# Analysis of the Danube Delta Natural Environment Based on the Historical and Archaeological Data Correlated with the Remote Sensing Techniques

Analiza cadrului natural al Deltei Dunării
pe baza datelor istorice și arheologice
corelate cu tehnici de teledetecţie

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**Abstract**

*Usually the study of the natural and archaeological sites is based on some specific observations undertaken in the areas of interest. Within GIS/SGI environment, the information gathered in the archaeological sites (on the ground and/ or bibliography) can be correlated with the one obtained by studying the natural environment, related to biotic and abiotic factors (solar radiation, relief, soil, water, vegetation, animal bodies and human factors), both temporally and spatially. Thus, a new vision of the natural evolution can be provided by specialists, by switching to a derived multidisciplinary approach based on remote sensing techniques.*

*Within this paper were approached elements related to the mapping of the main vegetation types, those based on free GIS data. For this, we considered several types of raster data (satellite imagery, scanned maps, satellite maps, etc.) and vector (CORINE Land Cover, Contour maps by DEM and SRTM processing, Relief units map, European Union Soil Map etc.).*

*From the earliest times Danube Delta was inhabited by humans. This is proved by the archaeological discoveries made in this area. According to them, the living stages identified in the Danube Delta closely accompanied the stages of evolution of the delta. All these aspects have been proved by the type (tumuli tombs, settlements and fortified settlement) and the distribution, in relation to the natural environment, of the archaeological sites. This fact is very helpful in the analysis based on the historical and archaeological data of the natural environment.*

**Key words:** Danube Delta, Tulcea Gulf, mainland, natural environment, spatial distribution of human settlements.

## Introduction

The Danube Delta evolution was studied on several researches (in general hydrological and geomorphologic point of view) carried on this area, since the middle of the 19$^{th}$ Century to the present. However, historical and archaeological studies performed in this area have revealed new aspects

regarding the evolution of the Danube Delta which bring important details on appearance and rate of change of the area.

The purpose of this study was to analyze the spatial distribution of human settlements and how people have used the natural resources of the Danube Delta. Usually, there is a close connection between the spatial location and social organization of human settlements, on one hand and the distribution of environmental resources on the other.

Based on data from historical and archaeological studies the spatial distribution of archaeological sites was established. These data were processed in GIS/ SIG dedicated applications. The influence of environmental factors on human communities studied provided the necessary background to study how the Danube Delta has evolved. This allowed an assessment of the stages of development of the Danube Delta in the different historical periods on the basis of knowing the characteristics, habits and areas occupied by human settlements.

**Material and Methods**

Within this paper we used digital data (data that are not available commercially in many cases) and paper scientific studies from different sources, as follows:

- Digital GIS / SGI data:
  1. *Raster format*
     - Romanian Geological Map, scale 1: 200000;
     - ASTER GDEM Ver2 (produced by METI and NASA in cooperation with the Japan-US ASTER Science Team);
     - Shuttle Radar Topography Mission (SRTM), highest-resolution topographic data generated from NASA's;
     - Landsat 7 (L7) Enhanced Thematic Mapper Plus (ETM+).
  2. *Vectorial format*
     - Relief Map Units (***shapefiles*** format) provided by geo-spatial.org;
     - CORINE Land Cover maps (***shapefiles*** format) accomplished by European Environment Agency at scale 1:100000;
  3. *Derivative work from Aster GDEM Ver.2*
     - The contour lines of 5 to 5 meters vectorial map;
     - The contour lines of 10 to 10 meters vectorial map;
     - The elevation classes;
     - The slope classification after gradient and exposure;
     - The triangulated irregular network (TIN);
     - The vegetation classification map (intersection between elevation, sloping gradient and exposure classes TIN and CORINE Land Cover maps).
  4. *Derivative work from SRTM:*

- The contour lines of 10 to 10 meters vectorial map;
- The contour lines of 1000x1000 meters resolution vectorial map (including the Black Sea);
- The elevation classes;
- The triangulated irregular network (TIN).

