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Assessment of land use and land cover changes in association with hydrometeorological parameters in the Upper Indus Basin

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Abstract

The Upper Indus river basin (UIB) is not only significant because of its freshwater supply for agriculture and hydropower electricity generation but also for its contribution to maintaining ecosystem services. Land cover and land-use changes (LULC) are linked to socio-economic, and local climatic and hydrological conditions. Annual LULC changes in the UIB between 2001 and 2016 are studied using Moderate Resolution Imaging Spectroradiometer (MODIS) land cover product. The LULC data from MODIS is correlated to ground-based runoff (1984-2016), precipitation and temperature data (1960-2016). Mann Kendall and Pearson's correlation tests are used for data analysis. The overall accuracy of the MODIS land product is 87% with the kappa coefficient value of 0.82. The mainland cover types in terms of area coverage are barren land 53%, grassland 31% and permanent snow and ice 15%. Vegetation like forestland, grassland, cropland and savanna increased significantly during the period of observation. Most of the barren land is replaced by permanent snow and ice and a reduction was observed from 55.29% in 2001 to 52.78% in 2016. On the other hand, annual total precipitation and annual river flow exhibit significant increasing trends while the annual mean temperature was observed to be slightly increasing. A strong correlation exists between snow and ice-covered area, vegetation and annual total precipitation. These results might be helpful to the concerned departments dealing with land planning, climate change, water resources and power generation.

Keywords: MODIS; UIB; trends; LULC; climate change; hydrometeorology

1. Introduction

Land cover is a dynamic variable reflecting the interaction between socio-economic activities and regional environmental changes (Munroe and Muller, 2007). The land cover represents the earth surface consisting of built-up area, water bodies, barren land, vegetation, snow and glaciers etc. On the other hand, land use indicates the management of the land, such as, amusement, agriculture or habitats for wildlife (Wu et al., 2008). Anthropogenic activities have been recognized as one of the most important causes of LULC changes as well as changes in natural environments (Bennett and Saunders, 2010). Additionally, emissions from industries, agricultural activities, and other anthropgenic actions affect climate through alteration in LULC (Hansen et al., 2012). LULC play critical role in the interface between the ground and the atmosphere, affecting local, regional and global climates (Pielke, 2005). The impact is likely to be substantial in areas with forest loss or gain as it will result in the alteration of carbon exchange (Brown et al., 2014).

The Upper Indus river basin (UIB) is not only important because of its freshwater supply for agriculture and hydropower electricity generation but also for the aesthetic beauty, high elevated mountains, glaciers, and support to maintain biodiversity. That is why UIB has attracted international and national researchers.

A lot of researches have focused on the hydrology of the UIB, they have found an increase in the stream particularly in the winter and spring seasons (Sharif et al., 2013; Khan et al., 2015; Adnan et al., 2017; and Yaseen et al., 2020). In contrast to the global projection for snow-covered areas, the UIB is exhibiting mixed trends. For instance, recent studies have shown that lower elevated basins are experiencing a decrease in the snow-covered areas while high elevated basins are gaining snow-covered area (Forsythe et al. 2012; Hasson et al. 2014; Bilal et al. 2019). Similarly, the temperature and precipitation trends are heterogeneous depending on the climatological conditions of the subbasins (Fowler and Archer, 2006; Khattak et al., 2011; Raza et al., 2015; Ali et al., 2017; Bilal et al., 2019; Azam et al., 2020). LULC changes have strong impacts on the microclimate of an area. Air temperature and near-surface moisture were reported to change in regions where forest is replaced by agricultural activities (Karl et al., 2012). Forest clearance for agricultural activities is also responsible for altering regional daily maximum temperature (Bonan, 2001). On the other hand, the introduction of irrigated agriculture can modify the regional precipitation pattern (Harding and Snyder et al., 2012). LULC changes also influence the hydrology of the area. In the Tana sub-basin Ethiopia, the expansion of cultivation land and decline in a woody shrub was responsible for the increase in discharges and deterioration of groundwater resources (Woldesenbet et el., 2017). Investigation on LULC changes is crucial to understanding the present and upcoming changing aspects of deforestation and the roots causes for instance, forest fires, urban development, agricultural activities, loss of flora and fauna, and global climate change (Radoux et al., 2014).

The LULC changes in the UIB and their relationship with the observed variation in cryosphere, hydrosphere and climatic parameters are still unknown. The present research is a pioneer study to fill the gap by correlating the LULC changes with climatic and hydrological parameters. Continuous monitoring of the LULC changes in UIB is important in understanding the dynamic forces which are responsible for the variation in climatic and hydrological parameters. This study aims to identify the LULC dynamics in the UIB during the periods of observation by satellite data and to discuss the correlation between LULC changes and the hydro-meteorological parameters. It is also significant to study the LULC changes to provide evidence-based support to improve water resource management, land management, flood and climate change-related policies and practices.

2. Data and Methods

2.1 Study area

The UIB is located between 72°–76°E and 34°–37°N having a total land area of 68917.95 km² as measured at Shatial bridge station. The elevation of UIB ranges between 877~8564 m ASL (Fig. 1). The UIP is known for the highest mount peaks one of them is the Godwin Austin (K-2). It is the main freshwater supply catchment area to the UIB (Bilal et al., 2019). Based on the Randolph Glacier Inventory 6.0, around 13082.94 km² area of the UIB is enclosed by glaciers. Most of the Indus runoff is a result of meltdown from these glaciers (Hewitt, 2005).

2.2 Digital Elevation Model

Shuttle Radar Topography Mission SRTM having a resolution of 30m was utilized for the delineation of the UIB. The SRTM DEM data is freely available at https://earthexplorer.usgs.gov/. Before delineation SRTM images were mosaicked and the study area was demarcated using the ArcMap software version 10.2.

2.3 MODIS

MODIS Land Cover Type (MCD12Q1) Version 6 is the combination of MODIS Terra and Aqua data. MCD12Q1 has a spatial resolution of 500m at yearly intervals (2001-2016). The (MCD12Q1 provides annually updated global landcover maps (Sulla-Menashe and Friedl, 2018). The latest collection 6 MCD12Q1 is consist of the six global land cover classification schemes.

