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Research Article

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Temporal and Spatial Variations of Zarrineh-Rood River Morphology Using RS and GIS

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Abstract

Identification of changes and their effects on the morphology of river bed and riverside lands is a necessity for river management. This study focuses to identify the trend of river morphological evolution and changes in the riverbed territory at the final 25-kilometer downstream section of the Zarrineh-rood River leading to Urmia Lake in West Azerbaijan during the last 50 years using aerial photos taken in 1955 and 1967, topography maps produced in 1996, and SPOT satellite images taken in 2011 with field survey. They were interpretated to 3 land types of sandy beaches, permanent riverbed and sandy barriers. Distinguished land type maps overlayd and compared using GIS ILWIS software. Surface area of land types, river meandering and sinusoidal coefficients were calculated and the trend of the river interpretated. Results showed that the area of the riverbed territory has reduced form 561.1 to 221.3 ha, and the riverbed morphology and the shape of river bends have evolved. From 1967 to 2011, natural features such as sand dunes inside the riverbed have reduced from 13.68 to 2.86 ha, which indicates high fluctuations of discharge and changes in hydrological and hydraulic conditions of the river. The number of meanders has decreased from 4 to 3 and the riverbed has become straighter and more arterial. Land types surface area of sandy beaches decreased from 503.66 to 140.78, permanent riverbed increased from 54.83 to 77.68 and Sand dune is almost stable. The sine coefficient of the river is about 1.5 that indicates river classified as meandering. Deposition plays a mail role in morphological changes. 60% reduction in the riverbed territory is alarming, and current riverbed with its sedimentation prone conditions will not be able to discharge floods with average and above average return period. The most effective factors in morphological changes are the changes in hydrological regime because of dam construction, reduction of runoff, and accumulation of sediment loads on the riverbed.

Keywords: Satellite images; River; Meander; Sedimentation; West Azerbaijan

Introduction

Rivers are exposed to change but morphological changes of big rivers are more prominent. River morphology and its developments have been subjected by many studies. Ahmadian Y [1] showed that from 1955 to 2000 (45 years) the plan area of the Tajan-River has extended from 927.43 to 2674.9 ha. The erosion-induced land degradation was estimated to be 33.1 m^3 in Iranian side and 3.9 m^3 in Turkmen side of the river. Morid [2] assessed 4 series of Landsat and IRS satellite images and discovered that meanders of Karun River have shifted toward the downstream side. Yang [3] assessed 6 series of MSS and TM satellite images and discovered that the Yellow river has changed from a direct arterial form to a weak meander form. Jinsit assessed the evolution process of Paglyn River's alluvial plain in the past 200 years by taking samples from 14 sections of the riverbed. The Results showed the increasing shrinkage of riverbed's width from 206.7 meters in 1821 to 53.9 meters in 1999. During the years 1821-1977, this river bed has moved 121 m and has also deepened. According to the study of Gharibreza and Masoumi [4], from 1967, 2 cut offs have happened in the Zohre River and the meanders of the riverbed has increased from 43 to 48, which means this river falls into highly developed meander category. The study of Farrokhi et al. [5] showed significant riverbed changes and shifts in Dez River and in interval the river bend is cut off by the water flow and its route has been shortened. According to Javaheri et al. [6], in a 150 km section of Karun River, meanders have been reversed and sedimentation in outer arcs of meanders has impaired the performance of basins. McCusker [7] performed a GIS based historical analysis on Pomperaug River for a period of 70 years and discovered riverbed changes as well as decreased sinusoidal deformation. The study of Musa showed that riverbed changes of Pascagoula River are because of mining activities and that river bed width has increased by 400-500%. The Little Colorado River has adjusted by an extreme flood in 1923, subsequent decline in peak discharge and mean annual flow by channel narrowing: The channel width and area of the river have decreased by approximately 90% over the study period (1936–2010). Tiwari and Nayan [8] reported that riverbank of the Ganga downstream was changed by more than 1000 m and there is significant amount of bank shifting occurred and Downstream of river was getting more erosion than upstream. The results of Mallick [9] revealed that the fluvial geomorphologic changes over the period of 45 years are considerably significant. Pathak et al. [10] conducted that there has been significant course change of Kodku Khola river during the last 19 years between 1988 and 2007. The analysis of Laha and Bandyapadhyay [11] showed a drastic increase in all of those parameters over the period of time. For increasing sinuosity, the river has been engulfing the large areas of left bank every year. Slater and Singer [12] found that 68% of stations have bed elevation change trends ($p<0.05$) with median values of +0.5 cm/yr for aggradations and –0.6 cm/yr for degradation. The results of Sarkar et al. [13] provide latest and reliable information on the dynamic fluvial-geomorphology of the Brah-maputra River for designing and implementation of drainage development

