Research Article

Land use and Cover Changes in the Northern Mountains of Pakistan; A Spatio-Temporal Change using MODIS (MCD12Q1) Time Series

Shakeel Ahmad[1], Muhammad Israr[2*], Rasheed Ahmed[3], Anam Ashraf[1], Muhammad Amin[4] and Nafees Ahmad[5]

[1]School of Environment, Tsinghua University, Beijing 100084, China; [2]Institute of Development Studies, The University of Agriculture, Peshawar, Pakistan; [3]Department of Soil and Climate Sciences, The University of Haripur, Pakistan; [4]Department of Environmental Sciences, COMSATS University Islamabad (CUI), Abbottabad Campus, 22060, Abbottabad, Pakistan; [5]Department of Economics, University of Malakand, Pakistan

Abstract | In the sustainable management of natural resources, land use and land cover (LULC) changes play an essential role. Pakistan is rich in biodiversity and provides ecosystem services to the country's population, especially the mountains of the northern highland. These areas have experienced extensive depletion of ecosystem services and are susceptible to fast LULC changes. Real-time monitoring and assessment based on spatio-temporal are important to know such LULC changes. This study examines LULC in the northern mountains of Pakistan from MODIS (MCD12Q1) time series from 2001 to 2018. LULC was classified into ten significant classes. Findings of the data revealed that shrublands (0.33-0.17%), grasslands (45.83-41.74), and cropland (12.71-10.47) were decreased significantly. At the same time, savannas, permanent wetlands, urban and built-up lands, natural vegetation, permanent snow and ice, and barren lands increased substantially over the entire period. Due to the lack of baseline data, the LULC map will play an essential role in the sustainable management of LULC in the Hindu Kush, Karakoram and Himalayan regions of Pakistan. For the sustainable maintenance of the mountainous ecosystem, comprehensive research is recommended about these LULC vulnerabilities locally and regionally.

Received | April 23, 2020; **Accepted** | June 28, 2022; **Published** | October 05, 2022
***Correspondence** | Muhammad Israr, Institute of Development Studies, The University of Agriculture, Peshawar, Pakistan; **Email:** misrar@aup.edu.pk
Citation | Ahmad, S., M. Israr, R. Ahmed, A. Ashraf, M. Amin and N. Ahmad. 2022. Land use and cover changes in the Northern Mountains of Pakistan; A spatio-temporal change using MODIS (MCD12Q1) time series. *Sarhad Journal of Agriculture,* 38(4): 1419-1429.
DOI | https://dx.doi.org/10.17582/journal.sja/2022/38.4.1419.1429
Keywords | LULC change, Natural resources and their distribution, Remote sensing, Climate/spatio-temporal changes

Introduction

Planning for sustainable economic, social, environmental, and land resources are critical because of population growth and global climate change (Ashraf, 2020; Matin *et al*., 2019). Due to the enormous burden of agriculture and urbanization, various human activities are underway to use the earth's natural resources, which are decreasing rapidly. Therefore, remote sensing satellite data are shown to be very useful for the analysis and mapping of land cover (Lasko *et al*., 2018; Levizzani *et al*., 2019). Even if the resulting spatial dataset has different resolutions, this change can be monitored using a GIS approach (Giuliani *et al*., 2020; Munsi *et al*., 2010). It is essential to fill in the literature about land use and land cover changes

(LULC) to control and plan resources effectively for sustainable future growth (Hishe *et al*., 2020; Mansour *et al*., 2020).

Changes in LULC is significant to meet the current demand of human needs like land, water and vegetation (Powers *et al*., 2019; Nath *et al*., 2018; Toure *et al*., 2020). Anthropogenic activities, *i.e*., deforestation, urbanization, agriculture build-up, and further land degradation, are responsible for these changes (Noszczyk, 2019). It may lead to a decline in biodiversity, natural resources, smashed food supply, severe political and social consequences (Purswani *et al*., 2020; Sánchez-Bayo *et al*., 2019; Gibb *et al*., 2018). The land-use dynamics of a region reflect natural and human environmental characteristics (Borrelli *et al*., 2017; Li *et al*., 2017). The physical environment varies from natural topography to the classification of water, natural resources, and land cover in an area (Aghsaei *et al*., 2020; Ngo *et al*., 2020).

Land cover change is influenced by social and natural factors, as the social factors have a significant impact on economies and increase in population while the natural factors control vegetation types by natural selection and changes in climate especially precipitation strongly affect vegetation's state and growth (Ahmad *et al*., 2017; Kweyu *et al*., 2020; Liu *et al*., 2020). According to Zou *et al*. (2020a; 2020B) that the leading cause of changing in quality of natural ecosystem is due to alteration in precipitation pattern. Numerous studies, such as Liu *et al*. (2019) and Ning *et al*. (2018), have shown that social, economic, and climate change is having a significant impact on LULC and ecosystems. Accurate and up-to-date global information on LULC changes is important to understand and assess the environmental impact of such changes.(Giri *et al*., 2016). LULC change is a crucial factor responsible for environmental transformation regionally and globally (Ketema *et al*., 2020; Xiao *et al*., 2006). Changes in LULC can be monitored by conventional techniques and satellite remote sensing (provides a large amount of data on a global and regional scale) (Halmy *et al*., 2020). Remote sensing and GIS are powerful tools for assessing spatiotemporal LULC changes (Kulkarni *et al*., 2020; Shen *et al*., 2020; Xiao *et al*., 2006). Consistent, historical, and accurate information about changes in LULC on the Earth's surface play a vital role in the sustainable development plan (John *et al*., 2020; Mustafa, 2020).

LULC provides a basic understanding of the dynamics of the mountain environment based on remote sensing spatio-temporal variations. Rapid overexploitation of natural resources and population increase have resulted in catastrophic global instability. LULC must be classified and analyzed to achieve optimal land cover, natural resources, development decisions, and planning. Mountain possess complex ecosystems. The mountain environment in the Hindu Kush, Karakoram, and Himalayan (HKH) regions is being influenced by natural and human factors such as climate change, population growth, urbanization, economic development (Ahmad *et al*., 2017; Chettri *et al*., 2020; Wang *et al*., 2020) and natural disasters like flash floods, glacial lake floods, landslides, and mudslides, degrading mountainous environment (Ahmad *et al*., 2018; Gul *et al*., 2020; Mukherji *et al*., 2019).

