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Geometric properties of the River Euphrates, Iraq: the nature of its slope variation

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Abstract The results of a bathymetric survey carried out during 1999, which yielded 152 cross-sections along the Euphrates River within Iraqi territory, was used for slope measurements. The values of slope coefficients were calculated at separations of 5 km. The slope coefficients were calculated first using the water surface method and secondly using the river bed method. The variation of the slope values along the river course were plotted and it was sub-divided into nine reaches according to changes in the slope values that represent the topographic nature of the river course or according to the existence of artificial structures such as irrigation barrages. The results of the slope variation within each reach were studied and the representative equation was determined with comparisons of the two methods of slope measurement.

Key words Euphrates River; Iraq; river bed; slope coefficient; water surface

INTRODUCTION

The control and intelligent use of water play a predominant role in operating, scheduling, and managing water supply systems, particularly in arid and semiarid regions where the amount and timing of precipitation are not adequate to meet the water requirements for agriculture, electrical power generation and human consumption. Water resources of Iraq historically have depended largely on the surface water of the Tigris and the Euphrates Rivers since the Mesopotamian civilization. More than 75% of the available water of Iraq comes from outside the territory. Both the Tigris and the Euphrates are international rivers, their sources originating in Turkey. The average annual flow of the Euphrates as it enters Iraq, estimated at Hit, is 28.67 km^3, with fluctuating annual values ranging from 10 to 40 km^3. Unlike the Tigris, the Euphrates receives no tributaries during its passage in Iraq (Fig. 1). All of the total annual flow of the Euphrates originates in Turkey and Syria (Al-Jabbari *et al*., 2000).

Hydrological monitoring is of particular importance in Iraq as it provides not only planning data, but also the information needed for operational water resources management.

Iraq has a very complex system of dams, barrages, regulators, pump stations, canals and irrigation systems that require specific flows to operate properly. Many hydrological studies have been carried out in Iraq, for example the Harza Engineering Company (Chicago) and Binnie, Deacon and Gourley (London) published a technical report in 1963. A final report on the hydrological survey of Iraq was produced for the Ministry of Agriculture. In 1982, the Soyuzgiprovodkhoz Institute, DG of Studies and Designs (USSR) presented the main functions of the centralized control system for operation and maintenance of the unified hydro-economic and irrigation systems. The

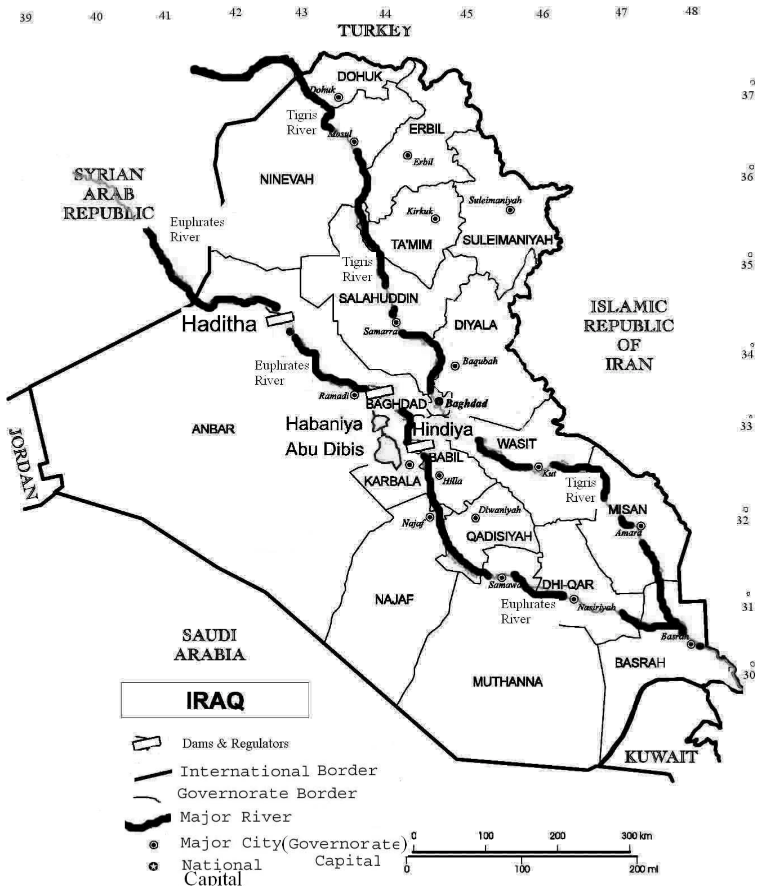

Fig. 1 Euphrates River in Iraq.