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programmes and erosion control schemes. According Nagata et al. [14] the development of meandering of Otofuke River during the flood attributed to the propagation of meandering downstream, which is triggered by the meandering flow from the meandering channel in the upstream. Gâştescu et al. [15] underlined complex changes and space–time pattern in bank erosion, sediment accumulation, channel length and active channel width. Channel lengthening was greater in the first 30 years. Ozturk and Sesli [16] found that Sinuosity and braiding of the Kizilirmak River both decreased in most of the sections downstream of dams; these sections were often subject to uncontrolled sand and gravel extractions.

Zarrineh-rood River has the biggest watershed into the Urmia Lake basin. Given to sufficient water and high agricultural potential, the lands adjacent to or slightly away from the river are the site of many villages. In wet years, a great portion of these lands are exposed to floods, which cause significant financial losses [17]. In recent decades, the river side farms have cultivated a large area of the riverbed territory and intensified the morphological changes of the riverbed by manipulating the boundaries of the river. Furthermore, construction of Bukan dam has triggered significant decrease in the river flow and the effect of runoff reduction in the morphological changes of the river bed [18]. The vast changes due to development activities and changes of land use cause the morphology changes on Zarrineh-rood river bed, so in this study was aimed to identify the morphological evolution of Zarrineh-rood riverbed and its consequences during a 50 year period.

Materials and Methods

The study area

The study area is the final 25-kilometer long section of Zarrineh-rood River in southeast of Urmia Lake (Figure 1). This river has a length of 217 kilometers and a basin area of 11729 km^2. Its average discharge is 62.1 m^3/s and its max flow discharge is 1552 m^3/s. The average annual precipitation of the study area is 392.2 in Dash band and 267.7 mm in Tazeh-Kand station. The area studied is the slightly sloped, alluvial lands adjacent to the river bed, which include highly fertile agricultural lands and gardens.

Research method

The 1:50,000 scaled aerial photos taken in year 1955 were used to provide the digital map of the riverbed territory in the studied section as the base year. The 1:20,000 scaled aerial photos taken in 1967, the 1:50000 scaled topographic maps pertaining to the year 1996, and the SPOT satellite images taken in 2011 were used to provide four data layers. The data layers were created in the GIS environment (after geo referencing) with RMSE of less than 0.5 using ILWIS software. The territory of different land types was determined by on Screen Digitizing. Digital layers created in GIS over lied and compared with the base map (1955) so that the trend of riverbed, changes of aadjacent land types and morphological evolution by the sine factor were determined in different time periods.

Results

Based on interpretation of aerial photos, satellites images and topography maps pertaining to the years 1965, 1967, 1996 and 2011, the boundaries of river territory were determined. Considering the differences in the riverbed morphology, the adjacent land types of the river territory was divided into 3 categories of sandy beach, permanent riverbed and sandy barriers. The boundaries of the land types during different time periods are shown in Figures 2-5, and the area of each land type is given in Table 1.

According to Table 1, after year 1955 the boundaries of lands in the river territory have changed. In the base year (1955), the area of all lands is 561 ha (Figure 2) and in year 1967 the area of riverbed is 482.16 ha. During this period, the area of permanent riverbed and sand barriers has increased and the area of sandy beaches has decreased (Figure 3). In year 1996, the riverbed area is 327.29 ha which is very lower than the base year. From 1955 to 1996, the area of permanent riverbed has doubled and in 1996 there is no longer any sign of sand barriers inside the permanent riverbed. These morphological changes indicate a wet year as compared with past periods. The notable outcomes of this wet year include the morphological changes in the riverbed, elimination of arcs and meanders and uncurling at the beginning of the section. Meander development coefficients have also changed in all arcs (Table 2 and Figure 4). In the latest data layer (SPOT images taken in 2011), the riverbed area is 221.3 ha (Figure 5). Comparison of land areas in different time periods shows a continuous decline. During the past 55 years (1955-2011) the riverbed area has decreased and sediment lands and sandy barriers have been taken over