It is important to have LULC changes data on a global and regional scale based on previous literature. In this context, the current study used MODIS (MCD12Q1) time series for the year 2001-2018 to generate information about LULC to help understand the mountainous ecosystems of Pakistan's northern highlands.

Materials and Methods

Study area

The study area is situated in the northern highland of Pakistan, with latitude and longitude of 71º, 40′-73º, 45′, and 34º, 35′-35º, 50′ respectively. Hindu Kush, Karakoram and Himalayan Ranges (HKH) are situated in this region. The area is spread over an area of 19068 sq.km. Narrow valleys and high mountains dominate the topography, with an elevation range of 448-5946 mean above seal level (m.ASL), as shown in Figure 1. It includes district Dir, Kohistan, Shangla, and Swat. The climate here in the summer season is warm and moderate, where the hottest temperature is about in between 33 and 16 degrees centigrade, respectively, in June and July. The season of winter is harsh and severely cold. In January, the mean minimum and maximum temperatures are -2 and 11 degrees centigrade, respectively.

Data sources and trend analysis

The spatial dataset comes from two different sources; "Digital Elevation Model" and "MODIS (MCD12Q1)" land cover type products for extraction and delineation of study areas (Friedl *et al*., 2010).

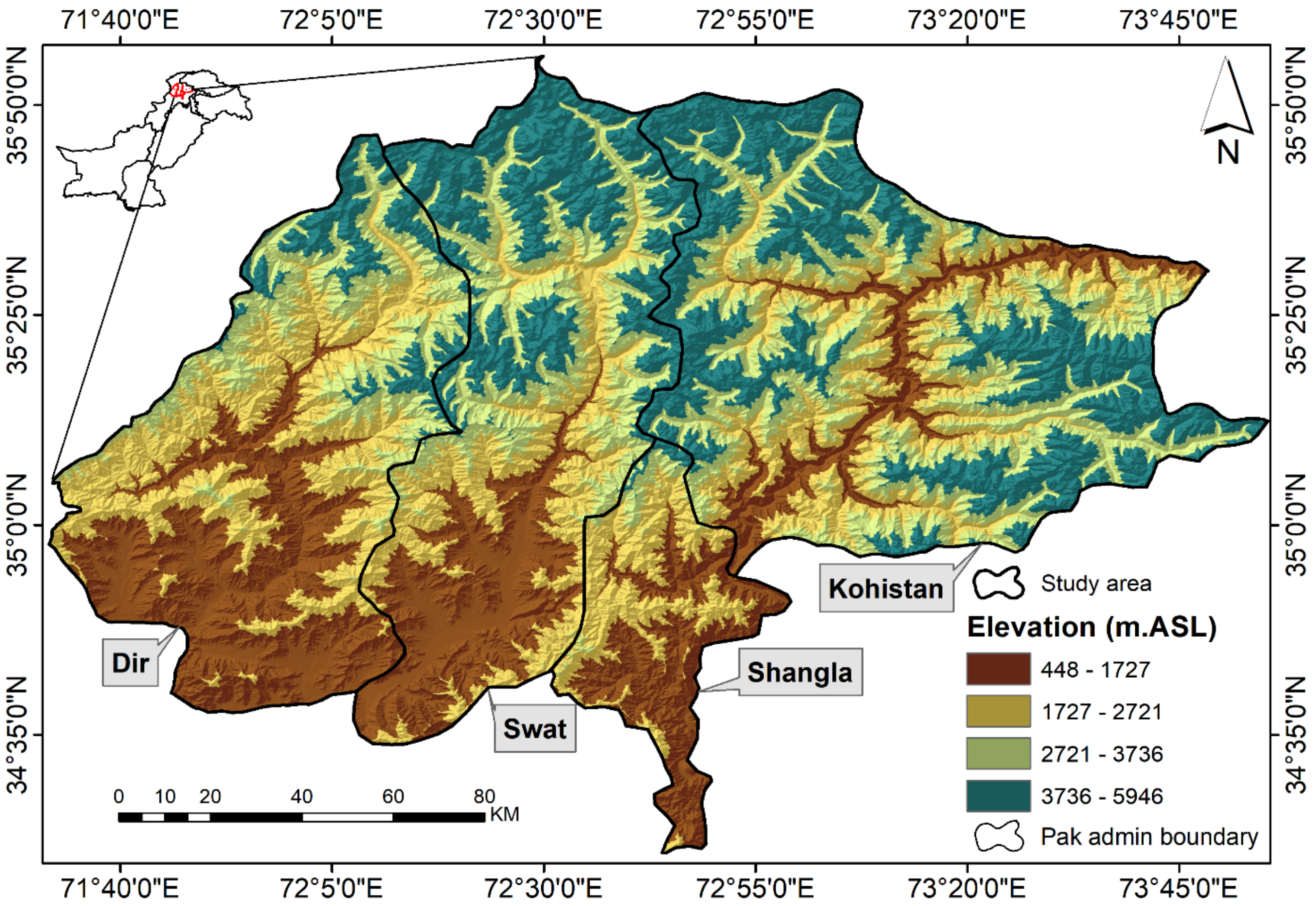

Figure 1: *Study area.*

The dataset of LUC is derived from USGS satellite imagery with a resolution of 500m, using MODIS standard grid maps, with a sinusoidal projection, for generating and classifying global land cover maps for 2001-2018 on an annual basis. They gained coverage of about 1200x1200 km on the equator. Data sets were analyzed to apply Z-statistic and MK trend test on a significant level of 5%. The MK rank-based non-parametric and Z-statistic trend test have been generally used to study the importance of monotonic trends in time series data (Gavrilov *et al*., 2016; Kendall *et al*., 1990; Mann, 1945). A MODIS time series were analyzed individually. After analyzing the data of MODIS were evaluated. Pre-and post-change detection methodologies are used to assess a detailed change detection, as shown in figure 4. An MCD12Q1 provides a "global land cover map" from 2001 to the present, in annual time steps and a spatial resolution of 500 meters. MCD12Q1 products are a "supervised classification of MODIS reflectance data" (Friedl *et al*., 2010; 2002; Ganguly *et al*., 2010). Figure 2 depicts the data source's comprehensive, detailed roadmap for the current study.