Mesopotamia Engineering Consultancy (1991) also conducted a study that proposed a water control system structure comprising 15 stations. FAO (2003) presented a draft project proposal for the rehabilitation of the hydrological network in Iraq. The most important factor that affects the river's course and its hydraulic, geometric, geomorphologic, hydrologic, and sedimentary properties is its slope. Therefore, it is essential to study and evaluate the slope coefficient for each 5 km reach along the Euphrates. Moreover, this study will provide direct values for the slope coefficient at each location proposed for agricultural or industrial projects, rather than estimated or calculated by indirect mathematical methods. The slope coefficient is essential for many applied irrigation, industrial and engineering applications, such as studies of mathematical models of river flow, soil type, and river meandering. In addition, slope coefficient studies will provide the locations of water intakes for different uses, as required by models for river water quality.

MATERIALS AND METHODS

The results of the 152 slopes values for each 5-km longitudinal reach of the Euphrates River are shown in Table 1. Evaluating these slope coefficients was done using two methods:

(a) The slope of the river bed, which indicates the slope by dividing the difference between the river bed elevations at two successive points by the horizontal distance between them.
(b) The slope of the water surface of the river, which indicates the slope by dividing the difference between the water surface elevations at two successive points by the horizontal distance between them.

Table 1 The slope of the Euphrates River along its course within Iraqi Territory determined by the Bed Level and Surface Water Level for each studied reach (segment).

No.	(km)	Bed L. (m)	Water L. (m)	Slope using bed level	Slope using water level	No.	(km)	Bed L. (m)	Water L. (m)	Slope using bed level	Slope using water level
1	2	160	164.54	0.26	0.207	40	340	46	58.3	–1.72	0.34
2	7.75	158.5	163.35	–0.4	0.369	41	345	54.6	56.6	0.82	0.34
3	10	159.4	162.52	0.16	0.228	42	350	50.5	54.9	0.717	0.28
4	15	158.6	161.38	0.363	0.229	43	356	46.2	53.22	–0.3	0.085
5	20.5	156.6	160.13	0.343	0.25	44	360	47.4	52.88	–0.22	0.114
6	27.5	154.2	158.38	0.217	0.188	45	365	48.5	52.31	0.012	0.018
7	39.5	151.6	156.2	0.372	0.124	46	396.5	48.15	51.75	–0.207	–0.006
8	50	147.7	154.9	–0.14	0.184	47	375	43.7	51.62	–0.3	0.035
9	55	148.4	153.98	0.089	0.204	48	378.5	44.75	51.5	0.039	0.016
10	64	147.6	152.15	0.118	0.145	49	385	44.5	51.4	0.04	0.06
11	76	146.2	150.41	0.375	0.296	50	390	44.3	51.1	–0.391	0.078
12	80	144.7	149.22	0.21	0.192	51	395.5	46.45	50.7	0.056	0.089
13	90	142.6	147.3	0.24	0.18	52	400	46.2	50.3	0.419	0.078
14	100	140.2	145.5	0.3	0.2	53	405.5	43.9	49.9	1.823	0.034
15	105	138.7	144.5	0.06	0.166	54	410	35.7	49.75	–0.78	0.313
16	110	138.4	143.67	0.12	0.088	55	420	43.5	46.62	0.34	0.104
17	120	137.2	142.79	0.15	0.029	56	425	41.8	46.1	0.12	0.1
18	130	135.7	142.5	0.104	0.028	57	430	41.2	45.6	0	0.1
19	185	130	141	0.588	0.724	58	435	41.2	45.1	0.68	0.1
20	240	97.7	101.18	0.18	0.418	59	440	37.8	44.6	–0.36	0.1
21	245	96.8	99.09	1.27	0.864	60	445	39.6	44.1	0.74	0.04
22	250	90.45	94.77	0.123	0.372	61	450	35.9	43.9	0.06	0.06
23	254.5	89.9	93.1	0.279	0.368	62	455	35.6	43.6	–0.28	0.06
24	260.25	88.3	91.02	0.278	0.277	63	460	37	43.3	0.8	0.06
25	265	87	89.73	1.2	0.382	64	465	33	43	–0.84	0.026
26	270	81	87.82	–0.08	0.694	65	470	37.2	42.87	0.36	0.042
27	275	81.4	84.35	0.98	0.634	66	475	35.4	42.66	–0.1	0.022
28	280	76.5	81.18	0.8	0.582	67	480	35.9	42.55	1.58	0.02
29	285	72.5	78.27	0.047	0.426	68	485	28	42.45	–1.26	0.9
30	289.3	72.3	76.44	0.527	0.806	69	490	34.3	37.95	0.594	0.05
31	295	69.3	71.85	1.2	0.688	70	505	25.4	37.2	–0.57	0.05
32	300	63.3	68.41	–0.07	0.002	71	515	31.1	36.7	–0.2	0.05
33	305	63.65	68.4	0.61	0.506	72	525	33.1	36.2	0.41	0.06
34	310	60.6	65.87	0.32	0.25	73	535	29	35.6	–0.19	0.06
35	315	59	64.62	0.75	0.209	74	545	30.9	35	0.07	0.06
36	321	54.5	63.37	–0.675	0.316	75	555	30.2	34.4	0.355	0.06
37	325	57.2	62.12	0.14	0.25	76	565	26.65	33.8	0.2	0.06
38	330	56.5	60.87	0.96	0.25	77	575	24.65	33.2	–0.235	0.06
39	335	51.7	59.62	1.14	0.264	78	585	27	32.6	–0.03	0.025

