

Hydrodynamics Influence Assessment on Mondego Estuary Eutrophication Process

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ABSTRACT

The south arm of Mondego estuary, located in the central western Atlantic coast of Portugal, is stressing by an eutrophication process due to massive nutrient loading from urbanised areas and diffusive runoff from intensively agricultural areas. The consequence is a structural change of the ecosystem, where the turnover of oxygen and nutrients is much more dynamic and macroalgae play an important role in the nutrient pathways of the ecosystem. A sampling program was carried out at three benthic sample points and at three other sites (river Pranto sluice, Armazéns channel mouth and Gala bridge) for water column monitoring. Available field data analysis allows concluding that the occurrence of green macroalgal blooms is strongly dependent on the hydrodynamic conditions, precipitation and salinity gradients. The aim of this work is to assess the role of estuarine hydrodynamics on the non-attached macroalgae control and the magnitude of nutrients tidal balance. Residence times estimation, allowed by mathematical modelling, can provide essential information about estuarine hydrodynamic behaviour, considering different scenarios, in order to select the better water quality management practises.

KEYWORDS

Estuarine environment management; eutrophication, hydrodynamics, mathematical modelling, Mondego estuary.

INTRODUCTION

The physical and chemical dynamics and the ecology of shallow estuarine areas are strongly influenced by the fresh water runoff and the adjacent open sea. The fresh water input influences estuarine hydrology by creating salinity gradients and stratification and assures large transport of silt, organic material and inorganic nutrients to the estuaries. The open marine areas determine large scale physical and chemical forcing on the

estuarine ecosystem, due to tide and wind generating water exchange (Berner and Berner, 1996).

As a consequence of nutrient enrichment, opportunistic macroalgae growth was strongly stimulated allowing the occurrence of macroalgae blooms and the extinction of *seagrass* in more shallow areas. This situation may result in anoxic system collapse, with the development of hydrogen-sulphide conditions, lethal to rooted macrophytes such as *Zostera* spp. So, it becomes crucial to obtain information on the mechanisms that regulate the abundance of opportunistic macroalgae and its spatial and temporal distribution. Depending on the tidal amplitude, depth, cohesiveness of plant material, current velocity, wind and wave-induced vertical turbulence, plants growing in shallow areas are suspended in the water column and transported out and eventually settled in deeper areas (Sfriso et al, 1992). In this system, available data analysis allows to conclude that the occurrence of green macroalgal blooms is strongly dependent on the hydrodynamic conditions, precipitation and salinity gradients (Martins, 2000).

The aim of this study is to assess the role of estuarine hydrodynamics on the non-attached macroalgae control, because the quantitative aspects of this phenomenon are not well known. Hydrodynamic modelling of Mondego estuary is being implemented in order to estimate residence times, current velocity and salinity distribution at different simulated scenarios, considering average tidal conditions. This task integrates a research project for estuarine water quality assessment supported by a hydroinformatic environment with several modules: pre and post-processing tools, hydrodynamic models and water quality models.

In the last decade a major effort has been done in integrating hydrodynamic and water quality models for estuarine environments. The correct simulation of the circulation patterns and the biogeochemical processes, supported by mathematical models, constitutes a very powerful method for enhancing systems eutrophication vulnerability assessment, in order to select the better water quality management practises, considering different scenarios (Duarte et al., 2001).

STUDY AREA

The Mondego river basin is located in the central region of Portugal, confronting with Vouga, Lis and Tagus, and Douro river basins, from north, south and east, respectively. The drainage area is 6670 km² and the annual mean rainfall is between 1000 and 1200 mm. The estuary (40°08'N 8°50'W) has a considerable regional importance due to the Figueira da Foz mercantile harbour, but is under severe environmental stress, namely an ongoing eutrophication process, due to human activities: industries, aquaculture farms and nutrients discharge from agricultural lands of low river Mondego valley.

This estuarine system is divided into two arms (north and south) with very different hydrological characteristics, separated by the Murraceira Island (Figure 1). The north arm is deeper and receives the majority of freshwater input (from Mondego river), while the south arm of this estuary is shallower (2 to 4 m deep, during high tide) and is almost silted up in the upstream area (Figure 2). Consequently, the south arm estuary water circulation is mainly due to tides, wind and the usually small freshwater input of Pranto River, a tributary artificially controlled by a sluice.



