AN INVESTIGATION OF THE IMPACT OF THE CLIMATE CHANGE ON RIVER DELTAS: CASE STUDY: THE DELTA OF R. PINIOS (THESSALY, GREECE) - CONCEPT AND PRELIMINARY RESULTS ON SURFACE WATER ENVIRONMENTAL STATE.

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ABSTRACT

The scope of the research project is to investigate the consequences of climate change on deltaic plains, as one of the most vulnerable coastal and wealth-producing ecosystems. The Pinios river delta, located in the region of Thessaly (Greece) has been selected as a case study, as one of the largest Greek rivers with very limited flow controls. But, despite the fact that deltaic plain is part of the NATURA network, human intervention continuous to occur at an increasing rate. The main objectives of the project are to: (i) study the relative contribution of fluvial fluxes (water/sediment), nearshore hydrodyanmics and climate conditions in the formation and evolution of deltas; (ii) evaluate the impact of human activities in the evolution of the River Pinios delta (e.g., alteration of riverine fluxes, agricultural pollution, over-pumping of the aquifer); (iii) assess and to evaluate quantitatively changes in the deltaic environment for different climate change scenarios, i.e. water balance, issues of water quality, desertification, coastal erosion, inundation; (iv) investigate the interaction between natural processes and parameters associated with socio-economic development and use; (v) develop Sustainable Development Strategies for the natural deltaic system, in order to mitigate the consequences of the climate change, towards a better management of the wealth-producing resources (i.e. fresh water yield); (vi) contribute to the training of young scientists in environmental issues, related to the impact of the climate change on coastal environments; and (vii) disseminate science based management strategies to the local and scientific communities. During the first phase of project implementation, the study of the surface and ground water and their interrelationship is investigated through: (i) the climatological conditions of the deltaic plain and the drainage basin; (ii) the determination of the subsurface geological/stratigraphical information provided by geophysical data; (iii) surface and water fluxes estimated on monthly measurements (quantitative and qualitative) of river flow and phreatic water table.

Keywords: Pinios Delta, climate change, water quality, river discharge, hydrology

1. INTRODUCTION

The coastal zone is of great environmental and social importance, as it includes a large number of coastal environments (e.g. coastal lakes, lagoons, deltas). Physical processes and human intervention can highly influence river delta formation and evolution. Climate change is expected to have an impact on coastal environments through (Mackay, 2007): (i) surface water flow and accumulation (i.e., changes in river flows as well as lake and wetland levels); (ii) groundwater recharge rates (i.e., the renewable groundwater resource and related levels); (iii) flood and drought events, depending previous meteorological conditions of the river systems (i.e. precipitation, air temperature, wind regime, humidity); (iv) erosion and sediment transport related to total rainfall amount and intensity and sediment transport; (v) water quality degradation due to increased water temperature and variations in runoff, affecting human health, ecosystems, and water use and finally; (vi) mean sea-level rise, i.e. the increase of global average sea level rise from ~1.8 mm/year, in the period 1961-2003, to ~3.1mm/year from 1993 to 2003.

Obviously, the low-lying coastal areas would be more vulnerable to climate change, with river deltas to be amongst them. The 17 largest deltas in Greece cover an area of some 4000 km^2, i.e. approximately 2000 km of the Greek deltaic coastline (~13% of the total coastline in Greece). Erosive processes such as the reduction of sediment supply due to dam construction had already affected them, while factors such as reduction of rainfall, temperature increase could led to desertification, while sea level rise could enhanced seawater intrusion and coastal inundation. Thus, it is of great importance for the national economy, to enhance the scientific knowledge in matters of environmental monitoring and management of the effects of climate change in the coastal zone, in general, and in particular in deltaic plains.

The scope of this contribution is, firstly, to provide a conclusive picture of the whole THALIS project (DAPHNE) and, secondly, to present some preliminary results concerning river discharge levels and quality of river waters.

2. THALIS PROJECT

2.1. Scope and objectives

The DAPHNE project aims: (i) to investigate the environmental impact of climate change on the natural evolution of river deltas; (ii) to consider scenarios of climate change and types of human intervention in order to develop new adaptation methods to relevant consequences (i.e. sea level rise); (iii) to train young scientists, post-graduate (MSc, PhD), in issues, such as the evolution and protection of sensitive coastal systems (i.e. river deltas); (iv) to collaborate with scientists from varying fields and to use state of the art methodologies and technologies, to describe at best the past, current and future characteristics of the delta.

