



## ADVANCE SOCIAL SCIENCE ARCHIVE JOURNAL

Available Online: <https://assajournal.com>  
 Vol. 05 No. 02. April-June 2026. Page# 1525-1533  
 Print ISSN: [3006-2497](https://doi.org/10.30662/assajournal.v5i2.1525-1533) Online ISSN: [3006-2500](https://doi.org/10.30662/assajournal.v5i2.1525-1533)  
 Platform & Workflow by: [Open Journal Systems](https://www.openjournal.org/)



## Spatial Land Use and Land Cover (Lulc) Changes in Swat River Basin from 1992-2022

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### ABSTRACT

*Land Use and Land Cover (LULC) changes significantly influence environmental processes and watershed dynamics. This study examines the spatio-temporal LULC changes in the Swat River Basin, Khyber Pakhtunkhwa, Pakistan, over a period of three decades (1992–2022). Multi-temporal Landsat imagery acquired from Landsat-5 TM and Landsat-8 OLI was processed using Google Earth Engine (GEE). A Random Forest (RF) supervised classification algorithm was employed to classify six LULC classes: snow cover, forest, agriculture, barren land, water bodies, and settlements. Classification accuracy was evaluated using Overall Accuracy (OA), Kappa Coefficient, Producer Accuracy (PA), and Consumer Accuracy (CA), yielding satisfactory results with the highest OA of 87% and Kappa value of 0.84. The findings reveal substantial changes in the basin's landscape. Snow cover decreased dramatically from 30% to 3%, while forest cover declined from 36% to 17% between 1992 and 2022. Conversely, agriculture expanded from 4% to 19%, barren land increased from 28% to 54%, and built-up areas grew from 1% to 5%. Water bodies remained relatively stable throughout the study period. The observed changes are primarily attributed to climate change, population growth, urban expansion, agricultural development, and deforestation. The study highlights the effectiveness of GEE and RF algorithms for long-term LULC monitoring and provides valuable information for sustainable watershed management and environmental planning in the Swat River Basin.*

**Keywords:** Land Use and Land Cover (LULC); Spatio-temporal Change Detection; Swat River Basin; Google Earth Engine (GEE); Random Forest Classification; Landsat Imagery; Watershed Management; Climate Change; Deforestation; Urban Expansion; Land Cover Dynamics; Remote Sensing.

### Introduction

Land use and land cover is an important tool for land management, planning and utilization of the resources (Mallupattu et al., 2013); Twisa & Buchroithner, 2019). The world is undergoing a rapid land use change, especially the conversion of forests and scrublands to agriculture and grazing land (Birhane et al., 2019). Land use directly impacts the natural environment so there are various factors that are impacting on river water discharge mainly are climate variability, change in land use and land cover due to anthropogenic activities. LLULC is continuously changing due to natural and human activities (Spruce et al., 2020) (Birhane et al., 2019). In recent decade degree of change in LULC is more rapid due to economic growth, increasing population, urbanization, deforestation and melting glaciers. Most of the researches in central Africa and south America have been conducted to check the impacts of climate and LULC change on the dynamics of River hydrology (William, 2019). The changing of River water flow can directly influence the supply of the water, so it is very important to manage the increasing demand of