Figure 1 - Location and aerial view of Mondego estuary.



noltii by green algae such as *Enteromorpha* spp. and *Ulva* spp.. There is a non-eutrophicated zone (site 1), where a macrophyte community (*Zostera noltii*) is present, up to a strongly eutrophicated zone (site 3), in the inner and shallower areas of the estuary, where the macrophytes disappeared while *Enteromorpha* spp. blooms have been observed during the last 15 years (Pardal, 1998)

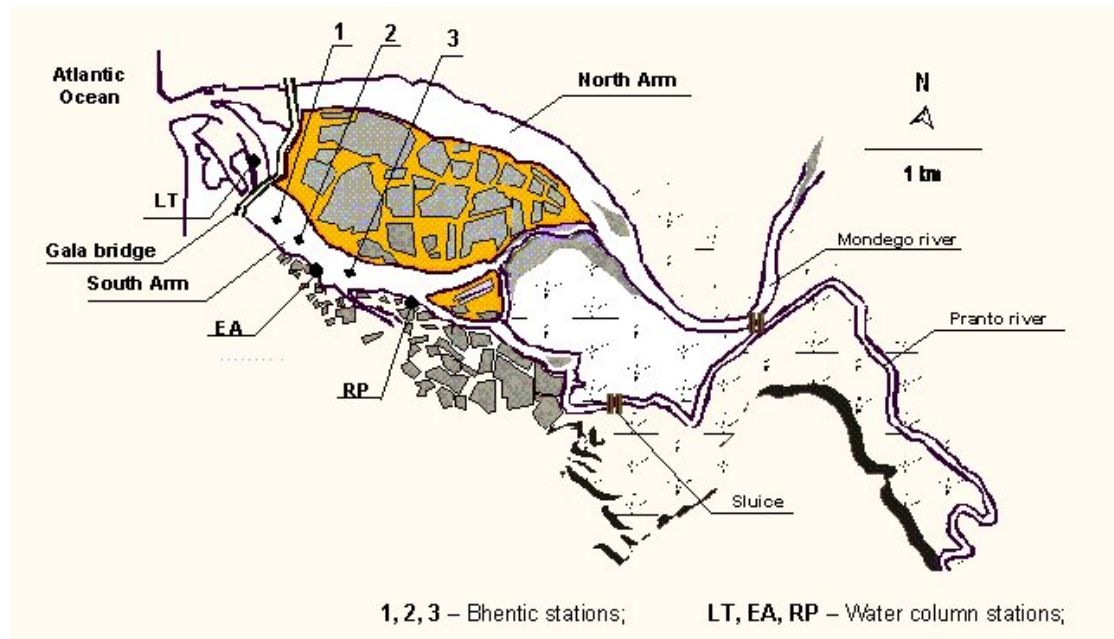


Figure 3 –Sampling stations location at south arm Mondego estuary

Most of the estuarine processes (physical, chemical and biological) are related to the salinity, because its variation, over a tidal period is one of the major characteristics of an estuarine system. Figure 4 shows the variation of salinity, water level and water speed during the tide cycle, being visible the increase of salinity with water level, when is hitting the high tide, and decreasing after that on the ebb point direction. The macroalgae blooms may not occur in exceptionally rainy years due to low salinity for long periods, as a result of the Pranto and Mondego rivers discharges (Pardal et al., 2000).

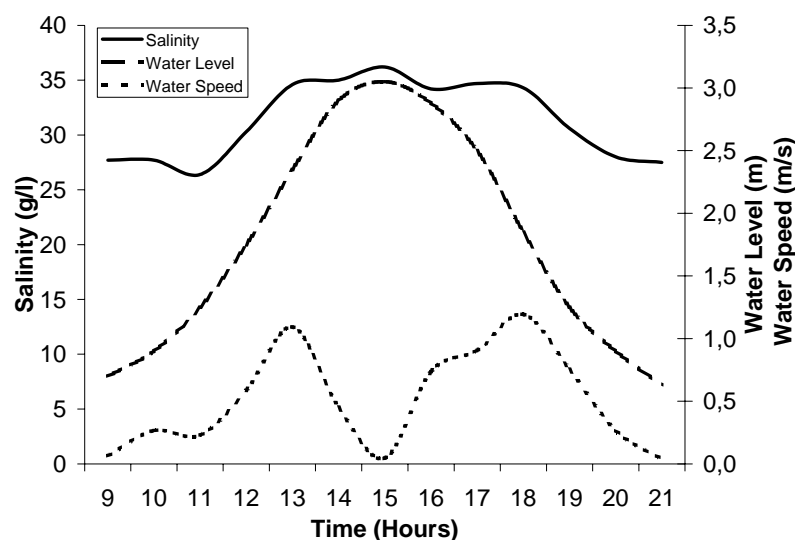


Figure 4 – Salinity, water level and water speed variation during tide cycle.

