Estimation Of Average Suspended Sediment Concentration In A Flow Depth By One Sample

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Abstract

In this research, an attempt has been made to have full understanding about the nature of the sediment in the flow. Due to the difficulties during flood periods, the attention was focused on the shortcut methods to measure the average sediment concentration in the water column. These methods use limited number of water samples. Two groups of data have been utilized. The first group covers the field work in Tigris River at Sarai site and middle Euphrates canals. The second group is outside Iraq which covers Missouri River in Montana. The data of the first group has been used for analysis of Imara's semi-empirical equation for the measurement of the average concentration in the water column. In this equation, an empirical constant, (a), was given a value of ***(10)*** in estimating the sediment load in the tributaries of Adhaim River. A uniformity index was suggested, to analysis the vertical distribution of different kinds of sediment, and then uniformity index for different kinds of sediment was calculated for Missouri river in the second group of data. The value of the empirical constant, (a) varied between ***(7.2)*** and ***(11.65)*** with an average value of ***(9.4)*** for group one data compared with the value of ***(10)*** used for the tributaries of Adhaim River. This value was accepted with a significance level ***(α = 0.05)***. The uniformity index gave a value close to ***(1.0)*** for clay and silt, and a value between ***(1.5)*** and ***(2.5)*** for sand depending on the sand's grain size.

"تخمين معدل تركيز الرسوبيات العالقة في عمق الجريان من عينة واحدة"

تم في هذا البحث محاولة لمعرفة طبيعة الرسوبيات في الجريان. لقد تم التركيز على الطرق السريعة المعتمدة على قراءات محدودة لقياس معدل تركيز الرسوبيات في العمود المائي نظراً للظروف الصعبة أثناء الفيضان. استخدم نوعان من مجاميع البيانات ، المجموعة الأولى شملت الأعمال الحقلية التي جرت على نهر دجلة في محطة السراي و قنوات ري تقع في الفرات الأوسط. أما المجموعة الثانية فقد شملت بيانات تخص نهر الميسوري في مونتانا. استخدمت كل من هذه البيانات في تحليل المعادلة شبه الوضعية المقدمة من قبل عمارة لقياس معدل تركيز الرسوبيات في العمود المائي. في هذه المعادلة يوجد ثابت وضعي (a) الذي أعطي قيمة (10) في استخدامات تخمين حمل الرسوبيات في فروع نهر العظيم. لقد اقترح مؤشر الانتظامية في تحليل التوزيع العمودي لهذه الترب و على هذا الأساس حسب هذا المؤشر في التربة النموذجية. . لقد اتضح بأن قيمة(a) تغيرت بين (7.2) و (11.65) مع معدل

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قيمة لها بلغ (9.4) بالنسبة لبيانات المجموعة الأولى بالمقارنة مع القيمة (10) التي استخدمت في فروع نهر العظيم. إحصائياً قبلت هذه القيمة بمستوى دلالة $(a = 0.05)$. أما مؤشر الانتظامية فقد أعطى قيمة مقاربة إلى (1.0) إلى الطين والغرين و قيمة بين (1.5) و (2.5) للرمل حسب حجم حبيبات الرمل.

1- Introduction

Water samples are taken from open channel flow for many reasons. One important reason is to measure the sediment concentration for suspended load. This measurement has many significant applications, one of them, is the decision of the economical life of the reservoir behind a dam. During the rainstorm, streams usually carry heavy sediment load especially at the peak discharge. Since they have high flow, the lateral sediment concentration gradient becomes negligible and the main variation is in the vertical direction. During the storm time, it is usually very difficult to take several samples in any water column. In this case, one or two samples are taken to estimate the average concentration in the column.

(Imara, 1997) used the decay function for the variation of sediment concentration and logarithmic distribution for velocity variation. By using integration and field experience, he suggested the following semi-empirical equation to find the average sediment concentration in the water column:

$$\frac{\bar{c}}{c_b} = \frac{a\,e^{b(d-b)}}{d}\left[1 - \frac{1}{e^{bd}}\right] \text{ ---------- (1)}$$

Where:

(c_b) is the concentration at depth (b) from the water surface, (d) is the depth of the column and (a) is an empirical constant equal to (10) based on Imara field experience.

The concentration measurements during high flows contribute the major amount of sediment accumulated in the reservoir behind a dam. The process of sedimentation of the reservoir decides the economical life time of the dam. There are two methods for the selection of sampling, the depth integrating sampling and point-integrating sampling. Analysis for wide range of data showed that measurements between (0.6) and (0.8) times the depth gave reasonable accuracy.

As the sediment gets coarser, the level of the measurement gets closer to (0.8) times the depth. It should be indicated that the level of measurement to give the average concentration in the vertical, is a function of flow, sediment characteristics, and fluid condition. Since these variables are highly varying, it is not expected to get reliable (or very accurate) mean concentration from using one-point method, for sediment investigation which requires this accuracy.