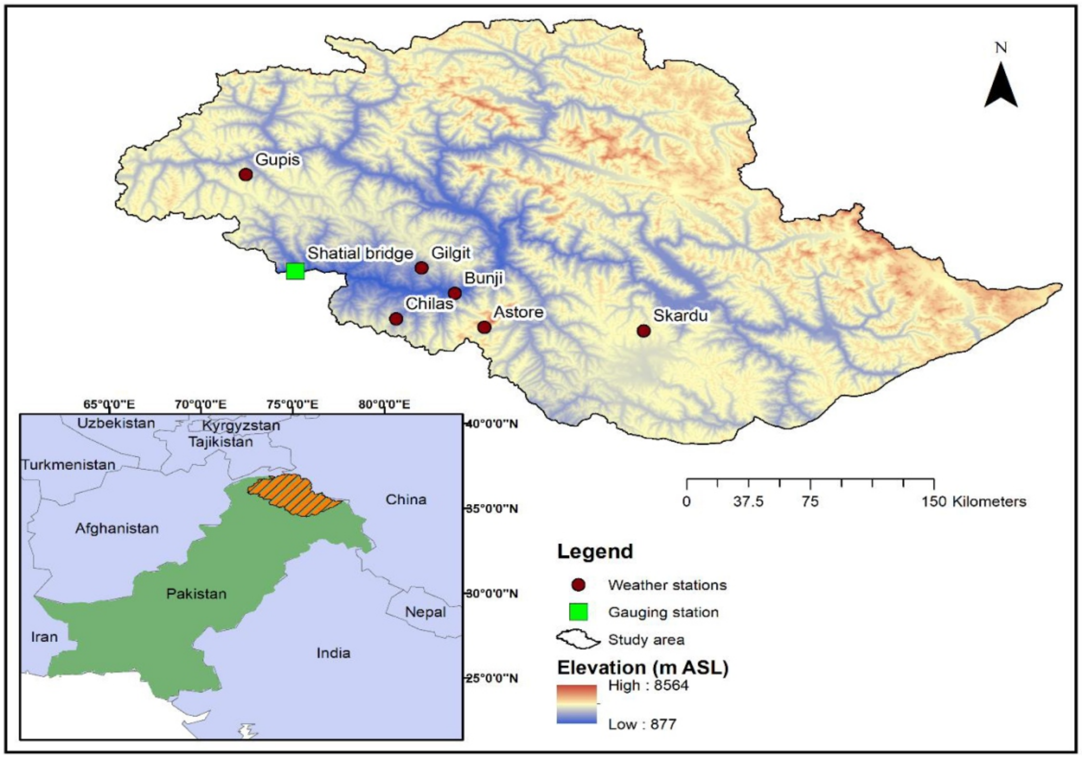

Fig. 1. Digital Elevation Model of the Upper Indus Basin superimposed with weather stations and gauging stations.

International Geosphere-Biosphere Programme IGBP is used in the current study. IGBP classification scheme has 17 land cover classes. A data set of ~ 32 MCD12Q1 images (h24v05 and h23v05) was acquired from https://earthdata.nasa.gov/. The projected tiles were mosaicked, and the study area was extracted using a 30-meter digital elevation model as a mask in ArcMap 10.2.

2.4. Accuracy assessment

Statically defensible and transparent accuracy assessments are essential to ensure the integrity of the products developed and enable end-user confidence and uptake (Wulder et al. 2018). 800 data points were collected randomly from the MODIS land cover product. Data points were imported to Google Earth Pro as Keyhole Markup Language KML layer and were checked in Google Earth Pro at different time intervals. The overall accuracy of the MODIS land cover product was 87%. Cohen's kappa coefficient value is 0.82 which means the almost perfect agreement between classification and reference data. The original 17 classes are simplified into 8 classes for a better understanding of the land-use changes (Table 1).

2.5 Hydrometeorological data

Monthly mean temperature and monthly total precipitation data from 1960-2016 were made available from six weather stations (Fig. 1) installed by the Pakistan Meteorological Department. The monthly mean temperature and total precipitation data of six weather stations are averaged to get a representative annual dataset of the UIB. For the correlation between hydrometeorological and LULC data, the annual dataset is selected from 2001-2016 as MODIS land product data is only available from 2001-2016. Besides, monthly river flow data of the Indus river at the Shatial bridge gauging station from 1984-2016 is used in this study to investigate the correlation between hydrometeorological data and LULC data. Monthly average River flow data was supplied by the Water and Power Development Authority (WAPDA).

2.6 Data analysis

Annual trends in mean temperature, average total precipitation, land cover classes and river flow were determined using Kendall's tau (τ) and Sen's slope (S) (Mann 1945; Sen 1968;

and Kendall, 1975). The Mann Kendall test is non-parametric, it does not need the data to be normally distributed, and secondly, the test is less sensitive to sudden breaks triggered by heterogeneous time-series datasets (Tabari et al., 2011). The Mann-Kendall (MK) test is applied to distinguish a trend in a series of climate and hydrology related data. The null hypothesis (H0) is that the data has no trend. The alternative hypothesis (Ha) means that the dataset pertains a trend. For the correlation between LULC and the hydrometeorological parameters, Pearson's correlation test is used with a 5% significance level.

3. Results and discussion

3.1 Land cover types

The land cover of the UIB is composed of 8 land cover classes namely; forestland, shrubland, savannas, grasslands, croplands, urban and built up, permanent snow and ice and barren land. Based on the land cover data from 2016, mainland cover types are barren land, grassland and permanent snow and ice accounting for 53%, 31%, and 15% respectively. The higher altitudes in the GB are mostly barren due to the harsh environmental conditions. At higher altitudes, trees usually cannot tolerate the harsh environmental conditions and that is why more than 55% of the UIB's land is barren. Grassland is the second main land cover class occupying 31% of the total land cover. These grasslands are vital for the ecosystem functioning and sustenance of the livestock. The third major land cover of UIB is the permanent snow and ice. Due to the higher elevation, UIB mostly gets precipitation in the form of snow. Permanent snow and ice contribute 15% of the total land cover. The total population of Gilgit Baltistan is 1.249 million with a population density of 17.12 per square kilometre. Thus, the built-up area covers only 0.3 % mainly distributed in valleys along both sides of the Indus river.

