A STUDY OF THE DELTAIC COAST MORPHOMETRY OF RIVER PINIOS IN RELATION TO ITS HYDRO- & SEDIMENT DYNAMICS

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Abstract

This paper refers to the study of the morphodynamic processes, on a seasonal basis, in the river delta of Pinios (Greece) with the application of the discharge effectiveness index (Ef) -which associates the water discharge (D) with the wave power (P)- and the estimation of the potential longshore sediment transport (Ql). The delta is characterised according to the classification proposed by Galloway (1975) and revised by Briggs et al (1997), as wave/fluvial dominated type of delta, having a cuspate shape like the deltas of San Francisco and Rhone. Wave processes are dominant during summer-autumn period (low values of Ef) and river processes are important in winter and spring (high values of Ef). The total potential longshore sediment transport is northwards and more intensive in the region to the south of its current mouth.

Key words: *discharge effectiveness index, Holocene, Aegean Sea.*

Περίληψη

Η παρούσα εργασία ασχολείται με τη μελέτη των μορφοδυναμικών διεργασιών, σε εποχιακή βάση, του δέλτα του ποταμού Πηνειού με τη χρήση του "δείκτη αποτελεσματικότητας της ποτάμιας απορροής" (Ef) -που συσχετίζει την παροχή νερού (D) με την κυματική ισχύ (P)- και τον υπολογισμό της δυνητικής παράκτιας στερεομεταφοράς (Ql). Το δέλτα ταξινομείται σύμφωνα με την ταξινόμηση που προτάθηκε από τον Galloway (1975) και αναδιαμορφώθηκε από τους Briggs et al (1997), ως δέλτα θαλάσσιων / ποτάμιων διεργασιών με ακιδωτό σχήμα όπως τα δέλτα του Sao Francisco και του Ροδανού. Οι κυματικές διεργασίες κυριαρχούν την περίοδο καλοκαίρι-φθινόπωρο (χαμηλές τιμές του δείκτη Ef) ενώ οι ποτάμιες διεργασίες είναι σημαντικές το χειμώνα και την άνοιξη (υψηλές τιμές του δείκτη Ef). Η συνολική δυνητική παράκτια στερεομεταφορά είναι προς το Βορρά και είναι πιο έντονη στην περιοχή νότια από το σημερινό στόμιο.

Λέξεις κλειδιά: *δείκτης αποτελεσματικότητας της ποτάμιας απορροής, Ολόκαινο, Αιγαίο πέλαγος.*

1. Introduction

Delta shapes and configurations adjoining seas and oceans are the result of fluvial-marine interaction; this involves factors such as water/sediment discharge, wave activity, tidal range,

winds, and nearshore currents (Wright 1985). For the analysis of the delta systems, a trilinear classification (fluvially, wave and tidally dominated) was derived by Galloway (1975) and revised by Briggs *et al.* (1997).

In the case of Greek deltas, such as Pinios, where the marine environment is microtidal, delta formation is a result of the interaction between fluvial and wave processes, where the quantitative inter-relationship is given by the "discharge effectiveness index" (Wright and Coleman 1973). The higher the index is, the greater the ability of the river to form its own delta geometry. Moreover, (for the case of Greek river deltas) the seasonal variations of water and sediment discharge can also play a significant role in delta formation.

The aim of the present contribution is to describe qualitatively and quantitatively the morphometry of the deltaic coast of R. Pinios, on the basis of Galloway's (1975) classification, the Wright and Coleman's (1973) discharge effectiveness index and the potential longshore sediment transport on a seasonal basis. The delta of the R. Pinios (drainage basin area 10.850 km^2) was chosen as representative of medium sized Mediterranean river systems e.g. Souman (Algeria) (drainage basin area 8.500 km^2), Goksu (Turkey) (drainage basin area 10.561 km^2), Arno (Italy) (drainage basin area 8.183 km^2) and Vijose (Albania) (drainage basin area 6.706 km^2) which have developed in coastal zones exposed to the open sea wave activity.

2. The Study Area

Figure 1 – Location of the Pinios river delta (original picture from Google Earth 2006)

The R. Pinios drains into the southern part of outer Thermaikos Gulf, in the northwestern part of the Aegean sea. The length of R. Pinios is about 257 km and the total catchment area is about 10.850 km^2, most of it having elevations lower than 300 m, while the higher areas are restricted to its northern boundary where heights are in excess of 1.500 m. As far as the deltaic area is concerned, it is about 69 km^2.

