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Numerical and Experimental Analysis of Rapid Delta Formation, Turkish coast

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ABSTRACT

The morphology of river mouths can be completely changed by dramatic flow changes caused by climate changes in catchment basins. Agricultural activities that overexploit water produce changes in sediment discharge that are reflected in sedimentation rates in dams. The basic aim of this study is to assess the causes and effects of rapid delta formation in Gomec (an important tourism centre on the Aegean Sea coast of Turkey), as a result of river catchment changes between 1998 and 2001. The rapidly developing delta covers an area of approximately 2 km length and 100 m width and was studied using numerical simulation and field studies. Bathymetric measurement, flow velocity and oceanographic parameters were measured. Bottom sediment samples were taken from the river and adjacent sea and sources were determined by mineral analysis. River flows and wave properties (determined from hindcast wind data) were used in the numerical model studies. The development of the delta was predicted for different scenarios. It is concluded that unless remedial action is taken, the delta will continue to develop rapidly and will produce both morphological and ecological impacts.

ADDITIONALINDEXWORDS: *Gomec River, Turkey, delta formation, accumulation, sediment transport, flood flow*

INTRODUCTION

The world's coastal regions cover 600 000 km length and vary from approximately one hundred to thousand meters in width. They cover about 18% of the earths land area. More than 80% of the world population lives in these regions (BURNS, 1997).

Coastal zones are sensitive to increasing populations. Rapid socio-economic developments coupled with a natural imbalance due to recent climate changes have created negative effects (CLARK, 1996). Coastal erosion has been reported along 80% of the coastal line in USA (EHLER *et al*., 1997).

Problems related to the natural functioning of coasts are not only due to human activity in this region. In addition, the activities in the hinterland may cause alteration and deterioration of the coastline. Furthermore, agricultural, domestic and industrial waste discharged into the rivers cause important problems. It is clear that one of the main causes of problems on coastal regions is river basin management. The change of coastal morphology because of river basin erosion also influences coastal zone uses.

In this study, the reasons for, and effects of, rapid delta formation in Gomec, an important tourism centre on the Aegean Sea coast of Turkey, are investigated.

STUDYAREA

Kuzulu and Gomec Rivers flow across the Gomec Plain which is located in the eastern part of Edremit Bay in the northern Aegean Sea. These rivers flood during the winter rainy season. Gomec plain is filled with alluvium (SOYKAN, 1999). The settled population in this region is mainly agrarian and its population in the summer season is between 10 000 and 20 000.

The weather during the winter is wet and warm. Annual average precipitation is 640 mm and its contributions during winter, spring, summer and autumn are 49%, 23%, 4%, 24%, respectively. Half of the total precipitation falls in the winter season when there is no vegetation on the ground. Riverine sediment flows through Gomec River mouth to the sea, and accumulates at the coast. In the sea, a shallow, turbid region 2 km length and 100 m width occurs as shown in Figure 1. In the rainy season the turbid area increases, the coastal morphological structure completely changes and small islets are formed (Figure 2., IRTEM and KAPDASLI, 2001). In Gomec, spits, deltas, marshlands, and lagoons are formed by sediment transported by previous floods. In the 1950's and 1960's the upper basin of Gomec and Kuzulu Rivers was covered by woodland. Afterwards woodland was destroyed and converted to olive groves and agriculture

