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Effects of Removing Bed Materials on River Flow Velocity

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Abstract

Nowadays, in Parts of Iran, are being used as sand and silt mines, and the removal of river bed materials are performed without studying its effects on hydraulic behavior. On the other hand, the flood plain lands are in danger of floods and bank erosion. Zarem Rood River in Tajan watershed due to removal of river bed material, two planes of before and after removal with scale of 1:1000 has been used as basic data. Using software HEC-RAS, ArcView 3.2 and extension HEC-GeoRAS, the flood zoning with different return periods to investigate water velocity and its changes, geometrical simulation of the bed, sides and flood way of rivers, and then by entering the results of HEC-GeoRAS into hydraulic software HEC-RAS for two before and after planes have been performed, and flow velocity for 3 return periods of 10, 50 and 100 years were analyzed. The results of this research showed that the velocities due to removal for floods with different return periods have increased whereas, water height and level during removal period have decreased.

Key words: ArcView, HEC-GeoRAS, Zaremrood River, Tajan Watershed.

Introduction

Rivers and flood plains are of the main sources of sand and silt and are paid attention by exploiters. Ease of removal of materials from rivers and low costs of its exploitation have made use of mountainous sources and stone parts less expensive. Removal of sand and silt from river has usually tremendous negative effects. Investigations show that one the reason for occurrence of floods and its human and financial damages are the result of measure and non-logical use of the river and bed materials, so use of comprehensive and overall management with the aim of controlled and optimum exploitation in flood hazard regions are necessary[1]. Also, as most economic and social activities are perform in flood plain and regions near the river due to being closer to water resources, so determination of geometric variations and hydraulic behavior of river due to removal bed material are necessary for management of flood plains and reduction of erosion. River hazard was studied by using RS, GIS and software MIKE-11 and HEC-1 with the cross sections of the river in Taleqan Watershed and finally determined the forbidden, conditional and permissible regions for industrial activities including removal of bed sediments and agricultural activities[2]. The role of vegetation and soil conservation and stabilization of Tajan-Harirood river bank was studied[3] using aerial photos of 1955 and satellite images of 1985 and field practices and their combination, assessed the morphological changes in Tajan River and with regression equations found the relationships between bank erosion and the vegetation river affected by soil moisture and found the result that in addition to vegetation, the width of vegetation in river alignment, have effective role on control of river bank erosion and by its increase, the bank erosion decreases and vise versa, so observance of limit of rivers and non-aggression to vegetation of river banks are very effective on bank erosion. The hydraulic behavior of Babolrood River was simulated, using GIS (ArcView 3.2 software) and HEC-RAS software[4]. She also proved that using GIS and HEC-RAS software had a great capability in simulation of bed and flood plain of river and determination of its hydraulic behavior. In studying crisis management and control of effective factors on occurrence of flood in Nekarood Watershed of Mazandaran province, it was found that special morphology of river and hydraulic characteristics, buildings and structures creation in the outskirt of river and aggression limits and bed of rivers and excessive exploitation of river burrow sources are the effective factors of flood occurrence on this watershed[5]. Using GIS and HEC-RAS software the effects of obstacles of river bed on hydraulic behavior was investigated[6]. He concluded that removal of obstacles had good effect on water height reduction and flood hazard. To determine direction and location of flow in the Vyas River, DEM (Digital Elevation Model) was used[7] as basic entry and stated thet DEM can not show the land surface locations with complicated relief and great regions (big areas). So, for geometric simulation of river, Triangulated Irregular Network (TIN) was purposed. HEC-RAS was used for estimation and limits of wetlands along 10 km of Wyoming-Greybull River in the USA and drew water surface profile for this river[8]. The limits of Vader Krick River in Austin, USA, was investigated by combination of two software HEC-RAS and ArcView GIS and found the result that the combination of this two geometric simulation software had a great capability[9]. GIS, could simulate flood plains during flood, based on the flood area, flood depth, duration of flood and damages caused by floods[10]. This method has experimental curves of depth-damage; design for different land use and one can use of a special kind of it in any special location. The most important instruments in HEC-GeoRAS are precision and time-saving in costs of river engineering, especially in great watersheds[11]. In a research called comparison of flow regimes, changes in velocity and Froude Number in two rivers were investigated using HEC-RAS and extention HEC-GeoRAS, and concluded that using HEC-RAS software can give suitable numerical quantities for studying regime and other hydraulic characteristics of river flow to researchers[12]. In a research, a section of Haraz River and its flood plain were simulated (3250 m in upstream of Amol, northern Iran) using Geographical Information System and river topographic maps of 1:500 scales, and then, Flood hydraulic behavior was simulated for different return periods using HEC-RAS software in two cases: existing condition (obstacles existence on canal) and no obstacles (improvement condition), and found that the existence of the obstacles on river canal increases Manning roughness coefficient, the depth and zone of the water, diverts water flow into banks and aggravates bank erosion[13]. Effects of sand and silt removal from Netherland coasts, concluded that the removal from the center of the river, had positive effect on hydraulic behavior of the river due to high concentration of flow in the center of the river[14]. Geometric changes of Maros River with sandy bed was investigating using cross section data series and proved that changes in flow regime on changes of formation of bed are effective[15]. The interaction of river canal to a new hydrological regime in south-western Australia was investigated and proved that field observation showed that canal interaction to hydraulic and hydrological changes in reaches with mild bed slop and sinus reaches due to degradation of vegetation and also to fine texture of bed caused reduction of coefficient of roughness, hence the erosion potential has increased more than locations with higher roughness coefficients[16]. The relationship and ratio of suspended sediment and geometry of canal and area of the region in delta of yellow river in China was investigated[17].