The lithology of the catchment area consists of alluvial and clastic deposits (68 %), calcareous formations (11,5 %), metamorphic rocks (15,2 %) and igneous rocks (5,3 %) (Poulos *et al.* 1996).

The climate of the nearshore part of the R. Pinios catchment can be described generally as "Mediterranean" while its central area is closer to the "continental" type with less rainfall and larger seasonal variations in air temperature.

The mean monthly water discharge of the R. Pinios is about 81 m^3/s (Therianos 1974) while the mean monthly discharges of the river are shown in Table 1. According to Poulos et al (1996) the annual suspended sediment load for R. Pinios accounts to 5,9x10^6 t.

Table 1 - Water Discharge in m^3/s (Therianos 1974)

J	F	M	A	M	J	J	A	S	O	N	D	AVERAGE
161	160	115	93	71	32	12	11	25	59	61	171	80.92

Due to the lack of monthly (seasonal) sediment flux measurements for the R. Pinios, its monthly variation of sediment load is deduced from the comparison between the measured water discharges of R. Pinios with the monthly values of water and sediment discharges of R. Aliakmon (Table 2), which is located to the north of R. Pinios, having a part of their catchment boundary in common. Moreover, both rivers having their catchments to the east of the Pindos mountain chain are characterized by similar lithological, climatic and hydrological conditions (Mimikou 1982).

Table 2- Monthly water discharge of the R. Aliakmon (D in m^3/s) (Therianos 1974) and suspended sediment load (S x10^6 in tones) (data made available by the Public Power Corporation)

	J	F	M	A	M	J	J	A	S	O	N	D	AVER.
D	116	121	137	102	77	47	29	21	22	26	62	113	72,75
S	8.04	12.84	7.00	4.41	1.85	0.35	0.21	0.03	0.15	0.62	6.17	11.30	4.41

The mean tidal range in Thermaikos is 19cm (Tsimplis 1994). The delta area is exposed to relatively high wave attack, due to the long fetches available from the north (about 105 km), the northeast (60 km), the east (123 km) and southeast (275 km). The bottom topography of the receiving basin is highly steep with slopes of 10 % and the depth overcomes 50 m at about 2,5 km from the shoreline (Poulos *et al.* 1996). The sediments of the receiving basin have a zonal distribution, because of the high values of wave power, from sand to clay and mud.

3. Materials and Methods

For the morphometric classification of the delta of R. Pinios, the satellite image from Google Earth (Fig. 1) and the classification proposed by Galloway (1975) and modified later by Briggs *et al.* (1997) have been used.

In order to describe quantitatively the relationship between river discharge and wave power on a seasonal basis, the "discharge effectiveness index" (Ef), as proposed by Wright and Coleman (1973), and given by Equation 1, has been utilised:

Equation 1 – Discharge Effectiveness Index

$$Ef = \frac{D}{b} \times \frac{1}{P}$$

where, D is the river discharge (in m^3/s), b is the channel width at the river mouth (in m), and P is the wave power per unit wave crest (in W/m).

Seasonal river water discharges were abstracted from Therianos (1974) and river mouth length was measured on the topographic chart Rapsani 1:50.000 (Institute for Geology and Mineral Exploration)

Wave power was calculated in offshore conditions and at breaking zone, using the Equation 2 (CERC, 2000):

Equation 2 - Wave power

$$P = \frac{1}{8} \times \rho \times g \times H^2 \times Cg$$

where, P is measure in W/m, Cg is the group velocity of the waves in m/sec, H is the wave height in m, ρ is the density of the sea water in kg/m^3 and g is the acceleration due to gravity in m/s^2.

Wave characteristics required for the calculation of wave power offshore have been estimated using wind data from Wind and Wave Atlas (Athanasoulis and Skarsoulis 1992) and wave forecasting equations as proposed from Coastal Engineering Research Centre (CERC 2000), while wave characteristics required for the calculation of wave power at the breaking zone have been estimated using the numerical model CEDAS (Coastal Engineering Design & Analysis System), with the bathymetry obtained from the topographic chart Rapsani 1:50000 (Institute for Geology and Mineral Exploration).

The derived seasonal wave power has been multiplied by the corresponding seasonal percentage of wind duration for each fetch direction, was used in order to calculate the actual wave power for each season.

