

## Extraction of structural curves, regression relations and structural regression relations in the tidal limit of the Karun River

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### Abstract

The Karun River is the most important tidal river in Iran. Two factors are governing of hydraulic conditions of tidal rivers (fluvial flows and tidal flows). Fluvial flow concerns hydrologic and physiographic conditions of watershed and characteristics of rainfall while tidal flows are produced by gravity of moon and sun, reflection wave from beach, effects of shallow water in estuaries and the shape of beach. Because tidal flows move to upstream and fluvial flows go toward downstream in the tidal limit of the tidal rivers, hydraulic conditions of this part are very complex. The measurement of discharge and velocity of current is impossible in this part. For determination of discharge-stage curve in tidal limit, an especial approach was applied in this research. Structural curves (an especial type of discharge-stage curve) were developed by using of discharge of fluvial flow in the upstream and tidal height in the downstream. For convenience of using of structural curves, these curves converted to regression relations. For determination of correlated water surface elevations to different return periods, structural regression relations were extracted by regression relations, joint probability method and combination coefficient. In this research, four methods made used of determination of combination coefficient. These methods are conventional method, desk study joint probability method, analytic joint probability method and developed analytic joint probability method by researcher. The results of developed analytic joint probability method by researcher have the best fitness by observed data in the Karun River. At the end structural regression relations showed correlated water surface elevation to each combined return period of fluvial flow and tidal flow.

**Keywords:** Iran, Karun River, tidal flow, surface water resource, watershed, hydraulic routing, fluvial flow.

### Introduction

Tidal rivers can be characterized as flat rivers in wide valleys with low slope which would eventually join estuaries or seas. Inundations resulting from combined effects of tidal flows and fluvial floods are the source of potential damages. Therefore, it is important to determine water surface elevations for each design flood accurately. Occurrence of tidal flows and fluvial flows are usually attributed to different sources. Tidal flows, in turn, may be caused by either astronomical or wave effects. Where, astronomical effects are periodic and wave effects is non-periodic. Shallow water variations in rivers and wave reflections from sea are some of the examples of wave effects. Astronomical effects are attributed to the gravity effects of the sun and the moon on the seas. Fluvial flow discharge depends on the amount of rainfall, regime of river (rainfall or snowmelt), intensity and duration of rainfall, shape and vegetation cover of watershed, the concentration time of watershed, slope of watershed and soil materials of watershed.

Hydraulic routing in tidal rivers usually poses as a complex problem. In the tidal rivers, tidal flow moves as a salinity wedge at below of fluvial flow. This wedge moves to upstream in tide while it goes toward downstream in ebb. Because of variation of direction of flow in the different depths and different times, measurement of velocity and discharge of flow is impossible. Preparation of discharge- stage curves is impossible by ordinary

methods. Structural curves can solve this problem. Samuels and Burt (2002) prepared these curves for the mouth of tidal rivers. But they can not extract them for other parts of tidal rivers.

On the other hand, because of interaction between tidal and fluvial flows, determination of design return period and correlated water surface elevation to it are very difficult. In order to obtain representative and optimum results, stochastic approaches should be considered alongside numerical and analytic methods. For design purposes, maximum water surface elevation is estimated for a given event. For determination of maximum water surface elevation in tidal rivers, different combination of return periods of fluvial flows and that of tidal flows have to be considered to establish the representative combined return period of the system. Return periods of two phenomena have to be combined by a suitable combination coefficient. The combination coefficient may be calculated by joint probability method. If combination coefficient is not considered, water surface elevation will be calculated more than actual value and cost of conservation of around lands of tidal river increases.

Many authors have studied the joint probability approach in fluvial flow and tidal flow interaction (Mantz & Wakeling, 1979; Acreman, 1994; Samuels & Burt, 2002). Mantz and Wakeling (1979) developed a formula for combination coefficient but no stochastic method was

utilized. Samuels and Burt (2002) and Acreman (1994) did not make use of the combination coefficient in their studies. Hawkes *et al.* (2002) made use of joint probability method for combination of waves and water levels in coastal engineering. Zhao *et al.* (2007) utilized joint probability method for estimating joint failure probability of series structural systems. Ayyub *et al.* (2009) applied joint probability method for studying of interaction between surges, waves, and precipitations. They made use of this method for evaluation of the performance of a hurricane protection system consisting of a series of basins and sub basins that define the interior drainage characteristics of the system. The protection against flooding was provided by levees, floodwalls, closure gates, and interior drainage system and pumping stations. Juang *et al.* (2008) developed joint probability distribution of  $a_{max}$  (peak ground surface acceleration) and  $M_w$  (moment magnitude of earthquake) can be readily combined with the conditional probability of liquefaction (given a pair of  $a_{max}$  &  $M_w$ ) to obtain the total probability of liquefaction at a given site in a specified exposure time.

