Chapter 8

Spatio-Temporal Assessment of Land Use and Land Cover of Harike Wetland in Punjab using Remote Sensing and GIS

Mridula Mandal[1], Priya Priyadarshni[1,2], Sunil Mittal[1], Puneeta Pandey*[1,2]

[1]Department of Environmental Science and Technology, School of Environment and Earth Sciences, Central University of Punjab, Ghudda, Bathinda, 151401, Punjab
[2]Centre of Environmental Studies, Institute of Interdisciplinary Studies, Faculty of Science, University of Allahabad, Prayagraj, 211002
*Email: *puneeta@allduniv.ac.in, puneetapandey@gmail.com*

Abstract. Wetland**s** are among the world's most important and threatened ecosystems. The Harike wetland in Punjab is considered a wetland of international importance and was declared a Ramsar site in 1990. The wetland in northwest India has been under stress due to various anthropogenic activities, leading to degradation in the past few years. There is a need to identify the threats and measures for its conservation. Remote sensing combined with Geographical Information Systems (GIS) helps in collecting and generating useful information which can be used to assess the changes in wetlands over a period of time. The present study aims to determine the Land Use and Land Cover (LULC) variation of the Harike wetland. Remote Sensing technologies have been used to evaluate the changes in wetland over a period of time. Landsat OLI/TIRS images for the years 2013 and 2022 were acquired from the USGS Earth Explorer Website. The images were pre-processed and classified to generate LULC maps. The results reveal that the water bodies and wetland area have declined respectively, while the area under agriculture and built-up area/ barren land has increased over the course of almost ten years. Efforts have also been made to study land cover features of the area for its ecological importance and continuous monitoring.

Keywords: Land Use Land Cover (LULC), Remote Sensing, GIS, Harike, Wetland

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1. Introduction

One of the most serious problems that our planet is currently facing is climate change, affecting ecosystems all around the world. Wetlands emerge to be essential landscapes within this global framework due to their distinct features and vulnerability to potential climate changes. According to the IPCC 2022 report, many natural systems are approaching the hard limits of their natural adaptation capacity, and other systems will reach those limitations as global warming continues. Some warm-water coral reefs, coastal wetlands, rainforests, and arctic and alpine ecosystems have already exceeded hard adaption limits and if global warming exceeds 1.5°C, some ecosystem-based adaptation measures will lose their effectiveness in providing benefits to people. The dynamics of land use and land cover result from human consumption and the exploitation of biophysical resources to meet its never-ending demands is a significant contributor to global environmental change (Fashae et al., 2017, 2020).

Wetlands are among the most productive and biologically rich ecosystems on earth (Richardson, 1995). It includes marshes, swaps, and bogs; and plays fundamental roles in maintaining ecological balance, biodiversity, and hydrological cycles. It is widely acknowledged that wetlands have significance in regulating local climate and mitigating the effects of climate change (Du et al., 2019).

Wetlands face increasing challenges as anthropogenic activities accelerate and rise in global temperatures, including sea-level rise, changing precipitation patterns, and extreme weather conditions. These stressors have an extended influence on land use decisions, causing changes in wetland ecosystems that have adverse consequences at both the local and global levels. Even with a slight change in the hydrological conditions of the wetlands, the biota responds with massive changes in species composition and richness and ecosystem productivity. Therefore, there is a need to safeguard these wetlands since they are at a higher risk of being exploited and destroyed which may have negative environmental consequences. The growing pace of climate change has had drastic effects, impacting the very structure of these ecosystems. The loss of wetlands has resulted from the deterioration of lake water quality caused by urbanization (Barrios, 2000). Effective conservation and mitigation efforts require an understanding of the intricate relationships that exist between wetlands, land use dynamics, and climate change.

With an annual rainfall of around 1150 mm, a diversified terrain and a climatic regime, India supports and sustains different and unique wetland habitats. The overall wetland area is estimated to be 15.98 Mha or 4.86 % of the country's total geographic area. During 2017-18, a total of 2,31,195 wetlands (area greater than or equal to 2.25 ha) were mapped. The overall decadal change in wetland numbers and area at the country level is estimated to be 8.86% and 4.18%, respectively (Gupta et al., 2021).

