MULTI-TEMPORAL IMAGE ANALYSIS FOR ALAZANI RIVER (GEORGIA) MEANDERING CHANGE DETECTION

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ABSTRACT

Human impact along with other elements of the environment has a great impact on the processes in the river basins. River meander dynamics and mobility are important indicators of environmental change related to climate changes and anthropogenic activities at local and river basin scales. This paper presents a study of spatial and temporal changes meandering Alazani (Georgia) in its middle stream and downstream. Alazani is the border of the country and the bank erosion here has the environmental and political importance as well. The aim of the present study was to identify spatial-temporal variations of channel length, meandering, and central line migration of the Alazani River. The analysis was carried out on a series of multitemporal and multispectral remotely sensed data acquired by different satellite missions during the time period between 1986 and 2019. Data from the Sentinel-2 missions and large-scale topographic maps (1:25 000) were considered. Supervised image classification with the combination of NDVI (Normalized Difference Vegetation Index) and MNDWI (Modified Normalized Difference Water Index) was used for Landsat image (1986, 1995, 2006, 2013, 2019) analysis, Sentinel data and topographic maps served to establish reference information about river morphological features in order to compare the results of the temporal analysis. The results demonstrated that the morphological changes are mostly related to the sediment supply and its regime. The direction of the migration rates varied towards the west and the east, with the dominant direction towards the west. Several meanders and ox-bow lakes remain as a result of migration.

Keywords: meander, migration, bank erosion, Alzani, Georgia

INTRODUCTION

Human impact along with other elements of the environment has a great impact on the processes in the river basins. That is why it is necessary to measure these changes, record, and model them to provide relevant information about climate change, erosion, and other global challenges. Geomorphology of alluvial river channels and their floodplains are the product of diverse climate and sediment characteristics, including runoff, sediment size and supply, topography and tectonic setting, and floodplain vegetation [1]. It is generally accepted that meandering is one of the most intriguing and highly dynamic processes occurring in alluvial riverine environments [2] and these dynamic processes benefit ecosystem health. River channel meander migration and cutoff processes drive the planform morphology and habitat attributes of floodplain rivers [3]. Numerous experiments have established that river geometrical data are of prime importance not only for flood protection planning but also for river management. Studying long-term large- scale dynamics on a river provides an important opportunity to quantify fundamental processes. An exact prediction or knowledge of the changes suffered by a channel is not possible considering the wide range of environmental and historical processes in the basin that contribute to its evolution [4]. Efforts to map and measure migrating meanders have resulted in fruitful insights into the dynamics of these fascinating fluvial forms [5].

The most common approach in studying the planform evolution of river meanders is to determine the migration rates and direction of their channel centreline [2]. Much research in recent years has focused on the characterization of river hydrogeomorphology which greatly benefits of spatially and temporally explicit information provided by remote sensing techniques [6-10]. Remote sensing and GIS may be used in combination to obtain scientific answers to historical and current morphological changes of river channel questions that would otherwise be difficult to get for reasons related to time and ground coverage. Unlike traditional geomorphology investigation methods that require intensive data collection through field surveys and processing, they provide excellent tools for river channel spatial data extraction, processing, storage, visualization, and analysis. The other advantage of RS and GIS is the use of accessible, inexpensive, and open-source remote sensing data that enables quick detection of morphological dynamics and how these changes affect river channels [11]. Observing changes in channel centerline data over time is a tested method of quantifying transitions in river geometry and measuring the lateral movement of a river channel over time. Performing these analyses using Geographic Information System (GIS) tools allows for automating measurements promptly, archiving results efficiently, and specifying a repeatable protocol.

This paper focuses on the study of spatial and temporal changes meandering Alazani in its middle stream and downstream. Our research was motivated by a common problem in studies of river migration: a lack of adequate snapshots through time to characterize river dynamics. Like Alazani River, many large rivers defining borders between countries, and being some of them very active, understanding their dynamics has also geopolitical consequences [2]. Alazani is the border of the country and the bank erosion here has the environmental and political importance as well.