3.2 Land-use change 2001 vs 2016

Analysis of the last 16 years annual land use data shows that savannas, grasslands, snow and ice, cropland and urban and built-up area are experiencing a positive trend. While, the area under forestland, shrubland and barren land is decreasing (Table 2).

Forests in mountainous areas are vital for socio-economic activities and biodiversity. Forests act as a filter, recharging underground aquifers, protecting watersheds, preventing soil erosion and mitigating climate change. The evergreen forest of the UIB is composed of the broadleaf and needle leaf forest. The most common tree species are Pinus wallichiana, Pinus wallichiana, Picea-Juniperus, Picea-Pinus, Pinus wallichiana, Picea smithiana, Pinus wallichiana, Betula utilis, Juniperus macropoda, Abies pindrow (Akbar et al., 2011). Data analysis shows that forestland in 2001 was 88 Km^2 which is reduced to 80 Km^2 in 2016 with a net change of -8 Km^2. Decreasing forest in the UIB was also reported by Ahmad and Abbasi (2011). However, the overall annual trend for forestland is positive. Similarly, the area under the shrublands also decreased by -21% throughout the observation. The possible reason for the reduction in forestland and shrubland is the dependency of the local community on scarce forest resources. People use timber mainly for construction and fuelwood. However, the land covered by savanna is increasing. About 0.34% of the area was covered by savanna in 2001 which increased to 0.42% in 2016 with a 22% per cent change. As mentioned earlier, due to the harsh environmental conditions and topography more than 53% of the land is barren in the UIB. The proportion of barren land was 55% in 2001 which is reduced to 53% in 2016. Spatial analysis showed that a major portion of barren land is replaced by snow and ice (Fig. 2). The UIB receives a significant amount of precipitation as snow in winter. Snow is melted as the summer temperature rises which results in the continuous fresh water supply for downstream agriculture and hydropower generation. More than 60% of its river flow comes from snow and glaciers melting (Immerzeel et al., 2010). The present study shows that the snow and ice area increased from 12% in 2001 to 15% in 2016. Recent studies also suggest steady and expanding glaciers and snow cover in the Karakoram and Hindukush region (Tahir et al., 2011; Forsythe et al., 2012; Bolch et al., 2012; Bhambri et al., 2013; Gardelle et al., 2013; and Bilal et al., 2019).

Table. 1. IGBP classification and reclassified classes by combining the count values of the respective classes.

IGBP classification	Reclassified
Evergreen Needleleaf forest	Forestland
Mixed forest	
Closed shrublands	Shrubland
Open shrublands	
Woody savannas	Savannas
Savannas	
Grasslands	Grassland
Croplands	Cropland
Urban and built-up	Urban and built-up
Permanent snow and ice	Permanent snow and ice
Barren	Barren

Table. 2. Comparison of land cover change 2001 vs 2016.

Class	2001		2016			
	Area Km²	Area %	Area Km²	Area %	Net change	Percentage change
Forestland	88	0.04%	80	0.04%	-8	-9.09
Shrubland	1101	0.53%	869	0.42%	-232	-21.07
Savannas	698	0.34%	852	0.41%	154	22.06
Grasslands	64819	31.26%	65336	31.52%	517	0.79
Croplands	217	0.10%	232	0.11%	15	6.91
Urban	60	0.03%	62	0.03%	2	3.33
Snow and ice	25735	12.41%	30441	14.69%	4706	18.28
Barren	114656	55.29%	109417	52.78%	-5239	-4.56

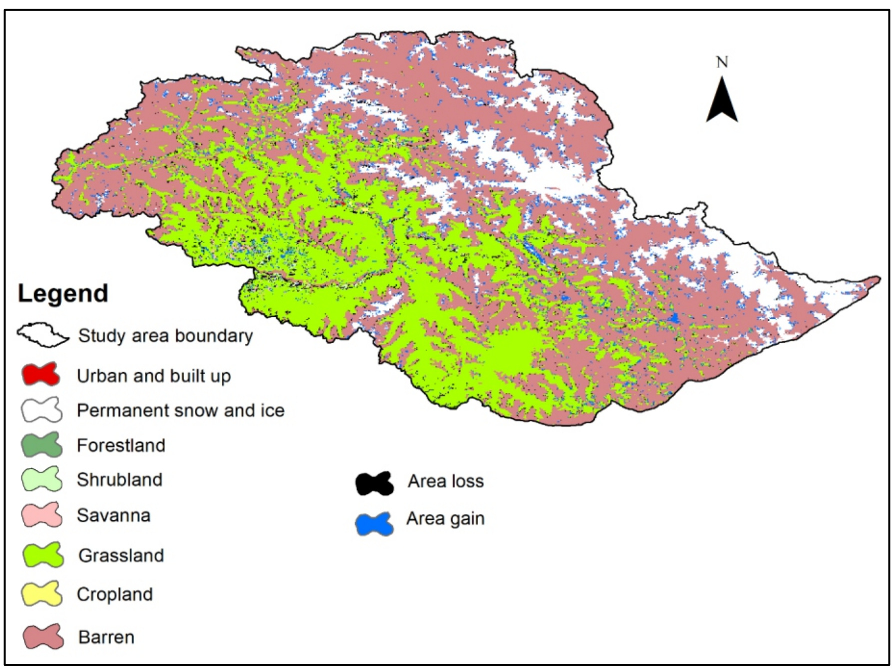

Fig. 2. LULC changes in the Upper Indus Basin. The black and blue colour represents the difference between 2001-2016. The black colour represents area loss while the blue colour represents area gain.

Grassland and cropland area also increased from 31.26% and 0.10% in 2001 to 31.52% and 11% in 2016. Grassland is vital for soil fertility and the sustenance of livestock and wildlife. Because of the harsh terrain urban area and agricultural activities are restricted to riversides in the valley bottom. Urban and built-up areas increased by 3% from 60 Km^2 in 2001 to 62% in 2016.