Table 1 (cont.)

No.	(km)	Bed L. (m)	Water L. (m)	Slope using bed level	Slope using water level	No.	(km.)	Bed L. (m)	Water L. (m)	Slope using bed level	Slope using water level
79	595	27.3	32.35	0.8	1.1	111	760	7	11.75	–0.18	0.032
80	600	23.3	26.85	0.15	0.045	112	765	7.9	11.59	0.19	0.022
81	610	21.8	26.4	0.28	0.08	113	770	6.95	11.48	0.07	0.198
82	615	20.4	26	–0.34	0.06	114	775	6.6	10.49	–0.17	0.033
83	620	22.1	25.7	0.36	–0.04	115	785	8.3	10.16	0.07	0.062
84	625	20.3	25.9	0.2	0.07	116	790	5.7	10.07	–0.05	0.062
85	630	19.3	25.55	–0.38	0.05	117	795	6.2	9.45	0.24	0.062
86	635	21.2	25.3	–0.1	0.05	118	805	3.8	8.83	0.07	0.061
87	640	21.7	25.05	0.02	–0.04	119	815	3.1	8.22	0.039	0.009
88	645	21.6	25.25	0.3	0.03	120	828	2.6	8.1	0.1	0.027
89	650	20.1	25.1	–0.04	0.03	121	835	1.9	7.9	0.05	0
90	655	20.3	24.95	0.15	0.016	122	845	1.4	7.9	0.034	0.289
91	663	19.1	24.85	–0.4	0	123	851	1.2	6.2	–0.267	0.017
92	665	19.9	24.85	0.06	–0.006	124	857	2.8	6.1	0.625	0.075
93	670	19.6	24.88	0.26	0.02	125	863	–0.95	5.65	–0.625	0.039
94	675	18.3	24.78	–0.04	0.786	126	869	2.8	5.42	0.384	0.04
95	680	18.5	20.85	0.04	0.03	127	875	0.5	5.18	–0.417	0.039
96	685	18.3	20.7	0	0.025	128	881	3	4.95	0.3	0.04
97	689	18.3	20.6	0.15	0.13	129	887	1.2	4.71	0.584	0.039
98	695	17.4	19.82	0.16	0.044	130	893	–2.3	4.48	–0.333	0.014
99	700	16.6	19.6	0.08	0.038	131	899	–0.3	4.4	–0.117	0.014
100	705	16.2	19.41	0.38	0.042	132	905	0.4	4.32	–0.15	0.014
101	710	14.3	19.2	0.08	0.034	133	911	1.3	4.24	0.234	0.014
102	715	13.9	19.03	0.12	0.066	134	917	–0.1	4.16	–0.233	0.014
103	720	13.3	18.7	0	0.29	135	923	1.3	4.08	0.567	0.014
104	725	13.3	17.25	0.18	0.01	136	929	–2.1	4	0.198	0.014
105	730	12.4	17.2	0.28	0.032	137	935	–3.25	3.92	–0.208	0.014
106	735	11	17.04	0.34	0.728	138	941	–2	3.84	–0.183	–0.02
107	740	9.3	13.4	–0.1	0.172	139	947	–0.9	3.96	0	0.005
108	745	9.8	12.54	0.5	0.056	140	953	–0.9	3.93	0.217	0.005
109	750	7.3	12.26	–0.08	0.042	141	959	–2.2	3.9	0.184	0.005
110	755	7.7	12.05	0.14	0.06	142	965	–3.3	3.87	–0.483	–0.995
143	971	–0.4	9.84	0.6	1.206	148	1048	–1.5	1.52	–0.073	0.013
144	976	–3.4	3.81	–0.046	0.006	149	1059	–0.7	1.38	–0.208	–0.008
145	1004	–2.1	3.74	–0.233	0.009	150	1047	–3.2	1.28	0.043	0.005
146	1013	0	3.66	0.072	0.078	151	1092	–5.1	1.08	–0.036	0.003
147	1038	–1.8	1.73	–0.03	0.021	152	1151	–3	0.95		