water to different stake holders such as household, industries, agriculture, tourism etc. (Cheng et al., 2016). The climate of the Himalayan region is susceptible and interlinked with global climate changes, the stream flow of this region is largely dependent on the cryosphere (Dar et al., 2022). Thus, better understanding about rainfall variability, change in LULC and their connection with the stream flow would enable planners to formulate the sustainable water management strategies (Javed, 2018). The basic purpose this study is to compute the spatio-temporal LULC change dynamics in Swat River Basin. The impacts of land use changes can affect the catchment, streamflow, to improve the planning and use of resources in river basin area. Swat River is the western tributary of Indus River system. The Indus river basin covers 65% area of the country including Khyber Pakhtunkhwa, Punjab, Sind and Baluchistan and it is a great source of fresh water which supplies 90% water to agriculture through largest irrigation network (Javed, 2018). The inflow of these rivers largely depends on snow melting of glaciers and rain water in catchment area. Surface water is the lifeline of human because all the sectors e.g. agriculture, industries household rely on the water. However, the water in Pakistan is under deficit and there is a dire need to manage and invest on water resources by increasing storage capacity, improving water use efficiency, managing surface water and ground water resources (Qureshi, 2011). So, this study will provide a better understanding about the temporal changes in hydrological regime of River Swat. According to IMF, Pakistan is on third in water scare counties Pakistan is facing water crises due to lack of water management, droughts, reduced rainfall and pollution (Zhang et al., 2021). A study on heihe river basin of Northwest China described that land use over time tempted slight decrease in surface runoff (Zhang, 2016; Hamdi Zurqani, 2018). Researches approved that shift of LULC dynamics always impact on stream flow (Toma et al., 2023).

### **Study Area**

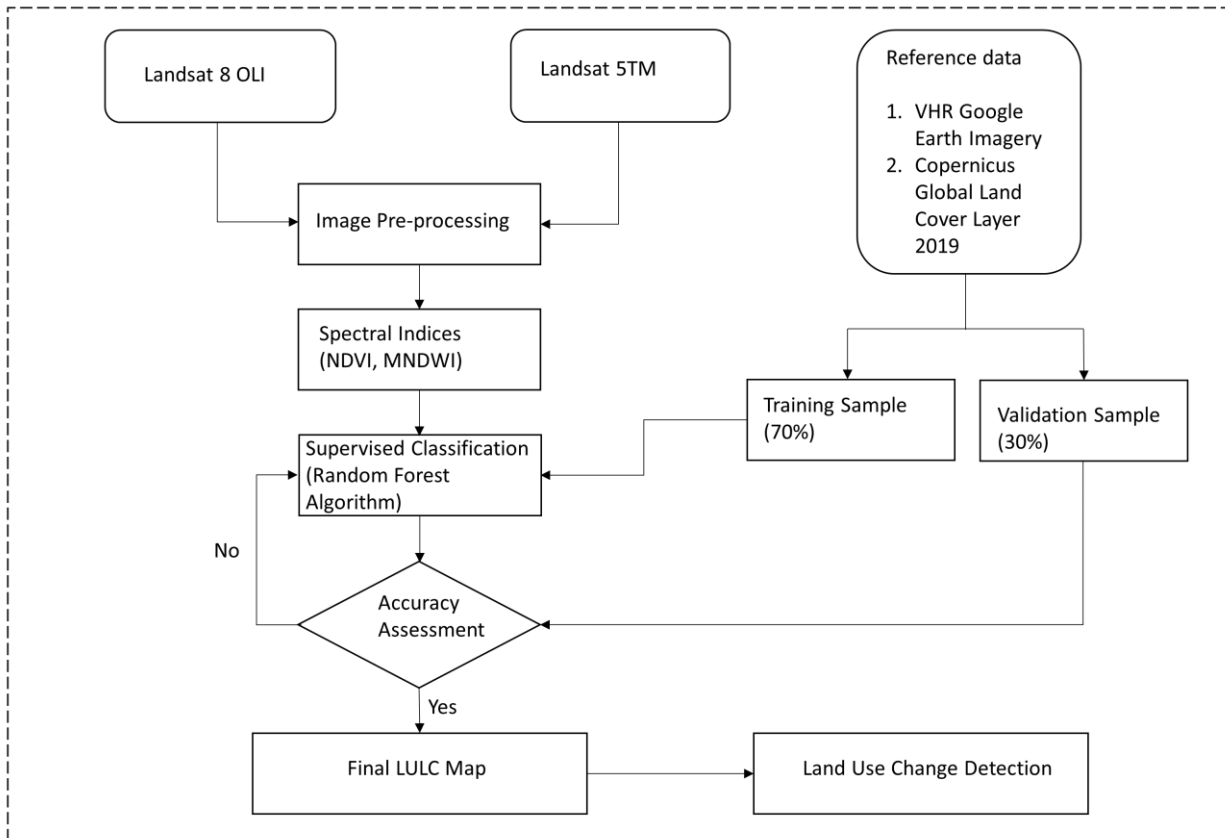
River Swat the study area is located in north of Khyber - Pakhtunkhwa Province. Swat River is a perennial River and originates from Hindu Kush mountains with the convergence of two tributaries Ushu and Gaberal at Kalam. It flows through the Kalam valley to Madyan and lower area of Swat valley up to Chakdara. The river drained into the Kabul River and has a total length of 240 km and width is 110 km. Geographical stretch of the catchment of Swat River is from 34° 00' to 35° 56' North latitude and 70° 59' to 72° 47' East longitude. The total catchment area up to Munda headwork is 14000 sq. KM. most of the catchment area of Swat River is hilly with altitude ranging from 340m to 4500m. Various studies on different aspects have been conducted in this region but many aspects yet to unfold (Sibtain et al., 2020 ;Ahmad et al., 2015). Swat district is fed by Swat River and its tributaries. It has total seventeen tributaries and it is formed by the c convergence of two tributaries Ushu and Gabral at Kalam (Nasir et al., 2020). Figure1