**5.** The Danube Delta's archaeological sites distribution map.

**6.** Digital scientific papers:

*a.* The Danube Delta Evolution During The Holocene: Reconstruction attempt using geomorphological and geological data, and some of the existing cartographic documents (PANIN, OVERMARS, 2012);

*b.* Man made deltas (MASELLI & TRINCARDI, 2013);

*c.* Early Anthropogenic Transformation of the Danube-Black Sea System (GIOSAN *et alii*, 2012).

*d.* River Basin (The International Commission for the Protection of the Danube River, 2015, http://www.icpdr.org/main/danube-basin/river-basin)

**7.** On paper scientific studies

*a.* Geology platform units and North Dobrogea Orogen/ Geologia unităţilor de platformă şi a orogenului nord-dobrogean (IONESI, 1994).

GIS data were obtained partly from the Internet, such as: Romanian Geological Map (scale 1: 200000), ASTER GDEM Ver2, Shuttle Radar Topography Mission (SRTM), Landsat 7 ETM+, Relief Map Units (*shapefiles* format), CORINE Land Cover maps.

Bringing raster data into shape file format was made in Quantum GIS (QGIS) application (free distributed under GNU license) and Saga GIS. Vector data were finally stored in three types of shape file files corresponding to the three types of vector geometry data, such as: point vectors type shape file, polyline vectors type shapefile and polygon vectors type shape file.

Of course, satellite images were processed in their turn depending on needs. The Landsat images were assembled for each spectral band separately and then the satellite images from three bands were combined together. In accordance with historical and archeological studies the Danube Delta's archaeological sites distribution map was carried out in the final stage.

**Results and Discussion**

The Danube Delta was formed on the basis of river sediments collected from a drainage basin with a total area of 801,463 square kilometres.

As is well known, the evolution and the current geomorphology of the Danube Delta are the result of the interaction between the river and the sea during the Holocene period. According to the classical theories at the beginning of the Holocene, when the level of the sea reached approximately the nowadays level, there was the so-called Tulcea Gulf and at its mouth,

between the Jibrieni promontory to the north and the Murighiol-Dunavăţ promontory to the south, was formed the Letea-Caraorman levees (the alluvial materials were carried southwards along the sea shore, by the marine currents, from the mouth of the Nistru, Bug and Nipru rivers) (Fig. 1 and 2). The oldest Danube branch, Sfântu Gheorghe, flew into the sea along Sfântu Gheorghe Fault (Fig. 2).

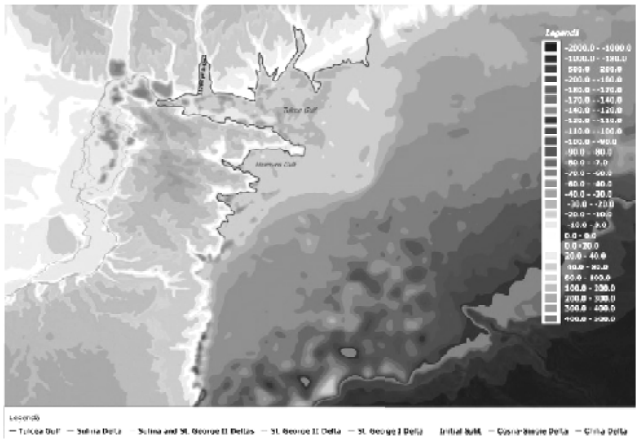

Fig. 1. The continental platform of Black Sea and Tulcea Gulf according to Contour lines of 1000x1000 meters resolution vectorial map (processing after SRTM)

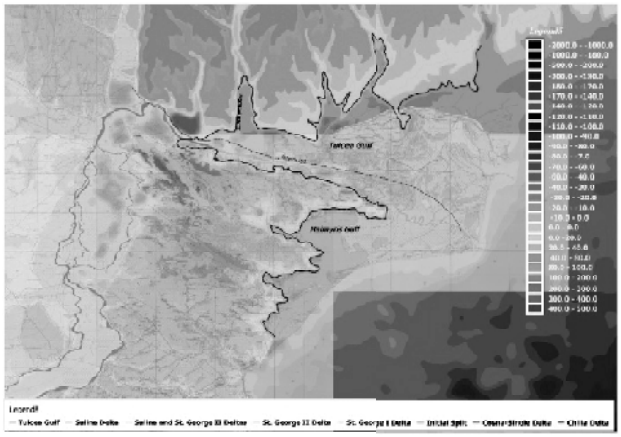

Fig. 2. The continental platform of Black Sea and Tulcea Gulf according to Contour lines of 1000x1000 meters resolution vectorial map (processing after SRTM and Geological Map, scale 1: 200000)