For the estimation of the longshore sediment transport, which affects delta morphometry, we used the seasonal potential longshore transport rate Ql that is given by the Equation 3 (CERC 2000):

Equation 3 - The potential longshore transport rate

$$Ql = \frac{0,39 Pl_b}{g \times (\sigma - \rho) \times \alpha'} \qquad \text{in (m}^3\text{/sec)}$$

where, Ql is measured in m^3/s, g is the acceleration due to gravity in m/s^2 the σ and ρ are the densities of sediment (2650 kg/m^3) and saltwater (1025 kg/m^3) respectively, a=0,6 (representing the sand porosity) and Pl$_b$ is the longshore energy flux factor given by the relation:

Equation 4 - Longshore wave power

$$Pl_b = 0,0884 \times \rho \times g^{3/2} \times H_b^{5/2} \times \sin 2\alpha_b$$

where, α$_b$ is the angle between the wave crest and the coastline and H$_b$ is the wave height at the breaking zone in m; the latter are provided by the CEDAS.

4. Results and Discussion

The delta of R. Pinios is cuspate in shape (Fig. 1). being similar to that of river San Francisco and Rhone. Thus, on the basis of its morphometry and according to Galoway's (1975) classification, wave energy is the dominant process in its formation while river processes (water and sediment fluxes) also play an important role. The seasonal variability in water discharge of R. Pinios is analogous to that of R. Αλιάκμον (Table 3; Fig. 2), both presenting their highest values in winter. According to Figure 2 the seasonal sediment load in Pinios river is expected to be similar, as far as the seasonal variations concerned, to the sediment load of Aliakmonas river with minimum

values in summer and autumn (about 14,2 % of the total) and maximum values in winter and spring (about 85,8 % of the total) following the variation of water discharge.

Table 3 – Seasonal variation of water (D) and suspended sediment (S) discharge of the rivers Pinios and Aliakmon

|		SPRING	SUMMER	AUTUMN	WINTER	TOTAL
PINIOS	D (m^3/s)	93.00	18.33	48.33	164.00	*323.66*
ALIAKMON	D (m^3/s)	83.88	14.73	22.14	84.58	*20.33*
	S(x10^6t)	*4.42*	*0.20*	*2.31*	*10.73*	*17.66*
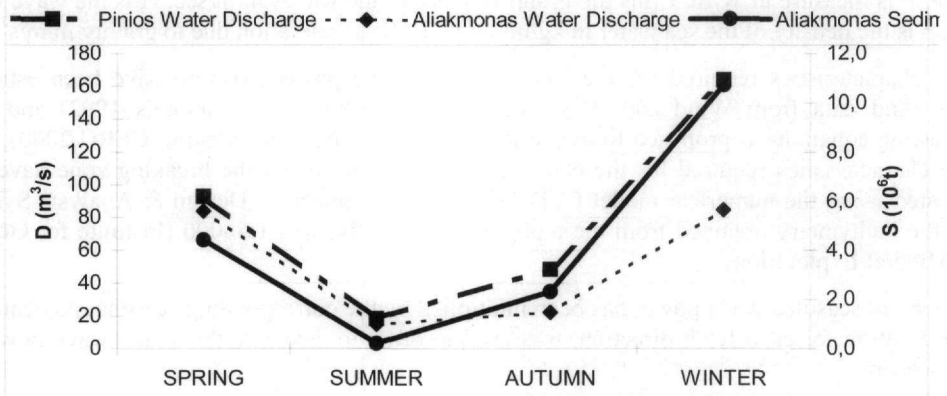
Figure 2 - Seasonal variation in water discharge (D in m^3/s) of rivers Pinios and Aliakmonas and sediment load (S x10^6 in t) of river Aliakmonas

Seasonal water discharges, derived wave power and calculated effectiveness indices (offshore and at the breaking zone) are listed in Table 4 and presented schematically in Figures 3 and 4. As it can be seen wave power is reduced from offshore to the breaking zone while discharge effectiveness index is increased. Moreover, high values of wave power occur in spring, autumn and winter.

The Ef values of river Pinios in comparison with other cuspate shaped world deltas like San Francisco (Ef=6.27x10^{-3} ; Wright and Coleman 1973) are higher due to the different spatial scale of these two systems. Therefore, successful comparisons can be made between analogous river/delta systems, as for example between the rivers Pinios and Aliakmon, (offshore Ef=2.40x10^{-2}; from Poulos *et al.* 1993) with the latter being characterized as fluvial dominated, as it has being formed in the semi-enclosed embayment of the inner Thermaikos Gulf.