### **Matiriats and Methods**

Satellite imagery of 1992, 2002, 2010 and 2022 with the interval of 10 years have been used to identify the LULC change in Swat River Basin. Selection of the images were made on the basis of quality and the availability of the images of the study area. Image of 2010 has been used instead of 2012 because of the unavailability of 2012 image (Landsat 5 stop working in 2012, Landsat 7 image is 98 available on a very poor resolution). In order to study LULC Classification Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) were acquired from the U.S. Geological Survey. Two tiles have been used to cover the entire area for both Landsat 5 and Landsat 8. Landsat images of dry season and without noise were selected because they are easier to analyze. This study used GEE to map the three-decade changes 1992-2022. To calculate the LULC change detection from 1992-2022 total six classes snow cover, forest, settlement/built up

area, barren land, water body, agriculture was generated in GEE to produce LULC change map (Hassan et al., 2016).

Different techniques were used to build land cover maps from these data utilizing Random Forest classification algorithms after receiving Landsat-5 and Landsat-8 data. The work of this study is shown in the flow chart in Figure 2.



**Fig 1. Methodological flow chart**

Firstly, Landsat-5 and Landsat-8 satellite images were collected free from Earth Explorer - USGS websites using GEE. Afterward, those satellite images were corrected by atmospheric correction, cloud shadow mask, terrain mask, geometric correction, haze reduction. After that normalized difference vegetation index (NDVI) and normalized difference water index (NDWI) were computed by taking the median values of 10- year gap (Xia, H.; Zhao, J.; Qin, Y.; Yang, J.; Cui, Y.; Song, H.; Ma, L.; Jin, N.; Meng, 2019). Then the training samples were created carefully to depict the following 6 classes: Snow, Forest, Vegetation, Water body, Bare land, and settlement. The training data, representing 70% of the sample in GEE to create the classification of Land use and land cover, whereas 30% of the data, representing the validation, were used to assess the performance of the classification. Final predictions across the study area were developed by combining calibration and validation data before running the code. The Land use change technique was applied and assessed by developing code in the Google Earth Engine using a supervised classifier algorithm and Landsat time series consequently for each selected year. The reference data was received from Google Earth Images, ESRI Global LULC. Random forest algorithm (RF) was applied to classify land cover maps of the study area (Loukika & Keesara, 2021) (Midekisa et al., 2017) (Feizizadeh et al., 2021)(Kelsey E. Nyland, Grant E. Gunn, Nikolay I. Shiklomanov, 2018).

$$\{h(x, \theta)k = 1, 2, \dots, i \dots\}$$

Where h= Random Forest

X=input variables

$\emptyset$ = independently identically distributed random predictor variables which are used to split each decision tree

Studies approved that Random Forest (RF) and Support Vector Machine (SVM) are more précised algorithms then Classification and Regression Tree (CART) (Sellami & Rhinane, 2023) (Shetty, 2019).