Harike Lake is a man-made lake at Harike Township in Punjab, formed by the confluence of the rivers Sutlej and Beas. It is a shallow reservoir that was built to store and provide irrigation and drinking water to regions of southern Punjab and neighbouring Rajasthan. Harike has emerged as an excellent waterfowl habitat over time. During migration, the lake is a major habitat for breeding, wintering, and staging birds, supporting around 200,000 ducks, geese, swans, and so on (SAC, 2013). Unfortunately, with the ongoing degradation of its water quality, the Harike wetland is not substantially stable. The adjacent agricultural land is consuming the marshy land and gets significant amounts of untreated industrial and domestic effluents from inflowing rivers, endangering its ecosystem (Singh et al., 2020). Seven streams drain the area, including the two largest rivers, the Beas and the Sutlej. Thus, substantial eutrophication of the wetland is caused by nutrient flow and sediments from the catchment's intensive agricultural use. During the pre-monsoon season, the majority of the wetlands exhibit severe eutrophication (SAC, 2013). There is a need to address the status and distribution of wetlands, as well as the causes and consequences of wetland loss. It is necessary to prioritise wetlands protection and restoration to achieve their sustainability to avoid additional wetland loss. To achieve this goal, continuous mapping of wetlands is required, whether by ground surveys or geospatial techniques such as remote sensing and geographical information systems (GIS) (Bhardwaj et al., 2017). There is a need to adopt scientific, technical, and socio-economic cooperation to conserve the wetlands (Bhatt and Kathiresan, 2011).

Geospatial data or wetland maps continue to be valuable resources for identifying the distribution and status of wetlands (Bassi et al., 2014), monitoring trends, depicting connectivity between wetlands and water bodies and among wetlands, evaluating wetland functions and values, and modelling ecological and hydrological processes and the impact of climate change. In the context of sustainable wetland management and monitoring, remote sensing and geographic information systems (GIS) have evolved as useful tools in the hands of environmental researchers, planners and policymakers (Castaneda and Ducrot, 2009, MacKay et al., 2009, Ozesmi and Bauer, 2002). Remote sensing has advantages for mapping land cover and land use, as well as analysing pertinent changes. The key advantages of remote sensing techniques include the potential for repetitive coverage, which is required for global modification discovery research (Fahad et al., 2020). Remote sensing images capture and preserve time-varying conditions, enabling identification and characterization of changes over time, offering a powerful advantage. Change detection is among the most common uses of digital image analysis (Lillesand et al., 2015). Since satellite sensors in their stable orbits view the same area on Earth repeatedly at fixed intervals, they are ideal for detecting and mapping global and regional changes, both natural and man-made. Time series of satellite images can be used to analyse such changes and help to predict long-term trends (Purkis and Klemas 2011). The present study intends to analyze the impacts of climate change on wetlands by assessing the changes in land use and land cover patterns using multitemporal satellite data.

2. Materials and Methods

2.1 Study Area

Harike Wetland (31.0875°N, 74.925°E–31.2375°N, 75.125°E) is located in Amritsar, Punjab. Spread over an area of 86 km^2 in the Tarn Taran, Ferozepur, and Kapurthala districts. This lacustrine wetland was developed in 1950 as a result of the construction of the Harike barrage to redirect water through two canals: the Ferozepur feeder and the Rajasthan feeder (Singh et al., 2020). Harike Wildlife Sanctuary is one of the largest wetlands in northern India, situated at the confluence of the Sutlej and Beas rivers as shown in Figure 1. The sanctuary is a paradise for bird watchers and serves as a home to rare species of migratory birds during the winter season. This marshy land experiences an annual rainfall of 668 mm. The southwestern monsoon, constituting about 70% of the annual rainfall, begins in the first week of July and extends into September (Chopra et al., 2001). The temperature ranges from a maximum of 44°C in summer (May and June) to around 3°C in winter (November to February). In recent years, the wetland has suffered several challenges, including clearing of forests for agricultural practices, diminishing surface area, grazing activities, decline in the water quality and illegal development in the wetland ecological zone. Despite the construction and implementation of a conveyor belt system and other biological control approaches, water hyacinth infestation remains a severe concern in the marsh (Bharadwaj et al., 2015)

