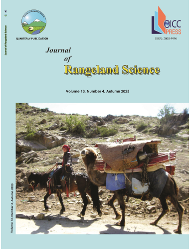

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Assessment of fire effect on water balance components under different land uses in central Zagros rangelands, Iran

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Abstract:
Fire occurrence may lead to a significant impact in many terrestrial ecosystems. This basin scale study attempted to evaluate the effects of fire on the water balance components in the Central Zagros, Iran in 2019. Two modeling frameworks including WetSpass-M spatial model and Bayesian Belief Networks were used to investigate the effect of fire on the amount of runoff, groundwater recharge and evapotranspiration. The first part of the study was water balance simulation at a monthly scale. In addition, the Bayesian belief networks were applied to explore and understand key issues effect on water balance after the fire. Calibration and validation of the WetSpass-M model were performed without considering the effect of fire (2000 – 2014) and then, the model was run again for the fire scenario by reducing manning roughness coefficient and increasing the θ coefficient. Subsequently, the water balance components of each class, i.e. sparse forest, sparse, semi-dense and dense rangelands were calculated. The percentage of changes in the water balance components was used for comparison. Calibration and validation were performed before finalizing the simulation. A Nash-Sutcliff 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 had increased the amount of runoff (13.5%) and it has reduced the amount of groundwater recharge (2.52%) and reduced the amount of actual evaporation (4.45%). The highest increase in runoff belonged to the sparse forest (15.8%), followed by dense (14.5%), semi-dense (13.7%) and sparse rangelands (12.5%), respectively. The results showed that runoff acts as the major factor affecting soil water balance (50.36%) followed by land use (10.49%), and infiltration (10.12%).

Keywords: Biomass burning; Water budget; Rangeland; Forest; WetSpass-M

1. Introduction

Fire is a major negative factor for the most natural ecosystems along with urban excessive development of agricultural lands [1]. It is also one of the most important physical factors that affect many environmental processes [2]. These impacts mostly lead to changes in land vegetation cover and soil characteristics [3]. Wild fires not only reduce the land cover of the natural ecosystems, but also result in soil damage which leads to increasing 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 indicating that burning of land surface reduces soil permeability [4]. This influences soil water balance as it can reduce the amount of infiltrated water [5], increase the surface flow, intensify the surface flow rate and has a high impact on partitioning of water compared to pre-firing conditions [6]. The degree of change in water balance components depends on the surface response and intensity of soil disorder [7]. The stability of soil structure after severe fires may lead to increasing bulk density and blockage of soil pores [8]. Certain changes in

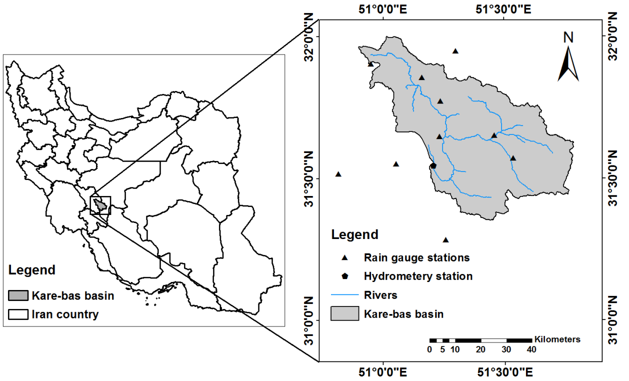

Figure 1. Map of the Karebas Basin in Chaharmahal va Bakhtiari province, Iran.

soil chemical characteristics and soil regime are expected after severe wild fire [9]. For many natural ecosystems, wild fire may lead to the change in structure and function of the ecosystems [10]. Wild fires are mostly due to human activities, however, they may also occur naturally. For instance, they might occur due to lightning [11]. Wild fires are also considered as a key environmental concern for plant ecosystems [12] whereas they annually destroy million hectares of ecosystems [13]. Iran is ranked as fourth in terms of forest fires in the Middle East and North Africa [14]. According to the Iran Statistic Center report, during the period between 2014 and 2018, as many as 9962 cases of fire have been recorded in Iran, which caused the burning of approximately 78000 ha of natural resources (National Agricultural Statistics, 2014 – 2018) [15]. It is expected that this trend will continue and/or will even increase in the future [16]. However, the risk of fire is not the same during the wet and dry periods. The results of Black showed that fires increase during the dry season and decrease in the wet season [17]. Increased wild fires can lead to a strict decrease in hydrological processes.