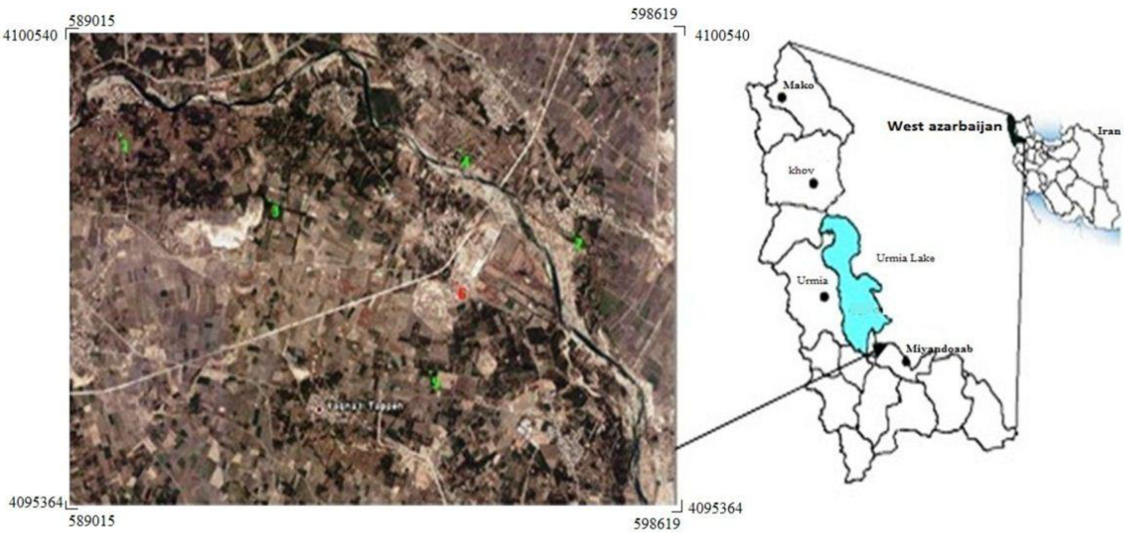

Figure 1: Location of the studied river section.

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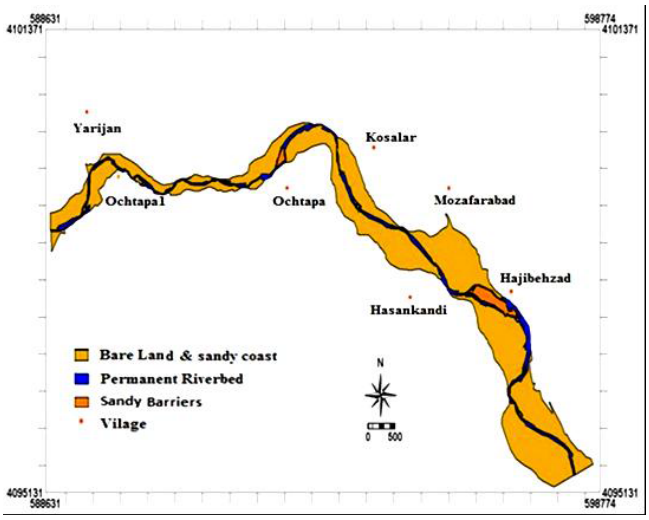

Figure 2: Map of the selected section in 1955.

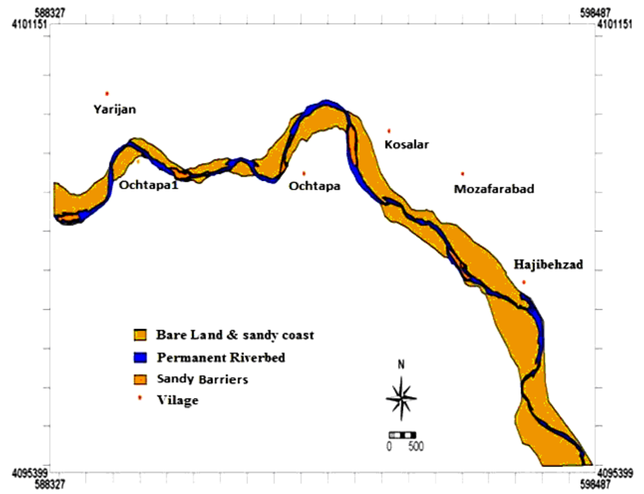

Figure 3: Map of the selected section in 1967.

and turned into agricultural lands and gardens by local residents. In some sections, this encroachment has continued up to the boundaries of the permanent river. In year 2011 the area of the permanent riverbed is lower than in 1996 but is higher than the base year because sand barriers have appeared inside the riverbed. This indicates a reduction in high-volume flood stream which makes the river incapable of full discharge of sediment load. In case of a wet year, these morphological changes and deterioration of dynamic condition of the riverbed can be dangerous and pose a threat to gardens, agricultural lands and village situated around the river.