Table 4 - Seasonal water discharges (D), wave power (P; per unit crest width) and discharge effectiveness indices (Ef) for the R. Pinios

	SPRING	SUMMER	AUTUMN	WINTER	AVERAGE
D (m^3/s)	93.00	18.33	48.33	164.00	*80.92*
P (W/m) offshore	89.99	52.10	304.97	107.94	*138.75*
Ef (x10^{-2}) offshore	0.47	0.16	0.07	0.69	*0.27*
P (W/m) at breaking zone	56.14	15.57	95.23	39.94	*51.72*
Ef (x10^{-2}) at breaking zone	*0.75*	*0.54*	*0.23*	*1.87*	*0.71*
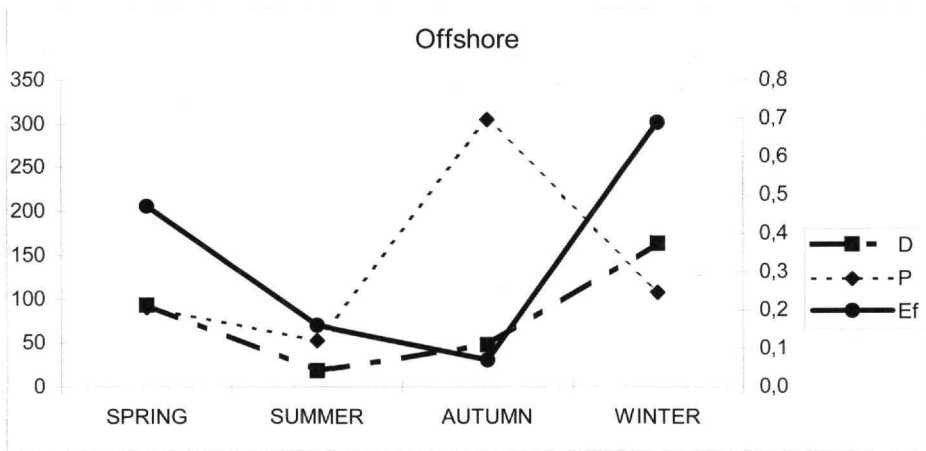
Figure 3 - Seasonal variation in water discharge (D in m³/s), wave power (P in W/m) and discharge effectiveness index (Ef) in offshore conditions (In the left column is the scale for D and P while in the right column is the scale for Ef)
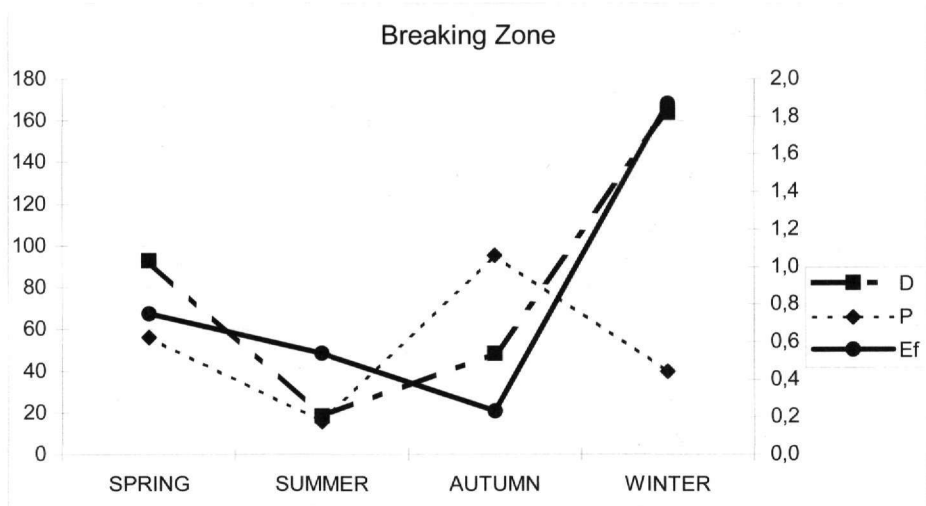

Figure 4 - Seasonal variation in water discharge (D in m3/s), wave power (P in W/m) and discharge effectiveness index (Ef), at breaking zone (In the left column is the scale for D and P while in the right column is the scale for Ef)