The main objectives of this research are: (i) to analyze natural processes of the deltaic environment of Pinios river, assess their role in delta formation and development, and link them with existing and/or anticipated socioeconomic activities, such as land-use; (ii) to create an expandable geo-database for detailed assessment of delta vulnerability, considering climate change scenarios; (iii) to develop mitigating strategies for aspects of deltaic plain degradation (i.e. desertification, flooding, salinasation, and land-loss due to sea-level rise), for the different climate change scenarios being applicable to other Greek deltas.

2.2. Workpackages

The structure of the project incorporates the following work-packages (WP) (Table 1).

Table 1: Work-packages of the THALIS-DAPHNE project (duration: 42 months)

WP-1. PROJECT MANAGEMENT & COORDINATION	
1.1. Coordinating implementation actions	
1.2. Educational Dimension - Contribution in life-long learning	
1.3. Process of internal evaluation	
WP-2. GEO-ENVIRONMENTAL DATA BASE OF EXISTING INFORMATION	**WP-5. CHEMICAL COMPOSITION – WATER POLLUTION**
2.1. Deltaic evolution	**5.1.** Quality of fresh water of the Pinios river
2.2. Water management	**5.2.** Chemical environmental study of the surface and ground water of the deltaic plain
2.3. Chemical status of surficial & ground waters	**5.3.** Investigation of the influence of human activities to the quality of surface and ground waters
2.4. Geo-database design and construction	**5.4.** Chemical environmental study of the impact of the river inflow to coastal waters
WP-3. CURRENT STATUS OF DELTAIC SYSTEM	**WP-6. WATER BALANCE OF DELTAIC PLAIN**
3.1. Mapping of contemporary geomorphological & terrain features	**6.1.** Seasonal measurements of the Pinios river discharge and correlation with historical data
3.2. Contemporary climatological and meteorological features of the river system	**6.2.** Investigation of seasonal availability/consumption of surficial and ground water
3.3. Coastal oceanography and sediment dynamics of the coastal deltaic front	**6.3.** Simulation of the development of chemical quality in ground water flow and its seasonal variability
3.4. Mapping of surficial structures including human activities(e.g. land-use) by remote sensing techniques)	**6.4.** Management tool for the water yield of the Pinios delta area
WP-4. GEOPHYSICAL & HYDROGEOLOGICAL RESEARCH	**WP-7. APPRAISALS & PROPOSALS ON MANAGING CLIMATE CHANGE IMPACT**
4.1. Geology of the R. Pinios deltaic plain	**7.1.** Future climate change under different emissions scenarios
4.2. Geophysical survey	**7.2.** Consequences of atmospheric changes (rainfall, temperature) in water budget (surface and groundwater),
4.3. Lithostratigraphy modelling of Pinios River delta	**7.3.** Desertification of the deltaic plain
4.4. Revised groundwater regime	**7.4.** Consequences of climate change (sea-level rise, storm frequency) in the morpho -logical evolution of the deltaic plain
WP-8. RESULTS: EXPLOITATION AND DISSEMINATION	
8.1. Briefing of public & contracted stake-holders	
8.2. Building and maintenance of the projects' webpage	
8.3. Scientific publications	

2.3. Consortium (Research Teams)

The four participating Research Teams (RT) are: (1) Coastal Geomorphology & Oceanography of the Department of Geography & Climatology, Faculty of Geology & Geoenvironment, UOA); (2) Environmental Geophysics of the Department of Geophysics

& Geothermy, Faculty of Geology & Geoenvironment, UOA); (3) Environmental Chemistry of the Laboratory of Environmental Chemistry, Faculty of Chemistry, UOA); and (4) Water Resources Management, of the Department of Civil Engineering Infrastructures, TEI of Larissa. In addition, Prof. George Voulgaris, geologist with expertise on Coastal Ocean processes, from the Department of Earth and Ocean Sciences of University of South Carolina (USA) participates as invited scientist.

2.4. Case study: The Delta of R. Pinios (Thessaly)

The present research examines the various natural aspects and human interventions of the deltaic plain of Pinios River, within the concept of river system (as described by (Coleman and Wright, 1975) and shown schematically in Fig 1a. Pinios was selected as a case study due to the following reasons: (i) it is the largest Greek river with its drainage basin within the Greek borders; (ii) it is the only river in Greece with still limited flow control (in only less than 10% of its catchment); (iii) its deltaic plain is subject to socio-economic development that includes a variety of activities; (iv) its delta is recognized as an environmentally sensitive coastal zone protected by the NATURA 2000 network (RAMSAR convention); and (v) there is a significant amount of information regarding the environmental state of its deltaic plain that allows research on future climate change scenarios for its system. Moreover, the major socioeconomic and environmental problems that Pinios delta is facing currently are related to: (i) conservation of the natural landscape; (ii) the quality of deltaic surface water and its effects on the ecology of wetlands and coastal sea waters, (iii) ground water quality (i.e. salinesation); and (iv) retreat of its deltaic coastline.

