Conference Paper, Published Version

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THE RATE OF BANK EROSION OF MEANDERING RIVERS

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The river bank erosion process, due to the importance of its negative impact on river environment and floodplain, was studied along the 82 km. meandering reach of Aras River. The study indicated that, during 45 years, 57 segments of the River bank with a total length of over 39.5 km. have been exposed to erosion. The results indicated that the maximum of areal average erosion rate was 9.3 meter per year, while the areal average of maximum point erosion was 5.5 m/y and the overall mean was 0.9 m/y. The study concluded that, among the erosion factors, the near bank stress was the most pronounced one and its magnitude varied between 8 to 25 pascal.

1. Introduction

The river bank erosion is one of the fluvial-geomorphologic processes with profound and continuous negative impact on river environment and its floodplain. The magnitude and extent of the impact depends on the erosion rates and its location with respect to human activities, capital investment and environmental condition. The destruction of riparian lands and its consequential damage to capital outlays plus sediment production and deposition at downstream reaches are some of the most pronounced impacts.

Although the factors causing bank erosion are limited in numbers however amongst them 2 or 3 factors play the most effective roles. Hydraulic forces which result from current velocity and wave action are the most basic factors in river bank erosion. For most river engineering projects, in general, and for river training projects, in particular, it is imperative to carry out a rather detailed study of erosion mechanism, obtaining a reasonable estimate of magnitude and rate of erosion especially for critical locations.

Erosion control and channel rectification were among the main objectives of the Aras River Project studies. Therefore, prior to embarking on formulation of any project or engineering action, it was required to examine erosion - deposition phenomena within the project area. Owing to availability of mapped information and data, which are not quite often the case, the study of erosion mechanism and spatial distribution of erosion rates along the river reach, was carried out with high level of precision.

2. River characteristics

2.1. Location

The Aras River catchments area and its tributaries are stretched over the territories of Islamic Republic of Iran, Turkey, the Republic of Azerbaijan and Armenia.The river originates from "Bin Kool Dagh" mountains in Turkey and after flowing for hundreds of kilometers in Turkey territory, approaches Armenia, I.R. of Iran and Azerbaijan borders. Then the river leaving the border line and after joining with the Kura River flows into the Caspian Sea at Azerbaijan Republic territory (Fig. 1).

The total length of Aras River is about 1070 km. out of which about less than 50% of its length constitutes Iran and Azerbaijan border. The reach under study along the river length is 82 km. which extends between Iran-Azerbaijan border starting point and Aras storage Dam Lake.

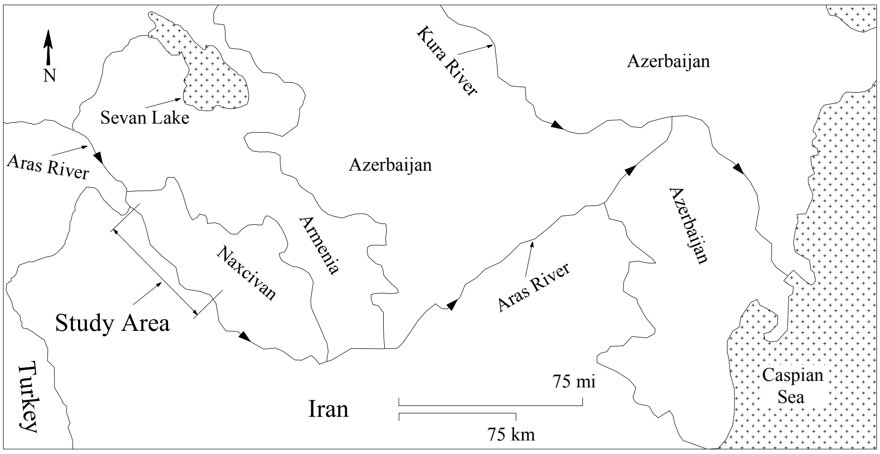

Figure 1: Geographical location of Aras River

2.2. Hydrological characteristics

The catchments area of Aras River is about 102000 square kilometers. Out of which almost 4200 sq. km. (41 percent) lays within the I.R. of Iran territory. The longtime annual average discharge of Aras River at the Aras Dam site is $190\,m^3s^{-1}$. The flood peak discharge at the end of studied reach for 2, 25 and 100 years return period are estimated 700, 1450 and 1900 m^3s^{-1} respectively.