Fire has a significant effect on water budget. The study conducted by Flerchinger and Clark indicates the first year after the fire had less evaporation, and more permeability in some areas, and runoff was left without significant changes as opposed to non-fires [18]. Gonzalez-Pelayo et al. examined hydrological processes such as runoff and infiltration from July 2002 to July 2004 on a plot scale in Spain [19]. 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. in Mazandaran province reported that the fire caused an increase of 18 and 52% in runoff and sedimentation respectively [20]. Results obtained by Heydari et al. in the semi-steppe rangeland of Karsanak Basin in Chaharmahal va Bakhtiari province, Iran showed that fire caused soil organic matter decrement in surface samples for the first and second years after the fire and reduced soil carbon sequestration of soil carbon in surface layer after the fire [21]. They also stated the negative effects of fire on soil properties in the first year were more significant than the 2^{nd} and 3^{rd} years.

WetSpass-M model 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 heterogonous land use for each cell instead of assuming a uniform area for each pixel [22]. WetSpass-M was used for the change assessment in studies related to investigate the impacts of land use changes on groundwater, simulation of water balance components [23], climate change effects on water resources [24, 25], assessment of the impacts of urbanization on water balance [26, 27], and studies related to the interaction between groundwater and water balance components [28, 29].

The aim of the current study was to investigate the relationship between fire and simulated water balance components using the WetSpass-M and Bayesian Belief Networks (BBNs) in the Karebas basin in the central Zagros, Iran.

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 2825 km^2 are located between Chaharmahal va Bakhtiari and Esfahan provinces in the central Zagros mountains, Iran (Fig. 1) with an elevation range of 1760 m to 3794 m above sea level. This area consists of sparse, semi-dense, and dense rangeland with sparse forests that cover 25, 20, 4, and 26% of the Basin area, respectively. According to the information released by Iranian Forest, Rangeland and Watershed Organization, the canopy density in sparse forests and sparse rangeland is 5 to 25% while the one in the semi-dense rangeland ranged from 25 to 50%. For dense rangeland, this value was more than 50%. Our field investigation showed human factors, especially socioeconomic problems are the main cause of the fire phenomenon. 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 [30–32].

2.2 WetSpass-M model description

The WetSpass (Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-steady state) model was developed by the Hydrological and Hydraulic Institute of the University of Brussels to predict the transfer of water and energy between soil, plant, and atmosphere in a quasi-steady state. A newer model version was developed by Abdollahi et al. named WetSpass-M with the ability of simulating interception, runoff, evapotranspiration, soil water balance, and groundwater recharge at a monthly time scale [33]. In this model, the overall water balance for a grid cell is calculated from water budget for vegetated area, bare soil, open water/reservoirs, and impervious surface of each cell [22]:

$$ET_{\text{raster}} = a_{\text{v}} ET_{\text{v}} + a_s ET_s + a_o ET_o + a_i ET_i \quad (1)$$

$$S_{\text{raster}} = a_{\text{v}} S_{\text{v}} + a_s S_s + a_o S_o + a_i S_i \quad (2)$$

$$R_{\text{raster}} = a_{\text{v}} R_{\text{v}} + a_s R + a_o R_o + a_i R_i \quad (3)$$

Figure 2. An example of the land cover in the control area.

Figure 3. An example of the land cover in the fire area.

where ET_{raster}, S_{raster}, R_{raster} values are evapotranspiration, surface runoff, and groundwater recharge, respectively (all units expressed in mm).

a_{v}, a_s, a_O, and a_i are related to areas of vegetated cover, bare soil, open water/reservoirs and impervious surface of the grid the cell, respectively.

The water balance in this model was defined as:

$$P = I + S_{\text{v}} + T_{\text{v}} + R_{\text{v}} \tag{4}$$

where P, I, S_{v}, T_{v}, and R_{v} are precipitation, interception, surface runoff, evapotranspiration and groundwater recharge respectively (all in mm) [34].