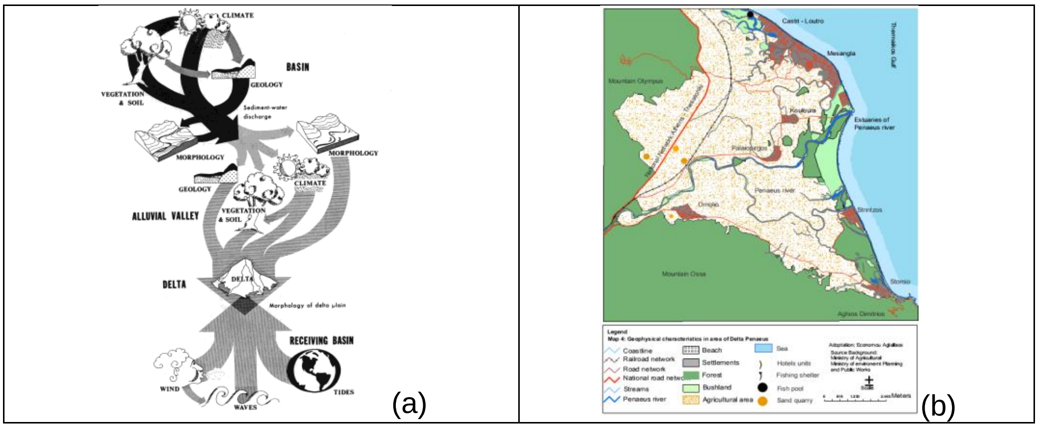

Figure 1: (a) Diagram representing the natural processes affecting a river system (Coleman and Wright 1975) and (b) Geophysical map showing the characteristics of the Delta of Pinios (Economou, 2009)

The drainage area of Pinios river covers an area of more than 10.000 km^2 with its upper part being mountainous (e.g., Olympus mountain, elevation of 2900 m) while the lower part is rather flat (e.g., Thessalian plain). Precipitation levels within its catchment vary from 400 to 1000 mm/year while the river's mean annual discharge ranges from 41 to 68 m^3/s. The Pinios deltaic plain (Fig. 1b) is approximately 62 km^2 and consists of alluvial (Holocene) sediment deposits characterized by vertical and lateral heterogeneity (I.G.M.E., 1982). Its cuspate shape indicates the dominance of wave activity on water/sediment influx (Foutrakis et al., 2007), considering the micro tidal character of Greek waters (Tsimplis, 1994).

3. DATA COLLECTION & METHODOLOGY RELATED TO HYDROLOGY

Fieldwork regarding on Pinios River deltaic plain hydrology began on July 2012 and will continue until October 2014. In table 2, the timeschedule of the data samplings are shown according to their area of study.

Table 2: Timeschedule of data sampling for the period 2012-2013

Type of Data	Frequency	Time-Period
Surface water samples, river discharge and free surface river level	Monthly	07/2012-9/2013
Ground water samples from wells in the river system	Monthly	07/2012-9/2013
In situ measurements of temperature, pH, conductivity and salinity of the water samples	Every 3 months	07/2012-10/2013
Water – sediments samples collected along the coast and the lower river route	Every 3 months	07/2012-10/2013
In situ meteorological data	continuous	1/4/2012
Geophysical surveys to determine the subsurface geological/stratigraphical information	Phase 1 Phase 2	2013 2014

3.1. Measurements of Pinios river discharge

The monthly measurements of river discharge are conducted, at three stations: bridges Gonnoi, Tempi-Agia Paraskevi and Palaiopyrgos, by using current flow meter (Valeport: models BFM 001 & 002). The in situ data will be in future time correlated with historical data provided by the Water Division of Thessaly. Water flow of secondary streams will be determined by water budget equations (Kotsopoulos, 2006). The *velocity-area* method is used in order to obtain accurate instant measurements of the river's discharge. During this method, flow velocities are measured at selected vertical points of known depth, across a pre-measured section of the river, at the Gonnoi, Agia Paraskevi and Palaiopyrgos bridges.

