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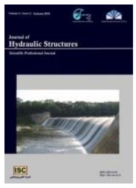

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Predicting Morphological Changes in Rivers Using Image Processing (Case Study: Qizil Ouzan River)

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Abstract

Morphological studies are among the most important topics in river engineering, dealing with the geometric shape, bed form, and longitudinal profile of the waterway, cross-sections, deformations, and lateral migration of rivers over time. Researchers worldwide have noted the capability of satellite imagery and its integration with geographic information systems (GIS) to provide comprehensive information about river conditions and monitor spatial changes at different time intervals. In this paper, a new method is proposed to detect the current morphology of different parts of the Qizil Ouzan river and its main branches using a CNN neural network with support vector machine (SVM) and multilayer perceptron (MLP). The results of the studies show that the current meander length of the river is more than anything else the result of non-river factors such as stream piracy and mass movements like landslides and lateral collapses of waterways. Moreover, using GIS software, the meander and its changes over different time periods were obtained and compared with each other. Also, the present research aims to predict river morphological changes using image processing in MATLAB. The results demonstrate the efficacy of combining these two methods for predicting the morphological changes of the Qizil Ouzan River.

Keywords: River Bed, Image Processing, Prediction, Morphology, Sediments.

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1. Introduction

The study of predicting morphological changes in rivers and investigating the influence of various factors on channel shape and structure is of great importance. Such studies can provide valuable insights into river behavior and how they respond to changes. The application of image processing techniques for analyzing data related to channel shape and structure can provide a powerful tool for better understanding river dynamics. It is important to identify factors influencing channel shape, including tectonic activities, slope processes, lithology, and the geological structure of the area using high-quality images with appropriate resolution for analyzing channel shape details. By conducting such studies, better planning and management of watersheds, prevention of potential hazards such as floods, and erosion control can be achieved. Furthermore, a deeper understanding of the geomorphological processes of rivers will be gained. Rivers, as natural conduits for collecting and transporting atmospheric precipitation that flows across the Earth's surface, have always been the focus of human communities. Major and minor civilizations throughout history have emerged and endured alongside these life-giving natural phenomena [1-4]. The lives, work, and efforts of many people have been directly dependent on river water, benefiting from its natural bounties. Providing drinking water and irrigation has been the primary need of human communities along riverbanks. However, many civilizations have also faced the indifference and wrath of nature throughout history. In numerous instances, floods and inundations, as well as erosion of riverbeds and banks, have inflicted significant damage on agricultural lands and the homes and dwellings of riparian residents [5]. Therefore, it is necessary to strive to understand the factors influencing erosion and changes in the natural course of rivers. Rivers and waterways are highly dynamic systems, and their position, shape, and other morphological characteristics are continuously changing over time A combination of factors, such as channel slope, flow rate, bed material characteristics, frequency and intensity of floods, etc., determine the morphology of a river in space and time [6]. In this regard, Leopold and Wolman [7] classified river morphological structures into three categories: straight, meandering, and braided, which are influenced by these factors. Among these patterns, the meandering pattern has attracted the most attention due to its prevalence in nature [8]. The river ecosystem is highly dynamic, and its lateral boundaries and morphological characteristics are continuously changing over time [9-10]. Monitoring morphological changes is the basis and foundation for solving applied geomorphological problems, and identifying and designing their processes is essential. Geomorphologists, to understand the nature and rate of changes, describe the past and present as a necessary principle and predict the future of processes [11]. On the other hand, geomorphological studies are among the most important topics in river engineering, dealing with the geometric shape, bed form, longitudinal profile of the waterway, cross-sections, deformations, and lateral migration of rivers over time [12]. Researchers worldwide have noted the capability of satellite imagery and its integration with geographic information systems (GIS) to provide comprehensive information about river conditions and monitor spatial changes at different time intervals [13-18]. Today, advances in image processing science have made it possible to calculate the morphological characteristics of rivers through photography. Due to the lack of geotechnical and soil mechanics studies (due to high costs and time-consuming nature) in many river engineering studies, image processing can be used as a suitable method for facilitating the extraction of bed material gradation curves and other particle characteristics [19]. Therefore, access to more accurate information about river morphology for hydraulic flow and flood modeling is provided, consequently increasing the accuracy of simulations.