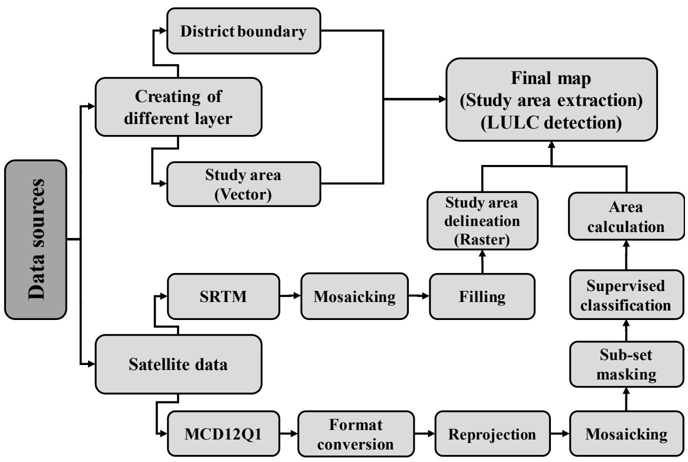

Figure 2: *Roadmap of data source.*

Land cover preprocessing

Initially, image preprocessing is essential for raw data, which typically involves image enhancement, terrain correction, and geometric correction. To make the data consistent, the UTM WSG-84 projection is assigned to it. The land cover data in Table 1 is generated from the MODIS Land Cover Dataset product MCD12Q1. NASA released the MODIS MCD12Q1 product, which used "annual observations” from the “Terra and Aqua satellites” to identify different kinds of land cover. MCD12Q1 data is presented in a hierarchical (HDF) format with about 10 × 10 slices utilizing a Sinusoidal grid. MCD12Q1 data can be used in geographic projections as global mosaics (Liang *et al*., 2015; Sulla-Menashe *et al*., 2019).

Table 1: *Product detail of MODIS MCD12Q1.*

“MCD12Q1 product information	
Data Format	HDF
Available Years	2001-2018
Projection	Sinusoidal
Spatial resolution	500 m
Temporal resolution	Yearly
Acquisition website	“https://earthexplorer.usgs.gov/”

Information about MODIS and HDF can be found at http://www.hdfgroup.org/products/ and http://modis-land.gsfc.nasa.gov/MODLAND_grid.html. The MCD12Q1 product is saved in HDF and is projected in a sinusoidal manner. Data preprocessing is required, which includes image mosaic, format conversion, reprojection, resampling, and subarea masking. After that, the MODIS HDF data is transformed to Geotiff. To finish the image mosaic and sub-setting, the data projection was transformed to WGS84/UTM.

Land cover classification

The valuable data from the multi-band raster images can be extracted through image classification. After classification, the resultant images can be utilized in LULC maps. In ArcGIS, reclassified options were used to recode the grid code based on classification, as shown in Table 2. The overall goal of image classification is to automatically classify all pixels as land cover classes (Lin *et al*., 2014; Lu *et al*., 2014; Zhang *et al*., 2017).

The study was divided into ten significant classes; “evergreen forest, shrublands, savannas, grasslands, permanent wetlands, croplands, urban and built-up lands, natural vegetation, permanent snow and ice, and barren land”. The legends for the MCD12Q1 product are shown in Table 2.

Results and Discussion

Spatio-temporal changes of Land cover in different years from 2001-2018

Spatio-temporal images of the study region from 2001 to 2018 were classified by using GIS techniques. By using supervised classification, LULC maps were created from satellite pictures. “Evergreen forest (EGF), closed shrublands (SL), savannas (SA), grasslands (GL), permanent wetlands (PW), croplands (CL), urban and built-up lands (UBUL), natural vegetation (NV), permanent snow, and ice (PSI), and barren land (BL)”. These were the ten significant classes identified in satellite images from 2001 to 2018. Figure 3 depicts the overall LULC change for the research area from 2000 to 2018.

Land cover changes

The LULC changes were classified from the MODIS images of 2001 to 2018, as shown in Figure 4. A detailed images of LULC change map was obtained and assigned codes from 1 to 10. The assigned codes were given to “evergreen forests, shrublands, savannas, grasslands, permanent wetlands, croplands, urban and built-up lands, natural vegetation”, permanent snow and ice, and barren land from 1 to 10, respectively.

Table 2: *Description of different classes of land cover.*

Class code	Land cover classes	Description
1	Evergreen Forest	Evergreen conifer, deciduous needle leaf/broadleaf, or mixed forest trees
2	Shrublands	Woody perennials cover
3	Savannas	Tree cover
4	Grasslands	Dominated by herbaceous annuals
5	Permanent Wetlands	Inundated lands with water cover and vegetated cover
6	Croplands	Cultivated cropland.
7	Urban and Built-up Lands	Including building asphalt, materials, and vehicles
8	Natural Vegetation	Herbaceous vegetation, natural tree, or shrub
9	Permanent Snow and Ice	Snow and ice cover area
10	Barren	Including rock, sand, soil with less than vegetation