GIOSAN *et alii* (2005) suggest younger ages for the initial stages of delta development (for example, in their view, the St. George I Phase could not be much older than ~5,500 – 6,000 yr. BP). This hypothesis seems to better correlate with the present-day understanding of water-level changes in the Black Sea during the Pleistocene – Holocene time.

New age determinations are now in progress and, probably, they will give a new understanding of the Danube Delta development timing during the Holocene (PANIN, OVERMARS, 2012).

Within this context of the Danube Delta evolution, both, vegetation and fauna, on one hand as well as the human factor on the other, follow closely the geomorphologic and hydrological transformations of this area. The evolution of the natural environment and the human settlements were analysed on the basis of the black-box theory. In order to achieve the objectives of this study, two sets of variables (independent and dependent) were selected. How the factors involved in the development of the Danube Delta are correlated between them was represented in a Ishikawa Diagram (the fish diagram – Fig. 3).

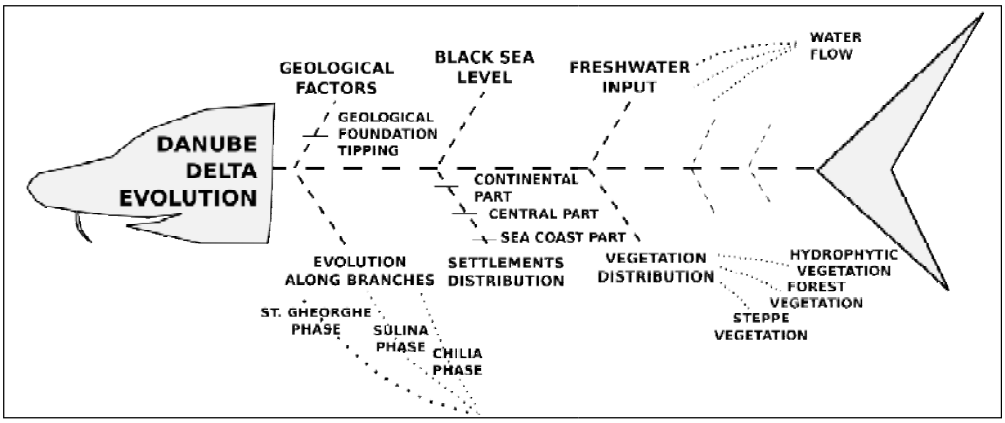


Fig. 3. The Ishikawa Diagram (fish diagram) of the environmental factors correlation

In the aim to determine the parameters to be addressed under these sets of variables, the identifying vegetation types of the last glacial period (that characterized that area) and the spatial distribution along each historical period of the human settlements was also very important.

Thus, according to Murgoci (1912) into the Caraorman loessoide deposits (at 3-6 m depth) the remains of *Elephas primigenius* (woolly mammoth) were found.

Generally, the woolly mammoth habitat is known as "mammoth steppe" or "tundra steppe". During the last Ice Age this habitat stretched across northern Asia and many parts of Europe, as well as the northern part of North America. It was almost similar to the grassy steppes of modern Russia, except that the flora was more diverse, abundant and grew faster. Because the woolly mammoth habitat was on the high-pressure areas (this was not covered by ice) at that time all this have happened. (Sourced from "World Heritage Encyclopedia", licensed under CC BY-SA 3.0 - Creative Commons Attribution-ShareAlike 3.0, https://creativecommons.org/licenses/by-sa/3.0/us/)

Also a special interest should be shown to the forest areas on current Letea and Caraorman sandbanks these maybe represent relict forests coming from the last Ice Age. That forest probably covered a region with the higher altitudes between the actual localities such as Periprava, Crișan, Dunavăţul de Jos until near the town of Sulina. Following the evolution of how the human settlements were distributed in space, during the historical ages, another set of parameters was obtained.