This research was carried out in 3 cross-sections. The results showed that in 2 cross-sections, the relationship between suspended sediment and canal geometry and area of the region was significant and in one cross-section, only the relationship between suspended sediment and geometry of canal was significant but the area of the region had no role.

In Zaremrood River, the excessive removal of bed material caused morphodynamic changes and instability of subsurface bed layers, along with sever side and bed erosion. This research aims are maximum instantaneous discharge rates in different return periods for the region using hydrometric data of Garmrood, simulation of geometry of river bed before and after removal, and comparison of flow velocity variations, roughness and geometry of canal in a 10 year period of removal of the river for the region.

Experimental

Introducing the region under investigation Zaremrood River is located 10 km of south-eastern part of Sari city, Mazandran Province, Iran and is one of 3 main tributaries of Tajan River. The region under study is the end part of Zaremrood and has a length of 5 km. It starts from Ghandikola village and continues up to Ahoodasht Bridge and is located between 53p 12' to 53p 09' eastern longitude and between 36p 26' to 36p 33' northern latitude. The coordinates of the route under study with UTM system are X=696802 and Y=4034022 and coordinates of the end of the route (Ahoodasht Bridege) are X=693686 and Y=4034862 (Fig.1).

Charactristics of hydraulic station used in the study are shown in Table 1.

In this research one-dimentional model of HEC-RAS was used in determination of water surface profile with different return periods. As the base of research is on comparison, so the flow rate with high return period was not consider and three return period of 10, 50 and 100 years were used just for comparison.

HEC-RAS software can not simulate the river and produce the flood zoning maps, by itself. Thus, for modeling of the region and river simulation for comparison of two new and old planes, ArcView GIS and extension HEC-GeoRAS (version 3.1.1), Spatial Analist and 3D Analyst were used. The basic maps had a scale of 1:1000 before and after removal.

To determine maximum instantenous discharge rate with different return periods, after homogenety test of maximum instantenous observed discharge rates during a period of 30 years of Garmrood station, the maximum annual discharge rates with return periods of 10, 50 and 100 years were estimated using Normal, 2 Parameter Log Normal, 3 Parameter Log Normal,

Table 1. characteristic and coordinates of Garmrood River

Name of the river	Name of the station	Geographical location	Height (m)	Year built
Zaremrood	Garmrood	53°09'53"E, 36°36'17"N	175	1981