3.2. Surface water quality

Surface water samples are collected in thoroughly cleaned 2L Nalgene bottles either directly by hand or by lowering appropriate sampling apparatus from river bridges while sub-surface estuarine samples were collected with a Niskin type sampler. Afterwards, the samples are filtered either on the same day or at the latest in the next two days while kept in refrigerated conditions until filtration. The filtration procedure is conducted using Nalgene filtration apparatus and pre-weighted Millipore membrane filters (mixed cellulose esters types with 8μm and 0.45 μm pore diameter).

Suspended particulate material (SPM in mg/L) estimated after filtrating of the water samples. Main cations (Ca, Mg, K, Na, Cl^-, SO_4^{2-}) are determined using flame emission atomic spectrometry (FAAS, Varian SpectrAA 200) and the anions using ion chromatography (Metgrohm). Nutrients (NO_3, NO_2, NH_4, PO_4) are measured spectrophotometrically with a Varian Cary 1E UV-visible spectrophotometer. Dissolved trace metals (Cd, Cu, Fe, Mn, Pb, Ni, Zn), aliquoted of the filtered water samples, are pre-concentrated using Chelex 100 resin and measured with atomic absorption spectrometry (FAAS Varian SpectrAA 200, Graphite Furnace AAS Varian GTA 100-Zeeman 640Z with autosampler). All samples are measured also for total dissolved Cr with Graphite Furnace AAS (Varian GTA 100-Zeeman 640Z). Samples in which total dissolved Cr is detectable (>0.6 μg/l) are also analyzed within 2-4 days for Cr (VI) (ELOT/EN/ISO 18412-2006). In the case of saline water samples, where the concentrations are lower and atomic absorption direct measurements are questionable due to the complexity of the sample matrix, total dissolved Cr is also analyzed using a co-precipitation method.

4. PRELIMINARY RESULTS RELATED TO HYDROLOGY

4.1. Water discharge

In figure 2 the mean monthly in situ measurements of water discharges (m^3/s) of the present investigation (see also table 3) are presented against historical data that incorporates two data sets: 1975/76 -91/92 (Water Division of Thessaly) and 1903/04-08/09, 10/11, 32/33-41/42, 51/52-55/56 (Therianos, 1974).

As it can be seen the monthly values of the historical data almost coincide for the period April–September, while for the period October–March differ significantly; this although maybe partially attributed to the different sampling locations need s further investigation. Project's measurements (Oct., Nov. and Dec. of 2012) are in a very good agreement with the corresponding values for the period 1975/76 - 91/92, indicating a rather stable flow regime.

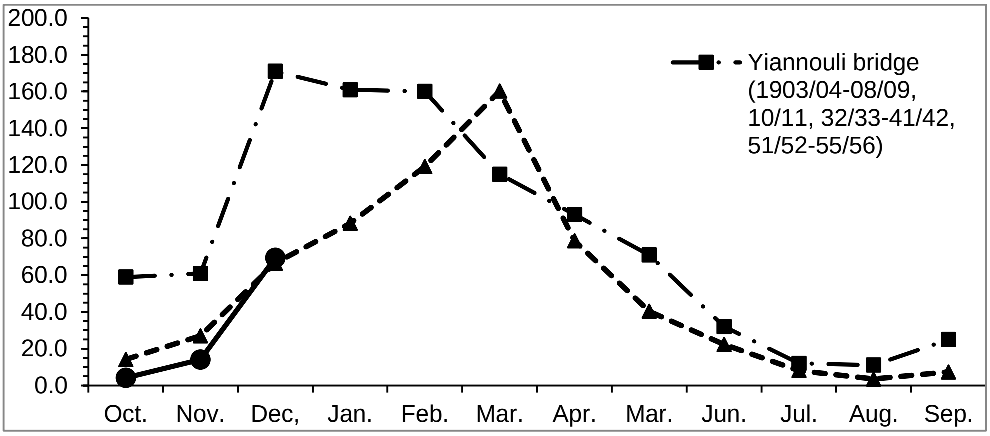

Figure 2: Monthly in situ measurements (•) of water discharges (m^3/s) compared with historical data (▲ : Water Division of Thessaly and ■: Therianos (1974)).

