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Impacts of changes in climate and land cover-land use on flood characteristics in Gorganrood Watershed (Northeastern Iran) during recent decades*

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ABSTRACT

This study evaluated the effects of changes in climate and land cover-land use (LCLU) on flood intensity and frequency in the Gorganrood Watershed (GW) located in the northeast of Iran during recent decades. For this purpose, hydroclimatic (precipitation, temperature, and river discharge) time series recorded at nine stations placed in the GW during 1973–2014 were used. Flood characteristics in terms of mean, maximum and number of peaks at five discharge stations (Galikash, Gonbad, Huji Ghushan, Tamar, and Tangrah) sited in the outlet of GW sub-basins were determined applying the Peak-Over-Threshold (POT) method to daily specific discharges. This is designed to remove the effect of the different size of sub-basins. The whole study period was divided into three 14-years segments (1973–1986, 1987–2000 and 2001–2014) based on satellite LCLU maps produced for 1973, 1986, 2000 and 2014. In the GW and its sub-basins during recent decades, both flood intensity and frequency increased, the climate became wetter and warmer, and LCLU mostly converted from rangeland to farmland. The partial correlation analyses identified that flood frequency in GW was primarily connected to the LCLU conversions, but moderately to observed wetter and warmer climate. Similarly, the Tamar sub-basin experienced effects of LCLU and climate on the maximum and the number of peaks. In Haji Ghushan, wetter and warmer climate resulted in more intense and frequent floods. Increases in precipitation appear to have played the most important role in the higher flood frequency in Galikash.

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Climate change; land use-land cover; flood characteristics; peak-over-threshold; Iran

Introduction

Extreme climatic events (e.g. floods, droughts and heat waves) can severely impact the society and natural environment (e.g. Nicholls and Alexander 2007). The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) identified that the intensity and frequency of

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*Irannezhad, M., Minaei, M., Ahmadian, S. and Chen, D., 20xx. Impacts of changes in climate and land cover-land use on flood characteristics in Gorganrood Watershed (northeastern Iran) during recent decades. *Geografiska Annaler: Series A, Physical Geography*, xx, xxx–xxx. DOI:10.1111/j.1468-0459.20xx.xxxxx.x such natural hazards are expected to change in the future (IPCC 2013). Flood is one of the most common and destructive extremes, influencing social life, economic development and ecosystem services around the world (Kellens et al. 2013). Hence, analysing flooding events has always been one of the main focal points in hydrological research communities (Rogger et al. 2012). Over the last two decades, major floods – most likely due to climate and land use changes – have further raised awareness in national and international authorities for the urgent need to reduce flood risks (Rogger et al. 2012; Uddin et al. 2013). On this basis, it is imperative to improve our understanding of factors controlling floods for developing strategies to mitigate the impacts of floods. This is certainly true for the Gorganrood Watershed (GW) in the northeast of Iran as one of the most important agricultural zones with about 600,000 people, who live at a high risk of experiencing flooding events (Statistical-Center-of-Iran 2006).

Factors controlling floods are generally divided into meteorological and physical categories. Climate and land cover-land use (LCLU) are the most important factors within these categories influencing watershed hydrology. Climatic conditions, particularly precipitation, play important roles in flood generation (Muzik 2001; Naess et al. 2005). Particularly LCLU affects surface runoff volumes, infiltration rates, and soil water redistribution patterns (De Roo et al. 2001, 2003). Previous studies have improved our knowledge on these factors individually, but many complex interactions need to be addressed for developing practical and effective flood mitigation measures under continuing climate and land use changes (www.floodsite.net 2013). As an example, some researchers have investigated the impacts of urbanization on watershed hydrology (Sim and Balamurugan 1991; Du et al. 2012; Suriya and Mudgal 2012). In an attempt to isolate the effect of LCLU from other factors, the 'paired catchment' approach has been used (Merz and Bloschl 2005; Merz et al. 2008).