Based on sediment investigation in the Missouri River system, (Straub, 1935) showed that the mean concentration of suspended sediment in vertical is given by:

$$\overline{c_s} = \left[\frac{3}{8}c_{0.2d} + \frac{5}{8}c_{0.8d}\right] \text{----------- (2)}$$

Where: - $c_{0.2d}$ and $c_{0.8d}$ are sample concentrations taken at (0.2) depth and (0.8) depth below the water surface, respectively.

This method does not give a correct idea about the size distribution of the suspended load, but gives accurate results over a considerable range of conditions (Grade et al, 1985) (Simons et al, 1977).

Due to the difficulties in using the above methods specially during the flood periods, more practical and conventional method has been suggested. Using logarithmic distribution for velocity variation and decay function for the variation of sediment concentration, Imara (1997) suggested equation (1).

Imara gave a value of 10 to the empirical constant (a) and used this equation to find the average concentration in the tributaries of Adhaim River during flood season. This method does not require a skilled person since the sample can be taken at any depth (b). For convenience and easiness, the depth (d) is taken at 10 cm or 20 cm from the surface.

In this research the attention is focused on the value of (a). Available field work will be utilized to have estimation for this constant.

2- Objectives:

The objectives of this research can be outlined as follows:

1. Making some understanding of the nature of the sediment and the parameters which affect its concentration in open channel flow.
2. Review and discuss all shortcut methods for the measurement of concentration in the water column.
3. Utilizing the available field data to analysis and discuss the constant (a) in Imara Simi-Empirical equation.

3- Available Field Data

The available field data can be divided into two main groups, field works in Iraqi rivers and field work outside Iraq.

3.1- Field Data in Iraq

The field data in Iraq was made on Tigris River at Sarai gaging station in

Baghdad, The available data for the water years 1965 and 1966 are obtained from the files recorded by the dams and reservoir general (2004), as shown in Table(1). The definition sketch of Tigris River at sarai gaging station is shown in Figure (1).

The second field work in Iraq was made on several canals which take their water from Euphrates River as shown in Figure (2). These canals can be divided into two sets, one is taken by (Saman, 1973) and the other is taken by (Mohammed, 1984). All the information about these canals, like name, hydraulic measurements and concentration are illustrated in Table(2) and Figure(3) for data of (Saman, 1973) and Table(3) and Figure(4) for data of (Mohammed,1984).

3.2- Field Data Outside Iraq

The field data outside Iraq is based on different variations of concentration with depth according to sediment grain size. The data are consisted of two groups, A and B. For group A, data are selected from Figure (5) for typical River, and group B data are selected from figure (6) for Missouri River.

4- Estimating the Empirical Constant (a)

Imara's equation is a semi-empirical equation which was obtained by assuming a decay function for the vertical distribution of the sediment. This equation was used to estimate the volume of sediment in the runoff of Adhaim branches after giving a value of (10) for the constant (a). In equation (1) the convenience of using this equation comes from using one value of the concentration in the column where it is difficult to take many samples in the stream cross-section. In using the above equation for Adhaim River branches, all samples were taken at (10) centimeter from the surface for any column. So, this equation was written in the following form: -

$$\frac{\bar{c}}{c_b} = \frac{a\,e^{0.1(d-0.1)}}{d}\left[1-\frac{1}{e^{0.1d}}\right] \quad \text{---- (3)}$$

This form of the equation is used in testing the empirical constant (a) with the available data. Table (4) shows that the value of (a) in Iraqi rivers and canals varies from (6.7) to (12.87). All the previous data were fitted with exponential type curve as shown in figures (7) and (8).

Typical concentration contours was made to check the logical distribution of this concentration in the cross-section. This typical distribution is shown in figure (9), (10) and (11). These contours show typical variation of concentration with depth as expected, i.e. the concentration increases with depth.

5- The Distribution Of The Concentration

The vertical distribution of the sediment concentration is known to vary exponentially. However, as the sediment becomes fine in grain size, this distribution gets closer to the uniform type. To get better understanding for distribution of several type of sediment, an index is proposed in this research to express the closeness of the distribution to the uniformity.

The uniformity index for concentration distribution is proposed to have the following form:-

$$u_i = \frac{\int^{A} (c)^2 dy}{\bar{c} \int^{A} (c) dy} \text{ ---------- } \quad (4)$$

Where: (c) is the concentration at depth (y), $(\bar{c})$ is the average concentration. For discrete value of the concentration with the depth, the above equation is written in the summation form i.e.

$$u_i = \frac{\sum_{i=1}^{n} (c_i)^2 y_i}{\bar{c} \sum_{i=1}^{n} c_i y_i} \text{ ------------ } \quad (5)$$

The uniformity index shall be analyzed using the data which cover the sediment distribution in Missouri River from group B, figure (6). This uniformity index gets a value of (1.0) for uniform distribution but as the distribution deviate more from uniformity; this index will get larger value. In flowing water, it is expected that the coarser the sediment, the larger the value of this index.