In the south arm of this estuary, the friction effect between the water and the bed is considerable and most noticeable during falling tide. So, the time of rising tide decreases at points farther inland and is much smaller than that of the fall.

Previous works (Martins et al., 2001) showed that spring blooms could occur when freshwater inputs into the system are little on both sides – from upstream (river Pranto sluice gates are often closed due to water deficit on rice fields) and from downstream (due to low influence of Mondego river water plume) – because salinity remains high, current velocities, turbidity and N/P ratios decrease, enhancing macroalgal growth and their fixation availability and reducing biomass losses to the ocean.

Since that nitrogen and phosphorus have an important role on the macroalgae growth, a monitoring program of those water nutrients were made on different parts of the system, so it could be integrated on the eutrophication processes that happen on the system. Nutrients dissolved on the water, bound on particulate matter and incorporated on vegetation (plants and algae) were quantified. Preliminary results are presented, respecting to a field sampling (on July 2001) carried out at the downstream exchange boarder of the south arm, near Gala Bridge. Hour samplings of water, suspended particulate matter and drifting vegetation were collected, to evaluate water nutrients transported. Simultaneously, attending to the relationships between external abiotic variables and macroalgae growth, temperature, salinity, dissolved oxygen and *pH* were also measured.

Mathematical modelling

Residence times (RT) are broadly recognised as important descriptors of estuarine behaviour and it can be a key parameter to assess hydrodynamic influence on estuarine eutrophication vulnerability, considering the effects of precipitation and river management practices on estuarine water quality. This dependency was suggested the usefulness of mathematical modelling application for residence times estimation, related with nutrients and macroalgae exportation or remaining periods in the south arm. The hydrodynamic model *RMA2* is used to compute water surface elevations and flow velocities for shallow water flow problems (US WES-HL, 1996). Figure 5 presents the 2D-H mesh considered in the estuary hydrodynamic modelling.

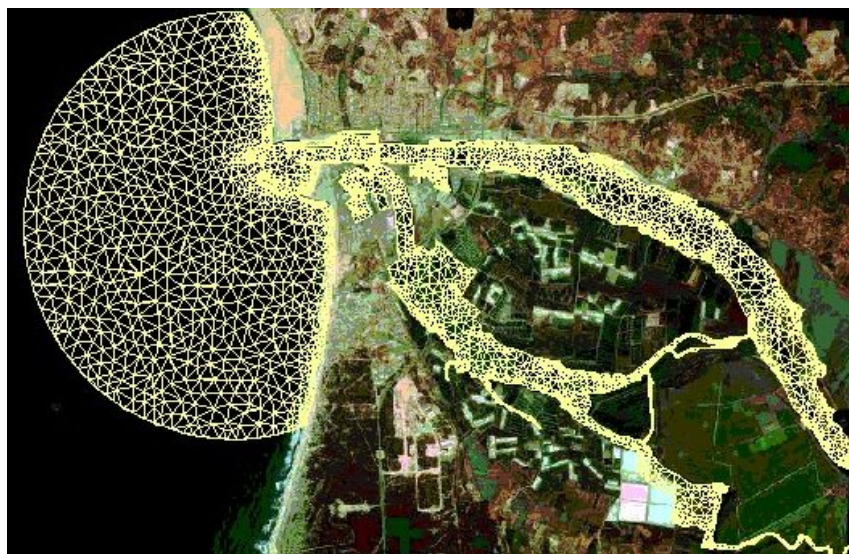


Figure 5 – Finite element mesh.

The quality model *RMA4* is an interface used to assess the migration and dissipation of a constituent, describing its concentration in two horizontal directions as a function of time and place. It uses the hydrodynamic solution from *RMA2* to define a flow velocity field for a given mesh and also reads a set of user-specified point loads as input.

RESULTS

Figure 6 presents the contributions of water dissolved, suspended particulate matter and vegetation tissues nutrients on tidal nitrogen and phosphorus balance, respectively. All different contribution of exported nutrients were higher than the imported ones.