Thus, if the traces of habitation from the Paleolithic Period were found only on the higher areas (mainland and the existing Caraorman Sandbank area), the traces of settlements from the Neolithic Period were found in the central part of the Delta (Mila 23 and the Ceamurlia Levee) or Popina Island (Fig. 4).

Based on archaeological studies made on the central part of the Delta, an absence of habitation traces dating from the Late Neolithic and Bronze periods was observed. Basically, settlements disappear from the central part of Danube Delta (Mila 23) and Popina Island to reappear in the higher areas such as Chilia Levee. Another interesting aspect was discovered in the continental areas adjacent to the Danube Delta along the actual active way and St. George Branch, between the actual localities Parcheş and Mahmudia. Thus, in this sector, rich in archaeological remains belonging to the Early Neolithic Period, no trace of habitation for the Late Neolithic and Bronze Age were found (Fig. 5).

The action of natural negative factors between 6000-1000 years Before Christ (since the Late Neolithic Period to the Iron Age), within the actual territory of the Danube Delta, could be proved by the disappearance of settlements on the Parcheş-Mahmudia sector and in the central part of the Delta (Fig. 6). The disappearance of the settlement traces from the Palaeolithic period from the Caraorman Sandbank area and the occurrence of these on the Ceamurlia Levee area on the Early Neolithic Period represents another interesting aspect.

All these aspects require a closer look, because there was observed a sequence of time without traces of settlements between the Neolithic Period and the Early Bronze Age and these place the Tulcea Golf phase in that period. However, whether the appearance of traces of settlement in the Levee Ceamurlia is linked or not with their disappearance of the Caraorman

Sandbank, their preservation across the Bronze Age is certainly related to the hydrological and geomorphologic processes that opposed to the natural factors with negative impact on human settlements arising between 6000-1000 years Before Christ. The emergence of human settlements in the Ceamurlia Levee area during the Bronze Age is originally linked to the formation of Initial Spit and transformation of the golf into a lagoon.

A migration of human settlements into the Caraorman Sandbank, Aegyssus Fortress (Tulcea) and Somova-Parcheş sector between Iron and Gaetic period was observed. The development of the settlements is related to the consolidation of the Danube banks and the formation of the Delta along the Paleo-Sfântu Gheorghe Branch (Fig. 7). Roman period is characterized by two main stages, namely Early Roman Period and Late Roman Period. Within the Early Roman Period traces of fortified settlements appear in the upper Danube, particularly in the Noviodunum Fortress (Isaccea) area.

The first fortified settlement from Noviodunum was raised on a emplacement located with 25-30 m north of the late Roman period and approximately 40-46 m north of the current bank line. These data are preliminary and were obtained from the information provided by Shuttle Radar Topography Mission (SRTM). However all these data indicate a change of Danube flow at the end of Early Roman Period, which probably led to the development of the Delta along the Chilia Branch.

Interesting that within Caraorman area, the settlement traces (from Gaetic Period) disappear in the beginning Early Roman Period, but on the Ceamurlia Levee area they are maintained. Perhaps those were caused by the restart along to the Paleo-Sfântu Gheorghe and Paleo-Sulina branchs path of the Delta formation. That lead to the occurrence and development of Delta Sfântu Gheorghe II and the development of Sulina Delta between III century B. Chr. and I century AD (Fig. 7).

After the year 400, in the middle Byzantine period, the Danube Delta is closer to the actual shape. Between 400 and 1000 Sulina Delta is under the erosion process, the aspect of Delta Sfântu Gheorghe II is finalized and the Chiliei Delta evolve until the Periprava area (Fig. 7).