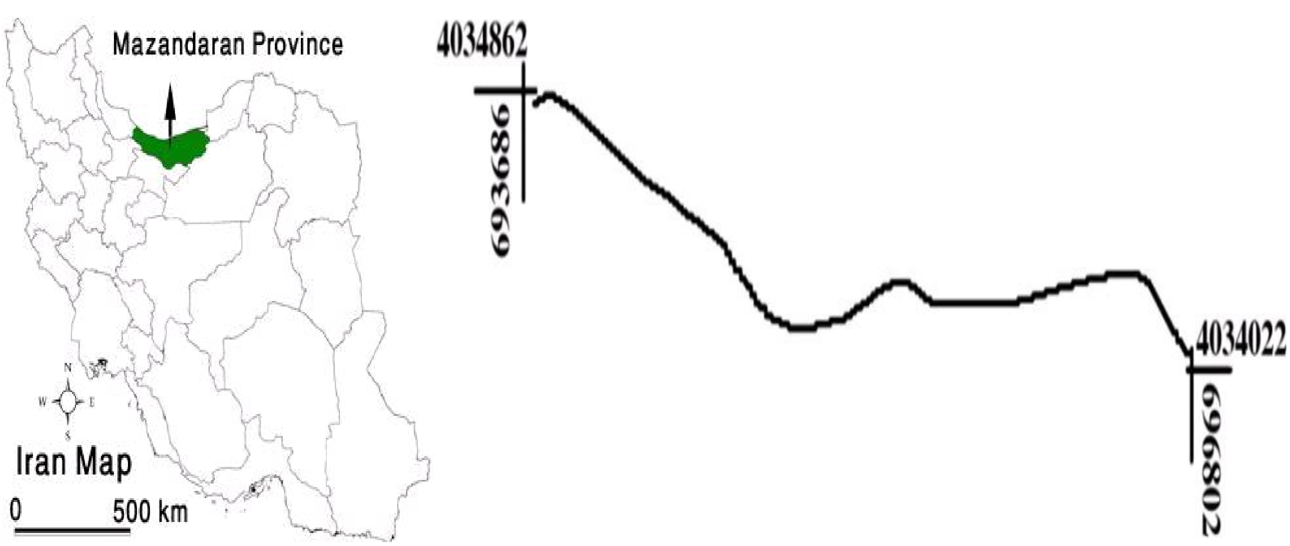

Fig. 1. The route under study of Zaremrood River (UTM coordinate system)

Pearson Type III, Log Pearson Type III, Gumbel Extremal Type I distributions[18], and to obtain this, the SMADA 6.0 software have been used.

The water surface profile was simulated in HEC-RAS using standard step by step method of energy, based on energy equation (equation 1).

$$y_1 + z_1 + \frac{\alpha_1 \times v_1}{2g} = y_2 + z_2 + \frac{\alpha_2 \times v_2}{2g} + H_e + H_f \quad \rightarrow \text{Eq.1}$$

Where:

y_1 and y_2 are water heights in cross-sections, z_1 and z_2 are canal heights of main canal cross-section from datum, $v_2/2g$ is the equivalent of velocity at section 1 and 2, g is acceleration due to gravity, H_e is energy head loss, H_f is friction heah loss, α_1 and α_2 are coefficients of correction of kinetic energy at section 1 and 2.

Head loss (H_e) due to change in cross-section is caculated by equation (2).

$$H_e = C\left|\frac{\alpha_2 \times v_2 - \alpha_1 \times v_1}{2g}\right| \quad \text{Eq. 2}$$

Where:

H_e is head loss due to expansion and contraction of flow, C is the coefficient of expansion and contraction of flow, α is the kinetic energy correction coefficient.

The height of head loss between two cross-sections is equal to sum of friction loss and height of loss due to opening or closing of river calculated by equation (3)[19].

$$H_f = L \times S_f \quad \rightarrow \text{Eq. 3}$$

Where:

H_f is friction loss height, L is the distance between adjacent cross-sections and S_f is the factor of friction.

For flow classification (devided into subcritical, critical and supercridical), the dimensionless Froude number is used (equation 4).

$$F\gamma = \frac{v}{g \times y^{1/2}} \quad \rightarrow \text{Eq. 4}$$

Where:

$F\gamma$ is dimensionless Froude number, v is average velocity (m/s), g is acceleration due to gravity (m/s^2) and y is the flow depth (m).

To determine Manning Roughness coefficient the Cowen method (equation 5) was used. So that, first, by field observations the charactristics of reaches and cross-sections of right bank, left bank and main bed of river are written separately and then the whole region was divided based on morphological charactristics and changes in bed materials and river and bank vegetation into old and new planes, and are numbered by Cowen method.

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)\, m_5 \quad \rightarrow \text{Eq. 5}$$

Where:

n_0 is base coefficient and is selected based on bed material, uniform, soft and straight canal. n_1 n_2 n_3 n_4 and m_5 peresent effects of irregularity of canal surface, changes in shape, size and cross-section, obstacles on the canal route, the effect of vegetation on flow velocity and degree of meandering of canal alignment, respectively.

In the next stage, the TIN layer was obtained as the basis for obtaining requiered for HEC-RAS from digit of 1:1000 maps for before and after removal planes for simulation of bed and flood plains of near river region (Fig. 2), and at the end, the obtained results were compared and analyzed.

