Monitoring Amu Darya River Channel Dynamics using Remote Sensing Data in Google Earth Engine

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Abstract: River morphological dynamics result from processes involving discharge flow, debris and sediment transport, channel migration, and floodplain erosion and accretion. Understanding the river channel dynamics is an essential component of the development of the most environmentally acceptable and sustainable fluvial projects. In this study, the upper part of the Amu Darya river channel dynamics using remote sensing data have been investigated. For this purpose, satellite imagery from four different periods ten years apart (1990-2000, 2000-2010, 2010-2020), have been used to map and monitor the dynamics of the river over the last three decades. The classification of the images was conducted in Google Earth Engine (GEE) using Landsat imagery. In addition to the river mapping and monitoring, a land cover change detection in the study area has been made. The results showed that the increase in irrigated areas, in the four specified periods was significant and played an important role in increasing the vulnerability of the study area to soil erosion which leads to river channel dynamics. The results showed that the use of Landsat and GEE can be a significant source of updated data for mapping and monitoring river dynamics, with a classification accuracy of the water areas higher than 90%. For future studies, we recommend using satellite imagery with a higher spatial and spectral resolution, like Sentinel.

Keywords: Amu Darya; river dynamics; google earth engine; landsat; classification; remote sensing

1. Introduction

River dynamics occur due to discharge flow, debris and sediment transport, channel migration, and erosion and accretion [1]. River dynamics can also occur as a result of anthropogenic activities, such as land-use changes, and these activities have become more influential than the natural forces [2]. Understanding the river channel dynamics is an essential component of the development of the most environmentally acceptable and sustainable fluvial projects. In order to assess the river changes, scientists have successfully used remote sensing data and techniques [3,4].

The main aim of this study is to investigate the changes in the upper part of the Amu Darya river channel that forms part of Afghanistan's northern border with Tajikistan, Uzbekistan, and Turkmenistan using Landsat imagery. In addition to the river mapping and monitoring, a land cover change detection in the study area has been made. For that purpose, Landsat-5 and Landsat-8 imagery integrated into Google Earth Engine (GEE), a cloud computing platform designed to store and process huge data sets for analysis and ultimate decision making [5], have been used. Since its inception in 2010, GEE has been used in different areas of research, such as vegetation mapping and monitoring [6,7], land cover mapping [7], agricultural applications [8], water monitoring [9], and many more.

Even though several studies have been conducted on a similar topic [10,11], this study also aims to investigate the land conversion that happened over the years due to the river channel dynamics. Thus, satellite imagery from four different years has been used, 1990, 2000, 2010, and 2020. The changes have been analyzed within three periods, 1990 – 2000, 2000 – 2010, and 2010 – 2020. For the land cover classification, the images were selected, preprocessed, and integrated to develop a machine learning classification through a Support Vector Classification (SVM) classifier in the GEE platform.

2. Materials and Methods

2.1. Study area

Amu Darya is the largest river in Central Asia with a total length of about 1.400 km. The river is formed as a result of the confluence of two rivers, Pyandzh and Vakhsh. Before diverting their flow, together with Syr Darya, Amu Darya was the main source of the formerly fourth-largest lake in the world, the Aral Sea [12]. The total catchment area is estimated at 465,000 km^2, the area of the effective drainage basin is 300,000 km2 [13]. The river is formed in the Tigrovaya Balka Nature Resource on the border between Afghanistan and Tajikistan and flows into the Aral Sea. The upper course of the river forms part of Afghanistan's northern border with Tajikistan, Uzbekistan, and Turkmenistan (Figure 2) ("Aral Sea watershed" by Shannon1 https://wiki2.org/en/File:Aral_Sea_watershed.png#/media/File:Aral_Sea_watershed.png).