Although some studies have already focused on the effects of climate and land cover interactions on floods (Muzik 2002; Li et al. 2009; Liu et al. 2011; Ouellet et al. 2012), more comprehensive efforts are required for regional flood risk assessments (Kwon et al. 2011). For the GW, only a few studies have evaluated the impacts of LCLU and/or climate change on historical floods (e.g. Sepehry and Liu 2006). Hence, simultaneous impact assessment of climate and LCLU changes on flooding events in the GW is well motivated.

The overall aim of this study is to assess the impacts of concurrent changes in climatic conditions and LCLU on flooding events in the GW, utilizing statistical analyses on observed relevant climatic, hydrological and LCLU data. The specific objectives are to: (1) detect historical floods using hydrological time series; (2) investigate the characteristics of the detected floods in terms of intensity and frequency; and (3) statistically assess the impacts of climate and LCLU changes on these flood characteristics. The outcomes of this work can be useful to develop adaptation and mitigation strategies for reducing flood risks in response to continuing changes in climate and LCLU.

Materials and methods

Study area and data used

The GW is located in the north-eastern part of Iran, covering a land surface area of 5254.2 km^2 between latitudes 36°57′–37°47′ and longitudes 55°08′–56°25′ with the altitudes from 15 to 2541 m above sea level (Figure 1a). The fertile soil in the GW is favorable for agricultural activities. About 600000 people are living in such high-risk floodplain area. The GW also surrounds Golestan National Park, which is a UNESCO World Heritage site containing valuable and old forests, large diversity of flora and fauna, and flood endangered species (Minaei and Kainz, 2018). The study area is geographically a complex region with remarkable variability in climatic conditions. The eastern and central parts of the GW are located in floodplains, while the southern areas are occupied by dense forests and dry highlands. The north of the GW is dominated by semi-arid uplands (Delbari et al. 2013).

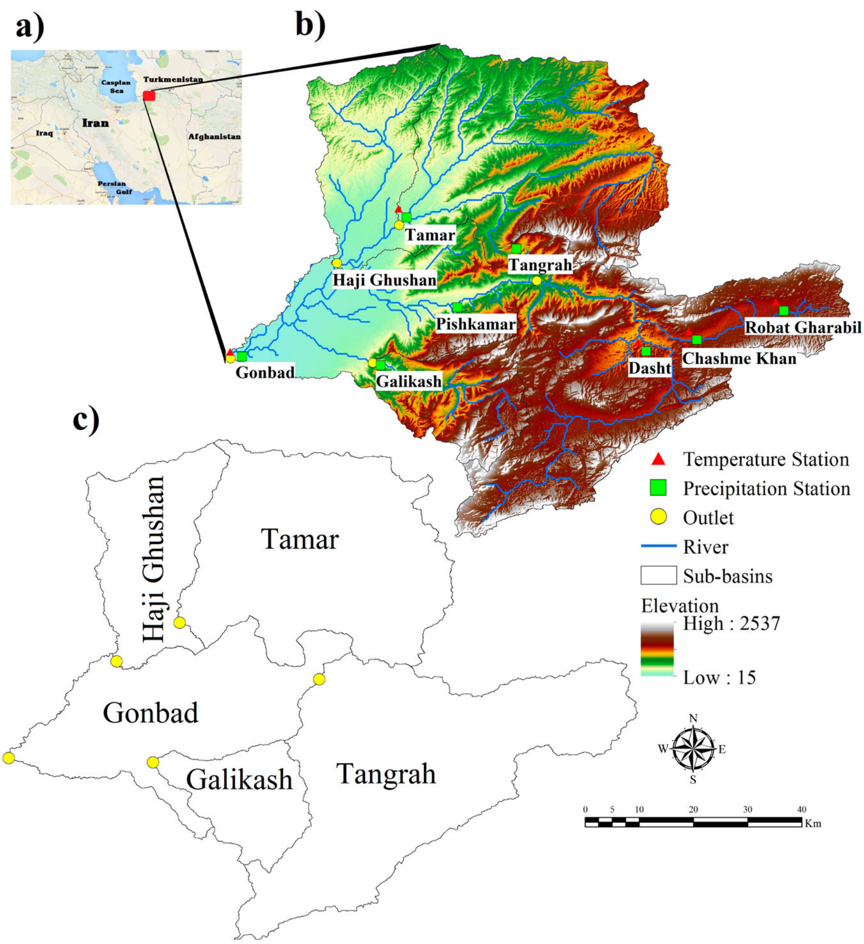

Figure 1. (a) The Gorganrood Watershed (GW) located in northeastern Iran, (b) locations of hydro-meteorological stations used, and (c) five sub-basins of the GW.