The distribution for concentration of suspended sediment for different particles-size groups at a sampling vertical, in the Missouri River are used with adaptation of (M.I.T) soil classification.

The concentration distribution in these figures is used in Eq. (5) to estimate the uniformity index.

All the results are shown in table (5). This Table shows that the fine sediment in flowing water gets an index value close to (1.0) and as the sediment gets coarse, the index value gets higher, reaching a value of (2.45) for coarser and very coarser sand. Figure (12) shows the relationship between uniformity index and mean diameter of sediment.

6- Analysis

All the available data were used to come up with full understanding about the sediment vertical distribution in flowing water and its relation with grain size. All these vertical distributions of sediment were used to calculate the empirical constant (a) in Imara's equation. The value of (10) was given to this constant in the report for sediment movement in the tributaries of Adhaim River. The result of the calculation on the first group and typical river from the second group is as shown in Table (6).

It is clear that the calculated value of (a) for Tigris River and Middle Euphrates canals ranges from (6.7) to (12.87), in first group, however, for the second group, the value of (a) for the typical river is (9.32). It should be indicated here that a value of 10 for (a) was used in branches of Adhaim River where there is small vertical concentration gradient of sediment in their flows. This is why the value of (a) in the Middle Euphrates canals is close to 10 since the vertical concentration gradient is considered small in these canals.

It is possible to test the goodness of fit of the calculated values of (a) (or the observed values) with the expected value of *(a)* which is (10) by (c^2 - test) using the data in Table (6) by:

$$\left[X^2 = \sum_{i=1}^{n} (O-E)^2 / E \right] \text{------} (6)$$

Where: O is the observed value and, E is the expected value which is considered to be 10.

The calculated (X^2) value for the first group (Tigris River and Middle Euphrates canals) and the typical River from the second group was equal to (2.7052). This value is less than the critical ($X^2{}_c$) for a significance level $(a = 0.05)$ which is (11.071). Therefore, the value of (10) for (a) will be accepted for the first group and typical river of data at a significant level $(a = 0.05)$.

As expected, when the sediment becomes coarser, the vertical distribution of this sediment deviates more from the uniform distribution. For materials like clay or silt the vertical distribution is very close to be uniform with uniformity index little larger than (1.0). However, for sand, this index has larger value ranges between (1.5) and (2.5) depending on the grain size of the sand.

The vertical distribution of the sediment distribution is known to vary exponentially i.e. as decay function. This was done to the two groups of data. The result indicates reasonable good fit with determination coefficient (R^2) reaching a value as high as (0.94).

7- Conclusions

Based on the data concerning sediment concentration in the vertical water column which are limited on Tigris River at Sarai station and Middle Euphrates canals with the limited number of samples in the column, the following conclusions may be drawn:

1-An exponential type distribution (as Decay type) seems to fit the vertical concentration distribution very well

with a determination coefficient (R^2) as high as (0.94).
2-The value of the empirical constant (a) in Imara's equation varied between (6.7) to (12.87) for group one data.
3-The average value of (a) based on the available data on Tigris river and middle Euphrates canal is (7.205) and (11.65) respectively.
4-The uniformity index suggested in this research gave a value close to (1.0) for clay and silt and larger value ranging between (1.5) and (2.5) for sand depending on the grain size of the sand, for Missouri River group.
5-The value of (10) for (a) was accepted for the data of the first group and typical river with a significance level $(a = 0.05)$.

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List Of Symbols

Symbol	Definition	Dimension	unit
a	Empirical constant in Imara’s Equation, also distance from the bottom.	-	-
b	Depth from water surface to a sample's location in Imara's equation.	L	m
C	Suspended sediment concentration, at distance y from the bottom, also any distance from top or bottom.	-	p.p.m.
C_b	Suspended sediment concentration at a distance (b) from water surface, in Imara's equation.	-	p.p.m.
$\overline{C}$	Average suspended sediment concentration in water column, in Imara's equation.	-	p.p.m.
$\overline{C}_s$	Mean concentration of suspended sediment in vertical,(Straub,1935).		
d	Total depth of the water column in Imara's equation.	L	m
D	Mean diameter of soil’s grains.	L	mm
χ^2	Chi-square.	-	-
O_i	Observed value for empirical constant from calculations of Imara’s equations.	-	-
E_i	Expected value for empirical constant in Imara’s equation, which be considered to be (10).	-	-

a	Significant level in chi-square test.	-	-
R^2	Determination coefficient.	-	-
u_i	Uniformity index.	-	-
y	Any depth from the bottom.	L	m
V	Vertical.	-	-
v	Flow velocity	LT^{-1}	m/s
u	kinematics viscosity	L^2T^{-1}	m^2/s