Analytical methods or numerical models were used by some researchers to solve the flood routing problem in tidal rivers but, no attention was paid to the combination of tidal surges and river floods return periods. A number of researchers (Parsons, 1918; Pillsbury, 1940; Perroud, 1959; Leblond, 1978; Godin, 1985) made use of analytical solution methods for elementary hydraulic routing in tidal rivers or tidal channels. Also Chuang & Yeh (2008) applied an analytical solution for tidal propagation in a leaky aquifer extending finite distance under the sea.

The advent of computer systems has lead many researchers to establish 1-D models to solve shallow water equations thereby estimating hydrodynamic conditions more accurately. However, due attention has not been placed on the combination aspect of the associated return periods of tidal surges and river floods. Sobey (2001), Sanders *et al.* (2001), Pan *et al.*, (2007), Kuiry *et al.* (2008), Ward *et al.* (2009), Irish and Canizares (2009), Bacopoulos and Hagen (2009) are recent examples of further efforts on numerical approaches to the problem. (Adib, 2008) applied ANNs method for determination of water surface elevation in tidal rivers.

### Materials and methods

In this work water surface elevation is determined by hydraulic routing for different combinations of fluvial and tidal flows. After determination of water surface elevation for different combinations of fluvial and tidal flows, structural curves will be drawn for different cross sections in tidal limit of the tidal rivers. The shape of these curves is similar to shape of discharge-stage curves in non tidal rivers. Because measurement of discharge is impossible in tidal limit of tidal rivers, water surface elevation of cross sections in tidal limit is a function of discharge of fluvial flow in upstream and tidal height in downstream. Tidal

flows can not effect on discharge of fluvial flow in upstream. Then these curves convert to regression relations.

### Structural curves

The results of hydraulic routing need to process. Structural curves are produced by processing of these results. Using of structural curves is easier than hydraulic routing. Necessary time for hydraulic routing is very high and this subject increases cost of determination of water surface elevation by hydraulic routing. But users can use of structural curves very rapidly also using of structural curves does not need to advanced knowledge. These curves can show tidal limit boundary in tidal rivers. These curves can distinguish different combinations of fluvial and tidal flows that produce an especial water surface elevation in considered cross section. These curves show sovereignty of tidal flow in the mouth of tidal rivers. In this part, fluvial flow can not vary water surface elevation. In tidal limit of tidal rivers it is observed that both tidal flows and fluvial flows are sovereignty. Structural curves show that if discharge of fluvial flow is higher than a particular discharge, fluvial flow will become governor other wise tidal flow will become governor. This particular discharge decreases by going toward upstream because a small discharge can overcome to tidal flows in upstream. This discharge is boundary between sovereignty of fluvial flow and sovereignty of tidal flow. By increasing water surface elevation in considered cross section, this discharge increases too. In this case, this discharge moves on bisector of second and forth area of Cartesian coordinate plain. In the other word, if discharge of fluvial flow increases, tidal height must increase in order to it can overcome to fluvial flow.

### Method of preparation of structural curves:

For preparation of structural curves, different fluvial flow hydrographs are exerted in the upstream of tidal river and different tidal height cycles are exerted in the downstream of tidal river. For a particular water surface elevation, different combinations of fluvial flows and tidal flows that can produce this water surface elevation are determined. By connection these combinations in Cartesian coordinate plain, structural curve is drawn for this particular water surface elevation. For drawing of structural curves, a great number of different combinations of fluvial flows and tidal flows are considered. These curves have small perturbations. For practically usage of these curves, they are smoothed in around mean water surface elevations that are produced by different combinations of fluvial flows and tidal flows. For using of these curves, discharge of fluvial flow in upstream and tidal height in downstream must be introduced to structural curve of considered cross section and water surface elevation is extracted by curve.