Table 1. Geographical coordinates and summary statistics for hydro-meteorological time series at the stations studied in the Gorganrood Watershed (GW).

				Study Period					
Station Name	Lat. (°N)	Lon. (°E)	Elev. (m)	Precipitation	Temperature	Discharge	Annual T_{Mean} (°C)	Annual Prcp. (mm)	Max. Daily Specific Dis. (m^3/s)
Cheshme Khan	37.30	56.11	1250	1975–2014	1975–2014	–	11.7	219.7	–
Dasht	37.28	56.01	1000	1986–2014 (9%)*	1986–2014 (9%)*	–	10.8	142.3	–
Gonbad	37.23	55.15	37.2	1961–2014	1961–2014	1956–2014	18.0	455.4	19.7
Robat Gharabil	37.35	56.30	1450	1975–2014	1975–2014	–	12.1	194.7	–
Tamar	37.50	55.50	132	1966–2014	1967–2014	1970–2014	16.7	471.1	34.9
Galikash	37.25	55.45	250	1972–2014	–	1966–2014	–	725.7	85.8
Pishkamar	37.35	55.61	976	1969–2014	–	–	–	478.4	–
Tangrah	37.45	55.73	330	1972–2014	–	1966–2014 (12%)*	–	728.3	44.5
Haji Ghushan	37.40	55.35	90	–	–	1984–2014	–	–	22.8

*percentage of missing data.

In the study area (Figure 1b) there are eight precipitation and five temperature stations (Table 1), Daily precipitation and temperature data were obtained from the Iranian Meteorological Organization and the Ministry of Energy. This study also used discharge records at the outlets of the five sub-basins in the GW (Figure 1b and c): Tamar (1519.6 km^2), Haji Ghushan (640.2 km^2), Tangrah (1747.1 km^2), Galikash (395.6 km^2) and Gonbad (951.7 km^2). For the GW, LCLU maps were provided by the classification of four cloud-free L1T Landsat images of the path/row 162/34 for the years 1973, 1986, 2000 and 2014 using pixel- and object-based remote sensing (http://earthexplorer.usgs.gov, http://glovis.usgs.gov). Aster Digital Elevation Model (DEM) data was obtained from the earth explorer website (http://earthexplorer.usgs.gov) and DSMW FAO soil data were taken from the geonetwork site (http://www.fao.org/geonetwork/srv/en/metadata.show?id = 14116). These maps mainly identified sex different LCLU classes throughout the study area: bare land, built-up areas, farmland, forests, mountain ranges and water bodies. All these LCLU classes over the GW and its five sub-basins for all four years studied (1973, 1986, 2000 and 2014) are illustrated in Figure 2.

Analysing flood characteristics under climate and LCLU changes

In the study area, historical floods were detected based on the Peak-Over-Threshold (POT) method utilizing the Water Engineering Time Series Processing (WETSPRO) tool (Willems 2009), which represents a generalization of the original Chapman method (Chapman 1991). Prior to applying the POT method, specific discharge (discharge/area) time series at the outlet of all the sub-basins located in the GW were calculated to remove the effect of their different sizes. As the GW shares