The evolution of Razim-Sinoie Lagoon Complex is linked to the general evolution of the Danube Delta. That was started from two gulfs of the Black Sea. These two gulfs are Halmyris Gulf and the Jurilovca Gulf. Its formation started about 8000 years before Christ and continued with a first phase of partial barring in the beginning of Delta Sfântu Gheorghe I formation. However it remains open until the Byzantine Period. The forfeiture of the Roman settlements and fortifications in that period is closely related to the closure of this sector through marine sand banks (Figs. 4, 5, 6 and 7).

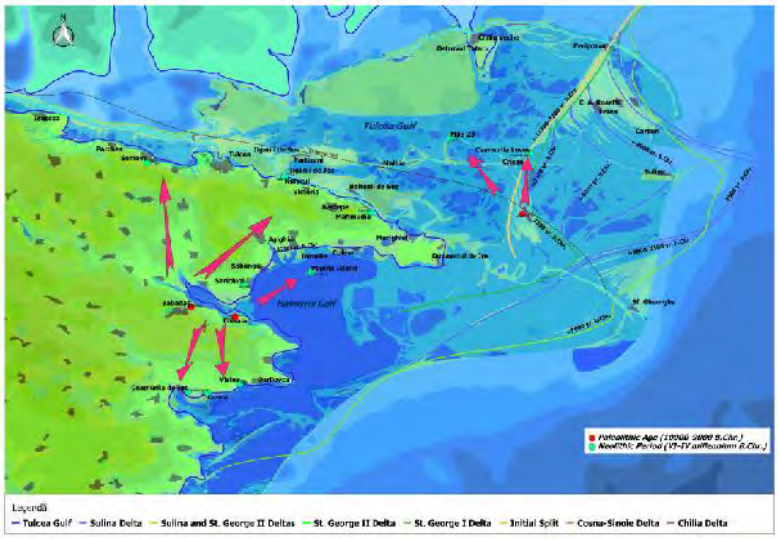


Fig. 4. The human settlements evolution between Paleolithic and Neolithic periods according to The Danube Delta's archaeological sites distribution map as well as the vegetation classification map and Contour lines of 1000x1000 meters resolution

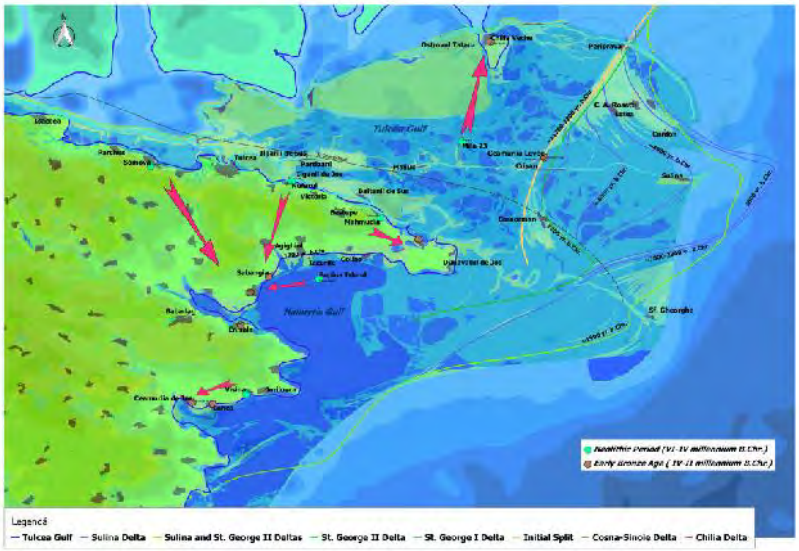


Fig. 5. The human settlements evolution between Neolithic and Bronze periods according to The Danube Delta's archaeological sites distribution map as well as the vegetation classification map and Contour lines of 1000x1000 meters resolution