**Accuracy Assessment**

Model assessment is an essential step in GEE. Without its model will not be considered reliable. In this regard several matrices were used in this study to perform the classification, namely, Kappa Coefficient (K), Consumer Accuracy (CA), Producer Accuracy (PA) and Overall Accuracy (OA) (Da’u Abba Umar, Mohammad Firuz Ramli, Abubakar Ibrahim Tukur, 2021)

$$\text{Kappa} = \frac{\text{overall accuracy} - \text{estimated chance agreement}}{1 - \text{estimated chance agreement}}$$

$$\text{CA} = \frac{\text{number of correctly classified samples in each class}}{\text{number of samples classified to bthat class}}$$

$$\text{PA} = \frac{\text{numc vber of correctly classified samples in each class}}{\text{number of samples from reference data in each class}}$$

$$\text{OA} = \frac{\text{number of correctly classified samples}}{\text{number of total samples}}$$

**Result**

**LULC Maps and Classification Accuracy**

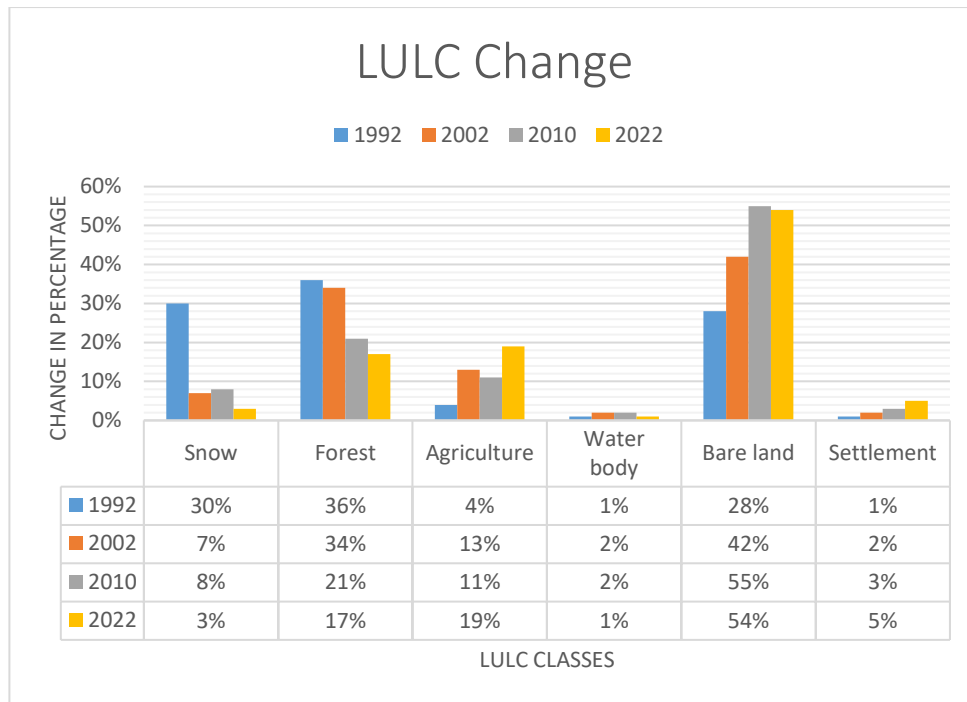
The study evaluates the performance of GEE Random Forest algorithm accuracy. Highest accuracy is obtained in the year 2002 that is Kappa Coefficient 0.84 and Overall Accuracy is observed highest in the year 2002 that is OA 0.87 (Table 1). Further Producer and Consumer Accuracy of all the classes were calculated. according to Table 1, snow appeared as the highest accuracy predictor then all other classes throughout 1992-2022. In 1992 PA of snow is 1% and CA is 0.98%, in 2002 and PA & CA is 0.96%, 2010 PA & CA is 0.91%, 2022 PA is 1% and CA is 0.97%. (Johnston & Smakhtin, 2014)