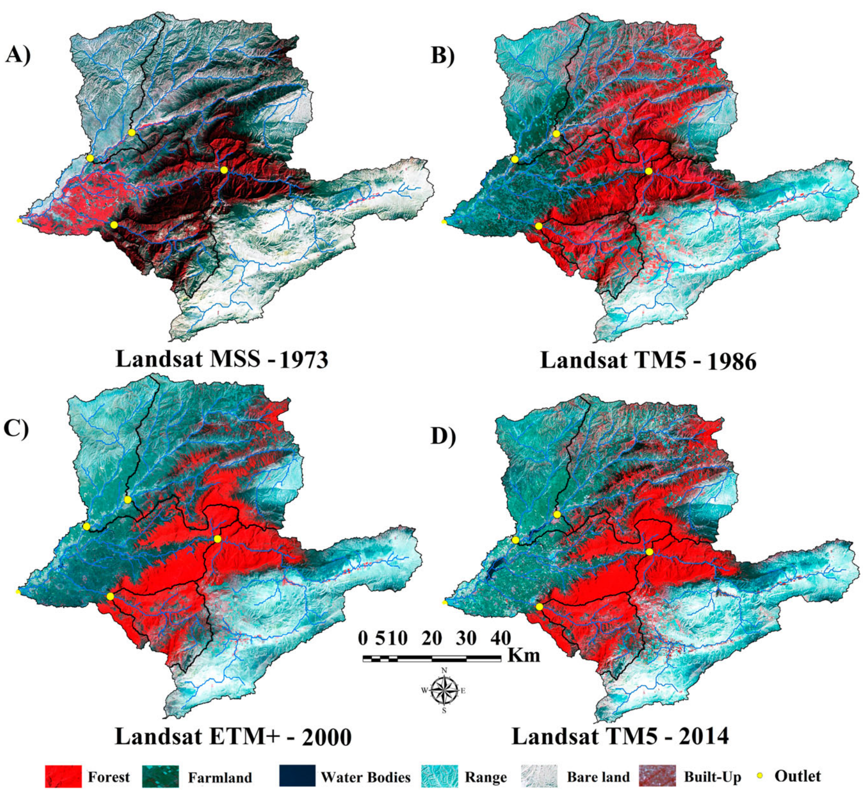

Figure 2. Land cover-land use (LCLU) maps for the Gorganrood Watershed (northeastern Iran) in (a) 1973, (b) 1986, (c) 2000, and (d) 2014.

its outlet with the Gonbad sub-basin (Figure 1c), specific discharge at the Gonbad station was calculated based on the GW area (5254.2 km^2). Similarly, specific discharge at the Haji Ghushan station was computed using the sum (2159.8 km^2) of both the Tamar (1519.6 km^2) and Haji Ghushan (640.2 km^2) sub-basin areas because the Tamar station is located in the Huji Ghushan sub-basin (Figure 1c).

Using the POT method, this study first defined the historical flooding events (or peaks) as the specific discharge values exceeding a sufficiently high threshold, which is calculated based on the Norm of Residuals method (Saeed Far and Wahab 2016). Then, main characteristics of such detected floods in terms of intensity (mean and maximum peaks) and frequency (number of peaks) were evaluated. Such characteristics were determined for the GW during recent decades. According to the years of the four LCLU maps (1973, 1986, 2000 and 2014), the average values of flood characteristics in different sub-basins were also calculated for the three time segments: 1973–1986, 1987–2000, and 2001–2014. Besides, for these segments, averages of annual precipitation and temperature (mean, maximum and minimum) were also computed. To measure the relationships between flood characteristics and the climate/LCLU over all four time segments, the partial correlation (rho) was used (Ben Aissia et al. 2012; Zaiontz 2014). Prior to the calculation of these rho values, the linear regression model was applied to the LCLU percentages in 1973, 1986, 2000 and 2004 for generating their annual values during 1973–2014.