2.3. Geomorphologic characteristics

The Aras River, along its relatively long length, contains all three types of channel patterns, namely straight or sinuous, braided and meandering. However, the Aras River in the reach under study is of meandering pattern with a low sinuosity of 1.5. The longitudinal slope of the reach under study varies between a minimum of 0.00019 and a maximum of 0.00035 and average is 0.00025.The width of cross section of main channel within the reach under study is mostly in 100-150 m range with a varying depth of 3 to 7 meters. The bankfull discharges along this reach are estimated mostly between 350 to 500 m^3s^{-1}.

2.4. Hydraulic characteristics

Based on the results of studies made, the bankfull discharge of the river can be considered to be about 450 m^3s^{-1}. For this discharge which forms the river channel, the average velocity in different sections varies between a minimum of 0.51 m/s to a maximum of 2.06 m/s and a median of close to 1.14 m/s. The hydraulic depth of flow of this discharge in different section varies between 1.82 to 4.55 meters with a median of 3.56 meters.

The available data on sedimentation is limited to sporadic measurements. The suspended loads are mainly composed of silt and clay which its annual discharge at the Aras dam site is reported at 9.15 million tons. The analysis of samples which have been collected during this study, from river bed and river bank indicate that the gradation of bed load is slightly larger than of banks material.

Generally the sediment is composed of sand, silt, small amount of clay and negligible gravel content (table1). The results of samples analysis indicate that the D_{50} of samples varied between 0.03 to 0.18 mm.

Table 1: gradation of sediment samples

parameter	class (percent)				D_{50} (mm)
	gravel	sand	silt	clay	
Mean	trace	62	30	8	0.1
Minimum	0	16	6	0	0.03
Maximum	3	94	70	18	0.18

3. Study of the erosion process

3.1. Theoretical and empirical basis

In practice, when tractive forces resulting from flowing water (eroding forces) exceeds the shear stress of river bed or river bank material (resisting forces), then the erosion process will be initiated. Furthermore, the erosion of riverbank surface materials, often leads to instability of bank profile and its subsequent massive failure. In general, the factors causing erosion are; water current velocity and waves due to wind or boat movement; mechanical factors such as freezing-melting and drying-wetting cycles; direct impact of animal ,human actions and boating strokes; and finally erosion can be caused by surface runoff and seepage which in most cases, water current shear stress $\tau = \gamma RS$ is the most pronounced factor.

Considering, the existing experiences, it is possible to determine the shear stress for canals of trapezoidal cross sections (regular geometry), based on the assumptional of two-dimensional flow. However in rivers and watercourses with irregular cross sections, due to significant effect of secondary current and necessity of three-dimension flow assumption, the determination of shear stress for these conditions is complicated. This complexity is due to the fact that secondary current and irregular cross sections impose a very complicated variation on shear stress. To sum up, the results of theoretical and empirical studies may be briefly concluded as follows:

1. The flow pattern in rivers and watercourses, due to variations in plan shape and cross sections and effects of factors such as pool and riffle is three-dimensional.
2. The maximum values of boundary shear stress occur in three-dimensional flow zones, near to the river bank, where the hydraulic gradient is locally significant. In other words, the maximum values are observed at the base of the outer bank in the meander bend (lane, 1951).
3. The location and rate of bank erosion depend on the frequency of flows, their associated shear stresses, and the critical shear stresses for entrainment of the bank material.
4. In a meandering channel, downwelling (i.e. flow towards the bed) associated with the secondary circulation causes a peak in the boundary shear stresses distribution. Similarly, locally low values occur where secondary circulation produces upwelling (Bathurst, 1979).As the tractive forces, at the vicinity of river bank increases in the flow direction, therefore local erosion of outer bank of meandering rivers occurs during flooding periods. Hence, the ratio of point shear stress to average shear stress has been used by some researcher, for the evaluation of erosion forces. The variation of this ratio is in the 2 to 2.5 ranges, as reported by most of the references. However, higher figures have also been cited in some references.