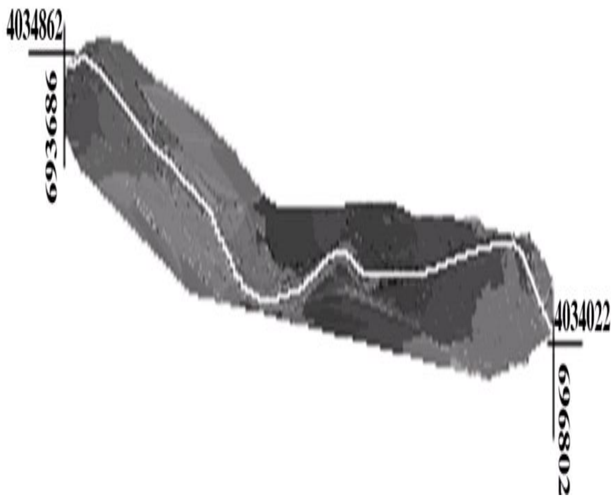

Fig. 2. TIN model of the region under study.

Results

Among different structural distributions used in this research, the Log Pearson Type III distribution had the least difference and highest fitness between observed and estimated values for hydrometric data of Garmrood River station (Fig. 3 and Table 2).

Table 2. Maximum estimated discharge rates for Log Pearson Type III

Return periods (Year)	10	50	100
Discharge rate (m^3/s)	217.41	420.90	525.20

Considering morphological characteristics and bed materials changes and river bank vegetations, the whole region was divided into 30 reaches for new plane and 11 reaches for old planes and were numbered by Cowen method (Table 3 and 4). The simulation results are observed in Figures 4 to 7.

Water flow velocity in reaches and different flows have considerable differences due to changes in cross-section, bed slope and roughness coefficient. Changes in velocity of main canal, left bank and right bank along reaches under study before and after removal, which is one of varied hydraulic factors in 10 year period of removal, and for 3 different return periods are shown in Figures 8 and 9.

Factors which are compared for plane before and after removal include velocity, cross-section and Froude No. in each cross-section of course, the shear stress is also among these comparable parameters which has main role in increase or decrease of bank erosion. Tables 5 to 10 include these factors and the numbers are for each plane and for 12 cross-sections selected in the beginning, middle and end of reaches were compared.

Discussion and Conclusion

Obtained data in Table's 5 to 10 show that in most cross-sections of the river, the velocity and Froude No. during removal increased, but the level of flow at each cross-section, decreased. By increasing Froude number, the flow regime changes from subcritical to supercritical[19].

Table 3. Manning roughness coefficient (n) in 11 reaches of old planes.

Reaches No.	Right bank	Main canal	Left canal	Cross-section No. of each reach
1	0.12	0.13	0.12	1-6
2	0.078	0.088	0.078	7-12
3	0.066	0.076	0.066	13-18
4	0.104	0.114	0.104	19-21
5	0.136	0.146	0.136	22-26
6	0.093	0.103	0.093	27-30
7	0.1	0.12	0.1	31-40
8	0.064	0.074	0.064	41-53
9	0.092	0.102	0.092	54-55
10	0.073	0.083	0.073	56-58

Table 4. Manning roughness coefficient (n) in 30 reaches of new planes

Reaches No.	Right bank	Main canal	Left canal	Cross-section No. of each reach
1	0.07	0.08	0.07	1
2	0.102	0.112	0.102	2
3	0.022	0.032	0.022	3
4	0.055	0.065	0.055	4
5	0.0383	0.0483	0.0383	5-7
6	0.025	0.035	0.025	8
7	0.035	0.045	0.035	9
8	0.045	0.055	0.045	10-11
9	0.04	0.05	0.04	12-14
10	0.064	0.074	0.064	15-17
11	0.08	0.09	0.08	18-20
12	0.055	0.065	0.055	21-23
13	0.052	0.062	0.052	24
14	0.027	0.037	0.027	25
15	0.041	0.051	0.041	26
16	0.065	0.075	0.065	27-30
17	0.0532	0.0632	0.0532	21-38
18	0.08	0.09	0.08	39
19	0.017	0.027	0.017	40
20	0.055	0.065	0.055	41
21	0.042	0.052	0.042	42
22	0.092	0.102	0.092	43-46
23	0.027	0.037	0.027	47-48
24	0.034	0.044	0.034	49
25	0.032	0.042	0.032	50-52
26	0.042	0.052	0.042	53
27	0.065	0.075	0.065	54-56
28	0.088	0.098	0.088	57-58
29	0.022	0.032	0.022	59
30	0.06	0.07	0.06	60

Table 5. Hydraulic results of flow for section 3774.573

Section 3774.573	Discharge rate (m^3/s)	Return period (year)	Velocity (m/s)	Cross-section (m^2)	Froude No.
Plane before removal	60	10	0.78	76.86	0.18
	90	50	0.95	103.97	0.22
	150	100	1.21	141.66	0.26
Plane after removal	60	10	3	20.08	1.01
	90	50	3.23	27.88	1.01
	150	100	3.65	41.13	1.01