Results and discussion

Representing the entire GW, Gonbad discharge station recorded the lowest values of mean and maximum flood peaks in recent decades, but experienced most frequent floods (Figure 3). At this station, both flood intensity (73% in mean and 68% in maximum peaks) and frequency (117%) showed increases over time (Figure 3). Such increases in intensity and frequency of floods were associated with wetter and warmer climate observed over the GW through the years 1973–2014 (Figure 4). Concurrently, farmland areas increased by 23% in the GW, while forest and range coverages decreased by 3% and 20%, respectively (Figure 5a). Such changes in LCLU showed positive correlations (rho = 0.38) with the number of peaks recorded at the Gonbad discharge station in recent decades (Figure 6c). As a comparison, our previous studies reported similar changes in

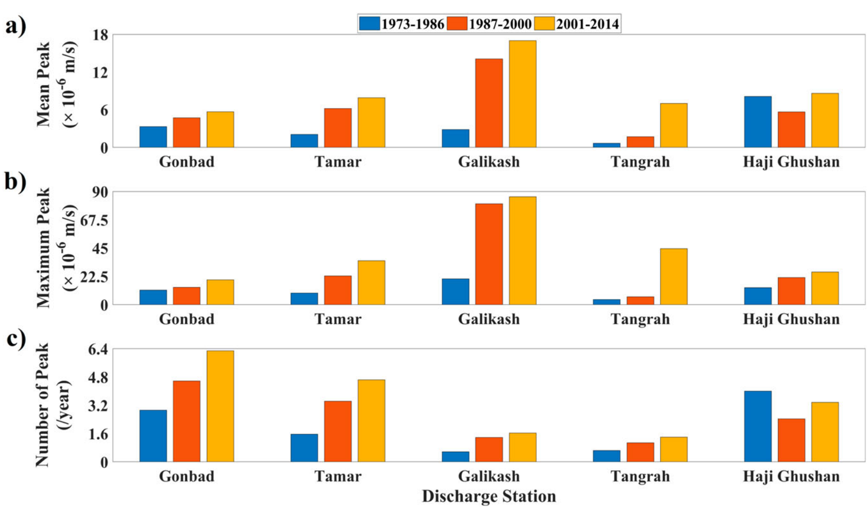

Figure 3. Typical flood characteristics in all five different sub-basins in the Gorganrood Watershed (GW) during three 14-years segments (1973–1986, 1987–2000 and 2001–2014) studied. The Gonbad discharge station represents the flood characteristics throughout the entire GW.

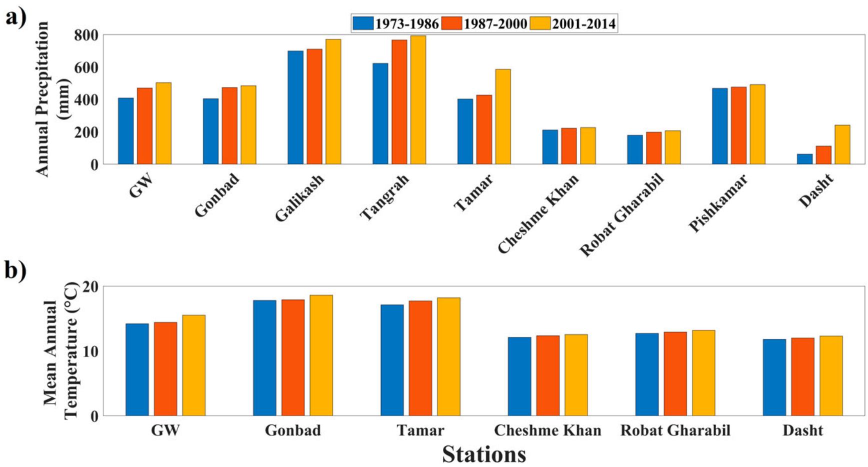

Figure 4. Changes in climatic conditions, including (a) annual precipitation and (b) mean annual temperature, over the entire Gorganrood Watershed (GW) and the meteorological stations located in its sub-basins during three 14-years segments (1973–1986, 1987–2000 and 2001–2014).

climatic conditions and LCLU in the GW during the last 40 years, but decreases in daily river discharge during the same period (e.g. Minaei and Irannezhad 2016; Minaei and Kainz 2016). This contrast is mainly due to the fact that we focus on peak daily discharge in this work, which was not formerly considered. Minaei and Irannezhad (2016) also concluded that declines in river discharge in the GW during 1953–2013 were primarily in response to the higher rate of evapotranspiration due to the warmer climate, although precipitation increased. Similarly, the present study found a higher significant correlation of LCLU with temperature (rho = 0.84) than with precipitation (rho = 0.54) in the GW. It indicates that the number of peaks in the GW is consecutively sensitive to changes in