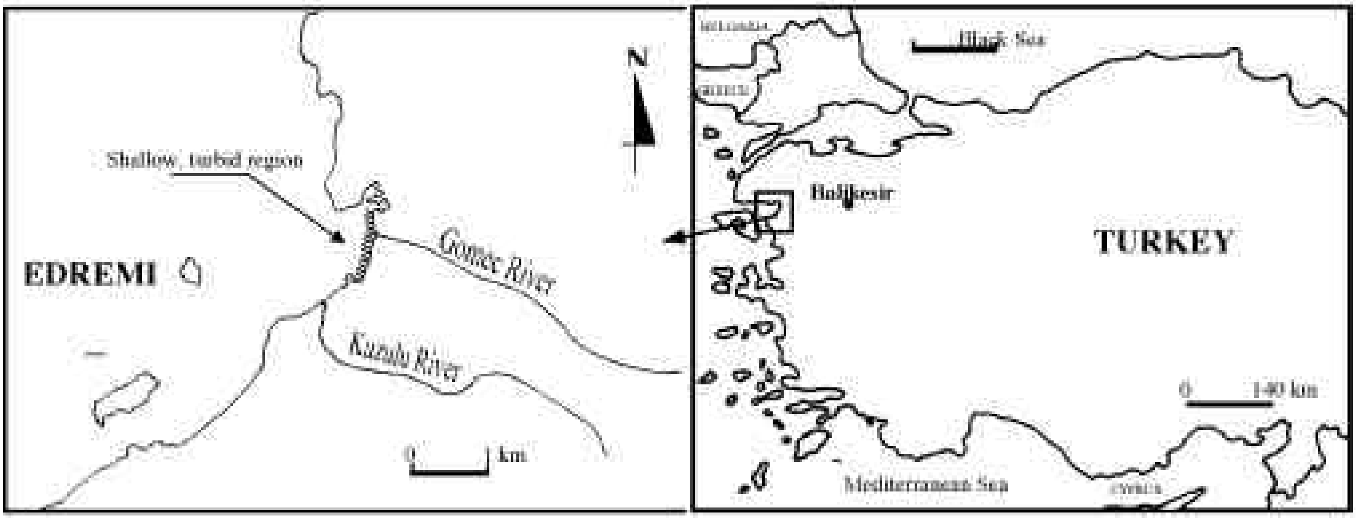

Figure 1. Location map

Figure 2. Gomec River mouth

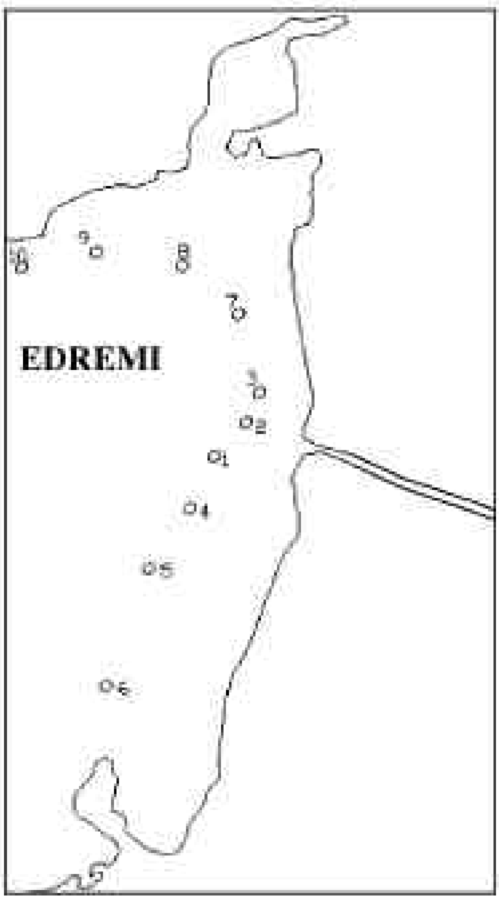

Figure 3. Measurement points

areas. This increased the erosion potential in the basin (STATE HYDRAULIC WORKS, 2000). Fertile soils coming from upper basin have been transported to the sea in the intensive precipitations during the last 40 years due to the lack of adequate river regulation studies, soil-saving dam. In February, 1998 floods caused damage to housing and food production in Gomec and as a result of this delta formation was enhanced.

FIELD MEASUREMENTS

In order to determine oceanographic properties of the delta region, field measurements were carried out in summer and autumn at 10 points as seen in Figure 3. The AANDERAA RCM 9 was used to measure flow velocity, flow direction, turbidity, temperature, and conductivity. The conductivity values were converted to salinity values. These measurements are given in Table 1 and 2. The coordinates were obtained with GPS. At the same time the wind speed was recorded by flowmeter. The summer measurements were completed over three days and the autumn measurements over two days. Tidal fluctuation was observed during these measurements. Measurement time for every point was approximately 30 minutes.

Table 1. Summer measurement

Point Number	Date	Flow Velocity (cm/s)	Flow Direction (Deg.M)	Turbidity (NTU)	Temperature (Deg.C)	Conductibility (Ms/cm)	Salinity (%o)
1	16.08.2001	6,356	207	3,764	19,2	51,916	38,4
	17.08.2001	7,334	203	2,216	19,0	51,916	39,0
	18.08.2001	8,800	228	2,092	19,1	51,916	39,1
2	16.08.2001	8,800	212	2,837	19,6	52,505	38,7
	17.08.2001	7,334	177	2,117	19,1	51,990	39,1
	18.08.2001	6,845	197	1,377	19,5	52,358	39,0
3	16.08.2001	6,356	218	2,514	19,6	52,653	39,1
	17.08.2001	4,400	187	2,315	18,9	51,695	38,7
	18.08.2001	7,334	201	1,082	19,6	52,505	39,1
4	16.08.2001	4,889	206	2,912	19,2	52,063	39,0
	17.08.2001	7,334	213	2,266	19,0	51,843	38,8
	18.08.2001	7,822	210	1,131	19,3	52,137	39,0
5	16.08.2001	8,311	222	1,968	19,7	52,653	39,1
	17.08.2001	9,289	228	1,524	19,5	52,358	39,0
	18.08.2001	8,800	206	0,887	19,3	52,063	38,9
6	16.08.2001	3,911	205	1,672	19,3	52,284	39,1
	17.08.2001	6,356	185	0,789	20,3	53,610	39,3
	18.08.2001	5,867	150	0,472	19,6	52,137	38,6
7	18.08.2001	3,911	105	1,672	19,2	52,063	39,1
8	18.08.2001	5,378	224	2,166	19,3	52,211	39,1
9	18.08.2001	6,356	210	1,131	19,7	52,653	38,9
10	18.08.2001	8,311	252	0,399	20,0	53,684	39,6