The amount of runoff in this model was calculated via Equation 5:

$$SR_m = C_{Sr} C_h (P_m - I_m) \tag{5}$$

$$C_h = \frac{P_m}{LP(P_m^{\alpha} + ET_m^{\alpha})^{\frac{1}{\alpha}}} \tag{6}$$

$$C_{Sr} = \frac{C_{wp}\bar{P}_{24}}{C_{wp}\bar{P}_{24} - RCD \times C_{wp} + RCD} \tag{7}$$

$$C_{wp} = \left(1 - \frac{A_{Imp}}{100}\right) C_{per} + \frac{A_{Imp}}{100} C_{Ipm} \tag{8}$$

$$C_{per} = W_1\left(\frac{0.02}{n}\right) + W_2\left(\frac{\theta_w}{1-\theta_w}\right) + W_3\left(\frac{S_p}{10+S_p}\right) \tag{9}$$

$$C_{Imp} = 0.9\exp(0.024 A_{Imp}) \tag{10}$$

Where SR_m, P_m, and I_m are the amounts of surface runoff, precipitation and monthly interception, respectively (all in mm).

C_h is a descriptive coefficient of soil moisture content (dimensionless) that is calculated from Equation (6) when the potential evapotranspiration is 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, the effect of evapotranspiration on surface runoff and evapotranspiration coefficient, respectively.

C_{sr}, C_{wp}, RCD, A_{Imp}, C_{per}, C_{Imp}, n and S_p are also the actual runoff coefficient (dimensionless), potential runoff coefficient, average daily precipitation (mm per day in month), level of regional consecutive dryness (mm), 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, respectively [35].

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) [34]:

$$R_m = P_m - SR_m - ET_m \tag{11}$$

$$Q_{b(t)} = \beta Q_{b(t-1)} + 0.001 N_m (1-\beta)\emptyset R_m \tag{12}$$

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 [36].

3. Research method

3.1 Water balance model data requirements

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

The volumetric values of surface water discharge were used to compare the simulated results with its observational values. The gauge station discharge values were separated into surface and base-flow [37] using a recursive digital filter method (WHAT software) which the equation of this method is presented in the following equation [38].

$$q_t = \frac{(1 - BFI_{max})\alpha \times q_{t-1} + (1-\alpha) BFI_{max} Q_t}{1 - \alpha BFI_{max}} \tag{13}$$

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 total flow at time t (all

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
Land use	Discrete	Dense, Semi-dense and Sparse rangelands, 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

in m^3/s), α the constant recession curve and BFI_{max} is the maximum value of the base-flow index.
The filter considers both the hydrological characteristics of the flow and the basin [38]. 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} were 0.75 and 0.36, respectively.

3.2 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 is affected by fire sites in each study, land uses including dense, semi-dense and sparse rangelands, as well as forest (total 12 sites) were visited for one-year fire. The term "one-year fire" refers to a location where fire has occurred over one year before the sampling. For each fire occurrence area, non-fire area (control) was identified adjacent to the sampling area (Figs. 1 and 2). The stratified random sampling method was used after preliminary identification and determination of study sites. In each sampling site, 20 plots of 4 m^2 were installed: 10 plots in the fire area and 10 plots in the control area [39]. The canopy cover percentage of each plant species was recorded.

3.3 Modeling method

The period of model 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 of the water balance. The first scenario was the modeling of water balance under non-fire conditions, which the model was applied using the prepared maps with no consideration of fire and the second scenario