Table (1): Field Data for Tigris River at Sarai Gaging Station.
*** (Achieved by the Dams and Reservoir General).**

Date of observation	location	Total depth (m)	Sample depth (m)	Velocity (m/sec)	Concentration (ppm)
7th.Mar.1965 Q =1831.09 (m^3/sec) Water level W.L.=31.71 m	I	13.06	a	1.261	561
			b	1.241	573
			c	0.813	623
	II	11.9	a	1.670	537
			b	1.670	553
			c	1.300	577
	III	10.1	a	1.417	494
			b	1.455	527
			c	1.319	670
	IV	7.5	a	1.144	509
			b	1.163	511
			c	0.891	644
	V	4.68	a	0.947	685
			b	0.930	731
			c	0.413	735
30.Jan.1966 Q =1999 (m^3/sec)	I	12.35	a	1.280	274.4
			b	1.241	427.8
			c	0.949	474.7
	II	12.25	a	1.533	353
			b	1.631	441.6
			c	1.339	505.4
	III	10.00	a	1.319	252.0
			b	1.475	359.8

Water level W.L=31.47 m			c	1.455	395.8
	IV	6.25	a	1.553	254
			b	1.105	266.1
			c	0.871	370
	V	2.10	a		
			b	0.526	300.3
			c		

Table (2): Field Data for Middle Euphrates Canal, Observed In 30-Jan-1973 [After Saman, I.Y.]

Canal name	Location	Discharge (m^3/sec)	Avg. velocity (m/sec)	Total depth (m)	No. of samples	Depth of sample from water surface (m)	Concentration (ppm)
Beni Hassan	12.300 km from Euphrates River	19.388	0.712	1.7 [a] 12.7 [b]	1	0.00	138
					2	0.85	152
					3	1.65	247
Beni Hassan	15.300 km from Euphrates River	18.596		1.65 [a] 11.35 [b]	1	0.00	145
					2	0.83	159
					3	1.60	236
Al.Kifil	58.200 km from Euphrates River	5.124		1.5 [a] 3.25 [b]	1	0.00	162
					2	0.75	186
					3	1.45	273
Al.Kifil	61.00 km from Euphrates River	4.914		1.05 [a] 5 [b]	1	0.00	163
					2	0.53	190
					3	1.02	261
Al.Nile	3.900 km from Satt Al.Hilla	3.735	0.704	1.05 [a] 3.35 [b]	1	0.00	229
					2	0.52	238
					3	1.02	291
Al.Nile	7.050 km from Satt Al.Hilla	3.141		1.04 [a] 4 [b]	1	0.00	217
					2	0.52	252
					3	1.00	295

a : the total depth of column in meters.
b : the horizontal distance (position of column) in meters.

c : depth of sample from river surface in meters.

Table (3): Field Data for Middle Euphrates Canals.
(Observed in Aug. + Oct.1984 [After Mohammed, R.I.]).

Canal name	Location	Q (m^3/sec)	Avg. velocity (m/sec)	Vertical	Y^a (m)	X^b (m)	No. of sample	$Depth^c$ of sample (m)	Concent. (ppm)
Satt Al.Hilla	(1km) from Euphrates River	229.556	0.855	I	4.30	25	1	1	159.25
							2	2	165.25
							3	3	192.25
				II	4.00	50	1	1	118.75
							2	2	125.75
							3	3	162.25
				III	4.00	75	1	0.00	189.25
							2	0.80	199.75
							3	1.50	243.25
Al.Mahawil	(7.700km) from Satt Al.Hilla	6.800	0.489	I	1.60	4	1	0.00	214.75
							2	0.80	219.25
							3	1.50	276.25
				II	1.50	7	1	0.00	262.25
							2	0.80	279.75
							3	1.60	325.25
				III	1.20	9	1	0.00	238.75
							2	0.30	309.25
							3	1.10	375.25
Al.Kifil	(0.500km) from Euphrates River	23.670	0.415	I	2.10	12	1	0.00	71.25
							2	1.00	128.75
							3	2.00	365.25
				II	2.50	16	1	0.00	191.25
							2	1.25	218.75
							3	1.90	313.25
				III	1.70	22	1	0.00	114.25
							2	0.85	161.25
							3	1.50	186.25

a: depth of vertical (m). b: horizontal distance for vertical from zero (m). c: depth of sample from surface water (m).

Table (4) The Calculated Empirical Constant Results.