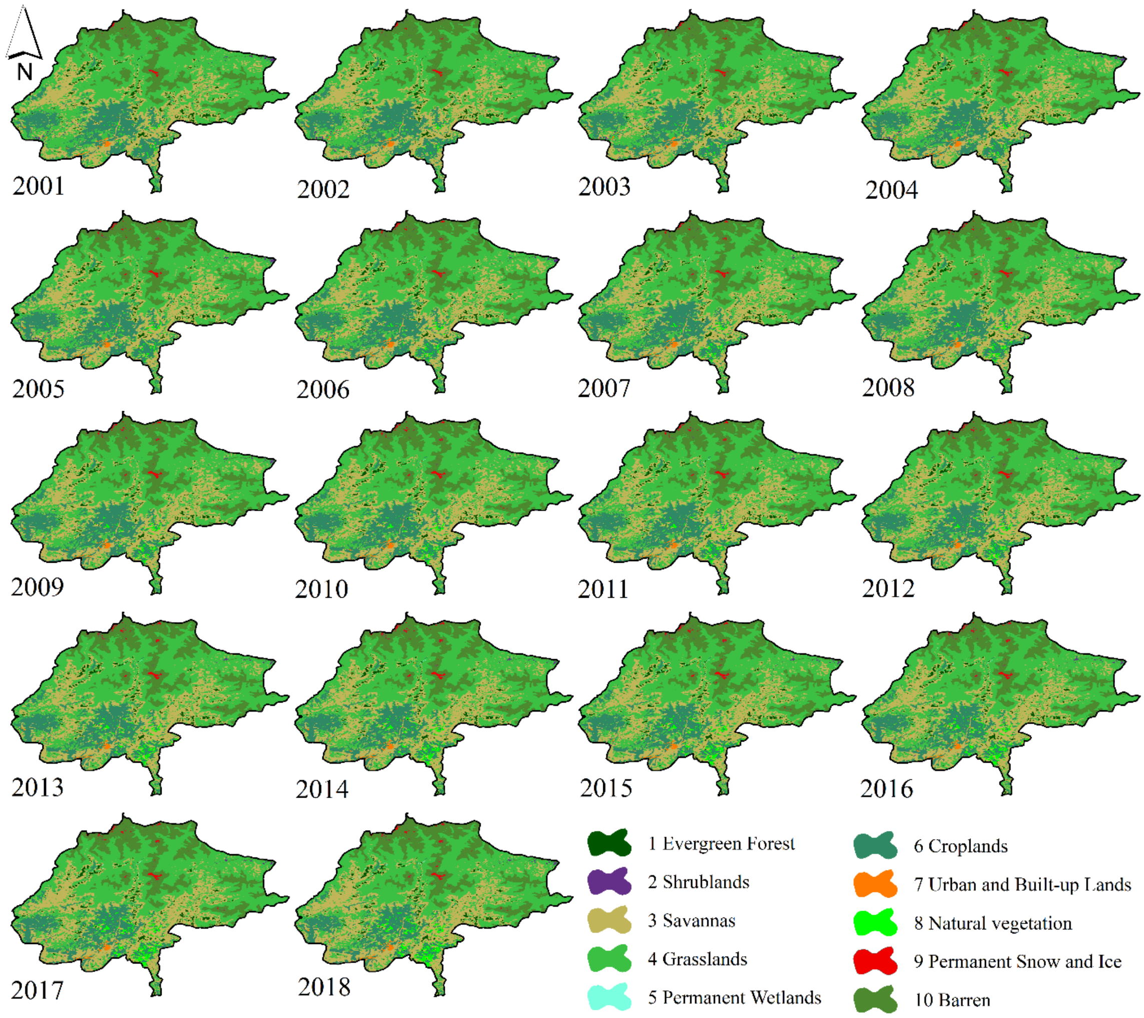

Figure 3: *Land use land cover spatio-temporal change of from 2001 to 2018.*

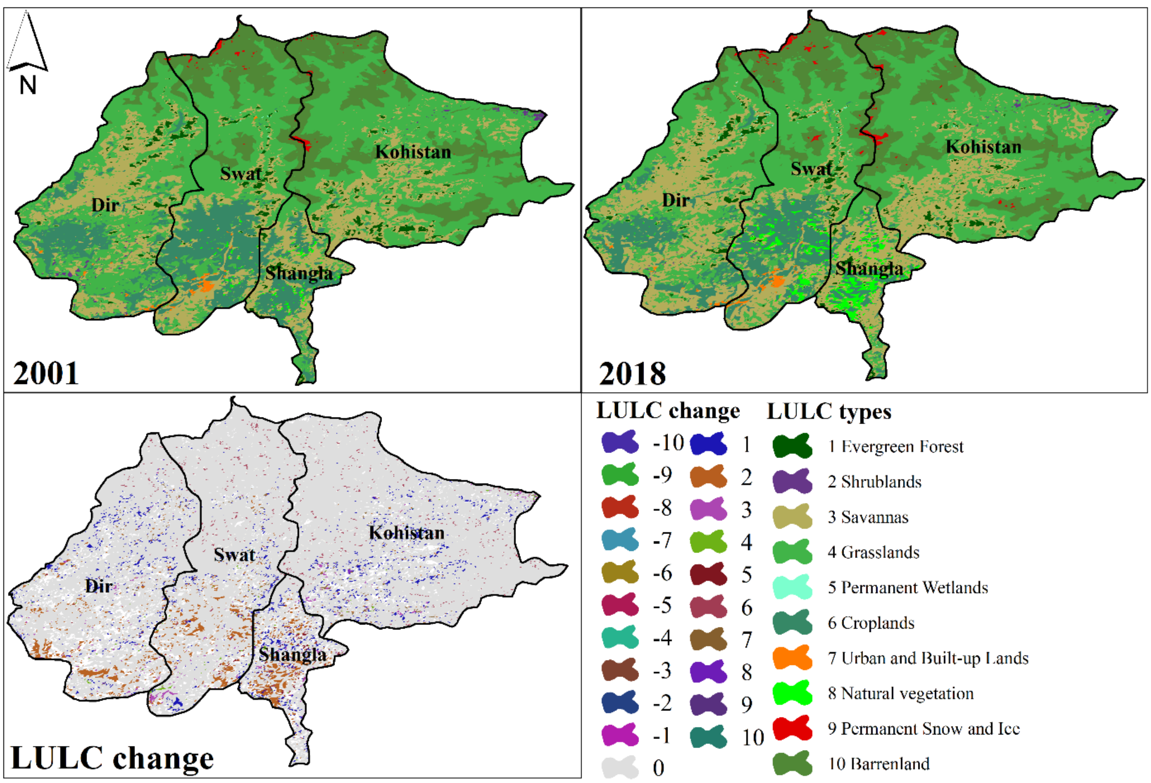

Figure 4: *Spatial pattern of LULC and types changes for the year 2001-2018.*

Table 3: *Land use land cover changes in sq.km and percent.*

	2001		2005		2010		2015		2018	
	Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	%
Evergreen Forest	404.9	2.1	341.1	1.8	330.9	1.7	374.6	2.0	403.3	2.1
Shrublands	63.4	0.3	51.9	0.3	29.5	0.2	31.7	0.2	32.3	0.2
Savannas	4187.6	21.9	4393.5	23.0	4423.4	23.2	4592.8	24.1	5001.5	26.2
Grasslands	8746.1	45.8	8379.2	43.9	8332.8	43.7	8268.9	43.3	7965.6	41.7
Permanent Wetlands	6.6	0.0	4.4	0.0	5.7	0.0	12.8	0.1	19.5	0.1
Croplands	2426.4	12.7	2540.0	13.3	2502.1	13.1	2222.8	11.7	1997.4	10.5
Urban and Built-up Lands	59.7	0.3	61.4	0.3	65.2	0.3	69.6	0.4	69.5	0.4
Natural vegetation	73.3	0.4	116.6	0.6	173.5	0.9	296.0	1.6	404.9	2.1
Permanent Snow and Ice	60.0	0.3	103.3	0.5	119.8	0.6	129.2	0.7	116.5	0.6
Barren	3056.0	16.0	3092.1	16.2	3100.8	16.3	3085.5	16.2	3073.0	16.1
Total	19084.0	100.0	19084.0	100.0	19084.0	100.0	19084.0	100.0	19084.0	100.0