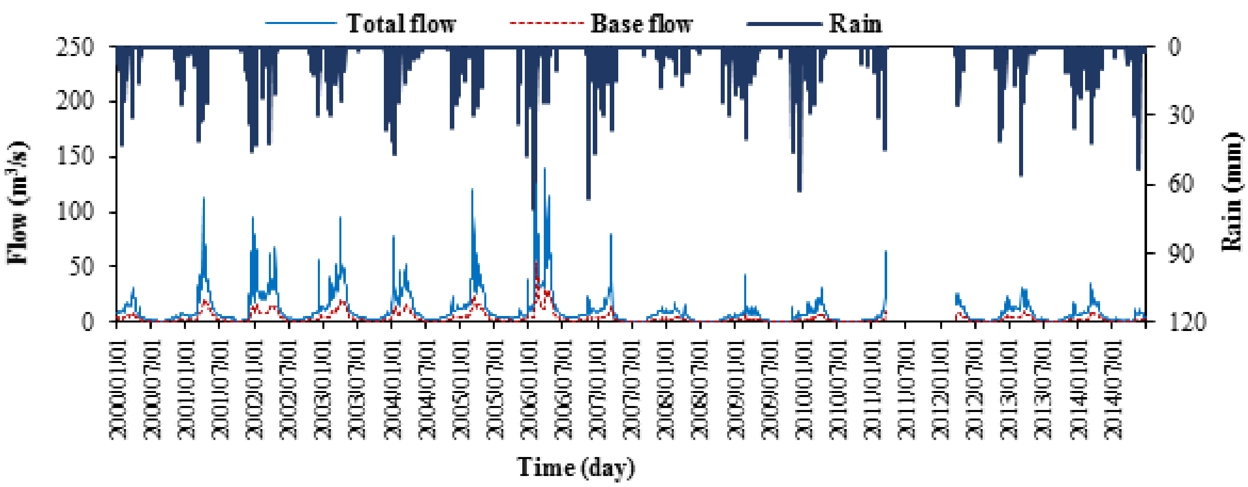

Figure 4. The separation hydrograph of the base-flow from total flow from studied basin.

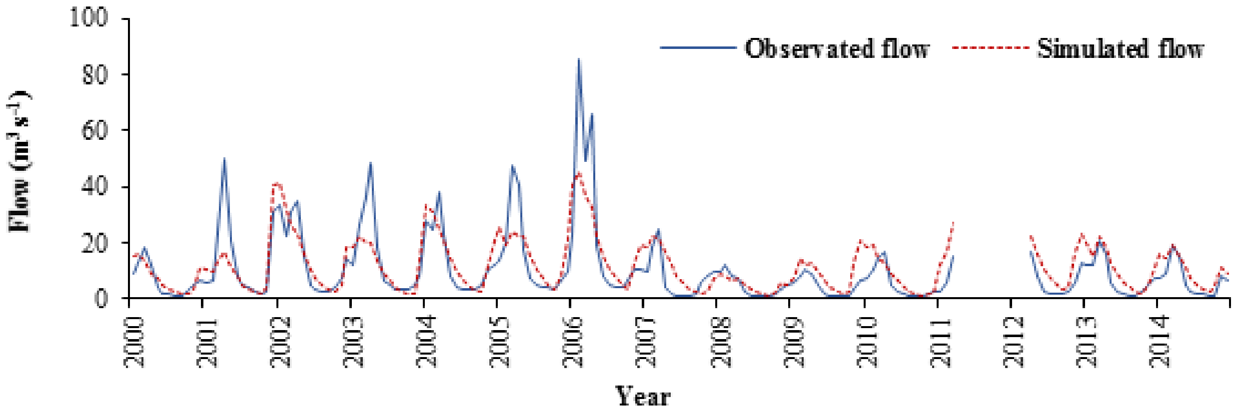

Figure 5. Simulated and observed flow hydrograph in Karebas Hydrometric Station.

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, sparse, semi-dense and dense rangelands. Literature review of Stoof et al. showed that the fire reduced the Manning soil roughness coefficient [40]. 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, sparse, semi-dense, and dense rangelands. Lastly, the simulated values for water balance components in both scenarios were compared.
In this study, the performance of the model was evaluated using the Nash-Sutcliffe efficiency coefficient which was calculated as follows [41]:

$$ENS = 1 - \frac{\Sigma(Q_{obs} - Q_{sim})^2}{\Sigma(\overline{Q_{obs}} - \overline{Q_{sim}})^2} \quad (14)$$

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.

3.4 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 was used for this purpose [42]. 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. 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 interconnecting variables, a directed acyclic graph (DAG) was established. By structuring the available information and expert opinions, a network diagram was created [43].
The mutual information analysis method was used to rank the degree of individual and conjoint influence of each input on output. 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 source information and independent variables used in the model. The containing variables in this table are based on the variables used in WetSpass-M.