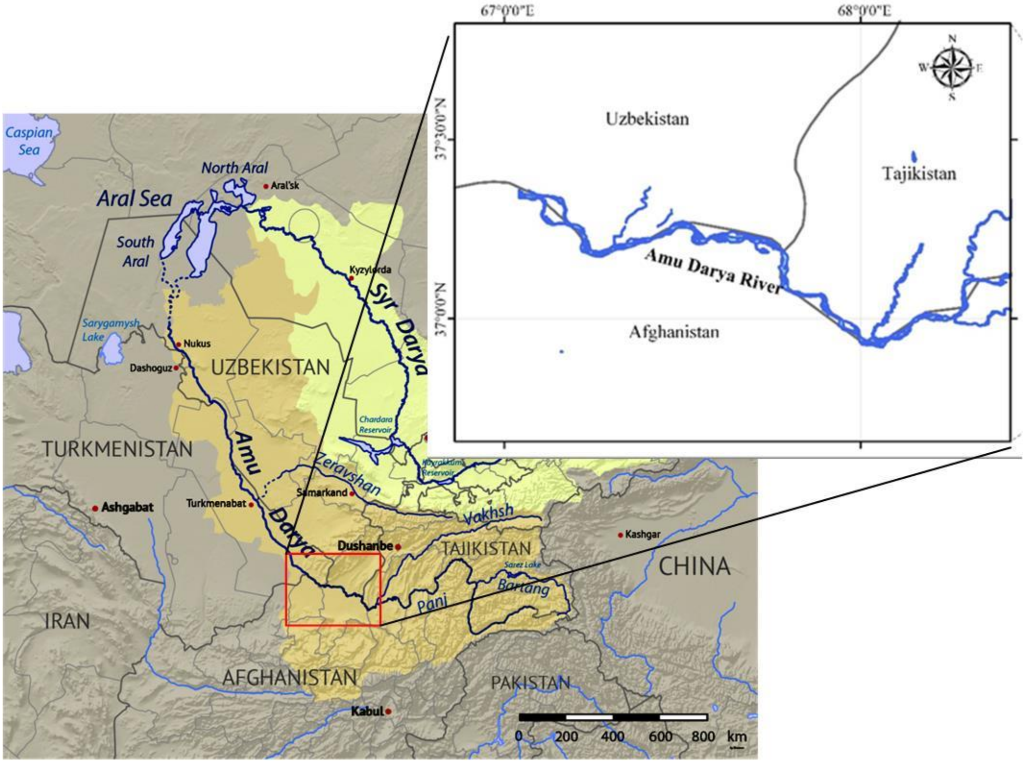

Figure 2. Study area.

2.2. Materials and methods

To classify the study area into four different classes, Water, Bare Land, Cropland, and Wetland, image collections from Landsat – 5 (1990, 2000, and 2010), and Landsat – 8 (2020), in the cloud computing platform, GEE has been used. The image collections were filtered by date and images from June and July were used in further processing. To get cloud-free imagery, the obtained images were reduced to a single image, calculating their median values. Six Landsat bands (Blue, Green, Red, Near Infrared, ShorthWave Infrared-1, ShorthWave Infrared-2), were used for the classification. In addition to the mentioned bands, two spectral indices calculated from Landsat data were added to the investigation; Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI). Details and equations of the indices are given in Table 1.

Table 1. Spectral indices used in the classification.

	Index	Used Bands	Equation
1	NDVI	Red, NIR	NIR – Red / NIR + Red
2	NDWI	Green, NIR	Green – NIR / Green + NIR

For the four classifications, the same samples have been used. Thus, the samples were carefully selected from the unchanged land covers over the years. The sample training was done over the Landsat data, with validation over high-resolution imagery from Google Earth. The classification was performed using a LIBSVM classifier. 50% of the samples were used in the classification, while 30% were used for the accuracy assessment where overall accuracy and kappa statistics were calculated for every year.

3. Results and Discussion

For every inspected year, classification has been performed within the GEE. 50% of the training samples were then used for the accuracy assessment analyses, and the results are presented in Table 2. As it can be seen from Table 2, the validation overall accuracy is higher than 0,87 in the four classifications, while the kappa statistics vary from 0.83 – 0.97.

Table 2. Accuracy assessment results.

	Year	Validation Overall Accuracy	kappa
1	1990	0,90	0,86
2	2000	0,96	0,95
3	2010	0,87	0,83
4	2020	0,98	

The results of the classifications are shown in Figure 2. While there are no significant changes in the Bare Land class, a shift of the river bed can be noticed in several points of the study area. For more detailed investigation, land conversion during the three investigated periods (1990 – 2000; 2000 – 2010; 2010 – 2020) has been made. The conversions between the classes are shown in Figure 3.