### Regression relations

Because using of structural curves is with visibility error, it is better that these curves convert to regression relations. The best regression relation was selected by

least square method for each cross section in tidal limit. Regression relation can show water surface elevation based on discharge of fluvial flow in upstream and tidal height in downstream. At each cross section in tidal limit, several regression relations are obtained. Each relation is suitable for a particular limit of discharge of fluvial flow and tidal height.

Different joint probability methods and combination coefficient:

a). In conventional method, design return period is equal to product of return periods of flood and tide. Two states are considered in conventional method. For M years design return period, two states are:

1. M years flood return period and one-year tide return period

2. One year flood return period and M years tide return period

Finally the highest water surface elevation that is produced by one of two states must be considered. In this method, combination coefficient is equal to 1.

b). In desk study joint probability method, contemporary data of fluvial flow and tide are ignored. Combination coefficient is calculated by Eq.1.

$$CC = N / (Q_T + S_T) \quad (1)$$

Where:

CC: Combination coefficient

N: Number of days of a year that floods can occur at them these days is usually between middle of fall and middle of spring.

Q<sub>T</sub>: Duration of flood hydrograph (day).

S<sub>T</sub>: Duration of tide (day).

If tidal river has not observed data sufficiently, it method will show relatively exact results.

c) Pay attention to contemporary data of fluvial flow and tide, combination coefficient is calculated in analytic joint probability method.

For determination of the combination coefficient, this method considers contemporaneous pairs of tide and floods. The numbers of pairs that have at least a member greater than the respective member of the considered pair are then counted. The number of observed pairs is divided by the number of counted pairs. The result is the return period of the considered pair. The product of river flood return period and tide return period in turn is divided by the return period of the pair considered. This implies the combination coefficient for the considered pair. The

average of all combination coefficients is then taken as the representative combination coefficient of the system. Equation2 shows this procedure.

$$CC = Avg\left(\frac{T_Q T_T}{T_{fs}}\right) \quad (2)$$

Where:

T<sub>Q</sub>: Return period of flood (year).

T<sub>T</sub>: Return period of tide (year).

T<sub>fs</sub>: Return period of contemporaneous pairs of flood and tide (year).

This method needs to a large amount of data. Results of this method are more exact than results of desk study joint probability method. But it considers a constant value

for combination coefficient. This subject reduces accuracy of results.

d) A new analytic joint probability method developed by researcher. After determination of combination coefficients of different pairs, a regression relation will be fitted on combination coefficients of pairs. The shape of regression relation is:

$$CC = \alpha (T_Q T_T)^\beta \quad (3)$$

Where:

α, β: are constants.

After determination of combination coefficient, combined return period is determined by Equation 4:

$$T_{QT} = CC * T_Q * T_T \quad (4)$$

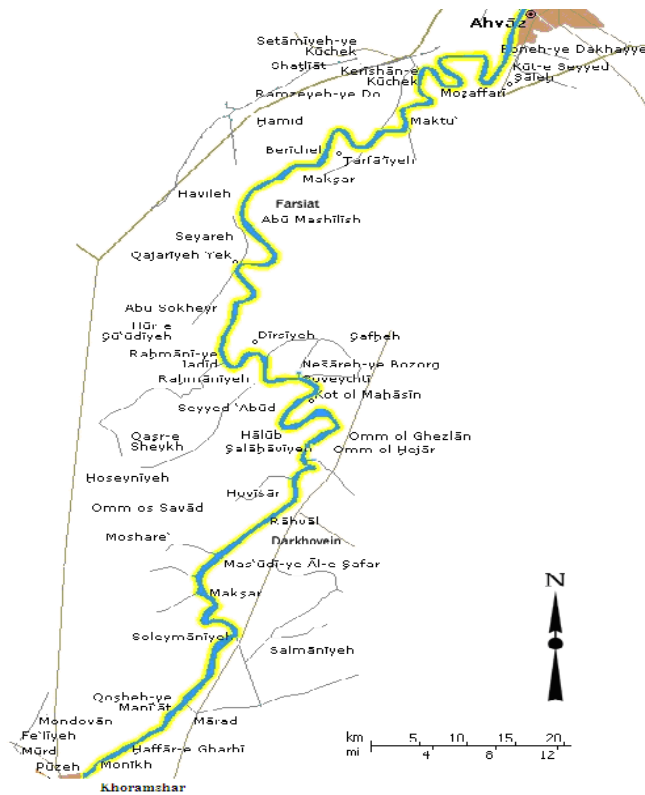
Where:

T<sub>QT</sub>: Combined return period (year).