Table 2. Autumn measurement

Point Number	Date	Flow Velocity (cm/s)	Flow Direction (Deg.M)	Turbidity (NTU)	Temperature (Deg.C)	Conductibility (Ms/cm)	Salinity (%o)
1	10.11.2001 11.11.2001	2,44 5,38	228,5 27,42	0,84 1,25	14,46 17,35	50,66 45,73	39,0 34,9
2	10.11.2001 11.11.2001	1,96 6,84	236,63 199,01	1,30 0,54	17,68 17,11	50,89 46,32	39,2 35,5
3	10.11.2001 11.11.2001	3,42 1,96	255,61 132,55	1,62 1,87	17,65 18,23	50,81 51,33	39,1 39,6
4	10.11.2001 11.11.2001	5,38 0,98	222,21 223,27	0,54 0,35	17,48 17,34	50,66 51,03	39,1 39,4
5	10.11.2001 11.11.2001	2,93 2,44	248,58 51,33	0,94 0,35	17,06 17,22	50,15 50,89	38,8 39,1
6	10.11.2001 11.11.2001	4,40 2,44	45,00 112,51	0,52 0,35	17,15 17,23	50,52 50,89	39,1 39,1
7	10.11.2001 11.11.2001	1,47 4,40	150,84 71,02	1,08 1,87	17,52 17,10	50,66 51,03	39,0 39,5
8	10.11.2001 11.11.2001	5,38 2,44	91,06 127,28	0,84 1,87	17,55 17,85	50,81 50,81	39,0 38,9
9	10.11.2001 11.11.2001	4,40 2,93	349,49 178,96	0,79 1,87	17,50 17,66	50,74 51,18	39,0 38,7
10	10.11.2001 11.11.2001	1,96 1,47	250,50 215,18	0,89 1,87	17,46 17,88	50,66 51,11	39,1 39,4

Table 3. Classification of bottom sediment

	Clay and silt (%)	Sand (%)	Gravel (%)
Islet	1.99	91.05	6.96
Coast	3.68	60.03	36.29
River Mouth	32.55	62.88	4.57
Upper basin	23.87	61.66	14.47

In addition, the texture of bottom sediment samples from islets, beach, river mouth and upper basin were analysed in laboratory as shown in Table 3.

As illustrated in Table 1. bottom sediments at the river mouth and the upper basin have similar textural characteristics. These results indicate that the muddy coastal sediment originates in the Gomec River.

BASIC EQUATIONS

The equations that are used in this study are given below as:

The Equation of Continuity

The equation continuity is given by

$$\frac{\partial}{\partial x}(uH) + \frac{\partial}{\partial y}(vH) + \frac{\partial \eta}{\partial t} = Q \quad (1)$$

$$H = h + h \quad (2)$$

where h is mean water depth (m), h is change in water level (m), H is total water depth (m), u is velocity component in x- direction (m/s), v is velocity component in y- direction (m/s), t is time (s), Q is injected water (m3/s).

As the continuity equation includes three unknown variables u, v, and h, two more equations are required to complete the solution of the problem. These are given by the momentum equations in two directions and introduced in the following section.