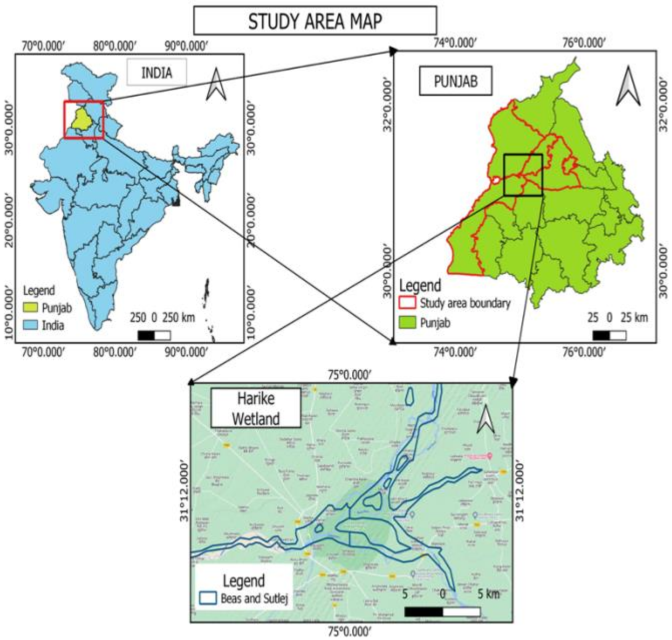

Figure 1: Study area map of Harike Wetland

2.2 Data and Software Used

For this study, satellite images of Landsat 8 OLI/TIRS (Operational Land Imager/ Thermal Infrared Sensor) for 2013 and 2022 covering the study area were obtained from the USGS website (*www.earthexplorer.usgs.gov*). The OLI and TIRS sensor images from 2013 and 2022 are Landsat Collection-2 Level-2 (L2) Data having the least cloud-cover, were taken into consideration for Land Cover Change analysis. Table 1 summarises the specifications of satellite images taken for the present study. The monsoon season in north-western India often lasts until September, so the satellite images for post-monsoon period were taken in the month of October. The water level rises during the monsoon season, with a maximum wetland area recorded towards the conclusion of the season, which is why satellite data were acquired for October (Bharadwaj et al., 2015). The satellite images were processed and classified using the Semi-Automatic Classification Plugin in the QGIS v3.22.8 software and maps were generated.

Table 1. Details of Landsat Images used for this study

Year	Sensors	Date of Acquisition	Cloud Cover	Path, Row	Source
2022	OLI/ TIRS	27-10-2022	0.39	148, 38	USGS
2013	OLI/ TIRS	18-10-2013	0.42	148, 38	USGS

2.3. Image Pre-processing and Classification

The primary objective of this study was to explore the dynamics of land use and land cover (LULC) and detect changes in the wetland area utilising multi-temporal satellite images. False Colour Composite (FCC) images were generated for 2013 and 2022 using a band combination of infra-red, red and green bands (Landsat 8: Bands 5-4-3) and visual interpretation of surface features, the photos were used to create LULC maps. Both FCC images were separately classified using Unsupervised and Supervised classification for the study. The unsupervised classification was performed using the ISODATA (Iterative Self-Organizing Data Analysis Technique) algorithm. It is a well-liked technique for grouping data according to their similarities. Using ISODATA, ten classes were created and reclassified to produce four main classes. Maximumlikelihood classifier (MLC) was applied to perform supervised classification, with a total of 240 training samples used for all the classes. Four LULC classes covering the surface of the study area were identified and classified, including Water Bodies, Wetlands, Built-Up Area/ Barren Land and Agriculture/ Fallow Land. This was followed by an accuracy assessment to ensure the reliability of the classification/ results. The generated LULC map was further used to detect decadal change over time.

3. Results and Discussion

3.1. Accuracy Assessment

LULC maps were generated using Hybrid Classification. This technique involves aspects of both supervised and unsupervised classification and is aimed at improving the accuracy or efficiency of the classification process (Lillesand et al., 2015). Hybrid classification approaches have been demonstrated to be useful in a variety of remote sensing applications, including land cover mapping and change detection. (Kantakumar and Nilamsetti, 2015, Bharadwaj et al., 2015, Zhang et al., 2011) also used hybrid classification to classify satellite images. Each LULC map was correlated to a data source to assess the accuracy of the classification.