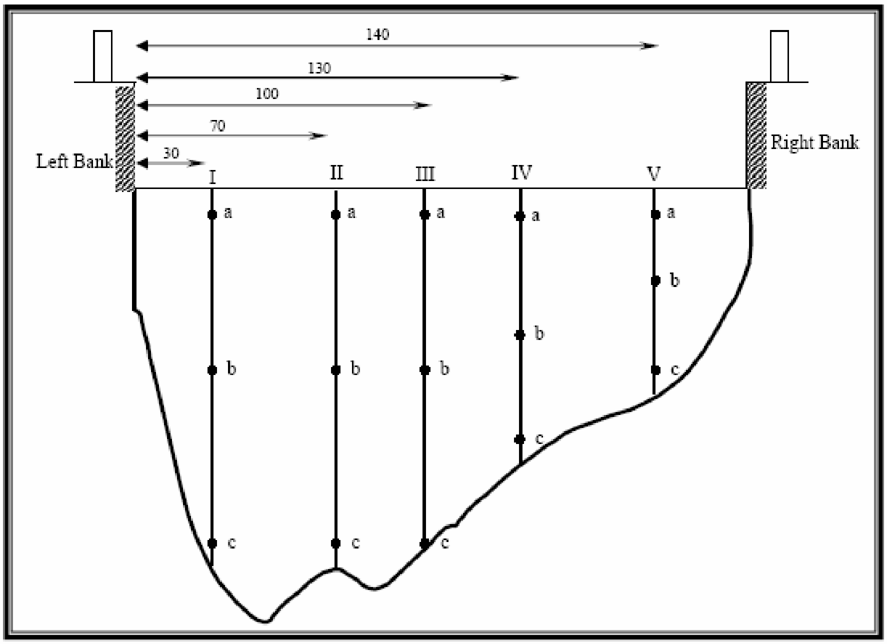
River name	**Site description**	**V**	***d* (m)**	**$\overline{C}$ (ppm)**	**C_b (ppm)**	**Empirical constant *(a)***	**Group average ($\overline{a}$)**
Tigris	Sarai site. Date in 7 Mar.1965	V1	13.06	585	560	5.114	6.70
		V2	11.9	555	538	5.43	
		V3	10.1	560	480	6.81	
		V4	7.5	550	475	7.852	
		V5	4.68	709	676	8.3	
	Sarai site. Date in 30Jan.1966	V6	12.35	355	200	6.18	7.71
		V7	12.25	375	246	7.86	
		V8	10	320	258	7.3	
		V9	6.25	298	228	9.5	
Euphrates	Middle Euphrates canals date 30Jan.1973	V10	1.7	172	137	12.55	11.27
		V11	1.65	178	143	11.56	
		V12	1.5	200	162	11.55	
		V13	1.05	200	172	11.14	
		V14	1.05	248	230	10.33	
		V15	1.04	250	228	10.15	
	Middle Euphrates canals date 4Oct.1984	V16	4.3	170	145	9.46	10.81
		V17	4.0	132	104	10.4	
		V18	4.0	210	168	10.26	
		V19	1.6	258	200	12	
		V20	1.5	312	262	11.15	
		V21	1.2	300	246	11.6	
	23Aug.1984 21Aug.1984	V22	2.1	120	75	14.5	12.87
		V23	2.5	240	192.5	11.1	
		V24	1.7	175	125	13	
Typical	1996 UNEP/WHO	V25	10	1086	685	9.32	9.32
Missouri	Kansas city , MO.1970	V26	3.5052	667	120	46.89	neglected
		V27	3.5052	875	250	29.52	
		V28	3.5052	940	380	20.8	

Table (5): Variation of the Uniformity Index with Mean Diameter of the Soil.

No.	Type of soil	Uniformity index	Mean diameter (mm)
1	Very coarse sand + coarse sand	2.45	1.3
2	Medium sand	1.74	0.4
3	Fine sand + very fine sand	1.52	0.13
4	Coarse silt	1.13	0.02
5	Medium silt	1.01	0.013
6	Fine silt + very fine silt	1.01	0.004
7	clay	1.10	0.002

Table (6) Result of the calculated empirical constant *(a)*

<table>
<tr><th>Location</th><th>Average Value of (a)</th><th>Average values</th><th>Used value in Adhaim tributaries</th></tr>
<tr><td>Tigris sarai site (1965)</td><td>6.70</td><td rowspan="2">7.2</td><td>10</td></tr>
<tr><td>Tigris sarai site (1966)</td><td>7.71</td><td>10</td></tr>
<tr><td>Middle Euphrates canals (1973)</td><td>11.25</td><td rowspan="3">11.65</td><td>10</td></tr>
<tr><td>Middle Euphrates canals (1984)</td><td>10.81</td><td>10</td></tr>
<tr><td>Middle Euphrates canals (1973)</td><td>12.87</td><td>10</td></tr>
<tr><td>Typical River (1996)</td><td>9.32</td><td>9.3</td><td>10</td></tr>
</table>



LEGEND
Location I is 30 ms from left bank.
Location II is 70 ms from left bank.
Location III is 100 ms from left bank.
Location IV is 130 ms from left bank.
Location V is 170 ms from left bank.