Theoretically, the results of both methods should be identical, but practically this is impossible due to the effect of bed resistance to water flow. This results in increasing variation between the two methods with greater loss of energy to overcome bed roughness, i.e. less erosion and more deposition and *vice versa*. When the differences become less, there is minimum loss of energy with high erosion and less deposition. The results indicated in Table 1 and the fieldwork undertaken during 1999 make this research the most recent evaluation of the slope variation of the Euphrates River.

RESULTS AND DISCUSSION

The results reflect a remarkable decrease in the slope values towards the south of Iraq to the Gulf. As expected, there are variable values in slope coefficients, which indicate that the slope values along the Euphrates River are not within the same range of slope mean values. Also abnormal slope values exist with negative values of slope coefficients (Table 1).

This could be due to the back water effect, which occurs behind barrages and dykes that exist along the Euphrates River course, or to the fact that the field surveying of the surface water and the river bed altitude levels were not carried out at the same time. Thus, the surveying may represent variable hydrological, climatological and operational conditions. These conditions may also reflect the variable results, especially of the slope coefficients measured according to surface water level, while there was less variation in river bed levels during the short, three-month, period of field surveying. The results of the field surveying of the water surface and river bed levels along the Euphrates River course are shown in Figs 2 and 3. The main observations that are indicated by these curves are:

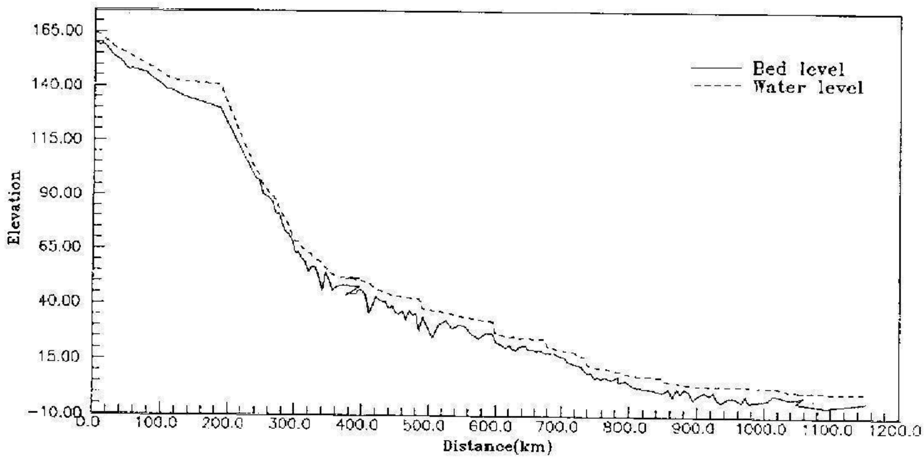

Fig. 2 Variation in the bed and water level of the Euphrates River course within Iraqi territory.

