Stednick, J.D., 2006. Streamflow and suspended sediment yield following the 2000 Bobcat fire, Colorado. *Hydrological Processes: An International Journal*. 20(8), 1661-1681. <https://doi.org/10.1002/hyp.5954>.
34. Leone, V., Lovreglio, R., Martín, M.P., Martínez, J. and Vilar, L., 2009. Human factors of fire occurrence in the Mediterranean. In *Earth observation of wildland fires in Mediterranean ecosystems* (pp. 149-170). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-01754-4_11.
35. Letey, J., 2001. Causes and consequences of fire-induced soil water repellency. *Hydrological Processes*. 15(15), 2867-2875. <https://doi.org/10.1002/hyp.378>.
36. Madsen, M.D., Petersen, S.L., Fernelius, K.J., Roundy, B.A., Taylor, A.G. and Hopkins, B.G., 2012. Influence of soil water repellency on seedling emergence and plant survival in a burned semi-arid woodland. *Arid Land Research and Management*. 26(3), 236-249. <https://doi.org/10.1080/15324982.2012.680655>.

37. Martin, D.A. and Moody, J.A., 2001. Comparison of soil infiltration rates in burned and unburned mountainous watersheds. *Hydrol Process.* 15(15), 2893-2903. <https://doi.org/10.1002/hyp.380>.
38. Mataix-Solera, J. and Doerr, S.H., 2004. Hydrophobicity and aggregate stability in calcareous topsoils from fire-affected pine forests in southeastern Spain. *Geoderma.* 118(1-2), 77-88. [https://doi.org/10.1016/S0016-7061\(03\)00185-X](https://doi.org/10.1016/S0016-7061(03)00185-X).
39. Moody, J.A. and Martin, D.A., 2009. Synthesis of sediment yields after wildland fire in different rainfall regimes in the western United States. *Int J Wildland Fire.* 18(1), 96-115. <https://doi.org/10.1071/WF07162>.
40. Naghipour, A.A., Bashari, H., Khajeddin, S.J., Tahmasebi, P. and Iravani, M., 2016. Effects of smoke, ash and heat shock on seed germination of seven species from Central Zagros rangelands in the semi-arid region of Iran. *Afr J Range For Sci.* 33(1), 67-71. <https://doi.org/10.2989/10220119.2015.1119194>.
41. Nash, J.E. and Sutcliffe, J.V., 1970. River flow forecasting through conceptual models part I-A discussion of principles. *J Hydrol.* 10(3), 282-290. [https://doi.org/10.1016/0022-1694\(70\)90255-6](https://doi.org/10.1016/0022-1694(70)90255-6).
42. Pan, Y., Gong, H., ZHou, D., Li, X. and Nakagoshi, N., 2011. Impact of land use change on groundwater recharge in Guishui River Basin, China. *Chin Geogr Sci.* 21, 734-743. <https://doi.org/10.1007/s11769-011-0508-7>.
43. Pandian, M., Rajasimman, U.A.B. and Saravanavel, J., 2014. Identification of Groundwater Potential Recharge Zones using WETSPASS Model in Parts of Coimbatore and Tiruppur Districts in Tamil Nadu, India. *International Journal of Water Research, Universal Research Publications.* 2(1), 27-32.