Depth a is one meter below the water surface.
Depth b is mid depth.
Depth c is one meter above the bed level.

Figure (1), Definition Sketch of Tigris River at north of Baghdad (Sarai gaging station): observed in (7/3/1965), and (30/1/1966).
After Irrigation General Director

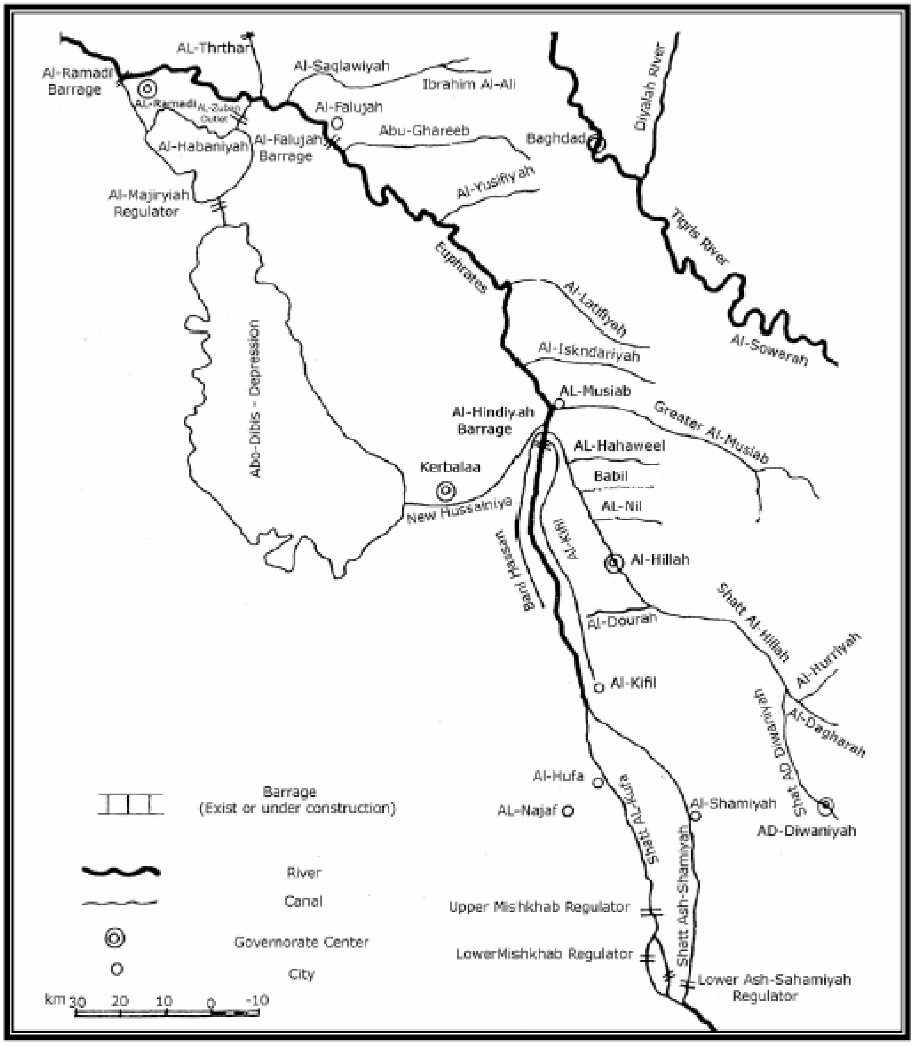


Figure. (2), Euphrates River Canals (After Mohammed, 1984)