4. Results and discussion

The graph of the base-flow separation from the daily total flow for measuring discharges over the period of 2000 – 2014 at the Karebas Hydrometric Station is shown in Fig. 4. By the means of a trial and error method, the initial calibration process of the water balance model was

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

Parameter	Parameter characteristic	Optimum value
Interception	a	2.50
Evapotranspiration	α 0.80	
Surface runoff	LP	2.80
Snow melting Factor	MF	0.02
Surface runoff	X	0.70
Base-flow	β	0.63
Nutrition Participant	$\emptyset$	0.15

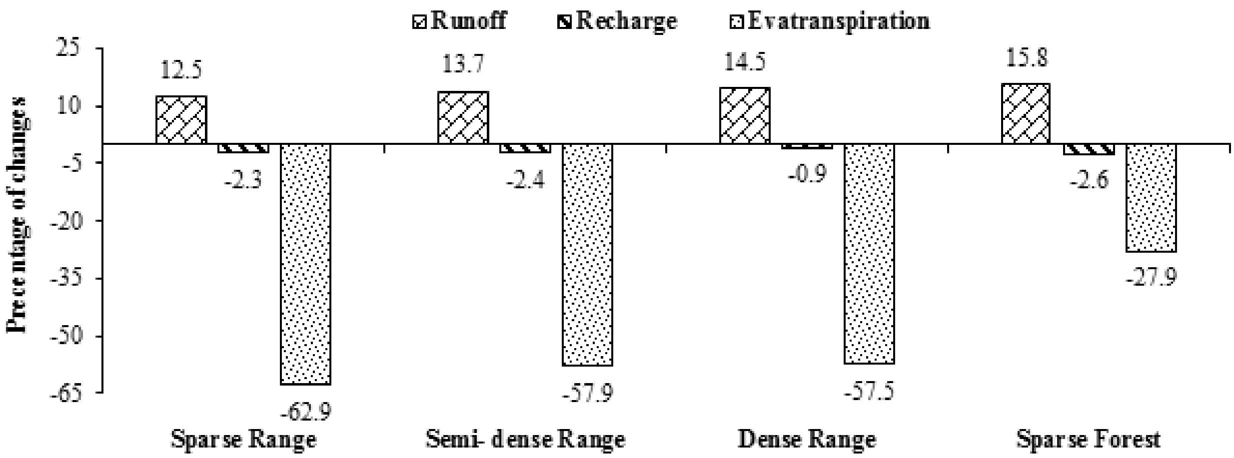

Figure 6. The variation of water balance components in different uses after the fire in the study.

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 the 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, the simulated flow are reliable [44].

4.1 Surface and sub-surface flow simulation

Fig. 5 shows the observed and simulated hydrograph of the Karebas Basin. The missing part in the graph is related to unavailability of discharge data of Karebas Hydrometric Station. As the Figure also shows, in wet months, the simulated flow rates are greater than the observational values. Although there is a difference between observation and simulation flows, in some peak flow in the hydrograph; in some other cases, the model has captured the peak well (simulated hydrograph in February 2006). On average, the highest simulation errors belong to March and April when the simulated discharge is typically less than the observational values. In these months, a combination of rainfall and the air warming leads to quick snow melt. This means the degree-day snow melt has shown a functional limitation over this period of simulation. The lowest flow simulation error belongs to September, which the model has simulated the flow of the basin with slight differences. In general, the simulated flow of the model has followed the trend of observational flow changes at Karebas Basin outlet.

Table 3. The results of statistical criteria for calibration and validation periods.