METHODS AND MATERIALS

Alazani River (Fig. 1) is the longest river in Georgia, collecting precipitation and snowmelt runoff from the southern slopes of the Caucasus mountain range, and flows from north to south with a length of about 413 km, ultimately discharging into the Mingechevir Reservoir. The number of left tributaries of Alazani is sharply higher than the right tributaries. The regime and character of the left tributaries have a significant influence on the formation of the Alazani bed. Unlike the right tributaries, they are characterized by flooding, flooding, have large-sized attraction cones, bring in a large amount of fossil material, which the rivers bring out in the Alazani meanders. The riverbeds are dry most of the time. The water flows only during the rains and is muddy. Alazani bed basically coincides with the depression axis but is shifted to the right by the south-east. On the Alazani plateaus, alpine sediments are represented by shallow sediments and clays, alternating with pebbles and conglomerates. The rocks in many places are very worn out and polished. Tupogenic sandstones and marls are found here in some places. Among the remnants of the Quaternary period are alluvial-diluvial clays, loams, and sandstones. Under the shore (at depth) are developed several tens of meters thick laminated clays and sands, which are characterized by very insignificant tightness, pressure, and sinking properties [12]. According to the results of the above-mentioned research, soil erosion rate is quite high within River Alazani and Iori basins [13]. The floodplain forests, which are of great coastal importance, are preserved in small areas of the country, including the Alazani floodplains.

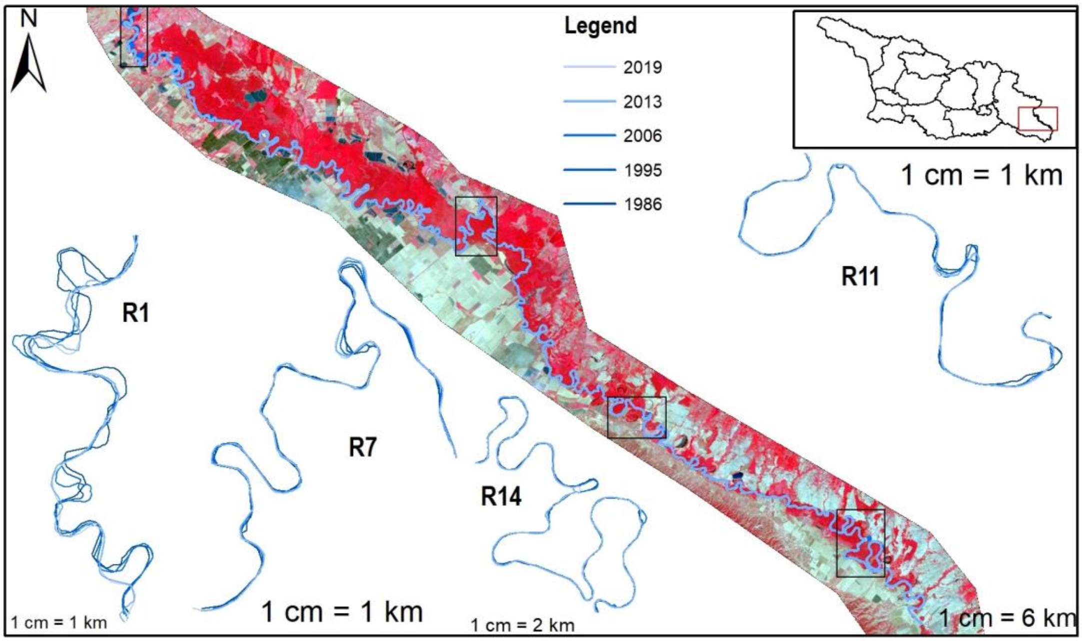

Figure 1. Study area

In this work, a semi-automatic image processing procedure is presented to study river channel change on a timescale of several decades. The procedure involves the recognition of river reaches and the extrapolation of morpho-dynamic parameters including channel centerlines changes.

Our research focused on the spatiotemporal analysis of the active river channels over approximately 34-year time-series datasets derived from Landsat (1986, 1995, 2006, 2013, 2019), topographical maps (published in 1965-70 (1:25,000 scale) (Table 1). Satellite images provide an extensive source of remotely sensed data to illustrate and explain the nature of the fluvial system’s spatiality over time.

Based on the cartographical data and GIS datasets 15 cross-sections have been delineated. At first, river centerlines were extracted by processing imagery data. For this thresholding of vegetation and water indices ware used. The Normalized Difference Vegetation Index (NDVI) is a specific radiometric index that exploits such a typical absorption/reflection pattern, and it is used to map green leaf vegetation. Typically, the NDVI is computed according to the following equation:

$$NDVI = NIR - R / NIR + R$$

where NIR and R are the near infra-red and the red bands. NDVI values can range between −1 and +1. Negative values correspond non-vegetation areas.

Among the common methods of surface water extraction to discriminate land-water interface Modified Normalized Difference Water Index. Likewise, NDVI, MNDWI is a radiometric index that exploits a typical absorption/reflection pattern for water mapping purposes. After, the MNDWI is computed according to the following equation:

$$MNDWI = G - MIR / G + MIR \qquad (2)$$

where G and MIR are the green and the mid infra-red bands.