*Structural regression relations:*

Structural regression relations show relation between water surface elevation and combined return period at each cross section in tidal limit. At first different combinations of tidal heights and fluvial flows that produce considered combined return period are specified. These combinations have to satisfy Eq. 4. Then these combinations are introduced to regression relations. Water surface elevation is extracted for each combination. Maximum water surface elevation of different combinations is distinguished. This maximum water surface elevation is water surface elevation of considered combined return period. At the end, a regression relation will fitted by least square method on different combined return period and their correlated

Fig. 1. Map of the Karun river in Iran



water surface elevation. This relation is structural regression relation of considered cross section.

**The Karun River**

The Karun River is the most important river in Iran. The characteristics of the Karun River are shown at Table 1. Studying reach is between Ahvaz in upstream and three branches of Khoramshar in downstream. The length of the reach is 188.760 km. This reach is shown in Fig.1.

The Karun River has not any tributary in this reach. Floods occur in the Karun River from December to April. Floods that occur from December to February have short durations and high peak flows. These floods are developed by heavy rainfall with duration of ten to fourteen days. Floods that occur in March and April have long durations and low peak flows. These floods were developed by rainfall and snowmelt with duration of seventeen to twenty days. Tidal surges are diurnal in the mouth of the Karun River. The highest tidal heights occur in June and July in the mouth of the Karun River. Floods do not occur in these months. Therefore tidal heights are selected which occur from December to May (WRI, 2000).

Governing stochastic distribution on annual maximum

*Table2. Peak discharges of flood hydrograph for different return periods in the hydrometric station of Ahvaz*

Return period (year)	0.1	0.2	0.4	0.5	1	2	5	10	20	25	50	100
Peak discharge of flood (CMS)	588	1166	1743	1929	2507	2802	3961	4606	5142	5297	5735	6118

*Table3. Tidal elevations for different return periods in three branches of Khoramshar*

Return period (year)	0.1	0.2	0.4	0.5	1	2	5	10	20	25	50	100
Tidal elevation (m)	2.73	2.84	2.94	2.98	3.09	3.18	3.35	3.46	3.56	3.6	3.7	3.8

discharges is log person III distribution in the hydrometric station of Ahvaz. Governing regression relation for return periods less than 1 year is:

$$Q_p = 2506.97485 + 833.23163 \ln T_Q \quad (5)$$

Where:

$Q_p$ : Peak discharge of flood hydrograph (CMS)

For different return periods, discharges of peak flow are shown in Table 2.

Governing stochastic distribution on annual maximum tidal elevation is Gumbel distribution in three branches of Khoramshar. Governing regression relation for return periods less than 1 year is:

$$HT_M = 3.08776 + 0.15699 \ln T_T \quad (6)$$

Where:

$HT_M$ : Maximum tidal elevation (m)

For different return periods, tidal elevations are shown in Table 3.

Manning's coefficient is from 0.022 to 0.03 in this reach. These values are determined by observed data in Salmaniyeh and Darkhovein. Darkhovein is 135 Km from the hydrometric station of Ahvaz and Salmaniyeh is at 160 Km

*Table1. The characteristics of the Karun river (given from reports of water research institute of iran (WRI)*

Source	Zardkooh baktiary mountain
Mouth	Arvandrod river
Length	890 km
Width	250-900 m
No. of tributaries	6
Area of watershed	66930 km <sup>2</sup>
No. of constructed dams	2

distance to the hydrometric station of Ahvaz.