3.2. The study method

The survey was carried out using topographic maps, aerial photos, satellite imageries, hydrological, morphological and hydraulic study of Aras River as well as some sampling and field measurements.

The existing topographic maps consist of border protocol maps and those maps which have been recently produced for the reach under study. The protocol maps which are to the scale of 1:25000 are based on 1954 aerial photos. In practice, these maps are of larger scale with reasonable accuracy.

The recent maps consist of a set of 1:2000 topographical maps produced in year 1999, covering the complete reach under study. In addition a set of maps produced in 2003 covering the small reach called the upper Qar Qooloogh was also available and used. Therefore, owning to the availability of these maps, a more accurate comparison of the reach under study between different periods has been made possible. Aerial photos were taken in 1966and satellite imageries belong to 1993 and 2002.

The geographic information system (GIS) was the main instrument for this analysis, while some other software were used to process the required information. Therefore, in the first step, all the information and documents collected, including maps, photos and field survey results were transferred into the GIS layers Then, using this system two sets of topo maps of two different period as well as a set of topo maps of upper Qar Qooloogh were compared in details.

The georeferenced satellite imageries and aerial photos were also utilized as auxiliary tools to identify the river changes as well as vegetation and geological conditions. In the meantime, the results of collected field investigations and measurements were also transferred into GIS layers.

Using the data and information built into the GIS and the established criteria, the river bank erosion process and its causing factors were evaluated. In the next step the eroded segments of the river were identified and required measurement were carried out to determine the length and width of erosion between the two periods,. Finally the rest of information about every identified erodible reaches such as longitudinal plan and cross sections, bank materials, vegetation and engineering measures taken were highlighted.

3.3. Conclusions

1. The studies carried out indicate that, during the 45 years period, 57 segments of river bank within the river reach under consideration have been exposed to the erosion process. The total length of eroded segments is 39.543 km., The largest and shortest eroded segments are 3016 and 47 meters accordingly. The highest amount of point lateral erosion measured, for this period, was 420.0 meters, while the second highest was about 200.0 meters, which is hardly close to 50% of the first one. Furthermore, only five successive erosion points' figures were greater than 100 meters. Figure 2 shows river plan (year 1999) and locations of some typical erosion points.
2. Therefore, two cases were considered. Case one with the exceptionally high figure included and case two without it. The summary results of study of erosion amounts and rates are presented in table 2. According to this summary, the maximum rates of point erosion for two cases are 9.3 and 4.4 m/y while the maximum of areal average erosion rates are 5.5 and 2.5 meter per year, accordingly. Finally the average erosion rates of total eroded segments (overall mean) for two cases are 0.9 and 0.8 meters accordingly, which are almost identical.

Table 2: Some statistical parameters of erosion data

Erosion	case	Maximum	Median	Max.of areal means	Mean of total
During 45 years (m)	1	419.1	20.0	246.9	38.9
	2	199.1	20.5	113.9	34.8
Rate (m/year)	1	9.3	0.44	5.5	0.9
	2	4.4	0.46	2.5	0.8

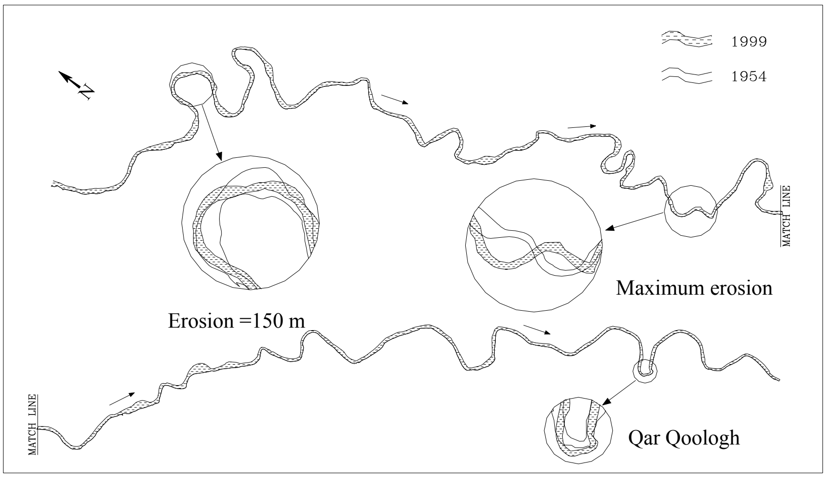

Figure 2: River plan and location of maximum erosion

3. In order to study the variations of erosion process along the river bank, the figures were grouped into six defined erosion rates category. The number of segments, their total lengths and their average erosion rates were calculated and are shown in table3. It may be observed that the largest total erosion length belongs to group 2.