The Momentum Equations

It is assumed hydrostatic pressure varies in all dimensions. The momentum equations in the x and y directions are then given by:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial \eta}{\partial x} + fv - \frac{g}{HC^2}(u^2 + v^2)^{1/2}u + \dots$$
$$\dots + \frac{k}{H}W_x|W| - \frac{Q}{H}(u - u_o) \quad (3)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial \eta}{\partial y} - fu - \frac{g}{HC^2}(u^2 + v^2)^{1/2}v + \dots$$
$$\dots + \frac{k}{H}W_y|W| - \frac{Q}{H}(v - v_o) \quad (4)$$

The Coriolis parameter f, is defined as

$$f = 2\ w \sin j \quad (5)$$

where j is the latitude and w is the Earth's rate of rotation, equal to $7.2722¥10^{-5}s^{-1}$. The wind shear stress parameter, k, is defined as:

$$k = \frac{\rho_a C_D}{\rho} \quad (6)$$

where g is acceleration of gravity (m/s^2), C is Chezy bottom friction coefficient m1/2/s, r_a is density of air (kg/m^3, C_D is wind drag coefficient, r is fluid density (kg/m^3), W_x is wind velocity in x-direction (m/s), W_y wind velocity in y-direction (m/s), is wind speed (m/s), u_o is velocity of injected water in x-direction (m/s), v_o is velocity of injected water in y-direction (m/s).

NUMERICAL MODEL

A numerical model was applied to investigate the hydrodynamic factors that contribute to delta formation at Gomec River mouth. The hydrodynamic model Aquasea was used. This programme was developed by Vatnaskil Consulting Engineers to solve shallow water flow and transport equations using the Galerkin finite element method. This model consists of a hydrodynamic flow model and transport-dispersion model.

The flow model can simulate water level variations and flows in response to various forcing functions in lakes, estuaries, bays and coastal areas. The water levels and flows are approximated in a numerical finite element grid and calculated on the basis of information on the bathymetry, bed resistance coefficients, wind field and boundary conditions.

The transport-dispersion model simulates the spreading of a substance in the environment under the influence of the fluid flow and the existing dispersion processes. The substance may be a pollutant of any kind conservative or non-conservative, inorganic or organic salt, heat suspended sediment, dissolved oxygen, inorganic phosphorus, nitrogen and other water quality parameters.

The model equations are approximated using a Galerkin finite element method on triangular elements in this programme (Figure 4). Continuous approximations are used for water elevation (h and H) and concentration, temperature or suspended sediments (c), linear within elements, but stepwise constant approximations for the velocities (u and v). Such a choice has been shown to lead to spatially stable approximations.

Boundary conditions must be applied to the external boundary of the model. Boundary conditions on closed internal boundaries are also permitted. These boundaries should have nodes on one side only. The default boundary condition on a newly defined boundary is no flow (or no flux for transport). Nodes on the boundary can subsequently be assigned sine wave/fixed values. Non-zero flow boundary conditions are most readily defined by applying a source/sink on nodes at the boundary (VCE, 1998).

Numerical Model for Gomec

The mesh was generated on triangular formation by inserting nodes manually (Figure 4).

In order to generate correct bathymetry, additional nodes were inserted at fast-varied depth sections. The mesh density was also greater inner parts of region than open external boundary.

The conditions defined in external boundaries are 'no slip'u = v = 0 for solid surfaces and time-dependent values for the open external boundary.

In order to test the model we defined only tidal effects on the open section and compared the results with measured values (Figure 5a and Figure 5b.). Two different scenarios were run for the study area. The first included tidal effects with a 12 m^3/s flood flow, which was calculated from hydrological studies by rational methods (Figure 7). H¢tide denotes height of tidal wave. In the second simulation only wave effects, which were obtained from a wave climate study, were considered and results are given in Figure 8. In the wave climate study, the measurements of Edremit Meteorology Station and the CERC Method were used. The average wave height was calculated as 1.05 m. and wave period as 6 sec.

THE RESULTS OF NUMERICAL MODEL

The results the numerical model study were compared with measured velocities, taken from local measurements in Figure 5a, Figure 5b and Figure 6. The numerical model velocity results and measured velocities agree in magnitude and direction. For example measured velocity values at 1st, 2nd and 7th points are 2.44 cm/s, 1.96 cm/s, and 1.47 cm/s, whereas calculated velocity values are 1.80 cm/s, 1.80 cm/s, and 1 cm/s, respectively.