For better cartographic representation, the produced change map was vectorized and used threshold. The results showed that SA, PW, UBUL, NV, PSI, and BLwere increased significantly over the entire study area from the last 18 years.

The classification results (Table 3) of 2001 reveal that "evergreen forest, shrublands, savannas, grasslands, permanent wetlands, croplands, urban and built-up lands, natural vegetation", permanent snow and ice, and barren lands occupy 404.91, 63.37, 4187.57, 8746.11, 6.58, 2426.38, 59.69, 73.31, 59.99, and 3056.04 km^2 of area respectively (Table 3). The satellite image was categorized into the same type and number of classes as in 2018 (Figure 3).

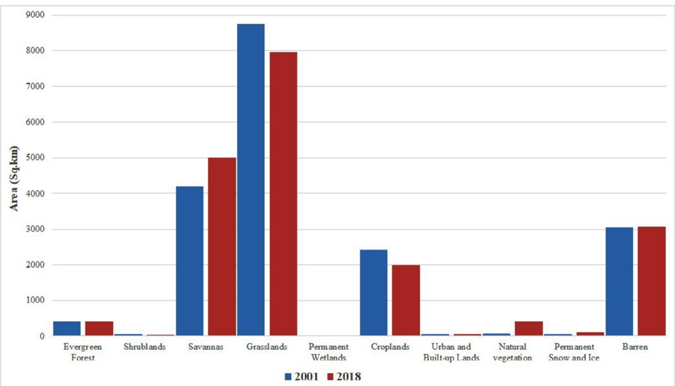

Figure 5: *Annual difference of spatial pattern of the year 2001-2018.*

The classification imagery of 2018 shows that "evergreen forest, shrublands, savannas, grasslands, permanent wetlands, croplands, urban and built-up lands, natural vegetation", permanent snow and ice, and barren lands occupy 403.28, 32.25, 5001.53, 7965.60, 19.46, 1997.35, 69.50, 404.90, 116.52, 3073.03 km^2 of area respectively (Table 3). The spatial patterns on an annual basis from 2001 to 2018 were presented in Figure 5 to understand changes in the land cover types over the entire study area.

Real change in land cover (percent)

The results revealed that the grassland had a larger area from 2001 to 2018. Still, the most significant changes in area were found as a decrease in the shrublands, grassland, and croplands, from 0.33% to 0.17%, and 45.83% to 41.74% and 12.71% to 10.47%, respectively (Table 3) as compared to other land cover types. At the same time, no changes in an evergreen forest from 2001 to 2018, from 2.12% to 2.11% over the entire study area.

It was also found from the current study that the percentage of permanent wetland, build-up land, natural vegetation, permanent snow and ice, and barren land increased from 2001 to 2018. Table 3 indicates that the percentage of savannas were increased by 4.27% over the period. The current study findings were similar to Liu *et al*. (2014) study findings. While on the other hand, within the Basin, Barren land decreased from 55.61% to 39.96% from 2001 to 2013, as demonstrated in Table 2.

Land cover changes and Z-statistical analysis

The land cover types and changes observed from MODIS images of 2001 to 2018, as shown in Figure 6, The natural vegetation is significantly increasing in Shangla and Swat areas, as compared to Dir and Kohistan, whereas savannas were also significantly increased all over the study area. The phenomena of LULC changes induced by a human and natural

Table 4: *Z-statistic of land cover types.*

Land cover classes	Local common names	Z-Test	Significant	Trend M-K	Value p
Evergreen Forest	Sada Bahar Jungle	0.86		No Trend	0.8038
Shrublands	Jharion Ka Jungle	-3.29	**	Sig Decrease	0.0005
Savannas	Wasee Medaan	3.92	***	Sig Increase	1.0000
Grasslands	Charagah	-4.91	***	Sig Decrease	0.0000
Permanent Wetlands	Martoob Zameen	3.56	***	Sig Increase	0.9998
Croplands	Zarayi Zameen	-3.20	**	Sig Decrease	0.0007
Urban and Built-up Lands	Shehri Qasba	5.36	***	Sig Increase	1.0000
Natural vegetation	-------------	5.36	***	Sig Increase	1.0000
Permanent Snow and Ice	-------------	4.01	***	Sig Increase	1.0000
Barren	Banjar Zameen	2.57	*	Sig Increase	0.9949

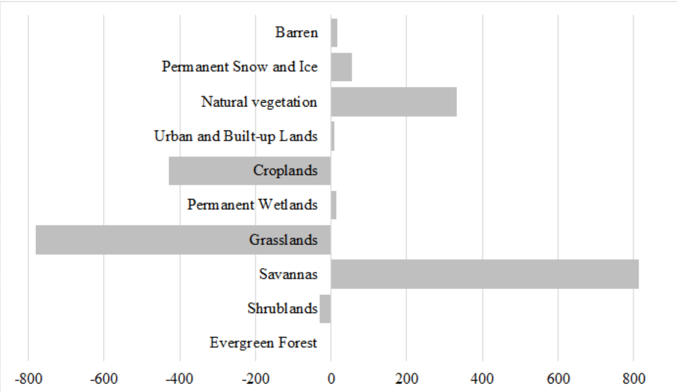

Figure 6: *Area wise significance of Land cover types.*

process, the spatio-temporal data were assembled for the last 18 years (Figure 2). The data of LULC types were divided into ten significant classes; EGF, SL, SA, GL, PW, CL, UBUL, NV, PSI, and BL.