Table 6. Hydraulic results of flow for section 3590.879

Section 3590.879	Discharge rate (m^3/s)	Return period (year)	Velocity (m/s)	Cross-section (m^2)	Froude No.
Plane before removal	60	10	0.79	75.58	0.21
	90	50	0.85	119.37	0.19
	150	100	0.83	227.65	0.16
Plane after removal	60	10	3.28	18.31	1.01
	90	50	3.62	24.86	1.01
	150	100	3.78	41.31	1

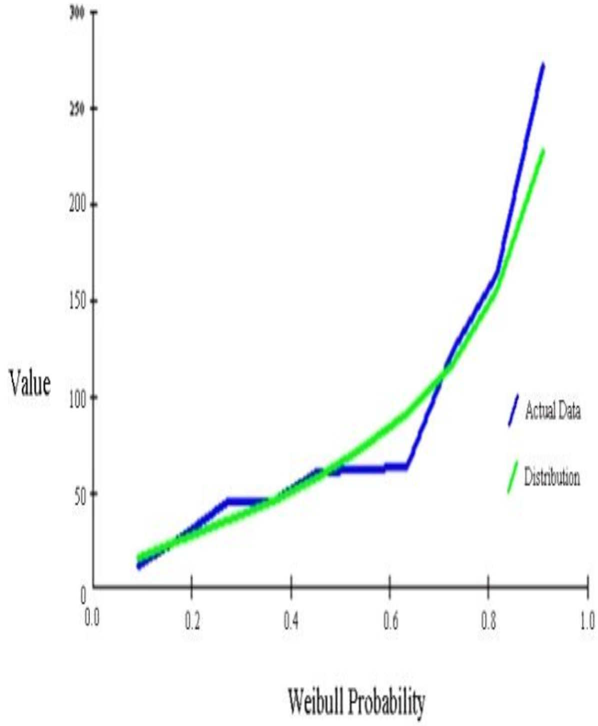

Fig. 3. A curve of fitness of observed and estimated data of Garmrood River station based on statistical distribution of Log Pearson Type III

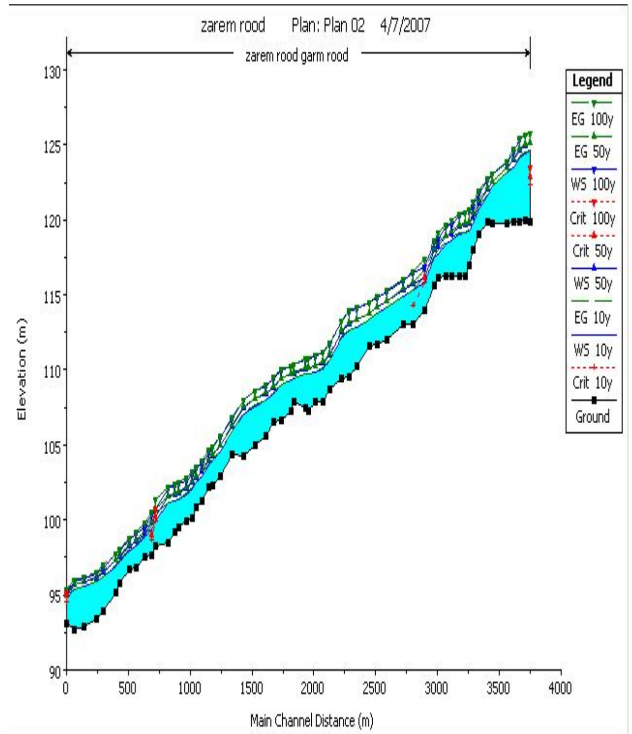

Fig. 5. Water surface profile for 3 return periods of 10, 50 and 100 years; plane before removal