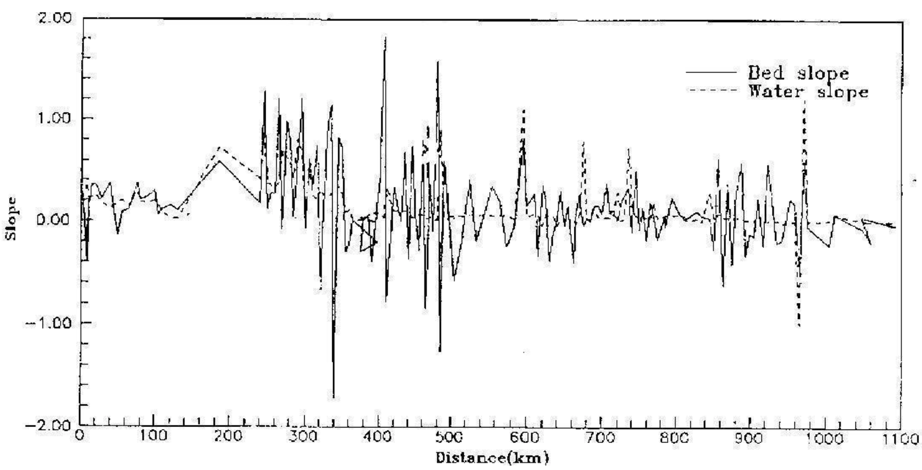

Fig. 3 Comparison between slope values using bed and water levels along the Euphrates course within Iraqi territory.

(a) A remarkable decrease in the river bed level and surface water level shown in its upper reaches in particular, and southwards in general towards the Gulf. The main reasons for this southward decrease in slope coefficient are the increasing river channel efficiency and other factors, such as the topography, shape and volume of the river basin, the river network, the intensity of erosional, transportational and depositional processes and the nature of the water flow. Therefore, the resulting river slope represents the Euphrates River's attempt to achieve self-equilibrium and, accordingly there should be a change in the geometric properties of the river cross-sections and redistribution of the river sediments.

(b) The calculated slope values according to the surface water level are much higher than those calculated from the river bed level.

(c) The comparison of the two methods (Figs 2 and 3) shows that the relative differences in the slope values of the surface water method are less than the relative differences of the other method. The latter method has values characterized by distinct instability with high values of the measured slope, especially within the river reach between 200 km to 1000 km. This reflects the existence of many effective factors on the river bed and that may represent the transition zone from the rocky nature to the sedimentary nature of the river bed.

(d) The slope values calculated using the river bed levels show a remarkably high variability and frequency that may indicate erosional and depositional processes occurring within the river bed, near the rock outcrops of river bars and meanders.

(e) The slope values calculated using the surface water levels show much more uniformity with less frequency but indicate nine main locations with unusual slopes due to large and small dykes and barrages along the river course such as Haditha Dam, Ramady, Falluja and Hindiya Barrages (Fig. 4 and Table 2).

(f) According to the general slope coefficient, the river course may be divided into four main reaches (Table 1), these are:

    (i) the river reach between 0 and 200 km;
    (ii) the river reach between 200 and 350 km;
    (iii) the river reach between 350 and 750 km;
    (iv) the river reach between 750 and 1200 km.

(g) The linear equations for the nine longitudinal cross-sections indicate that there is a direct relationship between the slope values in the upper reaches of the Euphrates (Fig. 4), and *vice versa* for the slope values in the lower reaches. These equations of the slope diagrams (Fig. 4) may be used to determine the Manning Coefficient of Roughness for the river bed for these locations after measuring the water discharge.

The Manning coefficient is very sensitive to the nature of the river course and its geometric properties. Moreover, this coefficient has a direct relationship with water flow velocity, water discharge, river cross-section shape and slope coefficient values. Values will depend on the sedimentological nature of the river bed, river levees, and the nature of the sediment load (both suspended and bed load). Also, there is an indirect relationship between river bed roughness and the water velocity needed for each discharge, due to the energy loss to overcome the bed roughness.