The classification accuracy of both supervised LULC maps was evaluated by comparing the classified maps to the high-resolution Google Earth Pro Time series as reference data. This evaluation demonstrated the classification results' dependability and validity. In the current study, the supervised LULC map for the year 2013 achieved an accuracy level of 80.834%, with a Kappa statistic of 0.745; while the LULC map for the year 2022 had an accuracy of 84.589%, having Kappa statistics of 0.794. The confusion matrix of various classes has been drawn in Table 2. A Kappa coefficient of 0.745 or 0.794

shows that there is 74.5 or 79.4% better agreement than by chance alone.

Table 2. Accuracy Assessment of LULC

LULC Classes	2013		2022	
	User Accuracy %	Producer Accuracy %	User Accuracy %	Producer Accuracy %
Water Bodies	88.334	94.643	84.746	100
Wetland Vegetation	80.0	90.566	91.667	90.164
Built-up Area/ Barren Land	63.334	95.0	91.667	97.368
Agriculture/ Fallow Land	91.667	60.440	100	66.667
Overall Accuracy %	80.834		84.519	
Kappa Coefficient	0.745		0.794	

3.2 Change Detection

Change Detection was performed by comparing classified maps to identify areas of LULC change in the study between different periods. The final LULC maps from 2013 (Figure 4) and 2022 (Figure 5) were evaluated to conduct a decadal change detection investigation of the Harike wetland. The attributes used to reflect the overall change in the research area were the same as those used to determine the current condition of the wetland. Table 3 compares the above-mentioned characteristics for the years 2013 and 2022.

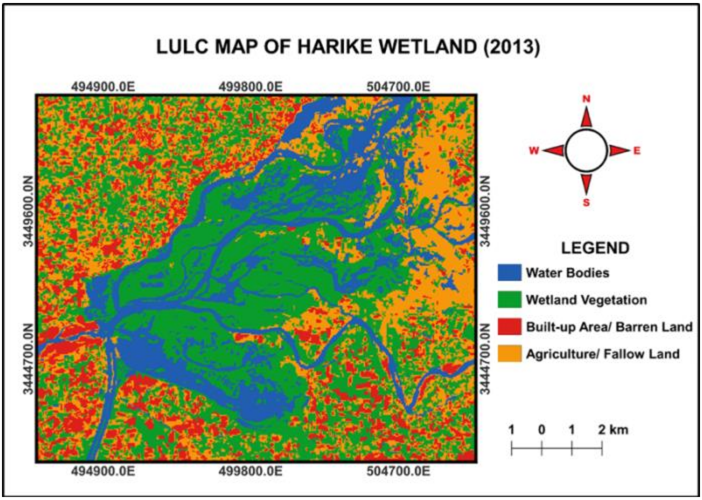

Figure 2. LULC Map of Harike Wetland by Unsupervised Classification (2013)

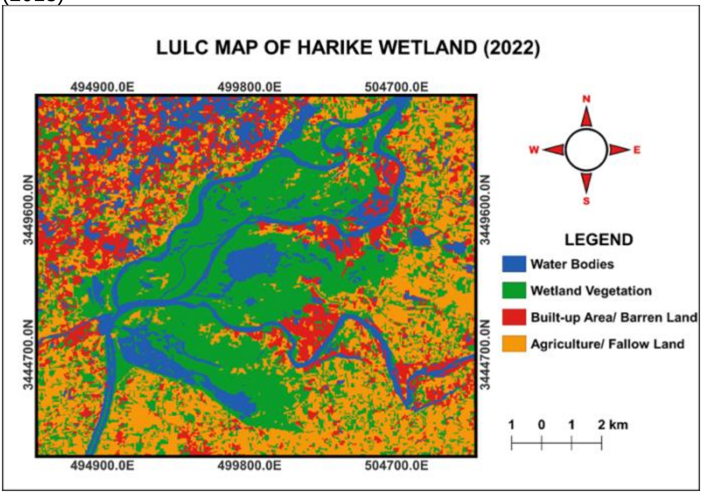

Figure 3. LULC Map of Harike Wetland by Unsupervised Classification (2022)