Table 1. Data type used in the study

Data Type	Scale/Resolution (m)	Dates	Source
Topographical maps	1:25 000	1965-1970	Institute of Geography, Georgia
Landsat 5 TM	30	1986	USGS Earth explorer
Landsat 5 TM	30	1995	USGS Earth explorer
Landsat 5 TM	30	2006	USGS Earth explorer
Landsat 8 OLI	30	2013	USGS Earth explorer
Landsat 8 OLI	30	2019	USGS Earth explorer
Sentinel 2	10	2019	USGS Earth explorer

Thresholds on the NDVI and MNDWI maps were set in order to select only pixels corresponding to water. Once the initial water map was obtained, centerlines were extracted by means of Voronoi diagrams [14] and further processed along with other quantities derived from transects of the surface coverage classified maps. The procedure was applied to a set of Landsat data cover the time period 1986–2019. The channel centerlines were extracted starting from the Voronoi diagrams of the areas representing the active channel. The centerline is represented by the polyline connecting the centers of all the highest circles inscribed in the Voronoi polygons. From the channels' centerlines and the transect sets, hydromorphological parameters were derived by means of an automatic procedure implemented using ArcGIS 10.8. Overlay analysis of temporal river layers was done to identify river bank shifting and channel migration.

For sinuosity, SI=meander length/straight length. A high value indicates high meandering and a low value goes towards the straightness. According to the sinuosity index, channels can be classified into three classes: straight ($SI < 1.05$), sinuous (SI 1.05–1.5), and meandering ($SI > 1.5$).

Finally, the lateral migration distance was calculated which is equal to the polygon area divided by the average stream length for the polygon (with average stream length equal to one-half of the polygon perimeter) [15].

RESULTS

As mentioned earlier, the main purpose of this work was to analyze spatial and temporal changes in Alazani River channel. The study area or central part of the river channel was divided into 15 cross-sections from north to south direction. According to table 2, the overall width of the channel increases in the middle of the river (cross-sections 8 and 9). The numberს in table 2 demonstrates quite an interesting trend, channel width increased in almost all cases during the 2006-2013 period.

The band length changes can represent channel development rates. We observe from table 3 that in the first period (1986-1995) the largest increase is in R8 while R9 shows the least one. 2013-2019 is a relatively stable period. In general, in the 1986-2019 period, the largest increase is in R8, R2, and R6 and decrease R1 and R9.

Table 2. Channel width changes

Cross Section	**1986**	**1995**	**2006**	**2013**	**2019**
1	120.81	104.23	83.70	160.20	170.27
2	85.95	61.85	99.84	103.78	99.72
3	74.51	81.29	49.89	70.26	65.65
4	63.74	87.48	62.82	88.46	96.80
5	88.33	87.94	66.91	93.28	92.17
6	108.97	96.87	66.26	92.24	86.00
7	72.54	99.76	65.20	86.00	61.81
8	129.77	129.01	93.35	113.10	154.45
9	70.31	131.27	110.39	123.61	133.18
10	102.47	79.89	52.72	70.83	57.52
11	105.53	108.03	65.23	101.75	76.53
12	122.13	69.24	65.03	79.37	87.47
13	150.53	203.08	100.35	180.96	110.77
14	104.85	102.03	83.20	110.22	138.00
15	103.27	119.04	73.76	93.19	76.46

Table 3. Number and length of reaches

#/Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1986	10.58	14.72	12.14	14.56	12.77	11.83	12.13	10.48	14.18	11.27	12.25	11.86	13.93	18.88	12.28
1995	10.23	15.36	12.24	14.89	12.84	12.42	12.22	13.39	11.43	11.44	11.78	11.85	14.08	19.00	12.31
2006	10.13	16.16	12.56	15.15	13.10	12.92	12.60	13.67	11.88	11.84	12.24	11.92	14.23	19.27	12.59
2013	8.64	16.17	12.66	15.34	13.21	12.93	13.08	13.86	11.90	11.78	12.03	11.97	14.39	18.36	12.40
2019	8.38	16.10	12.73	15.34	13.18	12.96	13.24	14.00	12.08	11.99	12.19	11.90	14.58	18.61	12.52

Using the method described above, Sinuosity values have been calculated for each reach for each channel. Since 1986 the river was flowing through the quite sinuous and meandering channel. It is apparent that in the majority of cases meandering tendencies of river Alazani have slightly been increased (fig. 2). However, the changes by periods are not sharp. The highest differences between the initial and final years are R6, R9, and R7 while the last reaches (R12-R15) are stable.