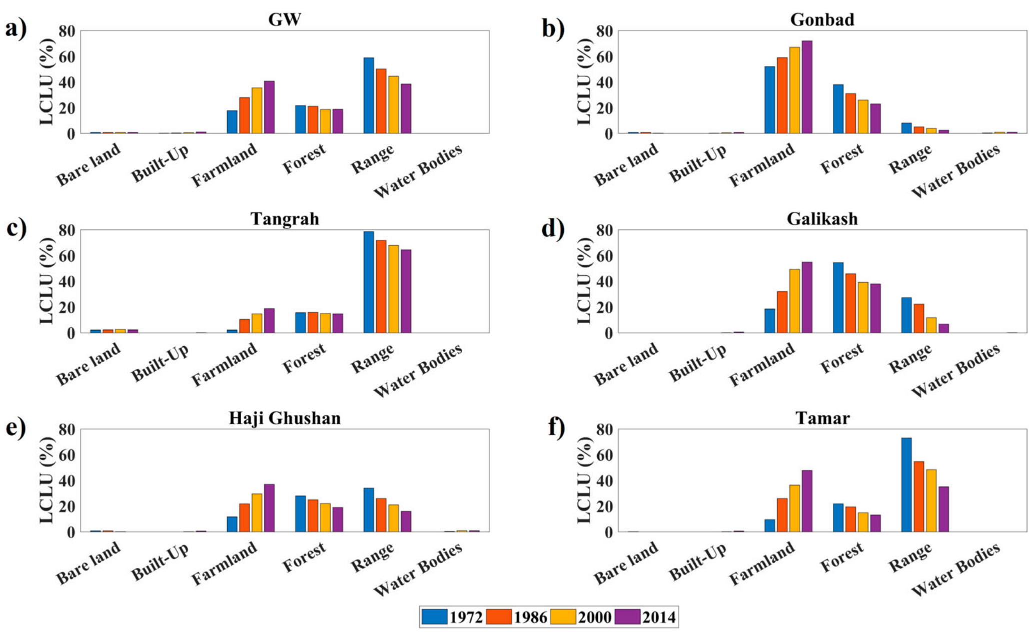

Figure 5. The percentages of land cover-land use (LCLU) in the Gorganrood Watershed (GW) and its five sub-basins in 1973, 1986, 2000 and 2014.