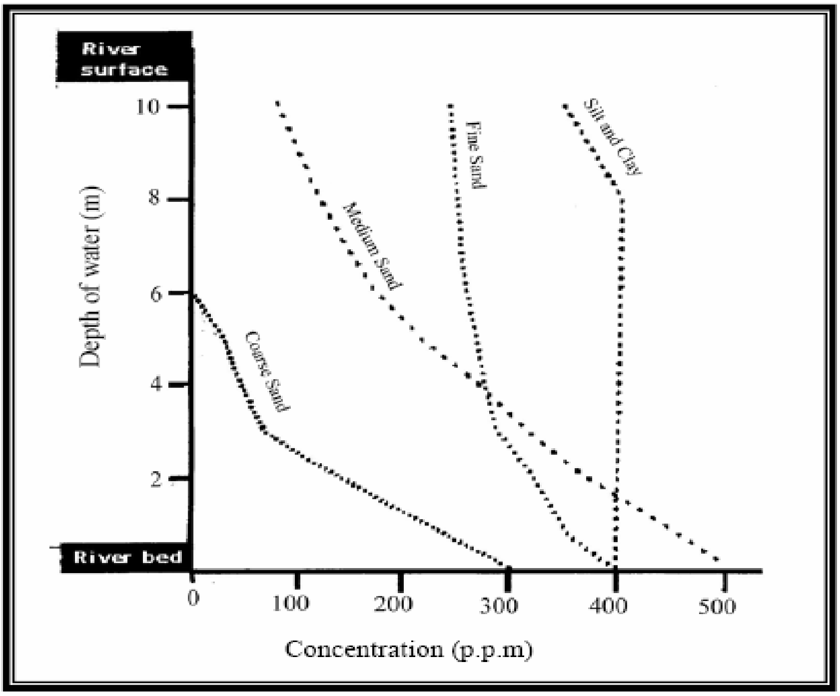


Figure. (5),Typical variation in concentration of suspended sediment with depth for Sand, silt and clay as measured at one field site (After Ongley, 1996)

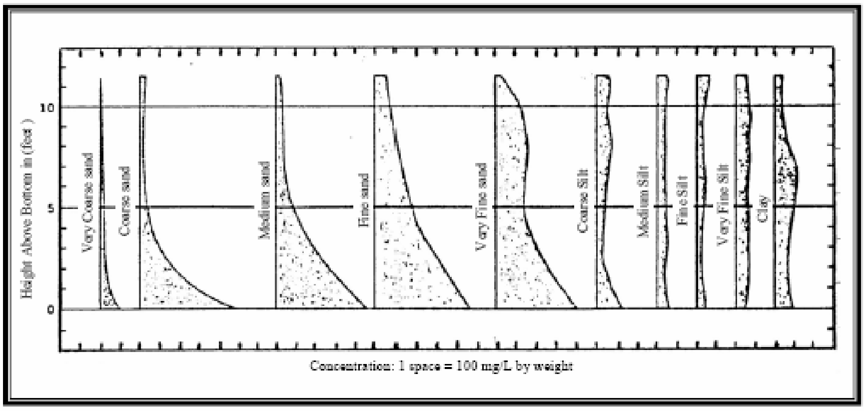


Figure (6), Discharge-weighted concentration of suspended sediment different particles-size Groups at a sampling vertical, in the Missouri River at Kansas City, Mo.

(After Guy, 1978)

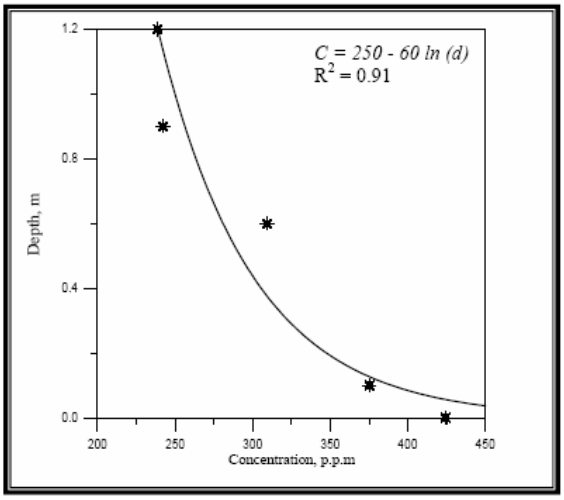


Figure (7): Vertical Distribution of sediment Concentration in Shatt Al-hilla for AL-Mahawil Canal, **[V21]**

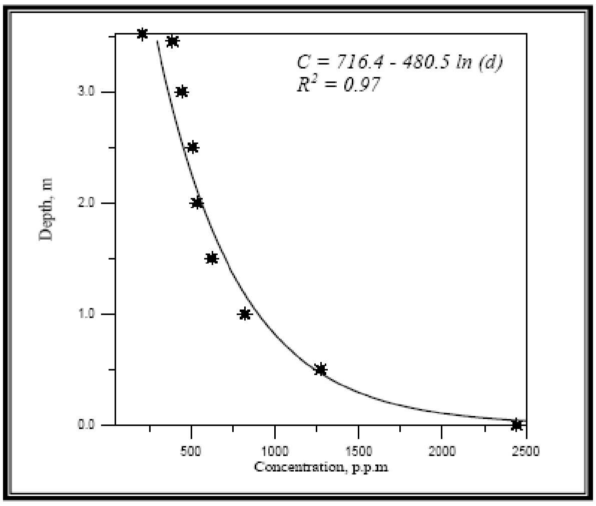


Figure (8): Vertical Distribution of sediment Concentration for Missouri River at Kansas City, Mo. **[V26]**