**Results**

Several structural curves are shown in Fig. 2 to 7 for a number of cross sections in tidal limit of the Karun River. Regression relations of these cross sections are shown (Table 4 to 11) at follow:  
 $H = HT$  (Regression relation in 187.746 Km from the hydrometric station of Ahvaz) (7)

Where:

H: water surface elevation (m)

HT: Tidal height in the mouth of tidal river (m)

Q: Discharge of fluvial flow in upstream (CMS)

For determination of combination coefficient in the Karun River, four joint probability methods are considered.

a) Conventional method:  $CC = 1$ .

b) Desk study joint probability method:

For determination of combination coefficient in this method, it makes used of Equation1.

The values of parameters of this equation are:

$N = 120$  days (January, February, March and April),  $Q_T = 19$  days and  $S_T = 1$  day therefore  $CC = 6$ .

c) Analytic joint probability method:

114 contemporaneous pairs of tidal elevations and fluvial flows are studied for the determination of combination

coefficient. A number of these pairs are shown in Table 9. Average and variance of combination coefficient are 4.31

*Table 4. Regression relation in 178.1065 Km from the hydrometric station of Ahvaz*

HT(m)	Q(CMS)	H(m)	Q(CMS)	H(m)
0-1.25	0-2000	HT	2000-4500	$Q/4500 + HT/1.62$
1.25-1.75	0-4500	HT	4500-5000	$Q/3333.333 + HT/3.8$
1.75-2.25	0-5000	HT	5000-5500	$Q/2750 + HT/5.5$
2.25-2.75	0-5500	HT	5500-6000	$Q/2400 + HT/6.96f$
2.75-3.25	0-6000	HT		
3.25-3.75	0-6000	HT		

*Table 5. Regression relation in 168.4277 Km from the hydrometric station of Ahvaz*

HT(m)	Q(CMS)	H(m)	Q(CMS)	H(m)
0-1.25	0-1000	HT	1000-2000	$Q/2000 + HT/1.8$
1.25-1.75	0-2000	HT	2000-2500	$Q/1666.667 + HT/3.299997$
1.75-2.25	0-2500	HT	2500-3000	$Q/1500 + HT/3.9$
2.25-2.75	0-3000	HT	3000-3500	$Q/1400 + HT/4.704$
2.75-3.25	0-3500	HT	3500-4000	$Q/1333.333 + HT/5.68$
3.25-3.75	0-4000	HT	4000-4500	$Q/1285.714 + HT/6.685726$
3.75-4.25	0-4500	HT	4500-5000	$Q/1250 + HT/7.75$
4.25-4.75	0-5000	HT	5000-6000	$Q/1333.333 + HT/6$