3.3. Annual land-use time-series data

Annual time series data analysis is important as it gives a detailed picture with more information about the area in question. Analysis of Kendall's tau (τ) coefficient values at 5% significance level shows some statistically significant increasing trends in grassland, urban and built-up area and snow and ice-covered area during 2001-2016. In contrast, a significant negative trend was detected in shrubland and barren land (Table 3). Forestland and cropland areas also exhibit slightly increasing trends, however, trends are not statistically significant. The use of annual time series land use data is a better option than decadal or randomly selected land use data. For instance, the forestland was 88 Km^2 in 2001 which is reduced to 80 Km^2 in 2016 with a net change of -8 Km^2. However, analysis of the annual time series data from 2001-2016 indicated an overall increasing trend in forestland. Thus, decadal and randomly selected LULC change data carries a considerable amount of uncertainties by neglecting the significant LULC changes between two time steps.

3.4. Hydrometeorology

The UIB is located between 877-8564 meters above sea level. The mean temperature fluctuates from -6°C in January to 17°C in July. Due to the greater elevation, lower temperature, lower pressure, orographic processes, winter westerly disturbances and the presence of perennial snow and glaciers a higher spatial variability exists in the hydrometeorological parameters (Bilal et al., 2019). In lower elevated areas like Gilgit (1550 m ASL) the summer temperature goes up to 30°C and drops to 7°C in winter. Annual average data assessment of six weather stations suggested a considerable rise in the annual total precipitation (τ =+0.198, $p<0.05$) and a slight non-significant increment in the annual mean temperature (τ =+0.042, $p>0.05$) (Fig. 3). Archer and Flower (2004) also reported an upward tendency in the total precipitation.

The river flow of the UIB is greatly dependent on the glacier and snowmelt. Seasonal snow is accumulated in winter which is melted down by the increase in summer temperature. Peak river flow at Shatial gauging station is observed in July and August 6000-6500m3s-1. Monthly runoff data at the Shatial gauging station also showed a substantial increase in the river flow (τ =+0.286, $p<0.05$) throughout observation 2001-2016. Similarly, total annual precipitation is significantly increasing (τ =+0.192, $p<0.05$) throughout observation in contrast to the non-significant positive trend in mean annual temperature (Fig. 3). These results are in agreement with the recent findings of Azam et al. (2020) and Yaseen et al. (2020).

Table. 3 LULC changes based on the annual time series data from 2001-2016.

Class	Kendall's tau (τ)	Trend	Net change (Km^2)
Forestland	0.31	Increasing	-8
Shrubland	-0.70	Decreasing*	-232
Savannas	0.008	Increasing	154
Grasslands	0.62	Increasing*	517
Croplands	0.15	Increasing	15
Urban and built up	0.72	Increasing*	2
Permanent snow and ice	0.86	Increasing*	4706
Barren	-0.86	Decreasing*	-5239

Note: * represent significance p<0.05.

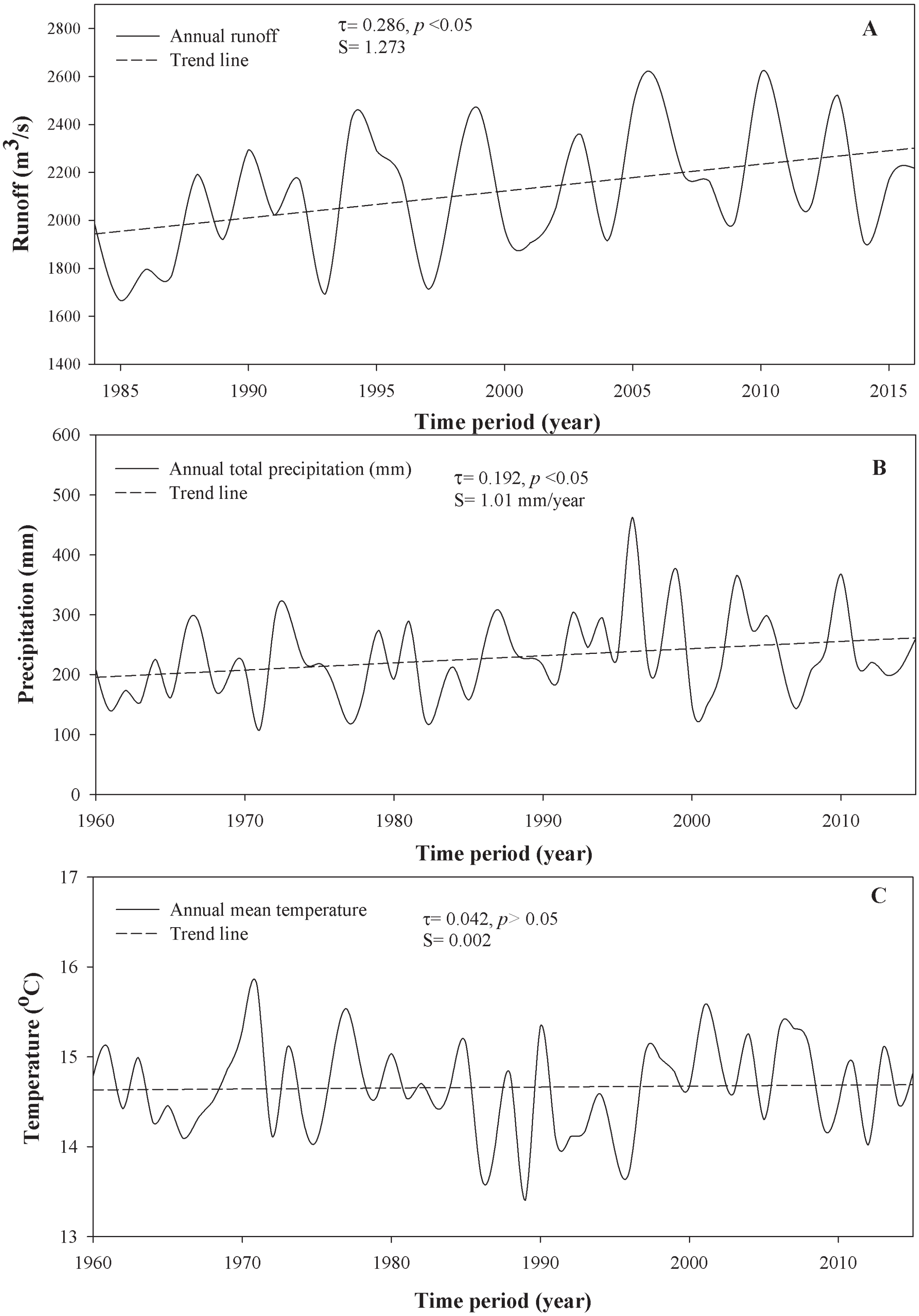

Fig. 3. Long term variation in (A) annual mean runoff 1984-2016, (B) total annual precipitation and (C) mean annual temperature in UIB from 1960-2016. τ is Kendall's tau, S= Sen's slope.