Table 3: R. Pinios. Monthly discharges (m^3/s) at two stations

Stations (location)	Coordinates	Oct. 2012	Nov. 2012	Dec. 2012
Agia Paraskevi bridge (at the valley of Tempi*)*	*39°52'44''N, 22°35'7''E*	4.2	14.1	69.5
Palaiopyrgos bridge (at the plain of the delta)	*39°54'49''N, 22°40'55''E*	5.6	19.1	75.8

4.2 Preliminary results of river water samples chemical analysis

A synopsis of the physical characteristics of the R. Pinios waters, spring water collected from the spring of Agia Paraskevi (Tempi) and at its lower route – mouth area is presented in table 3.

Table 3: Physicochemical parameters in water samples

Sample type	Temperature (°C)	Conductivity (mS/cm)	Salinity (psu)	pH	SPM (mg/l)
October 2012					
River water	17.3-23.9	0.539-0.602	0.3-0.4	7.6-8.6	8.3-39.3
Spring water	15.1-16.7	0.537-0.693	0.3-0.4	7.8-8.0	1.2-1.7
River mouth	18.5-23.4	4.52-55.1	2.4-36.8	7.5-8.0	3.8-36.3
November 2012					
River water	N/A	0.405-0.484	0.2-0.3	7.9-8.2	34.3-60.4
December 2012					
River water	N/A	0.328-0.387	0.2	7.2-7.5	pending

River waters from Tembi to its mouth area present a rather uniform picture with spring water to vary in terms of temperature and in SPM. Moreover no significant changes observed in river waters from October to December of 2012 with the exception of SPM, which has increases substantially in November. In general, the highest SPM concentrations in the river stations were always measured in Gonnoi bridge). The exceptionally high values of conductivity/salinity during October at the lower part of the river is attributed to sea water intrusion in river after the construction of a small dam for irrigation purposes about 1 km upstream from the bridge of Palaiopyrgos. At the bridge of Palaiopyrgos (approximately 4 km from the river mouth) the salinity of surface water was 1.3 psu, whilst at the subsurface layer (1.5-2 m below surface) salinity reached 27.8 psu.

The conclusive results of chemical analyses of water samples are presented in table 4. In the case of chromium, the maximum total dissolved concentrations did not exceed 50μg/l, which is the limit set by Hellenic and EU law.

Table 4: Ions, nutrients and dissolved Materials for sampling sites

Ions & Nutrients (μg/l)				**Dissolved metals (μg/l)**			
	River water	Spring water	River mouth		River water	Spring water	River mouth
Ca	60-475	116-194	285	**Cd**	0.03-0.69	0.04-0.17	0.06-0.29
Mg	20.5-942	19.7-23.3	668	**Cu**	0.19-1.3	0.24-18	0.33-1.1
K	1.1	0.8-0.9	259	**Cr**	<0.64-4.1	1.4-1.6	<0.64-1.2
Na	10.6-6257	7.5-8.0	4315	**Fe**	pend	pend	pend
Cl	pend	1.2-1.4	N/A	**Mn**	0.26-197	0.36-1.5	0.9-18.6
SO_4	pend	5.0-5.2	N/A	**Pb**	0.08-0.48	0.06-0.73	0.07-0.32
NO_3	0.22-3	1.1	0.34	**Ni**	pend	pend	pend
NO_2	0.002-0.058	0.002	0.005	**Zn**	4.1-33.5	4.3-71.8	12.9-23.1
NH_4	pend	pend	N/A				
PO_4	0.02-0.35	0.03	0.02				

5. CONCLUDING REMARKS

The expected benefits of the implementation of the THALIS DAPHNE project could refer: (i) to sustain agricultural development of coastal plains by addressing issues related to predictions of future water balance, local climatic conditions, coastline retreat; (ii) to help touristic development, mainly along the deltaic 'beach' front, that depends on the stability of the beach and water quality; (iii) to support coastal fisheries via the acquired knowledge on environmental status of coastal waters in relation to river discharge (nutrients, possible pollutants); (iv) to develop appropriate management tools and strategies, in line with the European and/or national environmental legislation, leading to a sustainable and integrated management; and (v) to educate local professionals, to inform the public and to train new scientists on MSc, PhD and PostDoc levels in issues of coastal environment.

Overall, the preliminary results do not show a significant alteration in water discharge compared to the period 1972-1995. The dissolved metal levels in the river are below the water quality criteria set by Greek and European law (Hellenic Republic 2010) for surface waters as well as existing US EPA water quality standards. However, as in the summer months a dam is constructed at the river's water downstream from Palaiopyrgos bridge, resulting in mixed sea and river water that should not be used for irrigation due to increased sodium and chloride levels can ause severe damage to plants (Loukas, 2010).

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