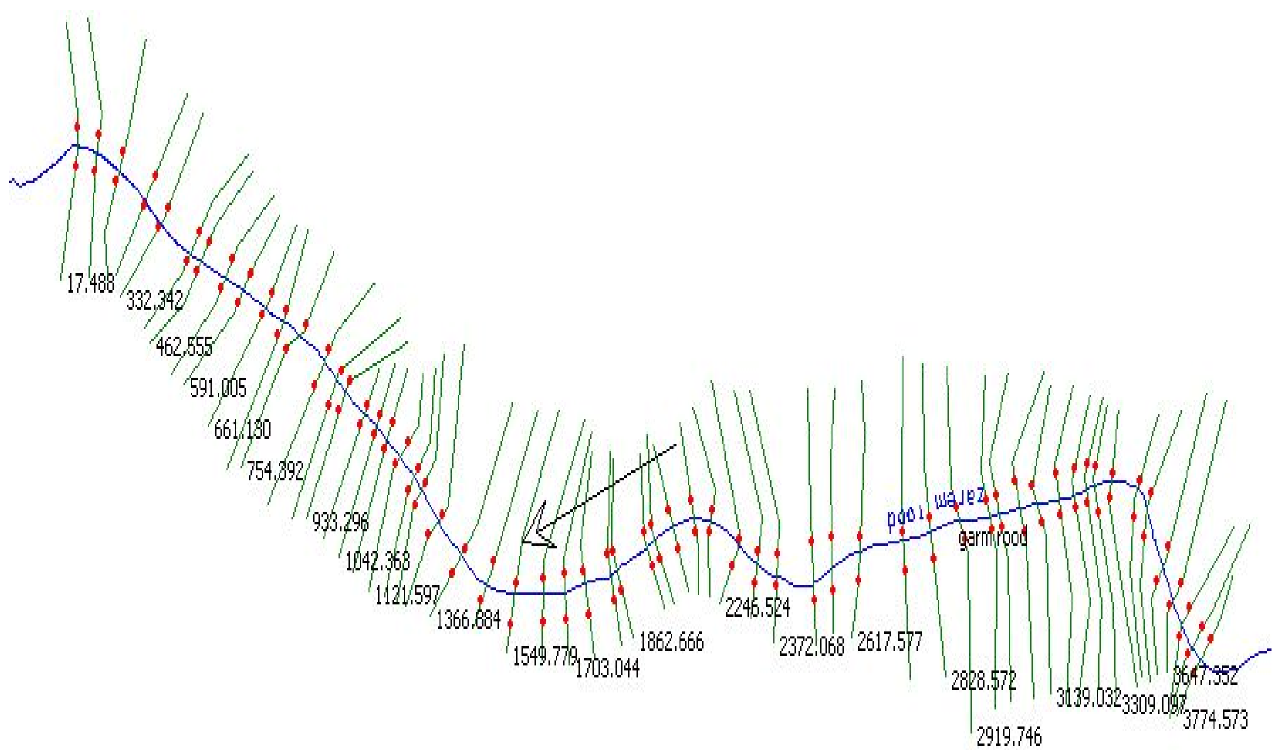

Fig. 4. Zaremrood River and cross-sections, before removal

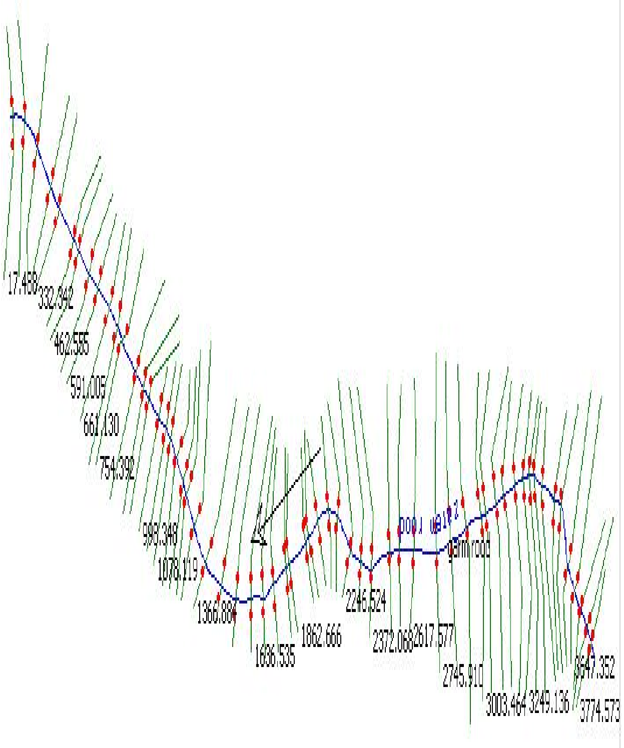

Fig. 6. Zaremrood River and cross-sections, after removal

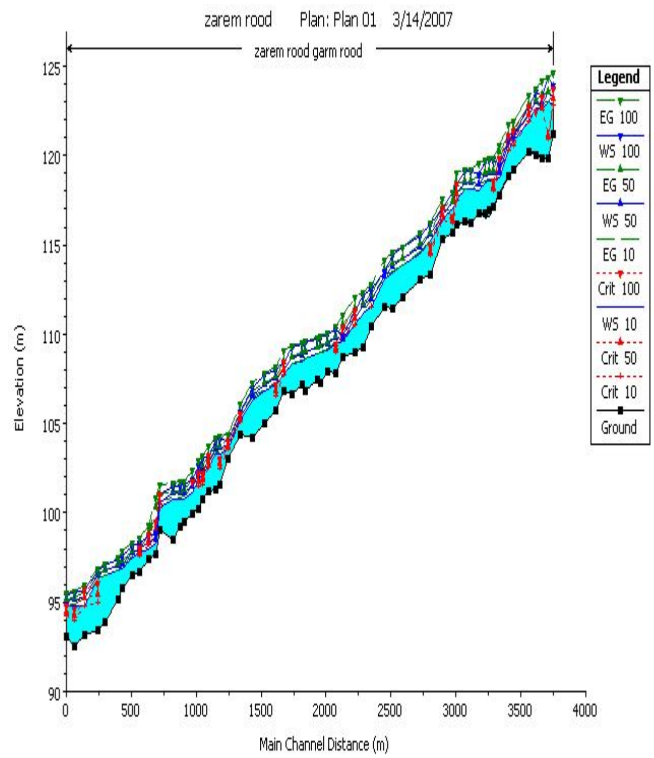

Fig. 7. Water surface profile for 3 return periods of 10, 50 and 100 years; plane after removal

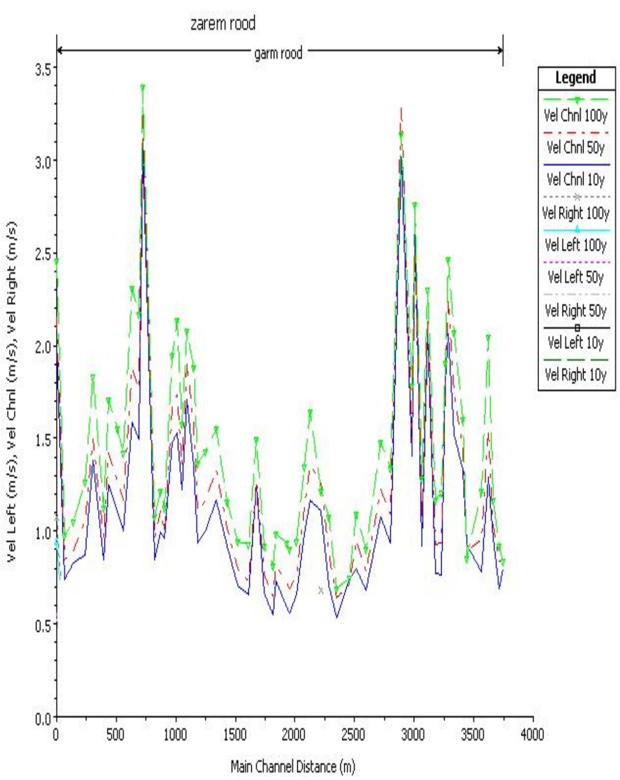

Fig. 8. Water velocity in 3 different return periods, plane after removal