3.5. Correlation

Mann Kendall trend test has indicated that urban and built up, grassland and permanent snow and ice area has increased significantly, while the area covered by shrubland and barren land has decreased significantly over the period of observation 2001-2016 (Table 3). Land cover classes are correlated with climatic parameters. For example, variation in the temperature and precipitation can alter the growth of shrublands, forest cover, snow and ice cover and eventually runoff. Five land cover classes (snow and ice, grassland, built-up area, shrubland and barren land) were selected based on the significance of the Mann Kendall trend test to look for the possible correlation among the land cover classes as well as with the climatic parameters. The selected land cover classes and climatic parameters were analyzed by Pearson's correlation at a 5% significance level (Fig. 4).

According to Pearson's correlation, a statistically significant negative correlation exists among shrubland, grassland, urban and build-up, and snow and ice-covered area. This indicates that a significant portion of shrubland has been replaced by these land cover classes. A similar strong negative correlation is observed between urban and built up, shrubland and barren land. Most of the population and agricultural land is situated at the bottom valleys where shrubland, barren land and savanna are the most common land classes. This negative correlation explains that shrubland and barren land has been converted to urban and agricultural land over the period of observation.

Similarly, the area covered by permanent snow and ice has a significant correlation with shrubland and barren land. As stated, earlier the snow and ice area has increased significantly with the net change of 4706 km² which has resulted in the decline of shrubland and barren land. Most of the areas at high altitudes are barren because of the harsh weather conditions making it not suitable for woody vegetation to exist. The spatial analysis also indicates that most of the barren land is replaced by permanent snow and ice at high altitudes. These outcomes are also established by the former research in the sub-basins of the UIB. Bilal et al. (2019) have found that snow cover in the UIB is increasing. Similar increasing trends were stated by Hasson et al. (2014).

It was further found that precipitation has a significant positive correlation with the snow and ice-covered area (Table 4). As the precipitation increases the snow cover also increases this is because most of the precipitation fall in the UIB as snow rather than rain especially in areas that are situated more than 5000m (Fowler and Archer, 2004; Immerzeel et al., 2010). Precipitation was further observed to have a non-significant positive correlation with forestland, savanna, grassland and cropland. This is a generally accepted phenomenon, an increase in soil moisture will increase vegetation growth. A similar positive correlation was found between vegetation growth and precipitation in the Huang-Huai-Hai River Basin, China (Yan et al., 2017). A similar weak direct correlation was observed between runoff, precipitation and snow cover and ice. This correlation is due to the dependency of the Indus River flow on glaciers and snowmelt. Mukhopadhyay and Khan (2015) estimated that upstream of Tarbela Reservoir 70% of the annual flow is meltwater of which 44% by snowmelts and 26% is contributed by glacial melts. A major portion of the UIB (90%) is not exposed to the summer monsoon. A small area about 10% upstream of the Tarbela reservoir is unprotected by high mountains and is directly exposed to the summer monsoonal precipitation (Immerzeel et al., 2010).

4. Discussion

LULC changes have a profound impact on the hydrological processes (López-Moreno et al., 2011). The possible effects of LULC changes in mountainous areas involve variations in evapotranspiration, discharges and snowmelt processes (Andréassian, 2004). Snowmelt rates are slower under forests as the thick canopy blocks most of the incoming solar radiation. The observed slight increasing trend in forestland could be one of the factors to the substantial expansion in the snow and ice cover area. Recent research on the cryosphere also suggest stable and advancing glaciers and snow cover in the Karakoram and Hindukush region (Forsythe et al., 2012; Bolch et al., 2012; Bhambri et al., 2013; Gardelle et al., 2013; Tahir et al., 2011; and Ullah et al., 2016).

Table. 4. Correlation between land cover classes and hydrometeorological parameters. Bold values present significance $p<0.05$.

Variables	Runoff	Temperature	Precipitation	Shrubland	Grasslands	Urban and built up	Snow and ice	Barren land
Runoff								
Temperature	0.00							
Precipitation	0.40	-0.25						
Shrubland	-0.44	-0.04	-0.41					
Grasslands	0.25	-0.31	0.21	-0.57				
Urban and built up	0.16	-0.21	0.53	-0.84	0.60			
Snow and ice	0.24	-0.19	0.50	-0.81	0.69	0.80		
Barren land	-0.26	0.21	-0.47	0.81	-0.76	-0.79	-0.99	