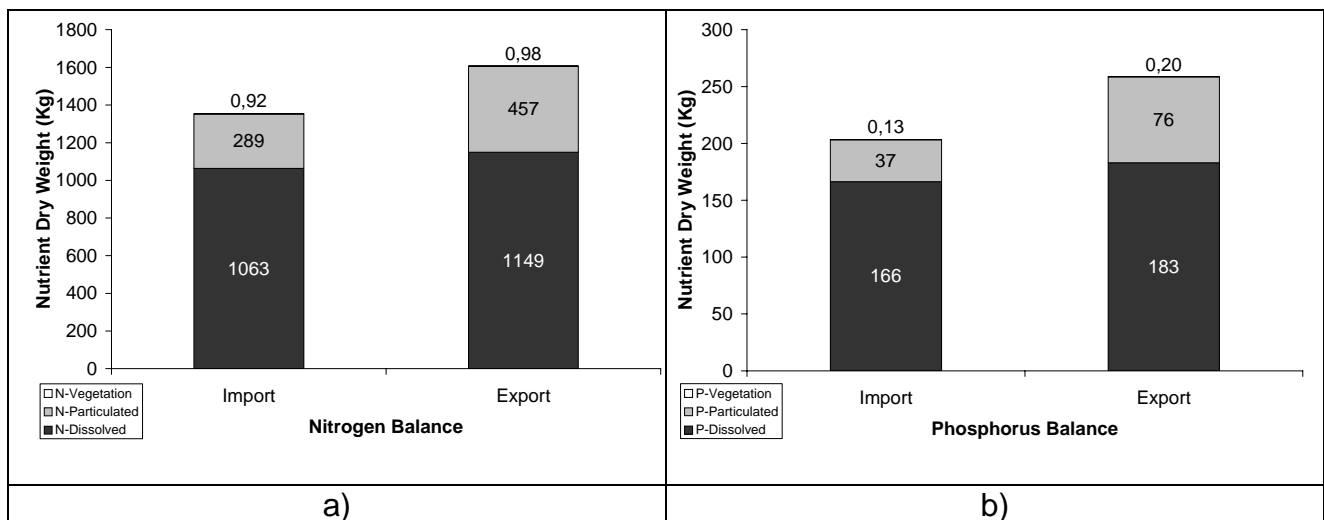


Figure 6 –Nutrients tidal balance: a) Nitrogen; b) Phosphorus

The fraction more representative on the nutrients transport was the one dissolved on the water, followed by the suspended particulate matter fraction. Not rare is to find really big percentage contributions of the vegetation-bound nutrients, not related on the present situation maybe because of the small amount of free floating macroalgae present on the estuary during this period of the year (macroalgae blooms are more often visible during spring and early summer).

Figures 7 and 8 present some results of hydrodynamic modelling (2D-H) of this estuary, concerning to velocity magnitude and flow tracer (during flood tide), and surface water elevation, respectively.

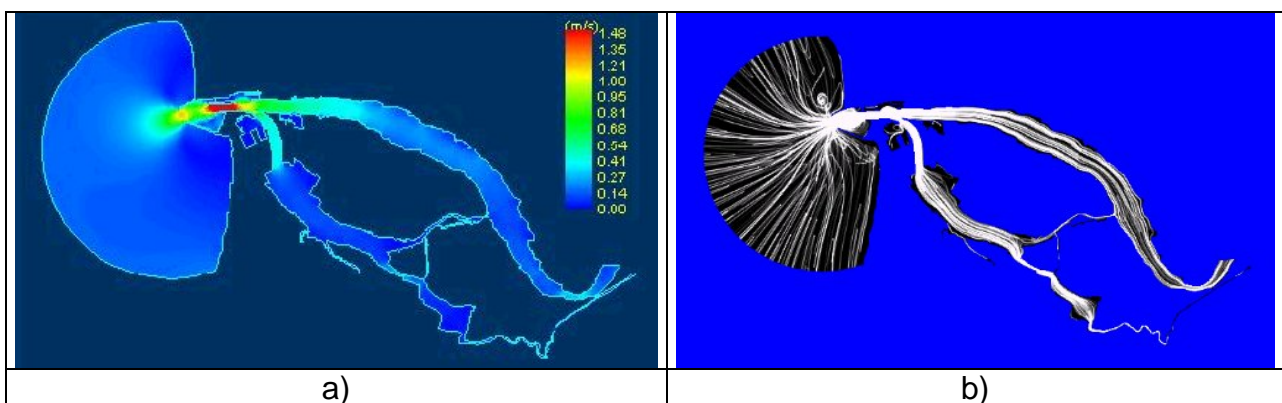


Figure 7 – a) Maximum velocity magnitude (flood tide); b) Flow tracer (ebb tide)