Period	Parameter	*ENS*	R^2
Calibration	Direct runoff	0.62	0.64
	Base-flow	0.60	0.62
	Total flow	0.61	0.65
Validation	Direct runoff	0.51	0.52
	Base-flow	0.67	0.70
	Total flow	0.58	0.59

4.2 The effect of fire on the components of water balance

The results of the percentage changes in fire/non-fire scenarios in runoff, groundwater recharge and evaporation are 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. 6 shows the percentage of changes in the water balance components after applying the fire effects. Under this condition, the amounts of actual evaporation and groundwater recharge in all land use classes (sparse, semi- dense, and dense 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 that post-fire evapotranspiration was significantly reduced in all three types of land cover, including grasslands, savanna, and croplands [17]. As shown in Fig. 6, the greatest reduction in actual evapotranspiration belongs to sparse, semi-dense, dense rangelands and sparse forest. The reason for this sharp change can be related to the type of land cover and its coverage characteristics. In sparse 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, the remaining materials and the renewed coverage increase after fire occurrence. The type of land utilization also has a great impact. For example, sparse and semi-dense rangelands are exposed to severe and moderate grazing respectively where as in dense rangelands, grazing is usually light. This is why the restoration of land cover may be accel-

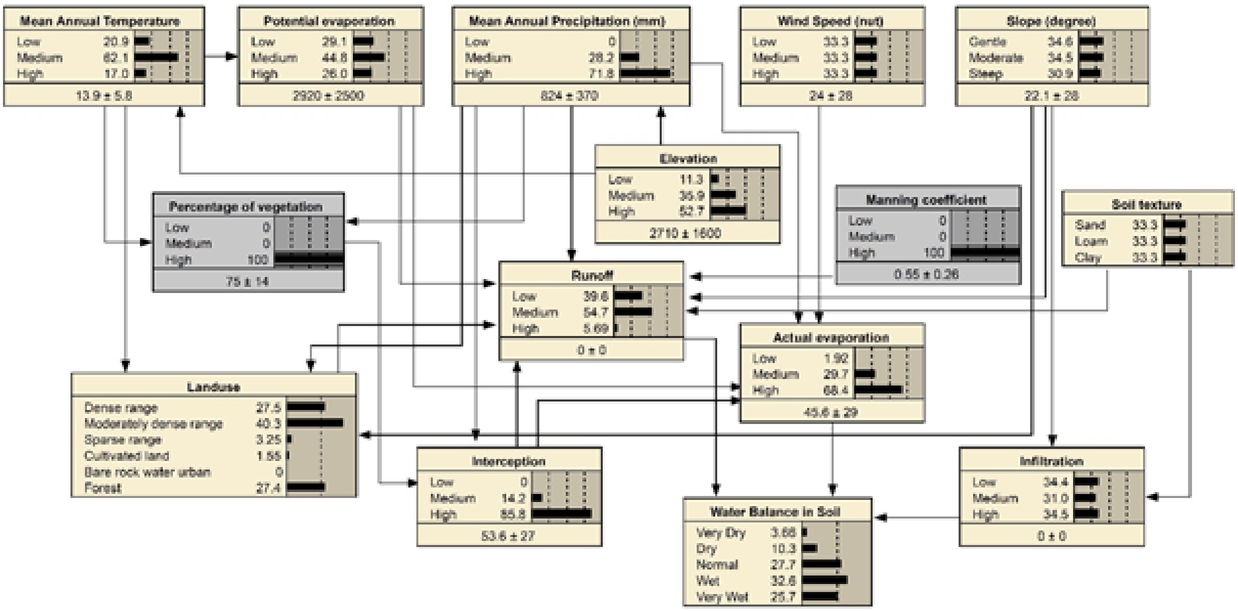

Figure 7. Soil water balance BBN model for non-fire scenario.

erated in dense rangelands while this takes a much longer time in sparse 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 and Shakesby and Doerr reported transmissibility as the responsible cause of reduction of infiltration [6, 45]. Gholami-Gohareh et al. stated an increment in fine particles like residual ash may be responsible for filling the pores and reduction in permeability of the burnt soil under the bush cover [20]. Reduction of permeability due to mild and severe fire is reported in some other studies as well (interested readers refer to [8, 19, 46, 47]). There was also little difference in the percentage of groundwater recharge. Jafarian and Sepehri stated that the intensity of the fire affects the amount of final infiltration of the soil [48]. Infiltration after the mild and control fire was not 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.

4.3 The results of BBN modeling

The graphical representation of BBN modeling for the first and second scenarios are shown in Figs. 7 and 8. The bar graph in Fig. 9 shows the probability distribution of each node changing according to its conditional probability. For the first scenario as (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.7). 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.8). 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 WetSpass-M, the highest percentage of change in water balance components belongs to the surface runoff 13.5% (Table 4).