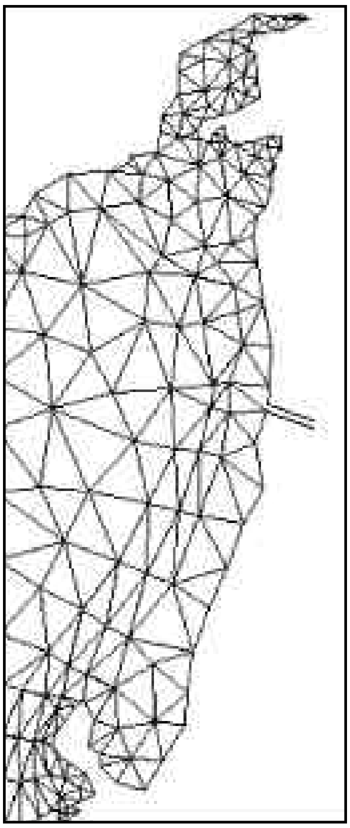

Figure 4. Mesh of study area

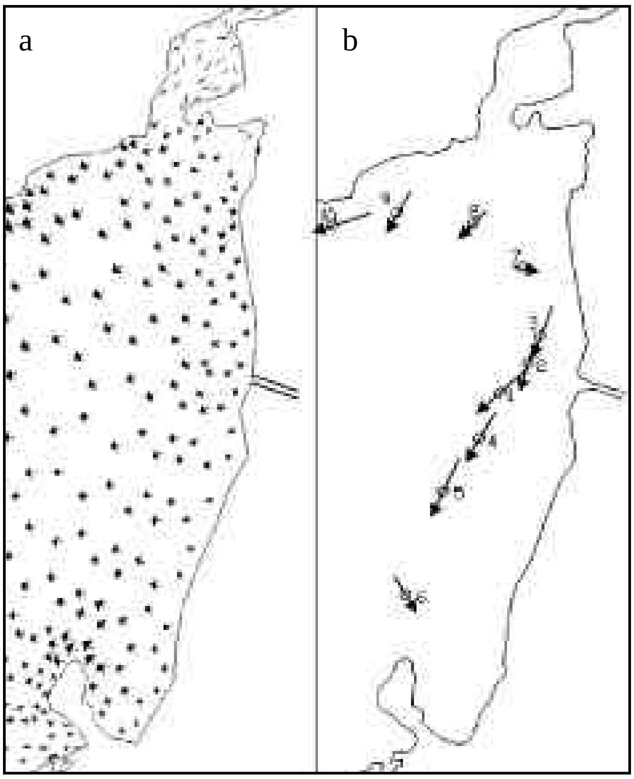

Figure 5 a. Calculated velocity vectors (H¢tide=0.60 m.,Ttide = 6 h.)
b. Measured velocity vector

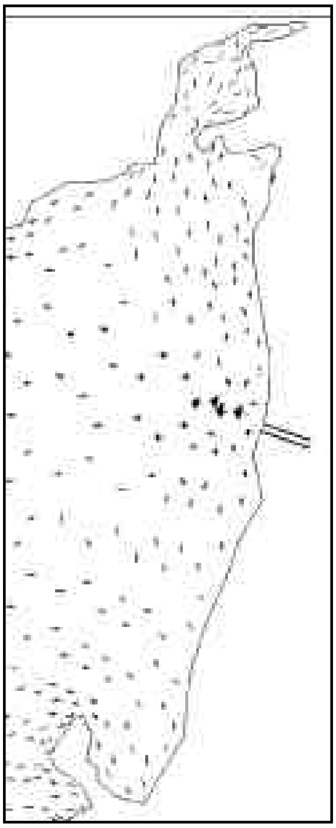

Figure 6. Velocity vectors (H¢tide =0.60 m., Ttide = 6 h. and Q = 12 m^3/s)

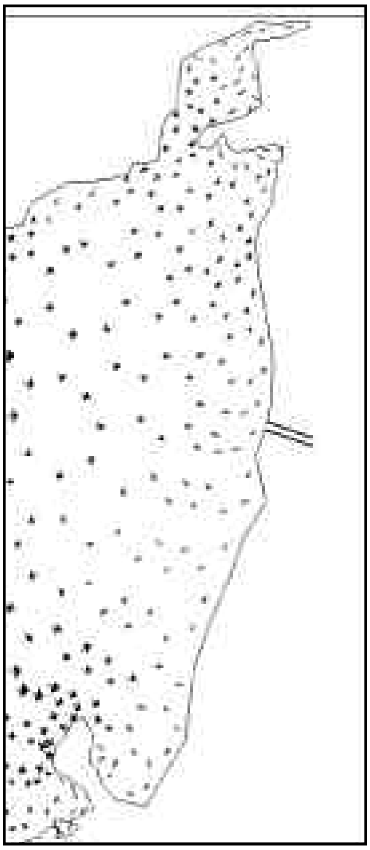

Figure 7. Velocity vectors (H¢wave =1.05 m. and Q = 0 m^3/s)

CONCLUSIONS

The first model scenario indicates that sediment transported by flood accumulates at nearshore region (Figure 6)

Under the second scenario, in the absence of flow from the river, the sediment is transported to the lagoon region by waves and accumulates in the nearshore region (Figure 7).

If the sediment transported from upper basin is not reduced, by sediment-retaining dams on the Gomec River or, afforestation and terracing works in the upper catchment, delta formation will continue. The results highlight the need for coastal zone management to be integrated with river basin management.

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