The results showed that LULC types were at α > 0.1 significant level and presented no change in the evergreen forest with z-value of 0.86. The SL, SA, PW, UBUL, NV, PSI, and BL indicated a highly significant increase (α > 0.001) in the entire data series with z-value of 3.92, 3.56, 5.36, 5.36, 4.01, and 2.57, respectively. While on the other hand, SL, GL and CL, showed a significant decrease at α significant level 0.05, with z-value of -3.29, -4.91, and -3.20.

Conclusions and Recommendations

The current study provides information about LULC to understand and promote sustainable ecosystems in the fast-growing area of the northern highland of Pakistan. Therefore, LULC spatio-temporal changes information based on satellite remote sensing approaches are the most prominent regional and global scale. The result of the study based on MODIS (MCD12Q1) time series over 18 years (2001-2018) revealed that shrublands (0.33-0.17%), grasslands (45.83-41.74), and cropland (12.71-10.47) were decreased significantly. Between 2001 and 2018, the number of savannas, permanent wetlands, urban and built-up regions, natural vegetation, permanent snow and ice, and barren terrain rose significantly. These data will eventually classify limited resources and significant environmental areas to manage natural resources better. As a result, due to a lack of reliable ground observations, the LULC map will play a critical role in the long-term management of LULC in Pakistan's Hindu Kush, Karakoram, and Himalayan regions. It is recommended to conduct more comprehensive research about these vulnerabilities locally, regionally, and globally to manage these resources effectively and comprehensively to maintain mountainous ecosystem sustainability.

Acknowledgements

We are thankful to NASA for providing MODIS and SRTM data (freely available), and we thank the USGS for providing the MODIS land cover (MCD12Q1) product dataset.

Novelty Statement

The current study is unique as it uses remote sensing and GIS technology to predict optimal environmental monitoring in the northern Pakistan to protect biodiversity in alpine ecosystems that are under threat at both the micro and macro levels.

Author's Contribution

Shakeel Ahmad: Data curation and analysis, methodology, software use and writing, visualization/review.

M. Israr: Methodology and visualization/review.

Anam Ashraf: Methodology, writing and visualization/review.

Rasheed Ahmed: Software use and writing, and visualization/review.

Conflict of interest

The authors have declared no conflict of interest.

References

Aghsaei, H., Mobarghaee Dinan, N., Moridi, A., Asadolahi, Z., Delavar, M., Fohrer, N. and Wagner, P.D. 2020. Effects of dynamic land use/land cover change on water resources and sediment yield in the Anzali wetland catchment, Gilan, Iran. Sci. Total Environ., 712: 136449. https://doi.org/10.1016/j.scitotenv.2019.136449

Ahmad, Israr, M., Liu, S., Hayat, H., Gul, J., Wajid, S., Ashraf, M., Baig, S.U. and Tahir, A.A. 2018. Spatio-temporal trends in snow extent and their linkage to hydro-climatological and topographical factors in the Chitral River Basin (Hindukush, Pakistan). Geocarto Int., 1-24. https://doi.org/10.1080/10106049.2018.1524517

Ahmad, Israr, M., Yaseen, A. and Ahmad, N. 2017. Climate change trend analysis on selected food crops at central Khyber Pakhtunkhwa of Pakistan. Int. J. Dev. Sustain., 6(12): 2082-2093.

Ashraf, A. 2020. Risk modeling of soil erosion under different land use and rainfall conditions in Soan river basin, sub-Himalayan region and mitigation options. Modeling Earth Syst. Environ., 6(1): 417-428. https://doi.org/10.1007/s40808-019-00689-6

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K.V., Montanarella, L. and Panagos, P. 2017. An assessment of the global impact of 21st century land use change on soil erosion. Nat. Commun., 8(1): 2013. https://doi.org/10.1038/s41467-017-02142-7

Chettri, N., Shrestha, A.B. and Sharma, E. 2020. Climate Change Trends and Ecosystem Resilience in the Hindu Kush Himalayas. In A. P. Dimri, B. Bookhagen, M. Stoffel, & T. Yasunari (Eds.), Himalayan Weather and Climate and their Impact on the Environment (pp. 525-552). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-29684-1_25

Friedl, M.A., Sulla-Menashe, D., Tan, B., Schneider, A., Ramankutty, N., Sibley, A. and Huang, X. 2010. MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. Remote Sensing Environ., 114(1): 168-182. https://doi.org/10.1016/j.rse.2009.08.016

Friedl., M., McIver, D.K., Hodges, J.C.F., Zhang, X.Y., Muchoney, D., Strahler, A.H., Woodcock, C.E., Gopal, S., Schneider, A., Cooper, A., Baccini, A., Gao, F. and Schaaf, C. 2002. Global land cover mapping from MODIS: algorithms and early results. Remote Sensing Environ., 83(1): 287-302. https://doi.org/10.1016/S0034-4257(02)00078-0

Friedl., M., Sulla-Menashe, D., Tan, B., Schneider, A., Ramankutty, N., Sibley, A. and Huang, X. 2010. MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. Remote Sensing Environ., 114(1): 168-182. https://doi.org/10.1016/j.rse.2009.08.016

Ganguly, S., Friedl, M. A., Tan, B., Zhang, X. and Verma, M. 2010. Land surface phenology from MODIS: Characterization of the Collection 5 global land cover dynamics product. Remote Sensing Environ., 114(8): 1805-1816. https://doi.org/10.1016/j.rse.2010.04.005

Gavrilov, M.B., Tošić, I., Marković, S.B., Unkašević, M. and Petrović, P. 2016. Analysis of annual and seasonal temperature trends using the Mann-Kendall test in Vojvodina, Serbia. Időjárás. 120(2): 183-198.