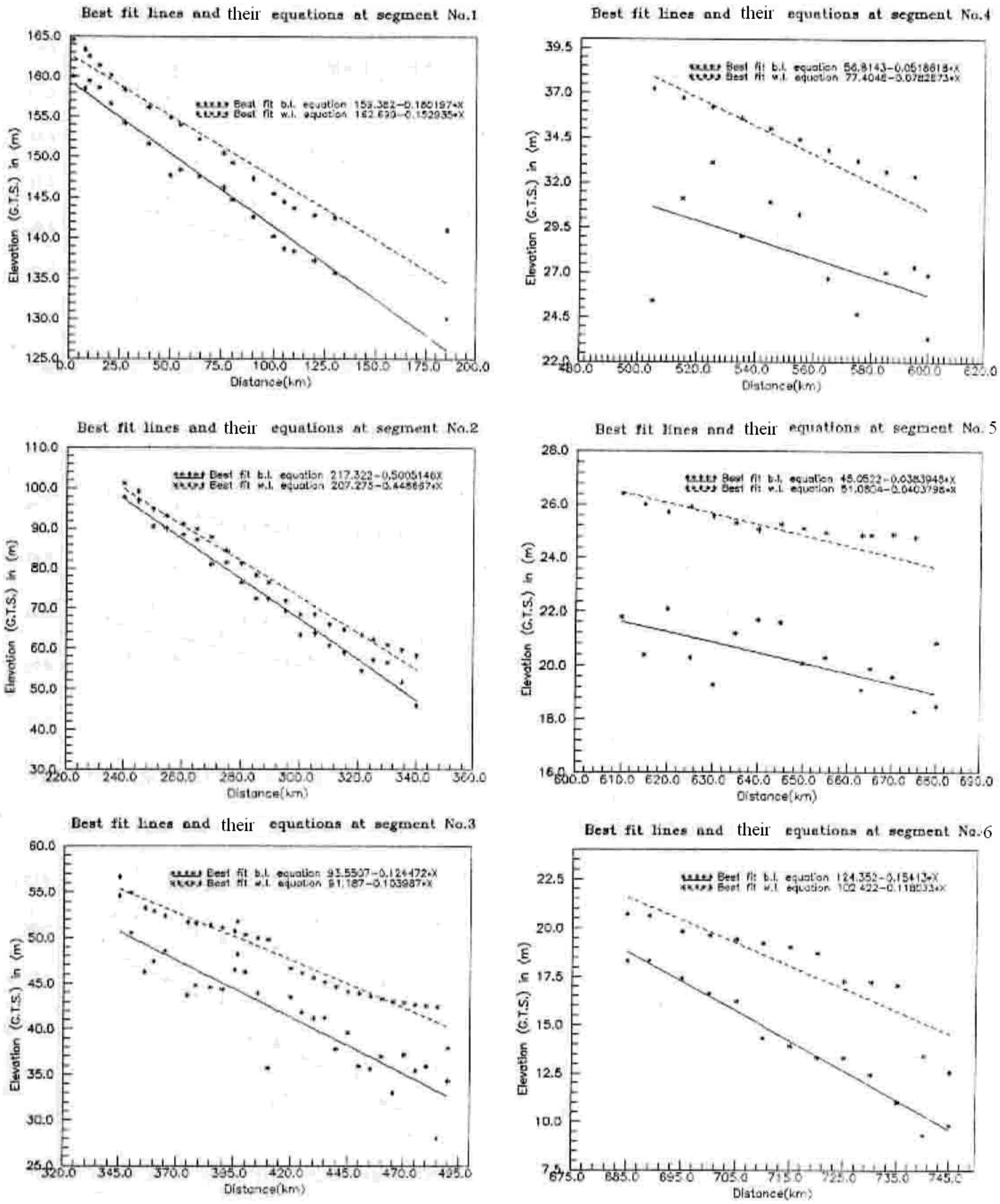

Fig. 4 cont. on next page

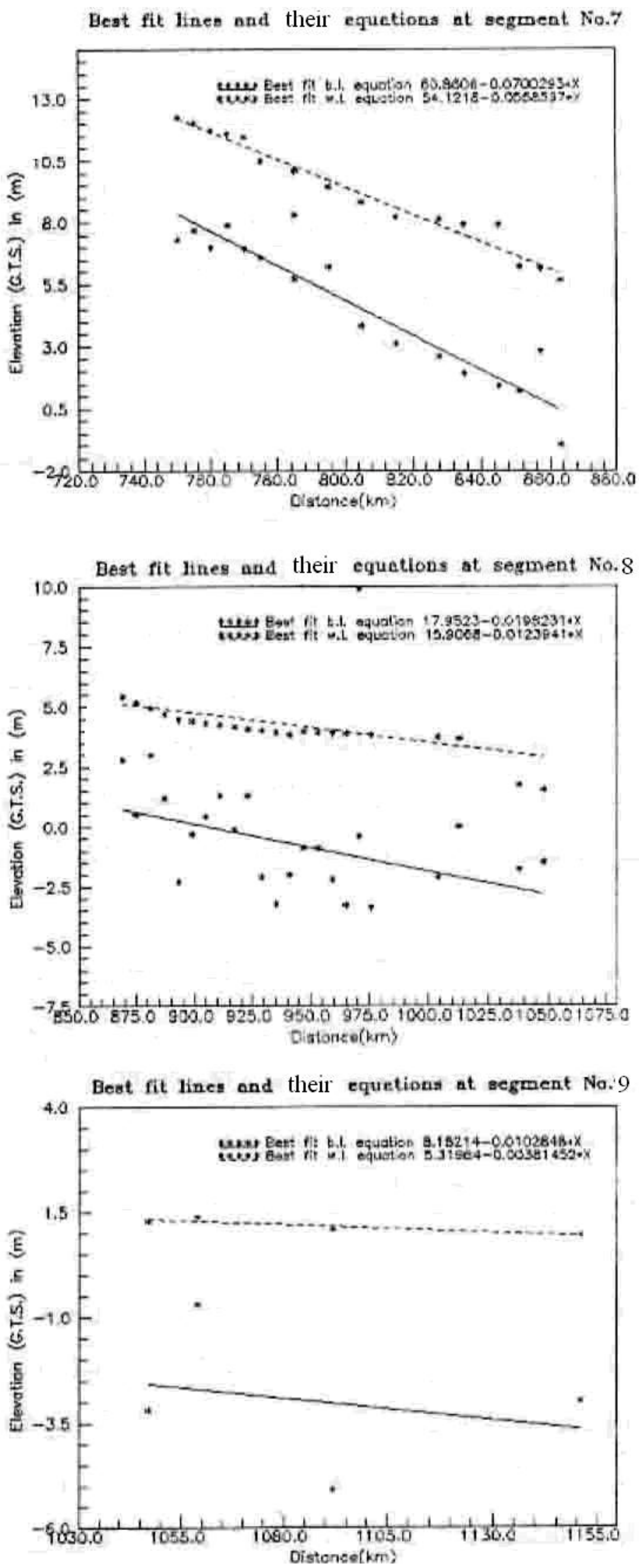

Fig. 4 Best fit lines and their equations at different segments from no 1 to 9.

Table 2 The slope values of the nine reaches (segments) of the Euphrates River.

Longitudinal reach no. of the Euphrates River	The Euphrates River slope using surface water method for nine longitudinal reaches	The Euphrates River slope using river bed method for nine longitudinal reaches
1	0.000155	0.0001837
2	0.0048	0.0055
3	0.000108	0.00001142
4	0.0000067	0.000153
5	0.0000333	0.000034
6	0.00011666	0.000134615
7	0.000051937	0.00006925
8	0.0000102	0.000019697
9	0.00000512	0.000009332

CONCLUSIONS

The most important conclusion from this study is the determination of slope variations along the Euphrates River, and also the existence of the nine main general slope reaches that represent the existence of the main irrigation dams, the regulating dams, and barrages as well as the abrupt topographic changes along the river course. This research suggests that the slope values measured from the river bed levels are of high significance compared with the surface water level measurements. This indicates that the three months of fieldwork may effectively represent the variation in hydrological properties with time of the flow of the Euphrates River during this period.

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