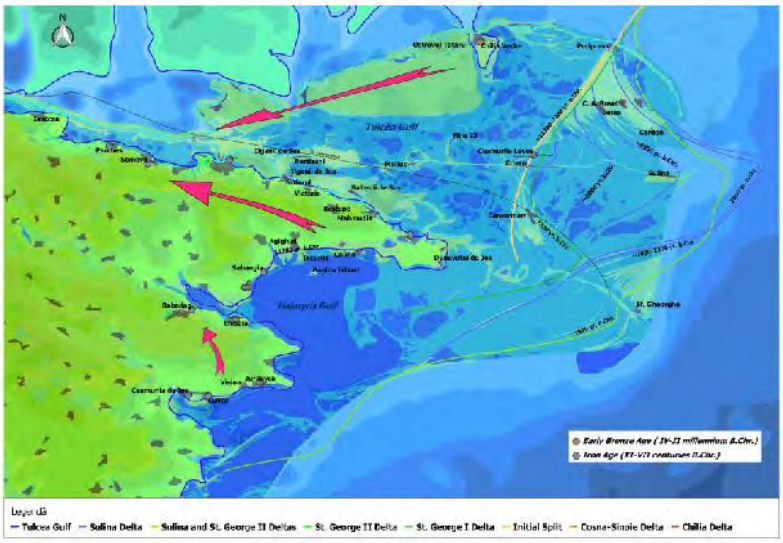


Fig. 6. The human settlements evolution between Bronze and Iron periods according to The Danube Delta's archaeological sites distribution map as well as the vegetation classification map and Contour lines of 1000x1000 meters resolution

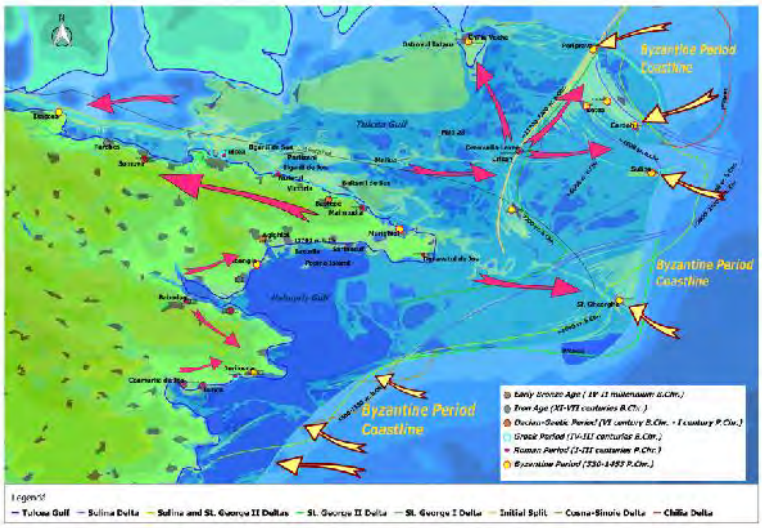


Fig. 7**.** The human settlements evolution between Early Bronze, Iron, Dacian-Gaetic, Greek, Roman and Byzantine periods according to The Danube Delta's archaeological sites distribution map as well as the vegetation classification map and Contour lines of 1000x1000 meters resolution vectorial map

The geomorphologic evolution of the Danube Delta has been closely followed by the evolution of the natural environment. The vegetation has passed from the characteristic steppe and forest to the aquatic and xerophil vegetation on the gulf and closed gulf periods. Starting from the period of the formation of the first fluvial sedimentation deposits the hydrophil vegetation has gradually expanded to its present level. The correlation between environmental factors (geological and hydrological factors, vegetation types) and the spatial distribution of human settlements/ different historical periods are shown in the table below (Table 1), where the indicators scale is represented by: High, Medium-High, Medium, Low-Medium, Low, Without. The indicators value, shown in the table, are the following: 5 (high), 4 (medium-hight), 3 (medium), 2 (low-medium), 1 (low), 0 (without). The graphical correlation of all those parameters are presented in the Fig. 8.