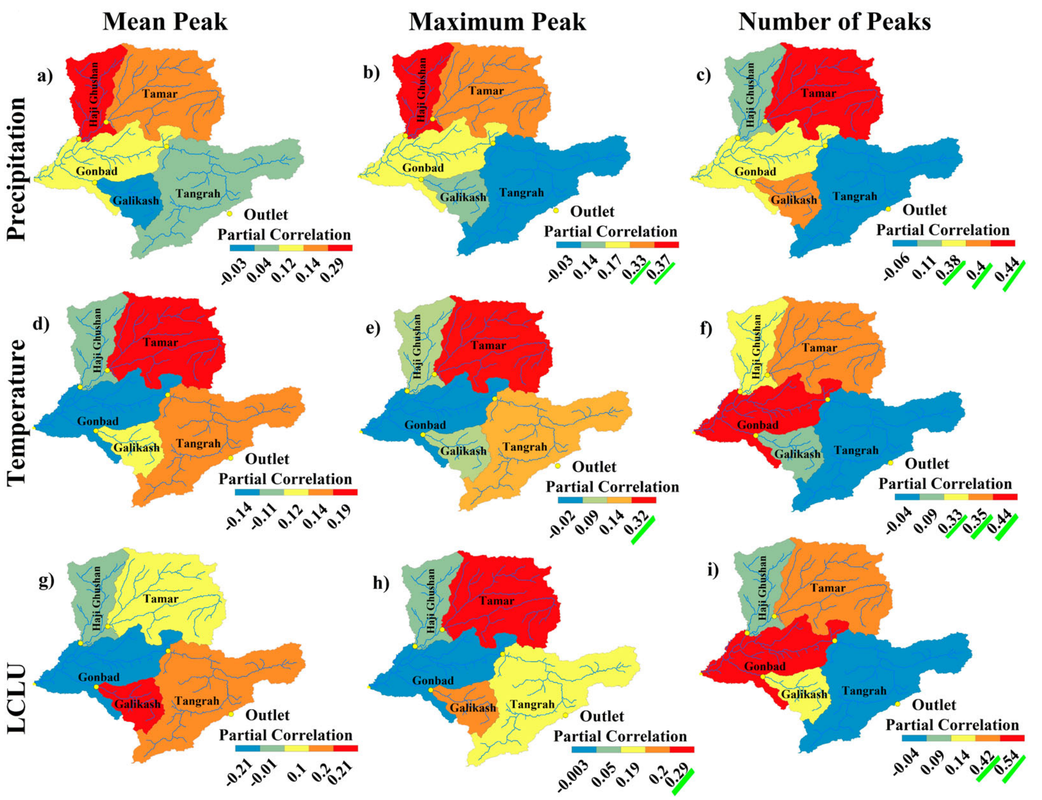

Figure 6. The partial correlations (rho) of mean, maximum and number of peaks with (a–c) annual precipitation, (d–f) mean annual temperature, and (g–i) the percentages of land cover-land use (LCLU), in all five sub-basins of the Gorganrood Watershed (GW) during 1973–2014.

LCLU, temperature, and precipitation. Such relationships were confirmed by identifying statistically significant ($p < 0.05$) partial correlations of flood frequency with LCLU (rho = 0.54), temperature (rho = 0.44) and precipitation (rho = 0.38) throughout the Gonbad sub-basin (Figure 6c, f and i). Such sequential effects of LCLU, temperature and precipitation changes on average annual flows were also reported in different watersheds around the world; e.g. the Weihe River drainage basin (Du and Shi 2012) and the middle reaches of the Yellow River basin (Zhao et al. 2014), China. In agreement with the GW mostly covered by rangeland (Figure 5a), Ling et al. (2014) also concluded stronger influences of temperature than precipitation on intra-annual runoff in the mountain head-streams of the Tarim River Basin in China.

Since 1973, the most intensive floods have been observed in the Galikash sub-basin, but at the lowest frequency (Figure 3). In this sub-basin, all mean, maximum and number of peaks increased in recent decades (Figure 3). The largest increases in flood intensity and frequency in the Galikash sub-basin were seen between the first (1973–1986) and second (1987–2000) time segments considered in this study (Figure 3). During the later one, the climate was slightly wetter (Figure 4a) and warmer based on the temperature measurement at the nearest station (Gonbad) (Figure 4b). Besides, the most significant LU change in the Galikash sub-basin between the years 1986 and 2000 was the conversion from forest (from 54.4% to 39.1%) and range (from 27.3% to 11.6%) to farmland (from 32% to 54.8%) (Figure 5d). Accordingly, more intense and frequent floods in the Galikash sub-basin might be referred to such decreases in the forest due mainly to its ability of diversion closure (Yuan et al. 2015). In this sub-basin, precipitation showed moderate positive correlations (rho = 0.40) with the number of floods (Figure 6c), but no clear relationships of flood characteristics with temperature and LCLU were found during 1973–2014 (Figure 6d–i). These results imply that increases in precipitation played the most important role in more frequent floods in the Galikash sub-basin during recent decades. Similar to this sub-basin, other studies also reported decadal variability in historical river discharge under changes in climate and/or LCLU in different parts of the world; e.g. Ye et al. (2013) concluded that annual runoff increased in streamflow throughout the Poyang Lake basin in China during 1970–2000 because of climate change, while decreased in 2000s due mainly to human activities like LCLU alterations.