2. Materials and methods

Qizil Ouzan is one of the longest rivers in Iran, originating from the Chehel Cheshme Mountains between Saqqez and Divandarreh in the Kurdistan and East Azerbaijan provinces. After joining the Hir River, Zanjan River, and Shahroud River, it flows into the Caspian Sea. In southern Gilan province, Qizil Ouzan merges with the flow of the Sepidrud Dam to form the large Sepidrud River. The Qizil Ouzan River passes through the western, northwestern, and northern parts of Zanjan province, forming border boundaries with Gilan, Ardabil, East Azerbaijan, West Azerbaijan, and Kurdistan provinces in some sections (Figs. 1 and 2). For this study, initially, a section of the Qizil Ouzan River between the coordinates (36°51'31.93"N, 48°57'24.57"E) and (36°52'14.30"N, 48°54'39.67"E), with an approximate length of 8,600 meters, was selected using Google Earth, and image processing was performed on that section.

Figure 1. Location of Qizil ouzan river

Figure 2. Google Earth image from one reaches of Qizil ouzan

3. Results

This paper utilizes a convolutional neural network (CNN). In this work, the Stochastic Gradient Descent (SGD) algorithm is used for training the CNN. The number of hidden layers of the neural network is set to 200. The Database folder contains images of the Qizil Ouzan River for four consecutive years from 2018 to 2021, which are used to obtain an estimate for the year 2022. For simplicity and faster processing, grayscale versions of the images are used. This work is carried out using a deep neural network. To run the processing, it is sufficient to execute the main code and wait for the features to be extracted and the results to be displayed. The implementation was done in MATLAB 2019a. The quantitative metrics used for evaluating the simulation results include classification accuracy, false positive rate, and specificity. The classification accuracy is obtained by calculating the confusion matrix. The confusion matrix is a square matrix of size $C \times C$, where C is the number of classes. The main diagonal of this matrix contains the correctly classified samples, and the off-diagonal elements represent the samples that are incorrectly assigned to a class other than their true class. After calculating the confusion matrix, the classification accuracy and two other quantitative metrics are defined by the following Eqs. 1, and 2.

$$\mathrm{FPR} = \mathrm{FalsePositiveRate} = \frac{\mathrm{FP}}{\mathrm{FP} + \mathrm{TN}} \tag{1}$$

$$\mathrm{Specificity} = \frac{\mathrm{TN}}{\mathrm{FP} + \mathrm{TN}} \tag{2}$$

Where:

- False Positive: A result that is declared correct but is incorrectly declared correct.
- False Negative: An incorrect result that is wrongly or erroneously declared as an error.
- True Positive: A result that is declared correct and is indeed correct.
- True Negative: A result that is declared incorrect and is indeed incorrect.

3.1. Pre-processing and Image Segmentation

As mentioned earlier, before applying the satellite images of the region to the deep neural network, pre-processing steps need to be performed on the images to obtain the region of interest (ROI). In this paper, we will work on different sections for pre-processing. The general steps of pre-processing are also shown in Fig. 3. The flowchart depicts the main steps involved in a pre-processing for image data. The first step is to remove environmental noises and distortions that may be present in the raw data. Next, noises or unwanted artifacts from the surrounding areas are removed. Finally, the image quality is enhanced, and the Region of Interest (ROI) is extracted from the pre-processed image for further analysis or processing. In the second stage, the areas surrounding the river are removed using the region growing method. In this paper, the automatic seed point selection method is used. In this method, neighboring pixels are continuously examined to determine whether they should be added to the region, and this process continues until the complete ROI is extracted. The final pre-processing stage involves image quality enhancement using the Wiener filter and CLAHE (Contrast Limited Adaptive Histogram Equalization) algorithms.