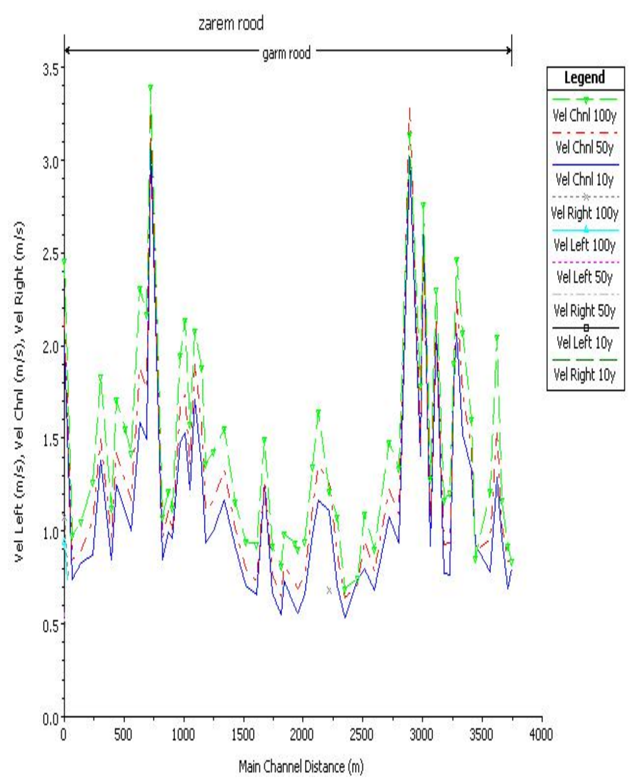

Fig. 9. Water velocity in 3 different return periods, plane after removal

Table 7. Hydraulic results of flow for section 2372.068

Section 2372.068	Discharge rate (m^3/s)	Return period (year)	Velocity (m/s)	Cross-section (m^2)	Froude No.
Plane before	60	10	0.54	111.64	0.12
removal	90	50	0.64	151.36	0.13
	150	100	0.69	262.16	0.13
Plane after	60	10	2.63	22.82	1
removal	90	50	2.25	39.98	0.8
	150	100	2.25	67.48	0.7