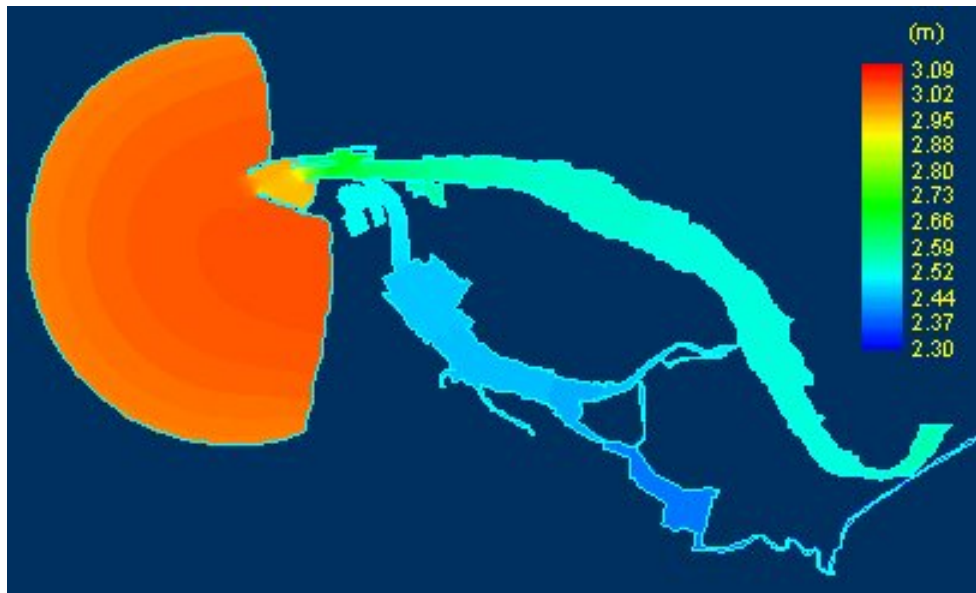


Figure 8 – Surface water elevation.

RT obtained from different simulated scenarios allow to establish the most sensitive zones to this estuarine eutrophication process, assuming that nutrients enrichment can be simulated by the tracer presence in most vulnerability zones of the system. For example, RT values obtained for scenarios S1 and S5, related with different tracer discharge duration (one and six hours, respectively) are depicted in Figure 9.

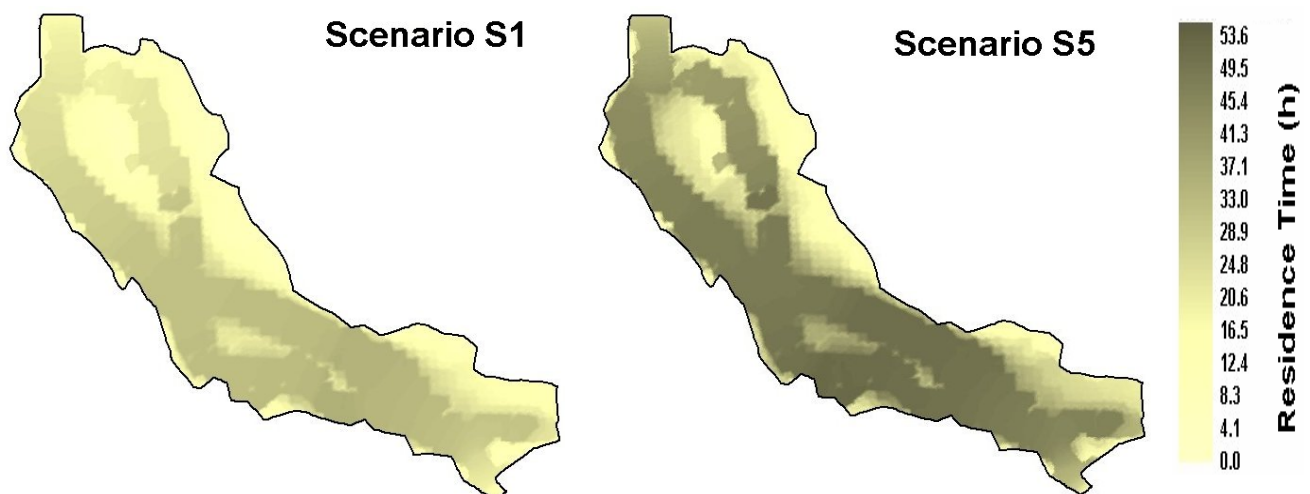


Figure 9 – Residence times spatial variation (effect of tracer discharge duration)

CONCLUSIONS

The time of rising tide decreases at points farther inland and is much smaller than that of the fall, due to the estuary south arm shallow waters.

Results obtained from hydrodynamic modelling, have shown the occurrence of a noticeable delay between the beginning of seawater entrance into the north arm and the south arm of this estuary.

Water quality modelling results confirm the eutrophication gradient measured in the south arm of the river Mondego estuary, validating the methodology applied.

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