Figures 2-5 show the maps of the riverbed territory in different time periods. In Figure 2, barren lands and sand coasts cover a significant area. In Figures 3 and 4 the area of these lands has gradually reduced and in Figure 5 this area has been minimized. The morphology of the riverbed has changed as showed from Figures 2-5. Figures 2 and 3 show three large meanders but in Figures 4 and 5 the riverbed is mostly straight. Table 2 shows the changes of meanders in different time periods.

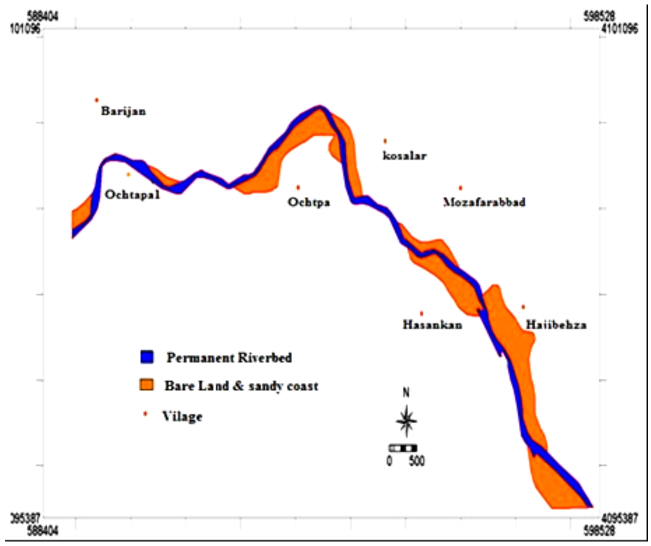

Figure 4: Map of the selected section in 1996.

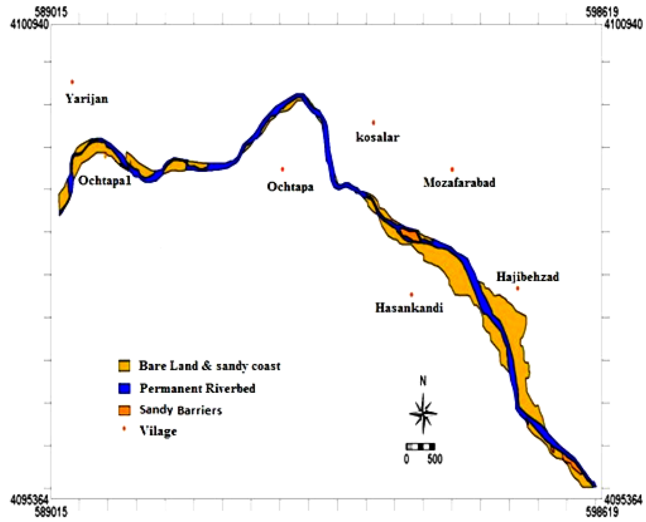

Figure 5: Map of the selected section in 2011.

Land types	Aerial photos (1955)	Aerial photos (1967)	Topographic maps (1996)	Satellites images (2011)
sandy beach	503.66	389.12	218.64	140.78
permanent riverbed	54.83	79.37	108.66	77.68
Sandy Barriers	2.65	13.68	-	2.86
total area	561.14	482.17	327.29	222.33

Table 1: Land types and their area in each information layer.

To better understand the trend of shifts and morphological evolution in the selected section, active riverbed maps pertaining to the base year 1955 is compared with the latest map of year 2011 (Figure 6).

Comparison of the riverbed morphology in 1955 and 2011 shows that at the beginning of the river has gradually transformed from its meander form to more straight, wide and arterial in 2011 as compared to 1955. The greatest shift in the river has occurred in the form of

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elimination of southern meander. According to Figure 6 and Table 2, during the 55 years, the shift and evolution in riverbed and meander form has been obvious. In 1955 (before the construction of dam) the river had four meanders with different sine coefficients which used to give new momentum to the river and increase its water and sediment load capacity. In 1967 the number of meanders increased to 5. In 1996 the number of meanders decreased to 2 and the riverbed became straighter. In 2011 the river has meanders in 3 points. Table 3 presents the details of morphological changes in the riverbed in the selected section.