The range was the dominant land cover type in the Tamar sub-basin over 1973–2000, while farmland prevailed during the years 2001–2014 (Figure 5f), which resulted from the concurrent increases (11%) in farmland and decreases in range (8.8%) and forest (2%) in this sub-basin over time (Figure 5f). Similar changes in LCLU were also observed in the Haji Ghushan sub-basin (Figure 5e). On the other hand, both precipitation and temperature increased across these sub-basins (Tamar and Haji Ghushan) in recent decades (Figure 4). Such wetter and warmer climate along with farmland expansion showed moderate correlations with both maximum peak and flood frequency in Tamar, with rho = 0.29–0.44 ($p < 0.05$) (Figure 6). In the Haji Ghushan sub-basin, precipitation and temperature positively correlated with the maximum peak and the number of peaks, while LCLU changes showed no clear relationships with the flood characteristics (Figure 6). These positive relationships were reflected in the increases in both flood intensity and frequency in the Tamar and Haji Ghushan sub-basins over time (Figure 3). In fact, flood characteristics in the Tamar sub-basin were affected by both climate and LCLU changes, while in the Haji Ghushan sub-basin only by climate change. Such different roles of climate and LCLU changes in river discharge regime throughout various sub-basins of a watershed were previously reported; e.g. Zhao et al. (2014) concluded that climate change was the dominant factor decreasing mean annual flow in two sub-basins (the Beiluo River and the Yan River) of the Yellow River (China), while LCLU in other its tributaries.

Both flood intensity and frequency increased in the Tangrah sub-basin over time, particularly during the last 14-year (2001–2014) (Figure 3). Similarly, the large alteration of land cover from range to farmland in this sub-basin was particularly observed during 2001–2014 (Figure 5c). Despite such changes in LCLU, the range remained as the dominant land cover in the Tangrah sub-basin in recent decades (Figure 5c). Across this sub-basin, climate slightly became warmer (according to the Tamar and Dasht meteorological stations) and wetter over the period 1973–2014 (Figure 4). This study, however, found no statistically significant relationships between flood characteristics and changes in both LCLU and climate in the Tangrah sub-basin during the past 42 years (Figure 4). Such insignificant ($p > 0.05$) correlations can only suggest that flood intensity might be influenced by changes in LCLU more than in climatic conditions (Figure 6).

Summary and conclusions

The present study examined dependencies of flood intensity and frequency in the GW (northeastern Iran) in recent decades upon climate and LCLU changes. Mean, maximum and number of peaks in the GW and its five sub-basins were calculated using Peak-Over-Threshold (POT) method to daily specific discharge time series measured at the outlet of the sub-basins. To assess changes in climatic conditions over the GW, long-term precipitation and temperature records at several hydro + meteorological stations distributed in all five sub-basins were evaluated. Utilizing satellite images, changes in different classes of LCLU (built-up, farmland, bare land, range, forest, and water bodies) in GW were identified for 1973, 1986, 2000 and 2014. According to these LCLU maps, the whole study period was divided into three 14-years segments: 1973–1986, 1987–2000, and 2001–2014. Major findings can be shortly summarized as follows:

- Climate was warmer and wetter across the GW during the last 14 years (2001–2014), compared to the second (1987–2000) and first (1973–1986) 14-year time segments.

- In the GW, alterations in LCLU were primarily related to the large conversion of range into farmland. Accordingly, the most dominant LCLU class in the GW changed from range to farmland by 2014.
- Most intensive floods in the GW were observed at the lowest rate of frequency through the last 42 years. the GW and its sub-basins experienced more intense and frequent floods during 2001–2014, compared to the years 1973–2000.
- According to the partial regression analysis, the changes in LCLU played the most important role in more frequent floods recently recorded at the Gonbad discharge station, which represents the entire GW. Both precipitation and temperature were also influential but have lower explanatory power than the LCLU. Similarly, LCLU and climatic changes affected the maximum and the number of peaks in the Tamar sub-basin during 1973–2014. In the Haji Ghushan sub-basin, the maximum peak was significantly correlated with precipitation, while the flood frequency was closely associated with temperature. However, the number of flood peaks showed moderate positive relationships with precipitation in the Galikash sub-basin.

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Disclosure statement

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