Fig. 2. Structural curve in 187.746 Km from the hydrometric station of Ahvaz

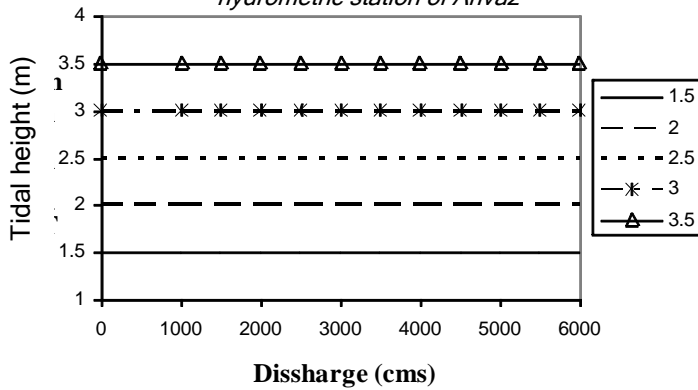


Fig. 3. Structural curve in 178.1065 Km from the hydrometric station of Ahvaz

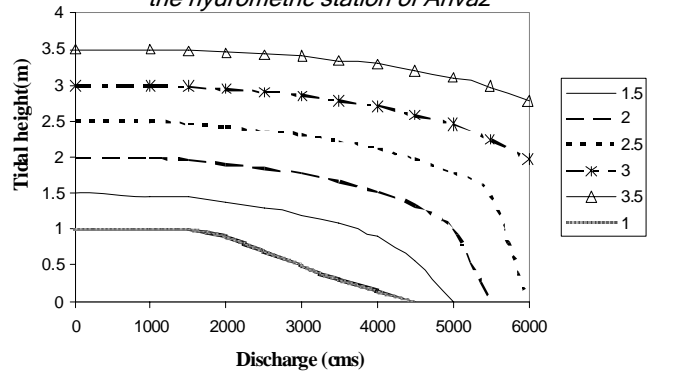


Fig. 4. Structural curve in 168.4277 Km from the hydrometric station of Ahvaz

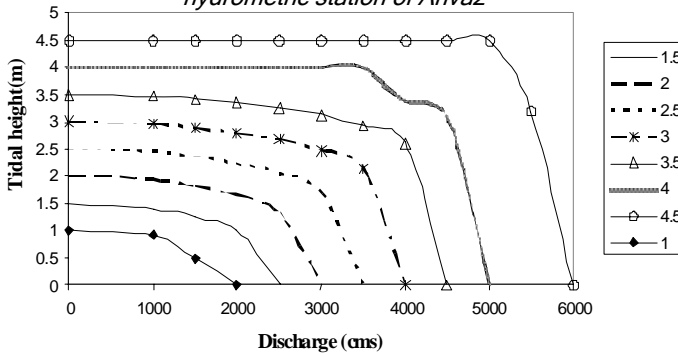


Fig. 5. Structural curve in 160.8809 Km from the hydrometric station of Ahvaz (Salmaniyeh)

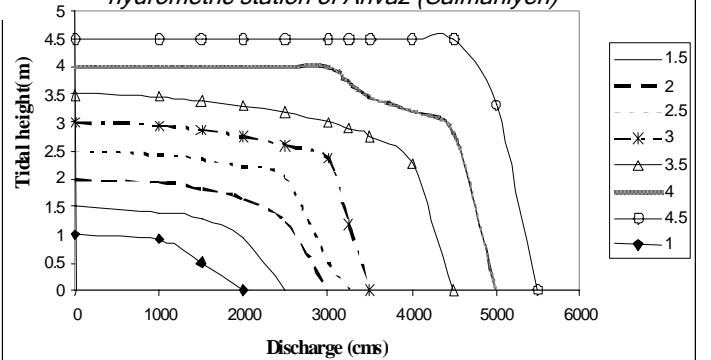


Fig. 6. Structural curve in 151.5372 Km from the hydrometric station of Ahvaz

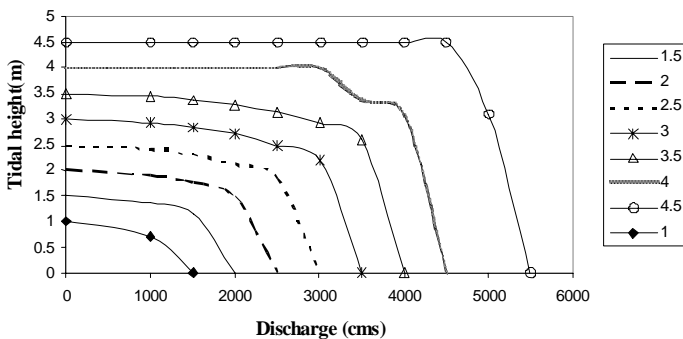


Fig. 7. Structural curve in 135.0325 Km from the hydrometric station of Ahvaz (Darkhovein)

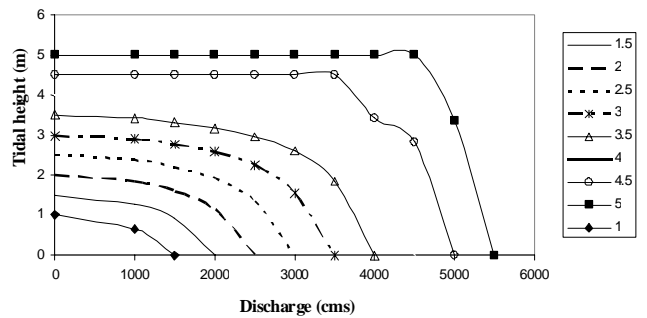


Fig. 8. Comparison between observed data & results of four methods in the Salmaniyeh