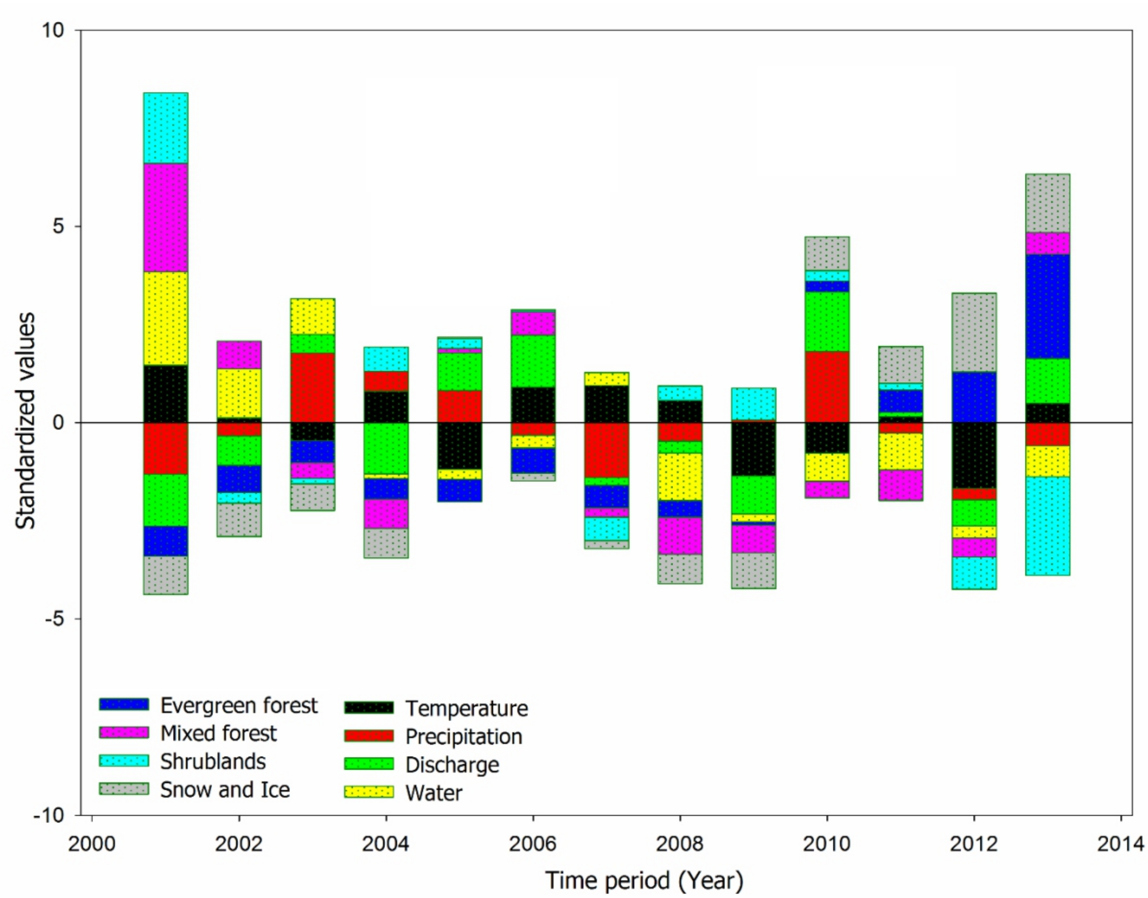

Fig. 4. Correlation between the hydrometeorological and land cover classes.

There has been growing interest that how plants will respond to more extreme precipitation in changing climatic conditions influenced by natural and anthropogenic activities. Changes in the soil water content due to variation in precipitation is likely to affect vegetation. Climatic characteristics like precipitation and temperature determine the probability of an area being a forest, savanna or desert (Hirota et al., 2010). Upward trends in the rainfall may encourage the growth of woody vegetation in savannah environments (Holmgren et al., 2013; Kulmatiski and Beard, 2013). The observed increasing trend in precipitation is very crucial for ecosystem transformation. An increase in the amount of precipitation is reported to boost vegetation growht in semi-arid and dry areas (Xiao et al., 2015). In the present study, the observed increasing trend in vegetation can be attributed to the increased precipitation. The latest research also indicates that vegetation greenness has increased in the Northern Hemisphere especially in China (De Jong et al., 2011; Piao et al., 2015; and Liu et al., 2016;).

On the other hand, changes in vegetation also influence land-atmospheric interaction. Vegetation dynamics are reported to play an essential role in regulating the monsoon rainfall distribution in West Africa (Hales et al., 2006; Xue et al., 2012). According to Snyder et al. (2004, 2010) reduction in the tropical forest cover is closely linked to increased warming and reduced precipitation. Therefore, an increase in the overall vegetation could also be one of the factors behind increasing precipitation in the UIB.

Indus river is the main fresh water supply source to the downstream areas for agriculture and hydropower generation. The significant increase in the annual Indus river flow is of great concern for the downstream flood-prone areas. Previous studies also support increasing runoff in UIB. Similar increasing trends were also reported in the UIB by (Ahmad et al., 2012; Sharif et al., 2013; and Khan et al., 2015). Variation in vegetation also affect runoff by canopy interception and increase evapotranspiration. Research suggests that forest cover has encouraging influences on the hydrological cycle, an increase in forest cover enable large-scale transportation of water vapour and promote precipitation at local to global scales (Liu et al., 2008; Sheil and Murdiyarso, 2009; Jiang and Liang, 2013). Even though large snow-dominated watersheds like UIB are usually robust to forest cover alteration as in comparison to large rainfall controlled watersheds (Zhang et al., 2017). Vegetation does play an important role in regulating the streamflow at the sub-basin level within the UIB. Tough, LULC time series data is available from 2001-2016, a significant increase in the grassland and snow and ice cover area could be attributed to the changing precipitation regime of UIB. Further research is needed to project the LULC changes in changing climatic conditions in UIB and their possible impacts on human and ecosystem services.

5. Conclusion

The present study utilized spatial-temporal assessment techniques, which increases our understating about the pronounced LULC changes in the UIB. Satellite and ground data have been used to study long term trends and interrelationships between LULC and hydrometeorology of the UIB. The overall accuracy of the MODIS land cover product was 87%. Cohen's kappa coefficient value is 0.82 which means a good agreement between classification and reference data. The MODIS land product is a reliable and efficient dataset for the identification of land cover classes in large basins like the UIB.

The UIB is a snowmelt and glacier melt basin. It is vital for the sustenance of biodiversity, highest peaks, storage of fresh water and continuous water supply for agriculture and hydropower. The UIB has observed significant variation in LULC pattern as well as in hydrometeorological parameters during 2001-2016. A significant increase in the land cover area has been observed in grassland, grassland urban and snow-covered area. The precipitation regime is going through a significant increase while the mean temperature is slightly decreasing. Data analysis also revealed that Indus River runoff has increased over the period of observation. The observed increase in the total annual precipitation could be the reason for increased vegetation in the UIB. Furthermore, intensification of the rainfall regime is globally expected to increase the woody vegetation. Positive changes in forestland, grassland, savanna and snow and ice cover area could be attributed to the changing precipitation regime of UIB. Modelling of the sub-basins within the UIB will further enhance our understanding of vegetation and increasing precipitation regime. The findings of the present research work are expected to help city developers, and local governments for planning and development, hazard, flood management and knowledge about LULC in the UIB.