In all three periods, the class Bare Land did not receive any additional area from the other classes, but small areas of Bare Land were converted to, generally, cropland. The classes Wetland and Water changed the most, with more than 40% conversion of the Water class to Wetland and Cropland. From 1990 to 2000, and 2010 to 2020, this conversion was 20% and 25%, respectively. As expected, the results showed that the river bed mainly shifts towards the Wetland and Cropland, or areas with soft soil. For a more detailed investigation, we recommend considering the geological characteristics of the river bed and its surroundings.

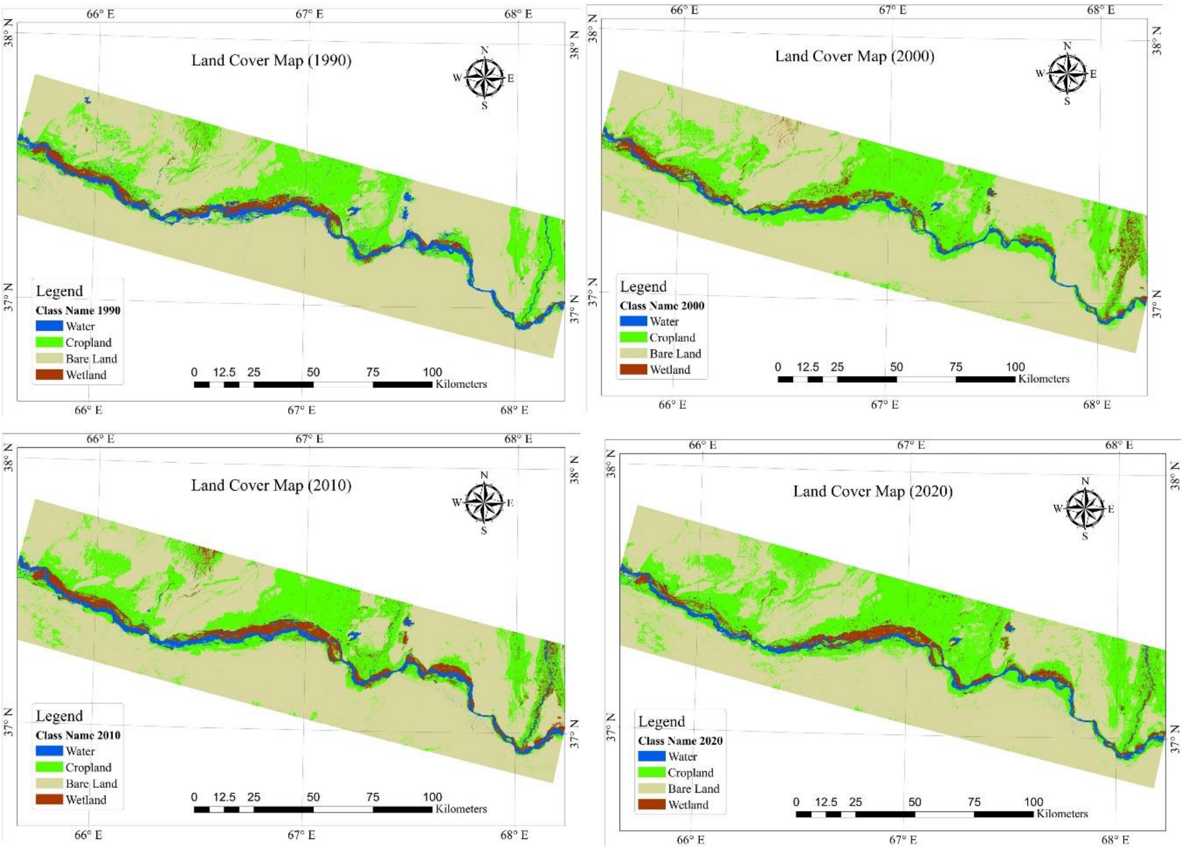

Figure 2. Classification results.