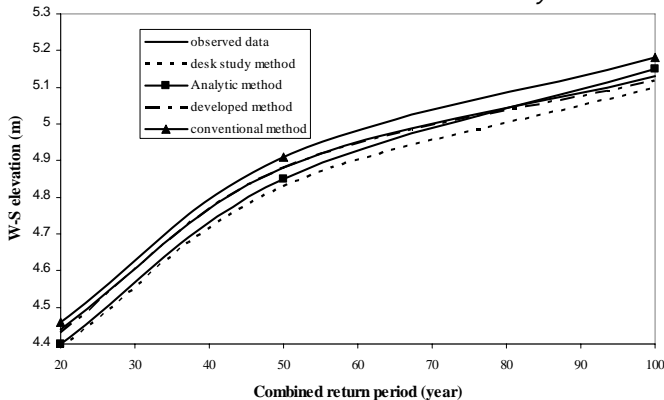


Fig. 9. Comparison between observed data & results of four methods in the Darkhovein

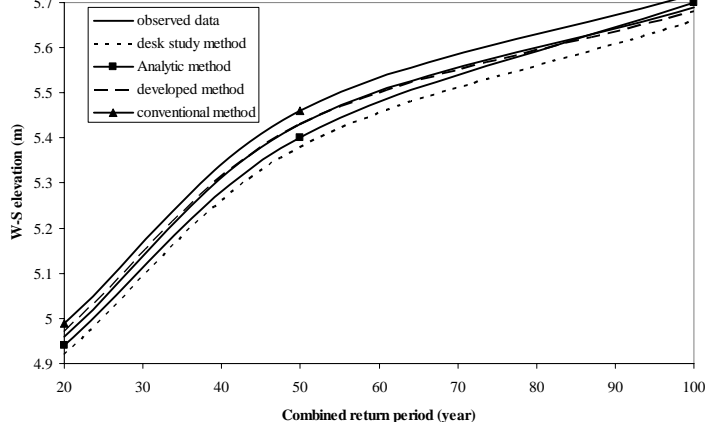


Table 6. Regression relation in 160.8809 Km from the hydrometric station of Ahvaz (Salmaniyeh)

HT(m)	Q(CMS)	H(m)	Q(CMS)	H(m)
0-1.25	0-1000	HT	1000-2000	Q/2000+HT/1.8
1.25-1.75	0-2000	HT	2000-2500	Q/1666.667+HT/3.199997
1.75-2.25	0-2500	HT	2500-3000	Q/1500+HT/3.66
2.25-2.75	0-2500	HT	2500-3250	Q/1300+HT/3.449333
2.75-3.25	0-3000	HT	3000-3500	Q/1166.667+HT/5.506657
3.25-3.75	0-4000	HT	4000-4500	Q/1285.714+HT/5.837153
3.75-4.25	0-4500	HT	4500-5000	Q/1250+HT/7
4.25-4.75	0-4500	HT	4500-5500	Q/1222.222+HT/5.5

Table 7. Regression relation in 151.5372 Km from the hydrometric station of Ahvaz

HT(m)	Q(CMS)	H(m)	Q(CMS)	H(m)
0-1.25	0-1000	HT	1000-1500	Q/1500+HT/2.1
1.25-1.75	0-1500	HT	1500-2000	Q/1333.333+HT/3.04
1.75-2.25	0-2000	HT	2000-2500	Q/1250+HT/3.675
2.25-2.75	0-2500	HT	2500-3000	Q/1200+HT/4.368
2.75-3.25	0-3000	HT	3000-3500	Q/1166.667+HT/5.086658
3.25-3.75	0-3500	HT	3500-4000	Q/1142.857+HT/5.942857
3.75-4.25	0-4000	HT	4000-4500	Q/1125+HT/6.9075
4.25-4.75	0-4500	HT	4500-5500	Q/1222.222+HT/5.5

Table 8. Regression relation in 135.0325 Km from the hydrometric station of Ahvaz (Darkhovein)

HT(m)	Q(CMS)	H(m)	Q(CMS)	H(m)
0-1.25	0-1000	HT	1000-1500	Q/1500+HT/1.95
1.25-1.75	0-1250	HT	1250-2000	Q/1333.333+HT/2.426668
1.75-2.25	0-1750	HT	1750-2500	Q/1250+HT/2.825
2.25-2.75	0-2000	HT	2000-3000	Q/1200+HT/3.216
2.75-3.25	0-2500	HT	2500-3500	Q/1166.667+HT/3.61666
3.25-3.75	0-3000	HT	3000-4000	Q/1142.857+HT/4.228575
3.75-4.25	0-3250	HT	3250-4500	Q/1125+HT/5.175
4.25-4.75	0-3500	HT	3500-5000	Q/1111.111+HT/6.288889
4.75-5.25	0-4000	HT	4000-5500	Q/1100+HT/7.436