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Authors' Contribution

Hazrat Bilal projected the main concept and design of the study with field data acquisition; analysis, interpretation of the data, and drafting of the manuscript. Chamhuri Siwar provided basic facilities for the collection of field data, Mazlin Bin Mokhtar performed analysis, interpretation of the data. Kasturi Devi Kanniah revised the manuscript critically for important intellectual content. Rajesh Govindan and Tariq Al-Ansari read and approved the final manuscript.

References

Adnan, M., Nabi, G., Poomee, M. S. 2017. Snowmelt runoff prediction under changing climate in the Himalayan cryosphere: A case of Gilgit River Basin. Geoscience Frontiers 8: 941–949.

Ahmad, S.S., Abbasi, Q. 2011. Assessment of Forest Cover Decline in Pakistan: A GIS Perspective. International Journal of Environmental Sciences 2: 220.

Ahmad, Z., Hafeez, M., Ahmad, I. 2012. Hydrology of mountainous areas in the upper Indus Basin, Northern Pakistan with the perspective of climate change. Environ Monit Assess 184:5255–5274.

Akbar, M., Ahmed, M., Hussain, A. 2011. Quantitative forests description from Skardu, Gilgit and Astore Districts of Gilgit-Baltistan, Pakistan. FUUAST J. of Biology 1: 149–160.

Ali, S., Ajmal, M., Khan, M. S. 2017. Assessment of precipitation trends in Gilgit Baltistan (Pakistan) for the period 1980-2015: an indicator of climate change. Journal of Himalayan Earth Science 50.

Andréassian, V. 2004. Waters and forests: from historical controversy to scientific debate. Journal of hydrology 291: 1–27.

Archer, D. R., Fowler, H. J. 2004. Spatial and temporal variations in precipitation in the Upper Indus Basin, global teleconnections and hydrological implications. Hydrology and Earth System Sciences 8: 47–61.

Azam, M. I., Guo, J., Shi, X., Yaseen, M., Tayyab, M., Hussain, Z., Dai, L., Bashir, H., & Tam, N. T. M. 2020. Spatial climatic variability and impact of El niño-southern oscillation on extreme precipitation of river catchment. Environmental Engineering Science, 37(5), 346–364. https://doi.org/10.1089/ees.2019.0440

Bennett, A.F., Saunders, D. A. 2010. Habitat fragmentation and landscape change. Conservation biology for all 93: 1544–1550.

Bhambri, R., Bolch, T., Kawishwar, P. 2013. Heterogeneity in glacier response in the upper Shyok valley, northeast Karakoram. Cryosphere 7 .

Bilal, H., Chamhuri, S., Mazlin, B. M. 2019. Recent snow cover variation in the Upper Indus Basin of Gilgit Baltistan, Hindukush Karakoram Himalaya. Journal of Mountain Science 16(2).

Böhner, J., Lucarini, V., 2017. Prevailing climatic trends and runoff response from Hindukush–Karakoram–Himalaya, upper Indus Basin. Earth System Dynamics 8: 337–355.

Bolch, T., Kulkarni, A., Kääb, A. 2012. The state and fate of Himalayan glaciers. Science 336: 310–314.

Bonan, G. B. 2001. Observational evidence for reduction of daily maximum temperature by croplands in the Midwest United States. Journal of Climate 14: 2430–2442.

Bourg, D. M. 2006. Excel Scientific and Engineering Cookbook: Adding Excel to Your Analysis Arsenal. " O'Reilly Media, Inc."

Brown, D., Polsky, C., Bolstad, P. V. 2014. Land use and land cover change. Pacific Northwest National Laboratory (PNNL), Richland, WA (US)

De Jong, R., de Bruin, S., de Wit, A. 2011. Analysis of monotonic greening and browning trends from global NDVI time-series. Remote Sens Environ 115:692–702.

Forsythe, N., Kilsby, C. G., Fowler, H. J. 2012. Assessment of runoff sensitivity in the Upper Indus Basin to interannual climate variability and potential change using MODIS satellite data products. Mountain Research and Development 32: 16–29.

Fowler, H. J., Archer, D. R. 2006. Conflicting signals of climatic change in the Upper Indus Basin. Journal of Climate 19: 4276–4293.

Hales, K., Neelin, J. D., Zeng, N. 2006. Interaction of vegetation and atmospheric dynamical mechanisms in the mid-Holocene African monsoon. J Clim 19:4105–4120.

Hansen M. C., Loveland, T. R. 2012. A review of large area monitoring of land cover change using Landsat data. Remote sensing of Environment 122: 66–74.

Harding, K. J, Snyder, P.K. 2012. Modeling the atmospheric response to irrigation in the Great Plains. Part I: General impacts on precipitation and the energy budget. Journal of Hydrometeorology 13: 1667–1686.

Hasson, S., Lucarini, V., Khan, M. R. 2014. Early 21st century snow cover state over the western river basins of the Indus River system. Hydrology and Earth System Sciences 18: 4077–4100. https://doi.org/10.5194/hess-18-4077-2014

Hewitt, K. 2005. The Karakoram anomaly? Glacier expansion and the 'elevation effect,'Karakoram Himalaya. Mountain Research and Development 25: 332–340.

Hietel, E., Waldhardt, R., Otte, A. 2004. Analysing land-cover changes in relation to environmental variables in Hesse, Germany. Landscape Ecology, 19(5), 473–489.

Hirota, M., Holmgren, M., Van Nes, E. H. 2011. Global resilience of tropical forest and savanna to critical transitions. Science 334: 232–235.

Holmgren, M., Hirota, M., Van Nes, E.H. 2013. Effects of interannual climate variability on tropical tree cover. Nature Climate Change 3: 755.

Immerzeel, W. W., Van Beek, L. P. H., Bierkens, M. F.P 2010. Climate change will affect the Asian water towers. Science 328: 1382–1385.