Table 8. Hydraulic results of flow for section 2102.441

Section 2102.441	Discharge rate (m^3/s)	Return period (year)	Velocity (m/s)	Cross-section (m^2)	Froude No.
Plane before	60	10	1	60.74	0.27
removal	90	50	1.13	79.80	0.27
	150	100	1.35	111.18	0.27
Plane after	60	10	1.30	46.01	0.40
removal	90	50	1.54	58.43	0.42
	150	100	1.88	79.79	0.45

Table 9. Hydraulic results of flow for section 1636.535

Section 1636.535	Discharge rate (m^3/s)	Return period (year)	Velocity (m/s)	Cross-section (m^2)	Froude No.
Plane before	60	10	0.66	91.37	0.17
removal	90	50	0.73	124.4	0.18
	150	100	0.93	167.04	0.20
Plane after	60	10	1.32	45.3	0.40
removal	90	50	1.47	61.3	0.42
	150	100	1.76	85.0	0.42

Table 10. Hydraulic results of flow for section 661.13

Section 661.13	Discharge rate (m^3/s)	Return period (year)	Velocity (m/s)	Cross-section (m^2)	Froude No.
Plane before	60	10	1.58	37.93	0.50
removal	90	50	1.88	47.93	0.53
	150	100	2.31	64.90	0.57
Plane after	60	10	4.03	14.89	1.98
removal	90	50	3.01	29.87	1.06
	150	100	3.75	39.96	1.15

Also, the slope in each section increased and as it can be observed from tables, the velocity increased as a result, but the level of flow decreased in each section.

Increase in velocity and creation of supercritical conditions, causes different hydraulic jumps along the reach, also increase in shear stress and force in the entrance of the reach, which in turn exerts more force from flow on to unit wet surface and as a result digging of walls and more bank erosion. Parallel to this result, it was concluded that interaction of canal with respect to hydraulic and hydrological changes of reaches with mild bed slope and sinus reaches due to degradation of vegetation and also fine textures of bed causes increase in erosion potential with respect to other reaches[16]. But, on the other hand, based on results obtained in this research, increase in the depth of river main canal was accompanied with flood height decrease during different return periods and removal period from the river. Removal of silt and sand from middle part of river has passive effect on hydraulic behavior of the river due to concentration of water in the middle part[14]. Removal of obstacles also has good effects on water height and flood hazard[6].

One of the main reasons that describe that removal from river under study has no effect on flood and water logging hazard, is presence of high old terraces in the river banks which are close to river in some parts of the region, and prevents development of flood zone in the river bank. Because of these high terraces and presence of regional villages in the bank and upstream of the river, fortunately in high return periods also, these villages are not under flood and water logging and only may have damages for return periods over 100 years. It is obvious that with reduction in water logging, the damage percentage and cost of removing sediments decreases too.

Based on the obtained results, morphology, bed and bank of the river under study and its hydraulic factors, including water velocity for different return periods, show sensible changes which can be related to material removal from rivers and also to behavior and natural changes of river during the time.

In this research, due to area of the studied region and meandering of the river, triangular irregular network (TIN) was used as by[7].

Similar to previous results[9] studying that for geometric simulation of bed and banks of canal, both HEC-RAS and ArcView GIS were used together, the water surface profiles obtained from this research, are good and reliable for next studies from technical and height amount order, and for its drawing hydraulic model of HEC-RAS were used.

Comparing the flow regimes using HEC-RAS and extension HEC-GeoRAS, the variations in velocity and Froude number in the two rivers were investigated[12] and concluded that using software HEC-RAS can give suitable numerical quantities for study of river flow to researchers[20-23]. So, with our result from this present research, we found that where the river has suitable vegetation with respect to other places, the Froude No. was less than 1 and so the flow changed from critical to subcritical one and we could obtain velocity, Froude No. and other hydraulic characteristics using this software and extension HEC-GeoRAS.

Also, due to increase in flow velocity, the probability of bank erosion in the studied reach, in regions with maximum velocity and stress for different return periods were investigated and the results related to flood mean velocity and maximum shear stress showed that due to limitation of river main bed for return period of 10-year and reduction in roughness coefficient of river banks due to vegetation reduction of material removal, the average flood in main bed is may time greater than average flood in the banks.

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