During the study period (1986-2019) it was observed that the river has shifted on both sides of the bank. The direction of lateral erosion showed that the right bank of the bed eroded more intensively. In the case of the right bank, the eroded area over the entire length of the river study section is almost doubled as the left bank. There are several possible explanations for this fact. The first two are natural processes, including the influence of the Coriolis effect and the attraction cones that appear at the confluence of the mighty tributaries of the Alazani. The third important factor is that no shore embankment is carried out on the right bank of the river, while active shore protection works have been carried out in some critical areas of the left bank. The overall trend shows that the third period (2006-2013) is the significantly active compare to other periods, which in our opinion is related to the climate factors and reduction of runoff. It should, however, be noted that relatively less lateral erosion in R5, R7, and R13 should be associated with relatively better protected natural vegetation.

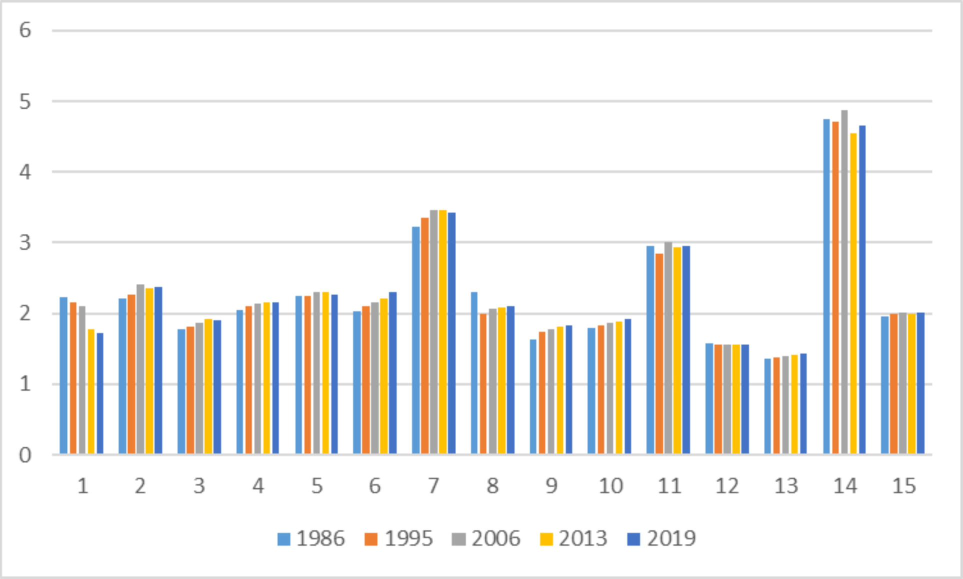

Figure 2. Changes in channel sinuosity

Table 4. Mean Lateral channel shift (m/y/km)

	1986-1995	1995-2006	2006-2013	2013-2019
1	8.31	6.93	14.07	8.57
2	4.39	4.33	6.80	4.82
3	4.44	4.08	4.33	4.26
4	2.82	2.70	3.94	4.90
5	2.55	1.53	3.43	3.38
6	3.54	2.58	4.77	4.31
7	3.01	2.59	3.56	2.71
8	3.05	2.93	3.73	3.33
9	3.11	2.00	3.34	3.85
10	2.81	2.04	3.83	3.38
11	3.31	2.42	3.54	4.39
12	3.01	2.25	3.42	3.99
13	2.58	2.12	3.33	3.60
14	3.18	2.96	4.96	4.09
15	2.83	3.45	4.73	4.84
Avg.	3.53	2.99	4.79	4.30

CONCLUSION

In order to achieve the aims of this study to reveal the recent channel evolution of the Alazani River (Georgia) during different periods within 34 years of data (1986-2019), we examined 15 reaches and the same number of cross-sections in the river channel. According to the delineated reaches total studded channel length increased in 11 of the 15 reaches, especially R8 and R2. As for sinuosity Alazani channel is quite stable, this could eventually lead to its natural development and is also related to the fact that engineering structures on the river bed were no longer created after the 1980s. 2006-2013 period is a very interesting in terms of lateral erosion. We think that in this case the particular intensification of lateral erosion must be related to climatic factors. Research has shown that more in-depth research is needed to obtain more comprehensive answers in the future. Future works should therefore include foll0w-up work designed to evaluate runoff, climate change, and land use/land cover changes.

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