44. Papakosta, P. and Straub, D., 2011. Effect of weather conditions, geography and population density on wildfire occurrence: a Bayesian network model. In M. H. Faber, J. Kohler, & K. Nishijim (Eds.), Applications of statistics and probability in civil engineering. p.93.
45. Paul, M.J., 2006. Impact of land-use patterns on distributed groundwater recharge and discharge. Chin Geograph Sc. 16(3), 229-235. <https://doi.org/10.1007/s11769-006-0229-5>.
46. Renard, Q., Pélissier, R., Ramesh, B.R. and Kodandapani, N., 2012. Environmental susceptibility model for predicting forest fire occurrence in the Western Ghats of India. Int J Wildland Fire. 21(4), 368-379.<https://doi.org/10.1071/WF10109>.
47. Robichaud, P.R., 2000. Fire effects on infiltration rates after prescribed fire in Northern Rocky Mountain forests, USA. J Hydrol. 231, 220-229. [https://doi.org/10.1016/S0022-1694\(00\)00196-7](https://doi.org/10.1016/S0022-1694(00)00196-7).
48. Robichaud, P.R., Wagenbrenner, J.W., Pierson, F.B., Spaeth, K.E., Ashmun, L.E. and Moffet, C.A., 2016. Infiltration and interrill erosion rates after a wildfire in western Montana, USA. Catena. 142, 77-88. <https://doi.org/10.1016/j.catena.2016.01.027>.
49. Shakesby, R.A. and Doerr, S.H., 2006. Wildfire as a hydrological and geomorphological agent. Earth-Sci Rev. 74(3-4), 269-307. <https://doi.org/10.1016/j.earscirev.2005.10.006>.
50. Shakesby, R.A., 2011. Post-wildfire soil erosion in the Mediterranean: review and future research directions. Earth-Sci Rev. 105(3-4), 71-100. <https://doi.org/10.1016/j.earscirev.2011.01.001>.
51. Shrestha, S., Bach, T.V. and Pandey, V.P., 2016. Climate change impacts on groundwater resources in Mekong Delta under representative concentration pathways (RCPs) scenarios. Environ Sci Policy. 61, 1-13.<https://doi.org/10.1016/j.envsci.2016.03.010>.

52. Soleimani-Motlagh, M., 2017. Evaluation of groundwater balance with emphasis on the fractionation of drought and over-exploitation of aquifer (Case study: Dashte al-Shater). Ph.D. in Watershed Management Science and Engineering. Faculty of Natural Resources and Earth Sciences. University of Kashan. Iran
53. Stoof, C.R., Ferreira, A.J., Mol, W., Van den Berg, J., De Kort, A., Drooger, S., Slingerland, E.C., Mansholt, A.U., Ferreira, C.S. and Ritsema, C.J., 2015. Soil surface changes increase runoff and erosion risk after a low-moderate severity fire. *Geoderma*. 239, 58-67.<https://doi.org/10.1016/j.geoderma.2014.09.020>.
54. Thomaz, E.L., Antoneli, V. and Doerr, S.H., 2014. Effects of fire on the physicochemical properties of soil in a slash-and-burn agriculture. *Catena*. 122, 209-215. <https://doi.org/10.1016/j.catena.2014.06.016>.
55. Wang, Z.M., Batelaan, O. and De Smedt, F., 1996. A distributed model for water and energy transfer between soil, plants and atmosphere (WetSpa). *Phys Chem Earth*. 21(3), 189-193. [https://doi.org/10.1016/S0079-1946\(97\)85583-8](https://doi.org/10.1016/S0079-1946(97)85583-8).
56. Wang, Y., Liao, W., Ding, Y., Wang, X., Jiang, Y., Song, X. and Lei, X., 2015. Water resource spatiotemporal pattern evaluation of the upstream Yangtze River corresponding to climate changes. *Quatern Int*. 380, 187-196.<https://doi.org/10.1016/j.quaint.2015.02.023>.
57. Willems, P., 2009. A time series tool to support the multi-criteria performance evaluation of rainfall-runoff models. *Environ Modell Softw*. 24(3), 311-321. <https://doi.org/10.1016/j.envsoft.2008.09.005>.
58. Woldeamlak, S.T., Batelaan, O. and De Smedt, F., 2007. Effects of climate change on the groundwater system in the Grote-Nete catchment, Belgium. *Hydrogeol J*. 15(5), 891-901.<https://doi.org/10.1007/s10040-006-0145-x>.

- 578 59. Yin, H., Kong, F. and Li, X.Z., 2005. GIS-Based forest fire risk zone mapping in Daxing'an
579 Mountains. *Ying Yong Sheng Tai Xue Bao. The journal of applied ecology.* 16(5), 833.
- 580 60. Zarei, M., Ghazavi, R., Vali, A. and Abdollahi, K., 2016. Estimating groundwater recharge,
581 evapotranspiration and surface runoff using land-use data: a case study in northeast Iran.
582 *Biol Forum Int J.* 8(2), 196-202.
- 583 61. Zhang, Y., Liu, S., Cheng, F. and Shen, Z., 2018. WetSpass-based study of the effects of
584 urbanization on the water balance components at regional and quadrat scales in Beijing,
585 China. *Water.* 10(1), p.5.<https://doi.org/10.3390/w10010005>.

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