Jiang, B., Liang, S. 2013. Improved vegetation greenness increases summer atmospheric water vapor over Northern China. J Geophys Res Atmos 118:8129–8139.

Karl, T.R., Gleason, B.E., Menne, M. J. 2012. US temperature and drought: Recent anomalies and trends. Eos, Transactions American Geophysical Union 93: 473–474.

Kendall, M. G. 1975. Rank Correlation Methods, Charles Griffin, London.

Khan, K., Yaseen, M., Latif, Y. 2015. Detection of river flow trends and variability analysis of Upper Indus Basin, Pakistan. Sci Int 27.

Khan, K., Yaseen, M., Latif, Y., Nabi, G. 2015. Detection of River Flow Trends and Variability Analysis of Upper Indus Basin, Pakistan. Science International 27: 1261-1270.

Khan, M. R., Lucarini, V. 2012. 21st Century Climatology of Snow Cover for the Western River Basins of the Indus River System. Hydrol. Earth Syst. Sci. Discuss. 10: 13145–13190.

Khattak, M. S., Babel, M. S., Sharif, M. 2011. Hydro-meteorological trends in the upper Indus River basin in Pakistan. Climate research 46: 103–119.

Liu, Y., Stanturf, J., Lu, H. 2008. Modeling the Potential of the Northern China Forest Shelterbelt in Improving Hydroclimate Conditions 1. JAWRA J Am Water Resour Assoc 44:1176–1192.

Liu, Y., Xiao, J., Ju, W. 2016. Recent trends in vegetation greenness in China significantly altered annual evapotranspiration and water yield. Environ Res Lett 11:94010.

López-Moreno, J. I., Morán-Tejeda, E. 2011. Impact of climate evolution and land use changes on water yield in the Ebro basin. Hydrol. Earth Syst. Sci. 15: 311-322.

Mannm, H. B. 1945. Nonparametric tests against trend. Econometrica 13: 245-259.

Milly, P. C. D., Dunne, K. A. 2002. Macro scale water fluxes 2, water and energy supply control of their enter-annual variability. Water Resour Res 38: 241249.

Munroe, D. K., Müller, D. 2007. Issues in spatially explicit statistical land-use/cover change (LUCC) models: Examples from western Honduras and the Central Highlands of Vietnam. Land Use Policy, 24(3), 521–530.

Piao, S., Yin, G., Tan, J., Cheng, L. 2015. Detection and attribution of vegetation greening trend in China over the last 30 years. Glob Chang Biol 21:1601–1609.

Pielke, R. A. 2005. Land use and climate change. Science 310: 1625–1626.
Radoux, J., Lamarche, C., Van Bogaert, E. 2014. Automated training sample extraction for global land cover mapping. Remote Sensing 6: 3965–3987.
Raza, M., Hussain, D., Rasul, G., Akbar, M., Raza, G. 2015. Variations of surface temperature and precipitation in Gilgit-Baltistan (GB), Pakistan from 1955 to 2010. J Biodivers Environ Sci 6: 67–73.
Sen, P. K. 1968. Estimates of the regression coefficient based on Kendall's tau. Journal of the American statistical association 63: 1379–1389
Sharif, M., Archer, D.R., Fowler, H.J. 2013. Trends in timing and magnitude of flow in the Upper Indus Basin. Hydrol Earth Syst Sci 17:1503–1516.
Sheil, D., Murdiyarso, D. 2009. How forests attract rain: an examination of a new hypothesis. Bioscience 59:341–347.
Snyder, P. K. 2010. The influence of tropical deforestation on the Northern Hemisphere climate by atmospheric teleconnections. Earth Interact 14:1–34.
Snyder, P. K., Foley, J. A., Hitchman, M. H. 2004. Analyzing the effects of complete tropical forest removal on the regional climate using a detailed three-dimensional energy budget: An application to Africa. J Geophys Res Atmos 109.
Sulla-Menashe, D., Friedl, M. A. 2018. User Guide to Collection 6 MODIS Land Cover (MCD12Q1 and MCD12C1) Product.
Tabari, H., Marofi, S., Aeini, A. 2011. Trend analysis of reference evapotranspiration in the western half of Iran. Agricultural and forest meteorology 151: 128–136.
Tahir, A. A., Chevallier, P., Arnaud, Y. 2011. Modeling snowmelt-runoff under climate scenarios in the Hunza River basin, Karakoram Range, Northern Pakistan. Journal of Hydrology 409: 104–117.
Ullah, S., Farooq, M., Shafique, M. 2016. Spatial assessment of forest cover and land-use changes in the Hindu-Kush mountain ranges of northern Pakistan. Journal of Mountain Science 13: 1229–1237.
Varhola, A., Coops, N. C., Weiler, M. 2010. Forest canopy effects on snow accumulation and ablation: An integrative review of empirical results. Journal of Hydrology 392: 219–233.
Woldesenbet, T. A, Elagib., N. A., Ribbe, L. 2017. Hydrological responses to land use/cover changes in the source region of the Upper Blue Nile Basin, Ethiopia. Science of the Total Environment 575: 724–741.
Wulder, M. A, Coops, N. C, Roy, D. P. 2018. Land Cover 2.0. International Journal of Remote Sensing 39: 4254–84.
Xiao, J., Moody, A. 2005. Geographical distribution of global greening trends and their climatic correlates: 1982–1998. Int J Remote Sens 26:2371–2390.
Xue, Y., Boone, A., Taylor, C. M. 2012. Review of recent developments and the future prospective in West African atmosphere/land interaction studies. Int J Geophys 2012.
Yaseen, M., Ahmad, I., Guo, J., Azam, M. I., & Latif, Y. 2020. Spatiotemporal Variability in the Hydrometeorological Time-Series over Upper Indus River Basin of Pakistan. Advances in Meteorology, 2020. https://doi.org/10.1155/2020/5852760
Zhang, M., Liu, N., Harper, R. 2017. A global review on hydrological responses to forest change across multiple spatial scales: Importance of scale, climate, forest type and hydrological regime. Journal of Hydrology 546: 44–59.