Gibb, R., Redding, D.W., Chin, K.Q., Blackburn, T.M., Newbold, T. and Jones, K.E. 2018. Effects of land use on zoonotic host communities: a global correlative analysis. The Lancet Planetary Health. 2, S2. https://doi.org/10.1016/S2542-5196(18)30087-1

Giri, S. and Qiu, Z. 2016. Understanding the relationship of land uses and water quality in Twenty First Century: A review. J. Environ. Manage., 173: 41-48. https://doi.org/10.1016/j.jenvman.2016.02.029

Giuliani, G., Mazzetti, P., Santoro, M., Nativi, S., Van Bemmelen, J., Colangeli, G. and Lehmann, A. 2020. Knowledge generation using satellite earth observations to support sustainable development goals (SDG): A use case on Land degradation. Int. J. Appl. Earth Observ. Geoinfor., 88: 102068. https://doi.org/10.1016/j.jag.2020.102068

Gul, J., Muhammad, S., Liu, S.Y., Ullah, S., Ahmad, S., Hayat, H. and Tahir, A.A. 2020. Spatio-temporal changes in the six major glaciers of the Chitral River basin (Hindukush Region of Pakistan) between 2001 and 2018. J. Mount. Sci., 17(3): 572-587. https://doi.org/10.1007/s11629-019-5597-2

Halmy, M.W.A., Fawzy, M. and Nasr, M. 2020. Application of Remote Sensing for Monitoring Changes in Natural Ecosystems: Case Studies from Egypt. In S. F. Elbeih, A. M. Negm, & A. Kostianoy (Eds.), Environmental Remote Sensing in Egypt (pp. 167-182). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-39593-3_6

Hishe, S., Bewket, W., Nyssen, J. and Lyimo, J. 2020. Analysing past land use land cover change and CA-Markov-based future modelling in the Middle Suluh Valley, Northern Ethiopia. Geocarto Int., 35(3): 225-255. https://doi.org/10.1080/10106049.2018.1516241

John, J., Bindu, G., Srimuruganandam, B., Wadhwa, A. and Rajan, P. 2020. Land use/land cover and land surface temperature analysis in Wayanad district, India, using satellite imagery. Annals of GIS, 1-18. https://doi.org/10.1080/19475683.2020.1733662

Kendall, M. and Gibbons, J. 1990. Correlation methods. In: Oxford: Oxford University Press.

Ketema, H., Wei, W., Legesse, A., Wolde, Z., Temesgen, H., Yimer, F. and Mamo, A. 2020. Quantifying smallholder farmers' managed land use/land cover dynamics and its drivers in contrasting agro-ecological zones of the East African Rift. Glob. Ecol. Conservation, 21: e00898. https://doi.org/10.1016/j.gecco.2019.e00898

Kharazmi, R., Tavili, A., Rahdari, M.R., Chaban, L., Panidi, E. and Rodrigo-Comino, J. 2018. Monitoring and assessment of seasonal land cover changes using remote sensing: a 30-year (1987–2016) case study of Hamoun Wetland, Iran. Environ. Monitor. Assess., 190(6): 356. https://doi.org/10.1007/s10661-018-6726-z

Kulkarni, G., Muley, A., Deshmukh, N. and Bhalchandra, P. 2020. *Land Use Land Cover Change Detection Through GIS and Unsupervised Learning Technique.* Paper presented at the Information and Communication Technology for Sustainable Development, Singapore. https://doi.org/10.1007/978-981-13-7166-0_23

Kweyu, R.M., Thenya, T., Kiemo, K. and Emborg, J. 2020. The nexus between land cover changes, politics and conflict in Eastern Mau forest complex, Kenya. Appl. Geograp., 114: 102115. https://doi.org/10.1016/j.apgeog.2019.102115

Lasko, K. and Vadrevu, K.P. 2018. Biomass Burning Emissions Variation from Satellite-Derived Land Cover, Burned Area, and Emission Factors in Vietnam. In K. P. Vadrevu, T. Ohara, & C. Justice (Eds.), Land-Atmospheric Research Applications in South and Southeast Asia (pp. 171-201). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-67474-2_9

Levizzani, V. and Cattani, E. 2019. Satellite Remote Sensing of Precipitation and the Terrestrial Water Cycle in a Changing Climate. Remote Sensing, 11(19). https://doi.org/10.3390/rs11192301

Li, X., Chen, G., Liu, X., Liang, X., Wang, S., Chen, Y., Pei, F. and Xu, X. 2017. A New Global Land-Use and Land-Cover Change Product at a 1-km Resolution for 2010 to 2100 Based on Human–Environment Interactions. Annal. Am. Assoc. Geograph., 107(5): 1040-1059. https://doi.org/10.1080/24694452.2017.1303357

Liang, D., Zuo, Y., Huang, L., Zhao, J., Teng, L. and Yang, F. 2015. Evaluation of the Consistency of MODIS Land Cover Product (MCD12Q1) Based on Chinese 30 m GlobeLand30 Datasets: A Case Study in Anhui Province, China. ISPRS Int. J. Geo-Infor., 4(4). https://doi.org/10.3390/ijgi4042519

Lin, J., Liu, X., Li, K. and Li, X. 2014. A maximum entropy method to extract urban land by combining MODIS reflectance, MODIS NDVI, and DMSP-OLS data. Int. J. Remote Sensing. 35(18): 6708-6727. https://doi.org/10.1080/01431161.2014.960623

Liu, Q., Yang, Z., Wang, C. and Han, F. 2019. Temporal-Spatial Variations and Influencing Factor of Land Use Change in Xinjiang, Central Asia, from 1995 to 2015. Sustainability, 11(3). https://doi.org/10.3390/su11030696

Liu, S.A., Li, X., Chen, D., Duan, Y., Ji, H., Zhang, L., Chai, Q. and Hu, X. 2020. Understanding Land use/Land cover dynamics and impacts of human activities in the Mekong Delta over the last 40 years. Glob. Ecol. Conserv., 22: e00991. https://doi.org/10.1016/j.gecco.2020.e00991

Liu., Yao, Z., Huang, H., Wu, S. and Liu, G. 2014. Land use and climate changes and their impacts on runoff in the Yarlung Zangbo river basin, China. Land Degrad. Dev., 25(3): 203-215. https://doi.org/10.1002/ldr.1159

Lu, L., Kuenzer, C., Guo, H., Li, Q., Long, T. and Li, X. 2014. A Novel Land Cover Classification Map Based on a MODIS Time-Series in Xinjiang, China. Remote Sensing, 6(4). https://doi.org/10.3390/rs6043387

Mann, H.B. 1945. Nonparametric tests against trend. Econometrica: J. Econ. Soc., 245-259. https://doi.org/10.2307/1907187

Mansour, S., Al-Belushi, M. and Al-Awadhi, T. 2020. Monitoring land use and land cover changes in the mountainous cities of Oman using GIS and CA-Markov modelling techniques. Land Use Policy, 91: 104414. https://doi.org/10.1016/j.landusepol.2019.104414