In spring, river discharge levels and wave power values (Figure 4) are very high (93.00 m³/s and 56.14 W/m respectively) decreasing to their minimum during summer (18.33 m³/s and 15.57 W/m respectively) with analogues reduction of the discharge effectiveness index. The latter reaches its minimum value in autumn (0.23×10^{-2}) because of the combination of high wave power (95.23 W/m) and low water discharge (48.33 m³/s). In winter the discharge effectiveness index reaches its maximum (1.87×10^{-2}) due to the high river discharge (164.00 m³/s). Thus, in the period from winter to spring, the corresponding high values of Ef suggest deltaic progradation while in the period summer-autumn the low values of Ef combined with the increased values of wave power, which are the highest in autumn, indicate that river delta is dominated by wave induced processes and the associated nearshore sediment transport.

The potential longshore sediment transport rate Ql has been calculated for the four regions of the deltaic coast, which have been defined according to their orientation (see Fig. 5). The seasonal values of Ql are given on Table 5.

Table 5-Potential longshore transport rate Ql (x10³) m³/season (+ transport from N to S)

REGION	SPRING	SUMMER	AUTUMN	WINTER	SUM
1	99.37	110.86	478.28	87.06	775.57
2	-350.21	-1.23	-527.23	-222.29	-1100.96
3	-1187.78	-457.20	-2020.02	-971.14	-4636.14
4	-20.76	-16.12	-87.30	-38.27	-162.44
SUM	-1459.38	-363.68	-2156.27	-1.144.64	-5123.97
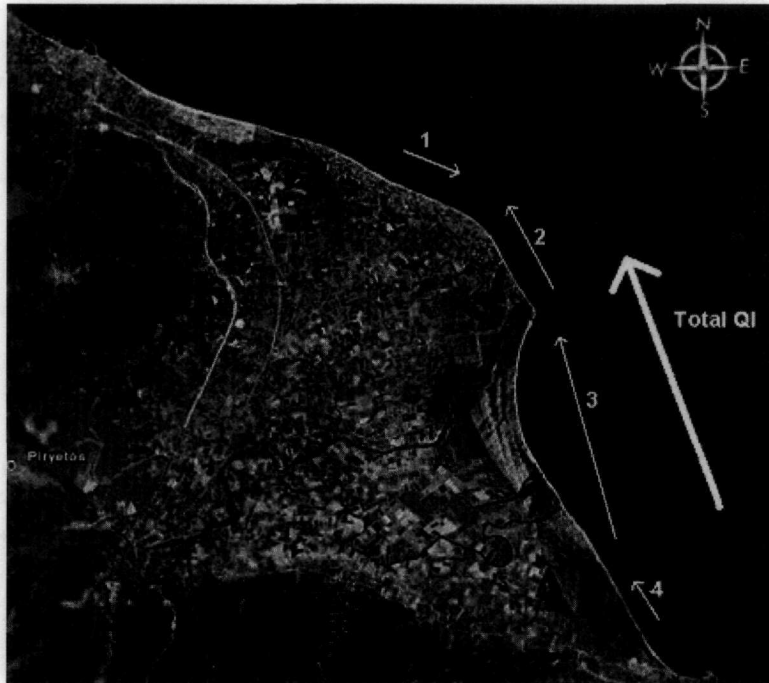
Figure 5 – Direction of the potential longshore transport in regions (1,...4)

In region 1 the potential longshore transport is from NW to SE while in regions 2, 3 & 4 the potential longshore transport is from S to N; hence, the overall annual potential longshore transport is from the S to the N. Furthermore, this northward direction of the potential longshore transport is preserved at all the seasons reaching the highest value in autumn (when Ef reaches also its highest value). The above is in agreement with the morphometry of the area near the delta mouth where the northern part is more developed in comparison to the southern part, in which a shoreline retreat during the last decades has been reported by Stournaras and Galani (1995); this retreat has been attributed to human activities and the natural abandoned of the old river mouth in the 1930's from a southern position (village Stomion) to the position that it is today.

5. Conclusions

The shape of the deltaic coast of R. Pinios is cuspate. Its morphometry is attributed primarily to wave and secondarily to riverine processes. Deltaic progradation takes place mostly in winter and spring.

The overall longshore sediment transport is directed to the north reaching its highest value during autumn and spring being more pronounced in the region located to the south of the modern river mouth.

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