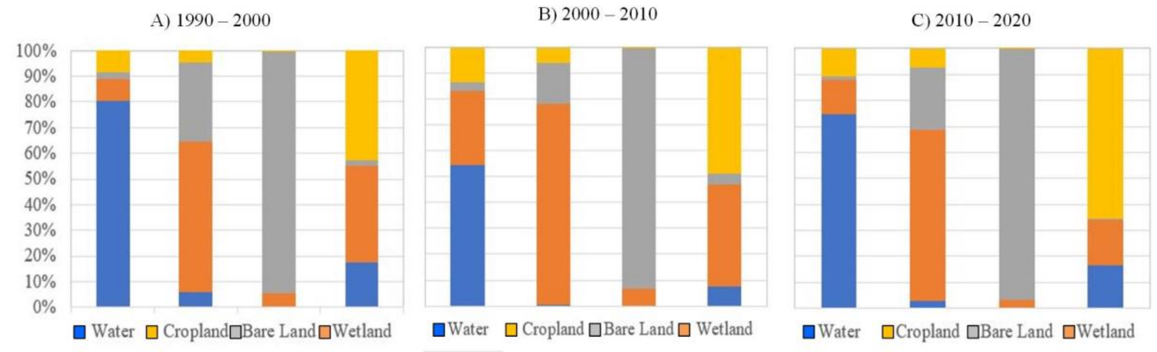

Figure 3. Land conversion results; A) 1990 – 2000; B) 2000 – 2010; C) 2010 – 2020.

Also, the dynamics of the river in the inspected years can be seen in Figure 4. The dynamics of the river are seen in the period between 1990 – 2000, and 2010 – 2020. According to the statistical analyses, the water area in 2000 was approximately 30.000 ha smaller than the area in 1990. The water area then gains approximately 19.000 ha in 2010 in comparison with 2000, and then it got lowered in 2020 for 11.000 ha. The results showed that the river dynamics mainly occupy the wetlands and croplands area, thus causing damages in farmers' land, and also some small villages around the river bed. It should be also mentioned that the river dynamics are constantly changing the natural border between the sharing countries, which causes even bigger problems for farmers to claim their rights [14].

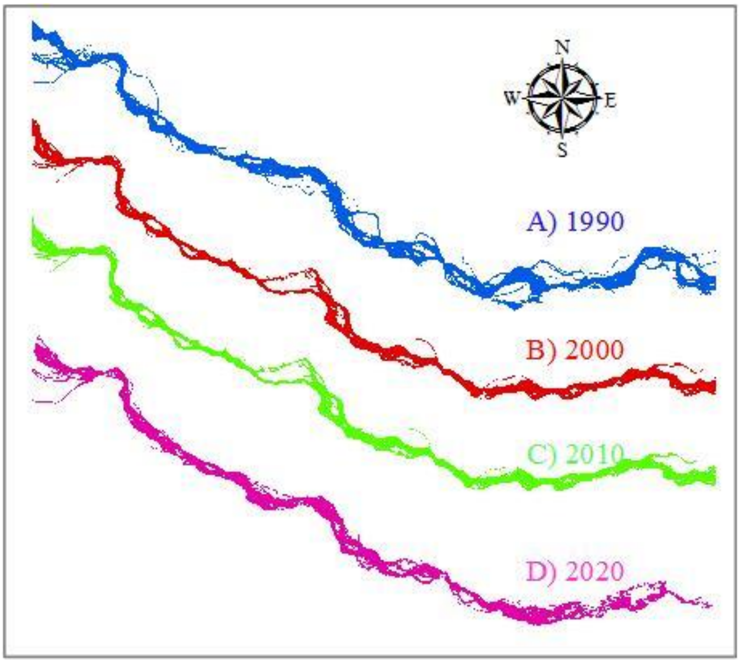

Figure 4. Amu Darya river dynamics; A) 1990; B) 2000; C) 2010; D) 2020.

5. Conclusions

This paper aimed to classify four Landsat images to investigate the river dynamics and land cover changes around Amu Darya river within GEE. The study area, the upper stream of the Amu Darya river channel that forms part of Afghanistan's northern border with Tajikistan, Uzbekistan, and Turkmenistan. The area is an example of a transboundary river shared by few countries, and updated river dynamics are of international importance. This study shows not only the river dynamics but also the land conversion that happens caused by the river dynamics.

For future studies, we recommend a more detailed investigation of the river dynamics with more classes and higher spatial resolution imagery.

Author Contributions: M.A.M. and G.K. conceived and designed the experiments; M.A.M. performed the experiments; G.K. did the supervision; M.A.M. and G.K. analyzed the data and the results; M.A.M. and G.K. wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

GEE: Google Earth Engine
SVM: Support Vector Machine
NDVI: Normalized Difference Vegetation Index
NDWI: Normalized Difference Water Index

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