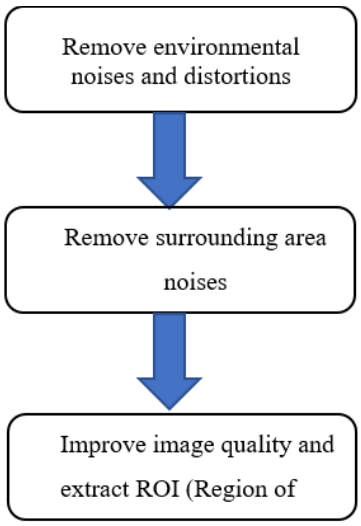

Figure 3. Preprocess flowchart for image processing

3.2. Results of Morphological Change Detection in the Region using CNN+(SVM+MLP)

Using the second fully connected layer in the convolutional neural network, a feature vector is obtained, and in this section, the results of applying this data to an SVM with a radial basis function kernel and an MLP neural network are presented. In this scenario, as before, 70% of the images were used for training and 30% for testing across all datasets. The test results of the trained network are presented in Table 1.

Table 1 - Quantitative Metric Results for Using CNN+(SVM+MLP) Method

Specificity	FPR	Classification accuracy (%)	Operated method
0.9532	0.0412	98.88	CNN+(SVM+MLP)

As observed in Table 1, the proposed method, which combines the CNN neural network with SVM and MLP, has been able to achieve higher performance and provide more desirable results. Based on this, it can be concluded that using the proposed method of this research, the detection of morphological changes in the region from satellite images is possible with an accuracy of 98.88%.

3.3. Simulation Codes

After determining the method, we move to the code written in MATLAB and execute it. After running, the neural network undergoes training. Depending on the system's speed and processor, this part may take several hours. In the end, the trained model is obtained (Fig. 4). The prediction for the year 2022 is performed here with the aid of a trained model. The final image is saved in black and white (Fig. 5).

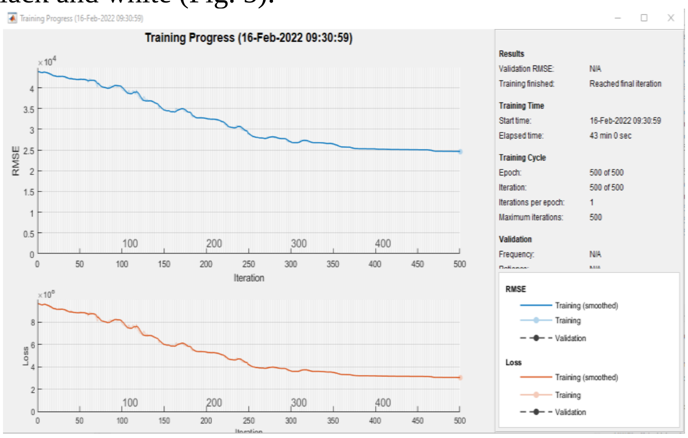

Figure 4. Trained model for image processing

Figure 5. Final output image after processing

3.4. Analysis of Some Morphological Changes

Next, we transfer the existing images in the database, as well as the final output, to ArcMap software version 10.6.1 to obtain some geomorphological properties, including the existing meander and its characteristics and the river length at that selected point, and compare them with each other. First, we GEOREFERENCE the aerial images of each year in the software separately, so that measurements at certain points are more accurate. Table 2 presents the river characteristics at a specific point and in different years for comparison. In general, any change in the loop of a meander bend, as well as a change in its geometric shape, necessitates erosion of the river banks. In all river meanders, a continuous process of erosion occurs with varying intensity on the concave or outer bank, and sediment deposition occurs on the convex or inner bank, forming point bar deposits. The cumulative effect of these two phenomena over time results in either the continuous displacement of the concave and convex bank apexes downstream or the lateral migration of the meanders perpendicular to the valley axis. In other words, there are two types of meander changes (i) Migration and progression downstream, (ii) Meander expansion and cut-off.