The most effective factor in morphological evolution of riverbed in the past 5 decades is the accumulation of predominantly fine-grained sediment load in most parts of the riverbed. With the construction of the dam, volume and frequency of flood discharges of Zarrineh-rood River decreased drastically. The significant reduction in flood and the change in hydrological regime of the river have contributed to accumulation of sediment loads in deposition prone areas. In the current circumstances, one of the reasons behind the morphological changes in the studied section is the sedimentation phenomenon and accumulation of sediments inside the riverbed. The emergence of high number of sand barriers and sand beaches inside the riverbed and its surroundings and the creation of arterial riverbed in the upstream sections (in comparison with the base year) are some of the consequences of dam construction and morphological evolution of the riverbed.

Years			
-1955	-1967	-1996	-2011
1.408	1.465	-	-
1.574	1.512	-	-
1.675	1.874	-	1.57
1.06	1.22	1.52	1.54
-	1.48	1.356	1.46

Table 2: The sine coefficients of the Zarrineh-Rood river in different time periods (1955, 1967, 1996 and 2011).

Conclusion

According to the obtained results it can be conclude:

A: Utilization of RS and GIS and acquisition of information layers in different time periods including satellite images, aerial photos and topography maps, are the best tools for determining the trend of river changes, identifying the critical or deposition areas in the riverbed and adopting the river management projects, which can be done with minimum possible time and expenses.

B: By determining the movement trends and identifying the erosion and sedimentation locations, some measures for alleviating the damages of riverbed evolution can be adopted.

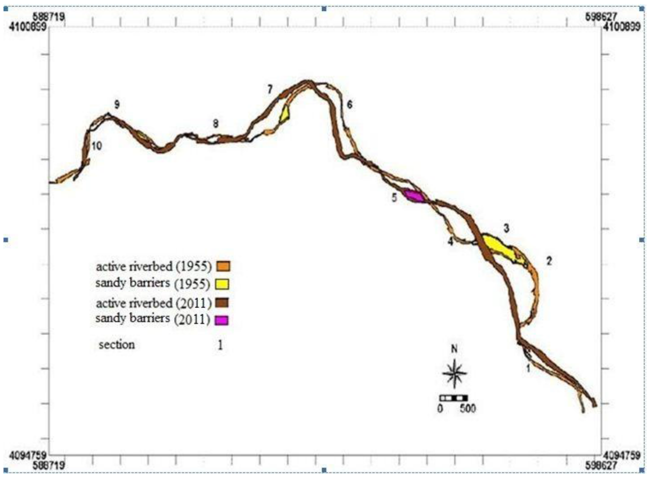

Figure 6: Integration of the active riverbed maps pertaining to the years 1955 and 2011.

Section	Size of shift (m)	Direction of shift	Changes in the time period
1	145	East	Meander's outer arc has been eliminated; riverbed has become arterial
2	450	West	Meander has been eliminated; riverbed has become straighter; permanent riverbed has become wider
3	249	East	meanders have started to form; possibility of local erosion; permanent riverbed has become wider
4	175	South-West	A two-pronged riverbed has appeared; a 400 m long and 80 m wide sand dam has formed, riverbed has become narrower than 1967
5	240	West	Meanders have formed at the beginning of section 5; there has been a 90 degree rotation in the riverbed; possibility of erosion in the curvature location; meander has become more straight
6	307	North	outer arcs of meander have been smoothed; two sand dams inside the riverbed have disappeared
7	90	South	Outer arcs of the forming meander have disappeared; a 300 meters long and 75 meters wide march has appeared; at the end of meander riverbed has become narrower
8	58	North	A meander with a north facing outer arc has appeared ;possibility of further erosion and shift; there has been some deposition in internal section
9	80	South	The riverbed is no longer two-pronged and there has been some deposition in the riverbed.
10	60	West	There has been a 90 degree rotation; riverbed has narrowed from 42 to 29 meters; possibility of erosion

Table 3: Morphological condition of the riverbed during 1955-2011.

C: Deposition plays a central role in morphological changes in the studied sections, so accurate identification of deposition sites and devising a plan to extract these sediments can contribute to better river management.

D: deposition sites are ideal aggregate sources for local residents, and a proper extraction operation can prevent unconventional shift and help stabilize the riverbed.

F: 60% reduction in the riverbed territory from 1955 to 2011 is alarming, and current riverbed with its sedimentation prone conditions will not be able to discharge floods with average and above average return period. In the absence of a solution, this issue will lead to further and more serious problems.

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