Table 1. Correlation of environmental factors and the spatial distribution of human settlements evolution/ different historical periods

| Input/ Output Value | | Pre-deltaic area | Paleolithic Period | Neolithic Period | Bronze Age | Iron Age | Getae (Gaetic) Period | Greek Period | Roman Period (Early) | Roman Period (Late) | Byzantine Period |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT | Geological foundation tipping | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 3 | 2 | 1 |
| | Black sea level | 1 | 1 | 1 | 5 | 4 | 3 | 3 | 3 | 3 | 3 |
| | Fresh water flow | 2 | 2 | 2 | 4 | 3 | 4 | 4 | 3 | 3 | 3 |
| OUTPUT | St. Gheorghe phase | 0 | 0 | 0 | 0 | 3 | 5 | 4 | 3 | 2 | 2 |
| | Sulina phase | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 3 | 1 |
| | Chilia phase | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 |
| | Settlements on continental part | 0 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | Settlements on central part | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| | Settlements on sea coast | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 3 | 4 |
| | Steppe vegetation | 5 | 5 | 4 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Forest vegetation | 4 | 4 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Hydrophytic vegetation | 1 | 1 | 1 | 3 | 4 | 4 | 5 | 5 | 5 | 5 |

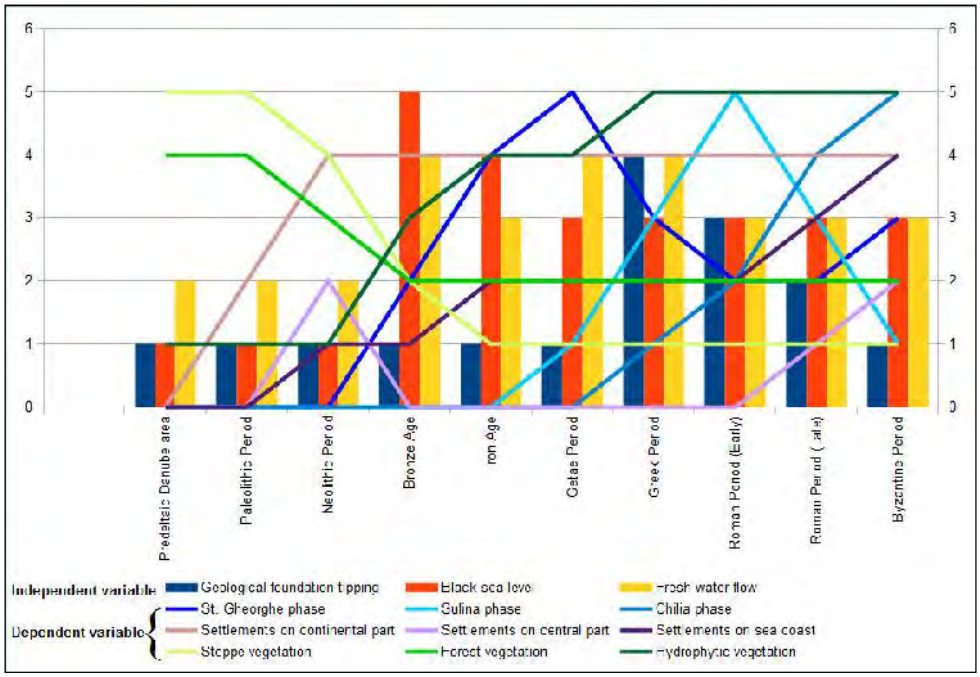


Fig. 8. The graphical correlation of environmental factors and the spatial distribution of human settlements evolution / different historical periods

## Conclusions

The scientific information exposed in this paper were obtained by including in the vectorial thematic layers of the general information about the situation of archaeological discoveries in the studied area, as well as the derivative work from satellite images. Based on all this information a conceptual model of the historical evolution of the region was obtained. In order to achieve this aim synthesis getting an image on the spatial and temporal evolution of the Danube Delta archaeological discoveries represents an important starting point.

Of course, the image obtained by using these data types must be filled with data acquired from stratigraphical, sedimentological, geomorphological and hydrological studies. For this reason, the conceptual model obtained by correlating historical and archaeological data with those obtained through remote sensing techniques represents a starting point for future research.

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*** Landsat 7 (L7) Enhanced Thematic Mapper Plus (ETM+).

*** Relief Map Units (shape files format), geo-spatial.org

*** CORINE Land Cover maps (shape files format) accomplished by European Environment Agency at scale 1:100000.

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