5. Conclusion

Comparison of the observed and simulated hydrographs of water balance model showed that the model was able to simulate stream flow components of Karebas Basin with satisfactory accuracy. The greatest difference between the observed and simulated flow rates is related to high flows occurring in March and April. A possible explanation for

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

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

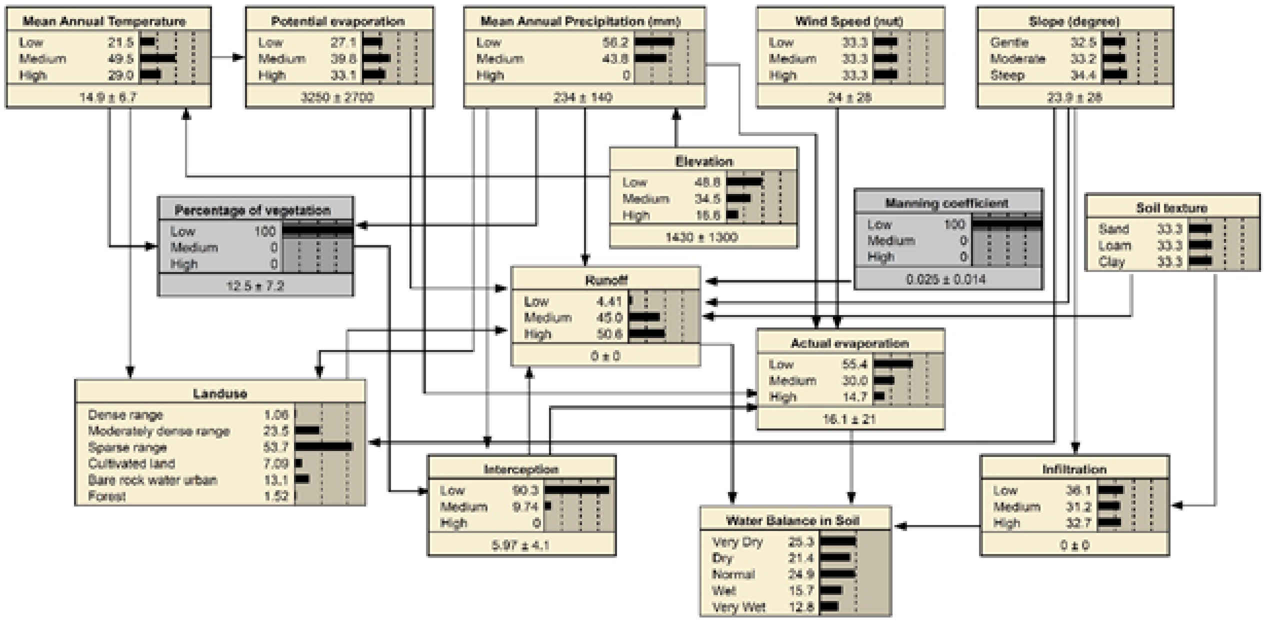

Figure 8. Soil water balance BBN model for the fire scenario.

this might be because the basin is relatively mountainous and during cold months, precipitation mostly falls in the form of snow. With increasing temperature during spring, snowmelt could be intensified. It seems that the internal degree-day module of WetSpass-M may not able to capture the intensified snowmelt runoff.

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

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

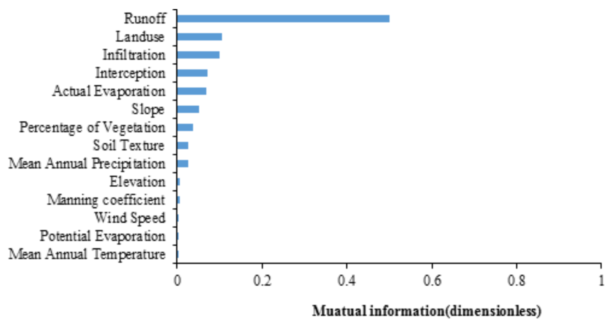

Figure 9. The results of sensitivity analysis of the factors sorted in descending order.

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Conflict of interest statement:
The authors declare that they have no conflict of interest.

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