Matin, S., Ghosh, S. and Behera, M.D. 2019. Assessing land transformation and associated degradation of the west part of Ganga River Basin using forest cover land use mapping and residual trend analysis. J. Arid Land, 11(1): 29-42. https://doi.org/10.1007/s40333-018-0106-y

Mukherji, A., Sinisalo, A., Nüsser, M., Garrard, R. and Eriksson, M. 2019. Contributions of the cryosphere to mountain communities in the Hindu Kush Himalaya: a review. Reg. Environ. Change, 19(5): 1311-1326. https://doi.org/10.1007/s10113-019-01484-w

Munsi, M., Malaviya, S., Oinam, G. and Joshi, P.K. 2010. A landscape approach for quantifying land-use and land-cover change (1976–2006) in middle Himalaya. Reg. Environ. Change, 10(2): 145-155. https://doi.org/10.1007/s10113-009-0101-0

Mustafa, Y.T. 2020. Multi-temporal Satellite Data for Land Use/Cover (LULC) Change Detection in Zakho, Kurdistan Region-Iraq. In A. M. F. Al-Quraishi & A. M. Negm (Eds.), Environmental Remote Sensing and GIS in Iraq (pp. 161-180). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-21344-2_7

Nath, B., Niu, Z. and Singh, P.R. 2018. Land Use and Land Cover Changes, and Environment and Risk Evaluation of Dujiangyan City (SW China) Using Remote Sensing and GIS Techniques. Sustainability, 10(12). https://doi.org/10.3390/su10124631

Ngo, K.D., Lechner, A.M. and Vu, T.T. 2020. Land cover mapping of the Mekong Delta to support natural resource management with multi-temporal Sentinel-1A synthetic aperture radar imagery. Remote Sens. Appl. Soc. Environ., 17: 100272. https://doi.org/10.1016/j.rsase.2019.100272

Ning, J., Liu, J., Kuang, W., Xu, X., Zhang, S., Yan, C., Li, R., Wu, S., Hu, Y., Du, G., Chi, W., Pan, T. and Ning, J. 2018. Spatiotemporal patterns and characteristics of land-use change in China during 2010–2015. J. Geograph. Sci., 28(5): 547-562. https://doi.org/10.1007/s11442-018-1490-0

Noszczyk, T. 2019. A review of approaches to land use changes modeling. Human and Ecological Risk Assessment: An Int. J., 25(6): 1377-1405. https://doi.org/10.1080/10807039.2018.1468994

Powers, R.P. and Jetz, W. 2019. Global habitat loss and extinction risk of terrestrial vertebrates under future land-use-change scenarios. Nat. Clim. Change, 9(4): 323-329. https://doi.org/10.1038/s41558-019-0406-z

Purswani, E., Pathak, B., Kumar, D. and Verma, S. 2020. Land-Use Change as a Disturbance Regime. In V. Shukla & N. Kumar (Eds.), Environmental Concerns and Sustainable Development: Volume 2: Biodiversity, Soil and Waste Management (pp. 127-144). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-13-6358-0_6

Saha, P., Bandopadhyay, S., Kumar, C. and Mitra, C. 2020. Multi-approach synergic investigation between land surface temperature and land-use land-cover. J. Earth Syst. Sci., 129(1): 74. https://doi.org/10.1007/s12040-020-1342-z

Sánchez-Bayo, F. and Wyckhuys, K.A.G. 2019. Worldwide decline of the entomofauna: A review of its drivers. Biol. Conserv., 232: 8-27. https://doi.org/10.1016/j.biocon.2019.01.020

Shen, Y., Shen, H., Cheng, Q., Huang, L. and Zhang, L. 2020. Monitoring Three-Decade Expansion of China's Major Cities Based on Satellite Remote Sensing Images. Remote Sens.,. 12(3). https://doi.org/10.3390/rs12030491

Sulla-Menashe, D., Gray, J.M., Abercrombie, S.P. and Friedl, M.A. 2019. Hierarchical mapping of annual global land cover 2001 to present: The MODIS Collection 6 Land Cover product. Remote Sens. Environ., 222: 183-194. https://doi.org/10.1016/j.rse.2018.12.013

Toure, S.I., Stow, D.A., Clarke, K. and Weeks, J. 2020. Patterns of land cover and land use change within the two major metropolitan areas of Ghana. Geocarto Int., 35(2): 209-223. https://doi.org/10.1080/10106049.2018.1516244

Wallace, K.J., Kim, M.K., Rogers, A. and Jago, M. 2020. Classifying human wellbeing values for planning the conservation and use of natural resources. J. Environ. Manage., 256: 109955. https://doi.org/10.1016/j.jenvman.2019.109955

Wang, W., Gauchan, D., Degen, A.A. and Shang, Z. 2020. Climate Change Mitigation and Pastoral Livelihood in the Hindu Kush Himalaya Region: Research Focuses, Opportunities and Challenges. In Z. Shang, A. A. Degen, M. K. Rafiq, & V.R. Squires (Eds.), Carbon Management for Promoting Local Livelihood in the Hindu Kush Himalayan (HKH) Region (pp. 25-43). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-20591-1_2

Xiao, J., Shen, Y., Ge, J., Tateishi, R., Tang, C., Liang, Y. and Huang, Z. 2006. Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing. Landscape Urban Plann., 75(1): 69-80. https://doi.org/10.1016/j.landurbplan.2004.12.005

Zhang, H.K. and Roy, D.P. 2017. Using the 500m MODIS land cover product to derive a consistent continental scale 30m Landsat land cover classification. Remote Sens. Environ., 197: 15-34. https://doi.org/10.1016/j.rse.2017.05.024

Zou, J., Ding, J., Welp, M., Huang, S. and Liu, B. 2020a. Assessing the Response of Ecosystem Water Use Efficiency to Drought During and after Drought Events across Central Asia. Sensors. 20(3). https://doi.org/10.3390/s20030581

Zou, J., Ding, J., Welp, M., Huang, S. and Liu, B. 2020b. Using MODIS data to analyse the ecosystem water use efficiency spatial-temporal variations across Central Asia from 2000 to 2014. Environ. Res., 182: 108985. https://doi.org/10.1016/j.envres.2019.108985