Table 3: classification of erosion rate

Group	Erosion Rate (m/year)	Segments	Total length	Average rate (m/year)
1	0.0-0.25	11	2238.3	0.16
2	0.25-0.5	22	12426.2	0.37
3	0.5-0.75	10	9775.4	0.64
4	0.75-1.0	4	3552.1	0.82
5	1.0-2.0	8	9215.8	1.24
6	2.0-3.0	1	1348.6	2.53

4. The results of study indicated that hydraulic force resulting from water flow or shear stress adjacent to the bank is the main bank erosion factor of the river reach studied. The role of other physical factors is negligible and limited to seepage factor. The effect of human factor is also small and negligible. In total the effect of all other factors have been about few percent of the total factor.

5. The average shear stresses for over 200 river cross sections were calculated, using Hec-Ras software. Then for Those cross sections located at bends, using the river width to curve radius ratios (B/r_c) and utilizing Agostini (1985) empirical formula, the maximum shear stresses was calculated. The results show that shearing stress in outer bends varies between 8 and 25 pascal.

6. It was observed that the maximum rate of point lateral erosion is 9.3 meters per year and the average is 0.9 meters per year. Therefore, it can be concluded that the ratio of maximum to average rate is close to 10 which according to data available in erosion literature may be classified as average to high category.
7. The study indicated that the erosion processes have occurred in all patterns including bends and straight reaches. However, its magnitude in bends has been up to several times of straight ones.
8. Comparison of three sets of maps available for upper Qar qooloogh reach revealed two distinctive point lateral erosion rates of 3.07 and 3.75 meters per year for (1954-1999) and (1999-2003) periods, accordingly.
9. The river dislocation at the point of maximum erosion does not follow the classical erosion process and river lateral movement rules. This phenomenon which may be called as "mirroring" is the result of several factors including local geological conditions. This is a unique phenomenon which deserves further investigations (Fig. 2).

References:

Bathurst, J.C., C.R.Thorne and Hey, R.D. (1979) “Secondary flow and shear stress in rivers bends” J. of Hyd. Eng. ASCE, 105(10), 1277-1295.

Change, H.H.(1988) “Fluvial processes in river engineering .” john Wiley & Sons. New York.

Comes, B.M. (1990) “Identification techniques for bank erosion and failure processes.” Hydraulic Eng. National conference ASCE, San Diego, California, July-Aug. 3, vol. 1:193-197.

Duan, G., L. Li and Sam, S.Y.Wang (1998). “Two dimensional bank erosion model for none cohesive bank material.” In proceeding of water resources engineering 98, Memphis, Tennessee.

Flinthom, T.P. and carling, P.A. (1988) “Prediction of mean bed and wall boundary shear in uniform and compositely rough channels.” In proceedings of international conference on river regime, wallingford, Ed.W.R. white, 267-287, Wiley Chichester.

Simon, A. and Langendoen, E.J. (2003) “Incorporating bank-toe erosion by hydraulic shear into the ARS bank stability model, Missouri river, Eastern Montana.” World water & environmental resources congress 2003 & related symposia.

Leopold, L.B. and Wolman, M.G.(1957) “River channel patterns; Braided, Meandering and Straight.” USGS professional paper 282-B, pp. 45-62.

Nagata, N., T. Hosoda, and Muramoto, Y. (2000). “Numerical analysis of river channel processes with bank erosion.” J. of Hyd. Eng. 126(4), 243-252.

Thorne, C.R.(1982) “Processes and mechanisms of bank erosion in gravel bed rivers”, (Ed.R.D.Hey, J.C.Bathurst and C.R.Thorne), 227-271, Wiley Chichester.