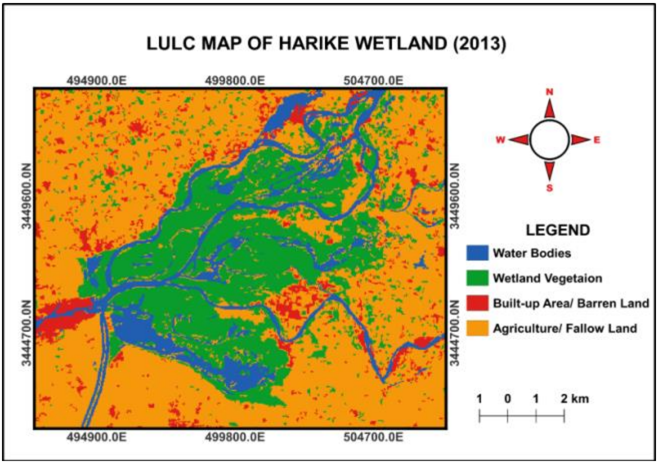

Figure 4. LULC Map of Harike Wetland by Supervised Classification (2013)

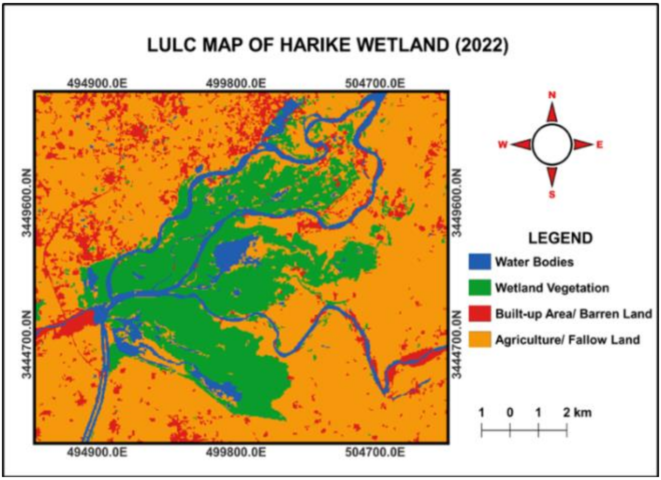

Figure 5. LULC Map of Harike Wetland by Supervised Classification (2022)

Wetlands displayed varying patterns of change, with some wetland areas degraded or converted to other land cover categories while others expanded or restored. Table 3 shows that the spatial expanse of water reduced over twelve years, possibly as a result of water that was released into or made available in the wetland; this results in an overall decline of 15.80 % (5.92 km^2). The negative sign in the table denotes a decrease in the area, while the positive represents an increase or expansion of the particular class. Wetland Vegetation loss was also seen within the same time, accounting for 11.10 % (9.89 km^2). In terms of area, both built-up area/ barren land and Agriculture/ Fallow Land were found to have expanded by 19.28% (11.71 km^2), and 0.97% (4.1 km^2), respectively.

Table 3. Area (km^2) distribution of different classes

Classes	2013	2022	Change	Change (%)
Water Bodies	21.69	15.77	-5.92	-15.80
Wetland	49.48	39.59	-9.89	-11.10
Built-up Area/ Barren Land	24.52	36.23	11.71	19.28
Agriculture/ Fallow Land	210.4362	214.5362	4.1	0.97

Previous studies on the wetland (Chopra et al., 2000, Mabwoga and Thukral, 2014, Bharadwaj et al., 2015) indicated that there was a very sharp decrease in the area under wetland, which was recorded up to 2007. A similar trend was found by (Singh et al., 2020) and it was that in the Harike wetland ecosystem of Punjab, Agricultural land and built-up forests, including plantation, increased to 0.05, 0.04, and 0.09 km^2, respectively, from 2014 to 2018. The rate of wetland conversion was 5% during 1973-1989 the number has risen to 22.5% during 1989-2010.