Class	1992				2002				2010				2022			
	PA	CA	OA	Kappa	PA	CA	OA	Kappa	PA	CA	OA	Kappa	PA	CA	OA	Kappa
Snow	1	0.98	0.84	0.79	0.96	0.96	0.87	0.84	0.91	0.91	0.85	0.78	1	0.97	0.8	0.75
Forest	0.86	0.83			0.95	0.84			0.89	0.83			0.98	0.9		
Agriculture	0.94	0.78			0.83	0.89			0.87	0.78			0.94	0.78		
Water body	0.99	0.94			0.95	1			0.92	0.92			0.92	0.94		
Bare land	0.73	0.85			0.86	0.89			0.83	0.89			0.79	0.84		
Settlement	0.82	0.8			0.72	0.79			0.77	0.72			0.79	0.78		

**Table 1.** Accuracy assessment results for all LULC classes. Producer Accuracy (PA), Consumer Accuracy (CA), Overall Accuracy (OA).

**Land Use Change Detection**

The basic aim of this study is to find out the three decades LULC change in Swat River regime from 1992- 2022 by using multi-temporal Landsat imageries data. Figure 2 contains the calculated LULC change in GEE. According to figure 2 snow cover area in Swat river basin decreased remarkably from 1992-2022 by about 30% to 3%. Respectively.



**Figure 2. LULC change matrix from 1992-2022 of Swat River regime**

This class faced a major shift in LULC in study area. Results showed that the forest area in Swat river basin had the largest share in 1992 representing 36% which declined 17% in 2022. Water bodies show almost a constant trend except a slight increase in the year of 2002 and 2010. It can be due to heavy rainfall and floods in 2010. Study revealed that other three classes face an increase trend in total LULC share. Agriculture area also increased 4% in 1992 to 19% in 2022. A high increased in barren land is computed 28% to 54%. Built up/ settlement area augmented 1% in 1992 to 5% in 2022. These values made significant change in LULC in Swat River basin.