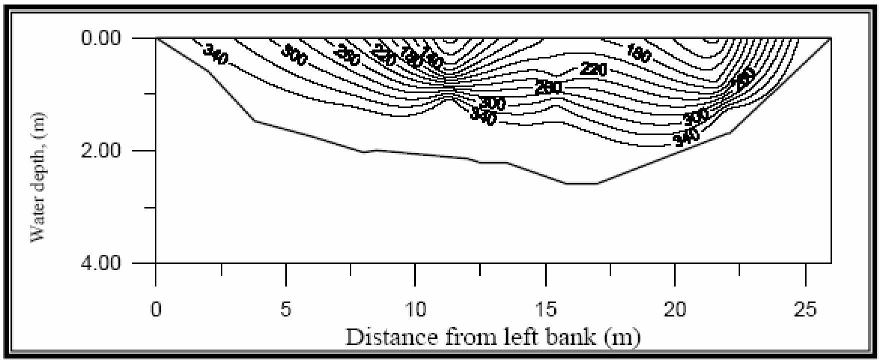


Figure (9): Contours lines for sediment concentration (AL-Kifil canal)

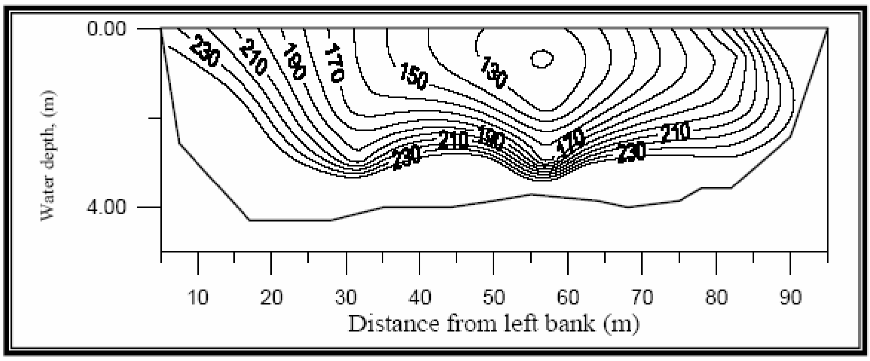


Figure. (10): Contours lines for sediment concentration (Shatt Al-Hilla Canal)

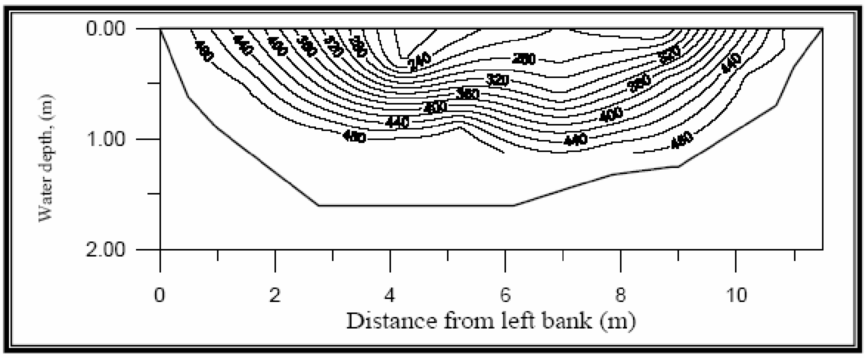


Figure. (11): Contours lines for sediment concentration (Al-Mahawil canal)

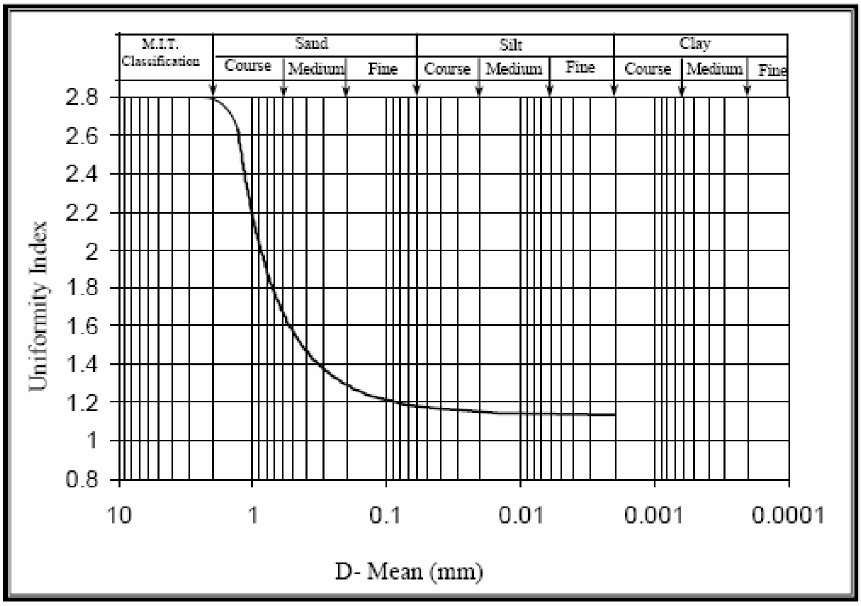


Figure. (12): Relationship between Uniformity Index and Mean Sediment Diameter For Missouri River group