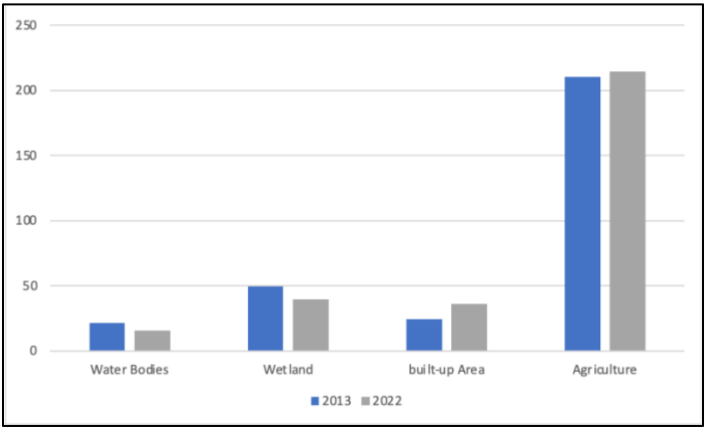

Figure 6. Land use and Land Cover Change between 2013 and 2022

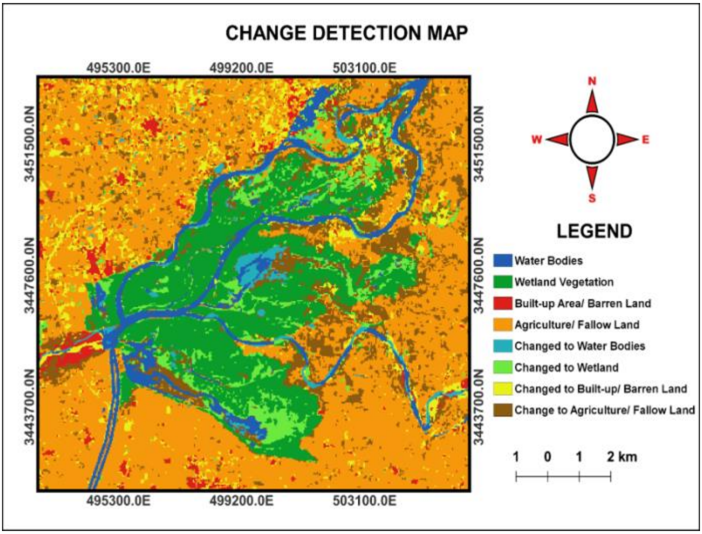

Figure 7. Change Detection Map

Ha Tien Plain has lost 77% of its area due to the conversion of the area for agricultural and aquacultural purposes, as revealed in change detection studies by (Fukenberg et al., 2014). Change detection analysis by (Fahad et al., 2020) showed that urban area and soil land levels had gone up by 3 and 20%, respectively. In another area, the vegetation has diminished, and wetlands and water bodies have also decreased. It is also suggested that rational land use policies should be adopted for the management of land resources and sustainable development (Shalaby and Tateishi, 2007). Thus, the current study agrees with the findings of other studies from around the world that increasing urbanisation and changing land use/land cover regimes pose serious threats to these wetland ecosystems, necessitating the development and implementation of strict management practices. Geospatial technology has proven to be a useful tool for monitoring changes in these ecosystems, allowing for the formulation of more effective solutions.

4. Conclusion

Wetlands are vital ecosystems that provide a variety of functions while also maintaining ecological equilibrium. They have, however, been the target of human intervention, making them one of the most endangered natural resources. Punjab has lost the majority of its wetlands, including the Harike wetland, which provides water to Southern Punjab and Rajasthan. The study assessed the wetland's status using GIS technologies and field surveys, indicating a drop in primary wetland classifications such as water and grassland and an increase in built-up land and agricultural land. Proper management and conservation are required to safeguard these valuable resources. To have an insight into the current condition of the Harike wetland in Punjab, LULC and change detection has been carried out using geospatial technology and remote sensing tools. Decadal change has been studied, which specifically includes Land Use and Land Cover Change in 2013 and 2022. Study results show that the water bodies and wetland areas have declined by 15.80 and 11.10%, respectively, while the area under agriculture and built-up area/ barren land has increased by 19.28 and 0.97% over nine years.

The probable reason for the reduction in the area of wetland could be because of the eutrophication phenomenon and, weed infestation, excessive pesticide use. The Harike wetland is shrinking in size and degrading in water quality while there is an increase in the built-up area. The natural biodiversity suffers as a result of urban land growth, which causes microclimate fluctuation and wetland degradation. Wetland managers can benefit greatly from open-source integrated remote sensing and GIS-based spatial change detection analyses, which can provide first-hand knowledge on problem areas and enable effective planning and execution of policies for maintaining and managing this valuable ecosystem. This Ramsar site is critical for environmental and economic preservation. Regular monitoring and surveying are required, and the dependability and precision of geospatial technology are proven.

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