The actual movement of meanders in nature can be considered a combination of these two cases. Each of the above movements is also a combination of components of changes in the bends. Pure longitudinal movement in a meander results from the translation of the bend loop, while lateral movement is caused by the expansion of the bend. Both types of these changes often occur at specific locations in a meander. Meanders increase the flow length and decrease the slope. The phenomenon of meander formation can be considered as the general stages of the river's adjustment to the valley slope through which it flows. The geometry of a meander is formed by erosion and sedimentation.

Table 2. River reach characteristics during different years in fixed position

Image Year	River Length (m)	Meandering width (m)	Meandering amplitude (m)	Meandering length (m)
2010	5010	1851	1569	2043
2013	5067	2326	1925	2221
2018	5380	1949	1602	2036
2021	5410	2001	1980	2150
Final Image	5497	2361	2108	2285

In areas where the river has few bends, meander changes do not occur as cut-offs but rather as downstream migration. Since this phenomenon occurs systematically, the rate of downstream progression is regular and consistent. Based on this, the alternating movement of the meander from one bank to the other can be defined. The duration of this periodic movement depends on the return period of floods and the composition of bank materials. Therefore, this periodic movement can have different durations in different reaches of a river. However, the periodic time is usually constant within a given reach.

Based on the mentioned points and Table 2, it is observed that the changes in the meander or bend of the river over time follow an approximately constant periodic pattern. However, in 2018, the periodic and increasing changes observed in previous years have decreased and become lower than the previous year. But again, in the following year, the upward trend resumed and increased. These changes could be due to the occurrence of floods or land-use changes in the riverbed, and errors in calculations and measurements cannot be ruled out. Furthermore, the changes in the characteristics and shape of the meander over different time periods, as determined by the ArcGIS software, are shown as an example in Fig. 6.

Figure 6. Method of measurement of amplitude, length, and width of meandering

4. Conclusion

Nowadays, with the increasing expansion of various methods of acquiring discrete studies such as scanners and digital cameras, image processing has found extensive applications. The resulting images from this data are always more or less accompanied by some noise and in some cases suffer from the problem of blurring the boundaries of samples within the image, which leads to a reduction in the clarity of the received image. The set of operations and methods used to reduce defects and enhance the visual quality of the image is called image processing. In general, the information received from image signals must be in a way that is understandable for systems. Therefore, methods must be found to convert the signal into data that is comprehensible for the system. In general, signals are analog and digital, and in either case, they must go through stages to be converted into the desired information. After these conversions, the features extracted from the image are considered as vectors. If the vectors extracted from the images have large dimensions, dimensionality reduction must be performed on them so that the data separation and classification can be done better. The Ghazal Ouzan basin is one of the basins that has undergone many geomorphological changes in recent centuries. The continuation of tectonic activities (formation of compressional ridges), mass movements, and the influx of a large amount of slope materials into waterways, as well as the occurrence of intermittent droughts, land-use changes, and the occupation of the river bed along its long course, are among these changes. The results of the studies show that the current morphology of different parts of the Ghazal Ouzan river and its main branches is more than anything else the result of non-river factors such as stream piracy and mass movements like landslides and lateral collapses of waterways. In general, rivers in mountainous areas like the Qizil Ouzan river in the studied area always adapt themselves to the changes in the channel slope and slope processes, and that is why we encounter various forms of waterways in different parts of these rivers. Tectonic activities, glaciers, mass movements, and changes in lithology and structure, which directly affect the erodibility of the channel bed rock, are known as non-river factors influencing channel geometry. Along with these factors and based on the results of this research, the phenomenon of stream piracy should also be added to the above cases. Additionally, using GIS software, the meander length and its changes over different time periods were obtained and compared with each other. It was observed that combined methods improve classification performance. In addition, using the CNN network alone did not provide satisfactory performance, but the features of this network along with SVM led to a good improvement in classification accuracy.

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