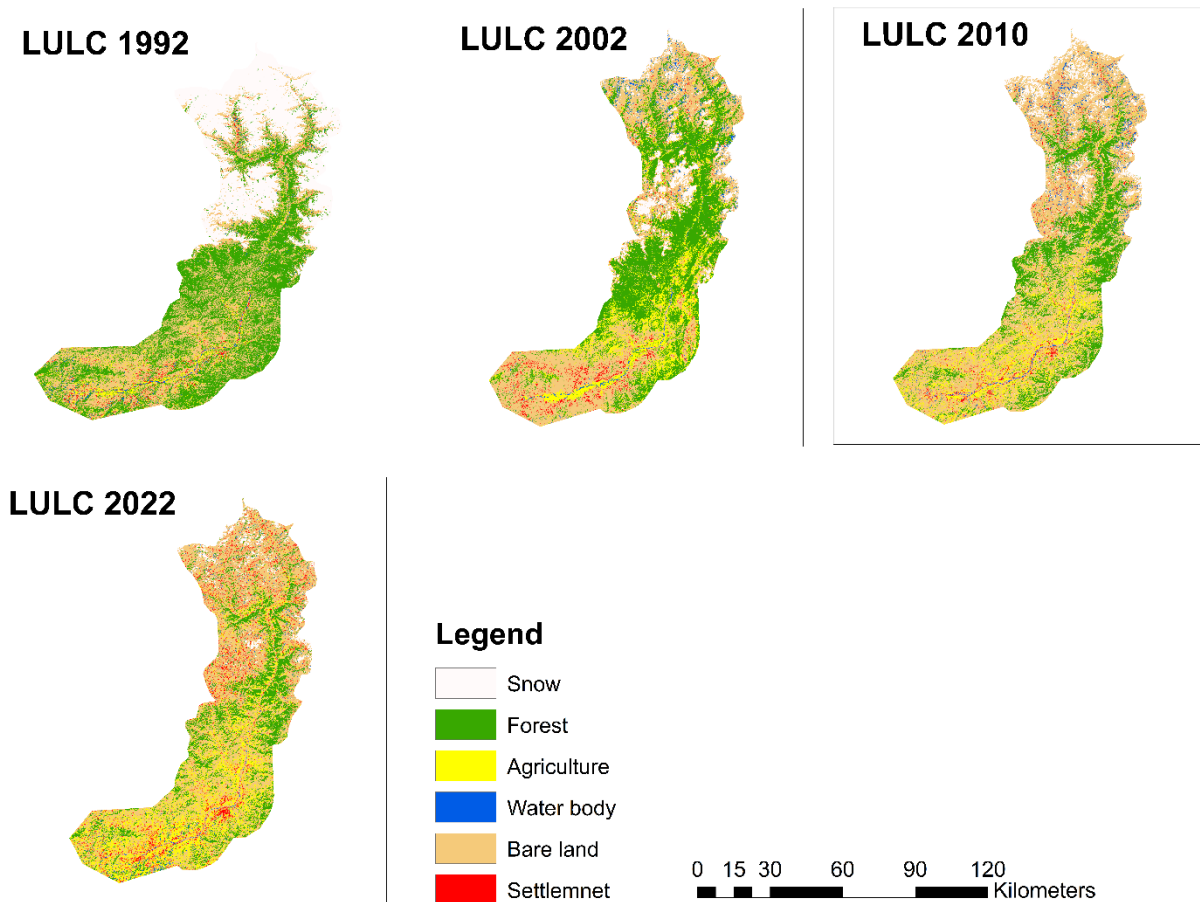


Figure 3. Spatial LULC change detection in Swat River basin from 1992-2022

Figure 3 illustrate the spatial and temporal change of LULC in Swat River regime. Decrease in snow and forest in last three decades are really alarming. If compare with the spatial land use distribution of 1992 to 2022 there is a massive difference in the spatial LULC patterns.

**Discussion**

Maps of land use and land cover from 192-2022 exhibited a drastic change in the landscape in Swat River Basin in term of snow and forest reduction. Snow fall and snow melt is highly variables across Swat River but a constant decrease is computed since last few decades (Dahri et al., 2011) Results revealed a remarkable decreased in forest and snow covered area in Swat River basin especially in Kalam region. This significant decreased in forest and snow cover area may be due to Climate change, large scale wood & timber cutting activities and expansion of agriculture and settlement (Arif et al., 2020) (Loukika & Keesara, 2021) . A study resulted that the main reason of deforestation in early decade was the expansion of Agricultural activities (Qasim et al., 2011). According to results an increase in settlement Agriculture and Barren land is calculated (Hassan et al., 2016). Increase in settlement is due to growing population in Swat district. In 1997 population of Swat was 1.26 and it increased by 2.31 million, in 2017 (Nasir et al., 2020). Barikot region is densely populated region and an increase of agriculture and built-up area is observed since last three decades (Qasim et al., 2011) This has To fulfill the need of the growing population cultivable land is keep on increasing and the important crops are wheat and maize (FAO, 2016).

**Conclusion**

This study successfully assessed the spatial and temporal dynamics of land use and land cover in the Swat River Basin from 1992 to 2022 using Landsat imagery and the Google Earth Engine platform. The Random Forest classification approach produced reliable results, demonstrating

its suitability for large-scale LULC monitoring. The analysis revealed significant transformations in the basin's landscape, characterized by a substantial reduction in snow cover and forest areas, alongside notable increases in agriculture, barren land, and settlement expansion. These changes indicate increasing anthropogenic pressure on natural resources and the growing influence of climate variability in the region.

The decline in forest and snow-covered areas is particularly alarming because of their critical role in maintaining ecological balance, regulating hydrological processes, and supporting biodiversity. Rapid population growth, expansion of cultivated land, urban development, and deforestation appear to be the major drivers of these changes. The findings emphasize the need for effective land-use planning, sustainable forest management, watershed conservation strategies, and climate adaptation measures to protect the environmental integrity of the Swat River Basin. Continuous monitoring of LULC changes through geospatial technologies is essential for informed decision-making and sustainable resource management in the future.

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