Table 9. A number of contemporaneous pairs of tidal elevations and fluvial flows in the Karun River and their combination coefficient

Discharge of fluvial flow in upstream (CMS)	Tidal elevation in the mouth of river (m)	Combination coefficient
807	2.6	2.53
4555	3.1	0.16
495	3.2	3.68
3162	2.7	0.62
4000	3	0.24
4986	3	0.04
557	3.3	2.75
3016	3.3	2.88

and 1.42 respectively. Correlation coefficient between tidal heights and fluvial flows is -0.042. Therefore CC=4.31 in this method.

d) Analytic joint probability method developed by

Table 10. Combination coefficient of different combined return period in analytic joint probability method developed by researcher

Combined return period (year)	2	5	10	20	25	50	100
Combination coefficient	1.002857	1.471789	1.967336	2.629732	2.887254	3.859383	5.158825

researcher:

In this method for determination of combination coefficient, it made used of Equation 8.

$$CC=0.61*(T_Q T_T)^{0.7202} \quad (8)$$

In this method, combination coefficient varies for different combined return period. This subject is shown in Table 10.

Comparison between the results of four methods and observed data is shown in Fig. 8 & 9 for Salmaniyeh and Darkhovein.

Based on Fig. 8 & 9, the results of analytic joint probability method developed by researcher have the best fitness with observed data. Therefore structural regression relations are prepared by results of analytic joint probability method developed by researcher. These relations are shown in Table 11 for a number of cross sections in tidal limit of the Karun River.

**Conclusion**

In this research, these types curve and relation were extracted. These curves and relations are useful tools for determination water surface elevation in the tidal rivers. They help to engineers and designer for improving their designs in river engineering. Structural curves and regression relations show water surface elevation as a function of discharge of fluvial flow in upstream and tidal height in the mouth of tidal river. In addition, structural curves and regression relations can show the boundary of the tidal limit in tidal rivers. For example, they show that the boundary of the tidal limit in the Karun River is Darkhovein. While structural regression relations show it as a function of combined return period. For design hydraulic structures that their design needs to a particular return period, structural regression relations will become very necessary. In this research, it was shown that analytic joint probability method developed by researcher has the best fitness with observed data. Because this method can vary combination coefficient based on variations of combined return period. But other methods have not this ability and they considered combination coefficient as a constant. Combination coefficient shows return period of simultaneity of tidal height and fluvial flow. This return period varies in different conditions and it should not consider a constant value. For each combined return period, engineers can apply analytic joint probability method developed by researcher for determination of maximum salinity concentration and maximum sediment concentration in the different sections of the tidal rivers. By using of analytic joint probability method developed by researcher and separation of tidal flow and fluvial flow,

researchers can distinguish maximum ebb velocity and maximum tide velocity for different combined return periods.

Table 11. Structural regression relations for a number of cross sections in tidal limit of the Karun River

Distance from hydrometric station of Ahvaz (km)	Structural regression relation
187.746	$H=0.157Ln(T_{QT})+3.0878$
184.525	$H=0.1517Ln(T_{QT})+3.1182$
183.1165	$H=0.1393Ln(T_{QT})+3.1752$
181.6565	$H=0.1374Ln(T_{QT})+3.1819$
178.1065	$H=0.1372Ln(T_{QT})+3.1853$
172.4607	$H=0.3411Ln(T_{QT})+3.1164$
168.4277	$H=0.3649Ln(T_{QT})+3.1591$
161.7029	$H=0.3807Ln(T_{QT})+3.1613$
160.8809 (Salmaniyeh)	$H=0.4126Ln(T_{QT})+3.1959$
155.4191	$H=0.4067Ln(T_{QT})+3.2281$
151.5372	$H=0.409Ln(T_{QT})+3.2916$
139.7234	$H=0.4435Ln(T_{QT})+3.3577$
135.0325 (Darkhovein)	$H=0.4914Ln(T_{QT})+3.4482$
129.4277	$H=0.4955Ln(T_{QT})+3.5413$

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