

DRAINAGE NETWORK CHARACTERISTICS OF ATHENS PLAIN AT THE END OF THE 19TH CENTURY

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Abstract

Kephissos River is the main fluvial system of the hydrological basin of Athens. It drains the central part of Attica and almost the entire urban area of the city of Athens. In this paper, we present the results of both the qualitative and quantitative analysis of the initial drainage network of the plain before the urbanization through the processing of digitized data with GIS software.

The initial drainage network of the basin, plotted with the use of a very detailed mosaic of maps, was constructed by German cartographers (Curtius E. and Kaupert J.) at the end of the 19th century. For the analysis of the drainage network the Laws of drainage composition were used and values for the D and F indices were calculated.

One of the major aspects of this article is to reveal information about the fluvial and environmental conditions in the plain of Athens before the urbanization of the area. This kind of information is very critical because until that time (end of the 19th century) the fluvial system of Kephissos was natural, without any human intervention.

Key words: *Kephissos, network patterns, historical maps, landscape.*

Περίληψη

Ο ποταμός Κηφισός με τους παραποτάμους του αποτελεί το κύριο ποτάμιο σύστημα αποστράγγισης της υδρολογικής λεκάνης των Αθηνών. Αποστραγγίζει το κεντρικό κομμάτι της Αττικής και ένα πολύ μεγάλο μέρος του πολεοδομικού συγκροτήματος της Αθήνας. Στην εργασία αυτή παρουσιάζονται τα ποιοτικά και ποσοτικά αποτελέσματα της ανάλυσης του αρχικού υδρογραφικού δικτύου του Κηφισού ποταμού πριν από την αστικοποίηση της υδρολογικής του λεκάνης. Η μελέτη αυτού του φυσικά αναπτυσσόμενου υδρογραφικού δικτύου, έγινε με την χρήση ψηφιακών δεδομένων τα οποία αναλύθηκαν σε λογισμικό Γεωγραφικών Συστημάτων Πληροφοριών.

Η αποτύπωση του αρχικού υδρογραφικού δικτύου της λεκανοπεδίου των Αθηνών έγινε με τη χρήση και την ψηφιακή επεξεργασία εξαιρετικά λεπτομερών ιστορικών χαρτών που κατασκευάστηκαν από τους γερμανούς χαρτογράφους Curtius E. και Kaupert J. στα τέλη του 19^{ου} αιώνα. Για την ανάλυση του υδρογραφικού δικτύου εφαρμόστηκαν οι

νόμοι της υδρογραφικής σύνθεσης και προσδιορίστηκαν οι τιμές της υδρογραφικής πυκνότητας και συχνότητας.

Ένας από τους βασικούς στόχους της εργασίας αυτής είναι ανάδειξη των φυσικών και περιβαλλοντικών συνθηκών του πεδίου των Αθηνών πριν από την αστικοποίηση της περιοχής. Μια τέτοια πληροφορία είναι εξαιρετικά χρήσιμη και αποτελεί σημαντικό γεωμορφολογικό - περιβαλλοντικό εργαλείο προσδιορίζοντας και παράλληλα διαχωρίζοντας τις φυσικές διεργασίες εξέλιξης του ποτάμιου συστήματος από τις ανθρωπογενείς επεμβάσεις.

Λέξεις κλειδιά: Κηφισός ποταμός, υδρογραφικό δίκτυο, ιστορικοί χάρτες, μορφολογικό ανάγλυφο.

1. Introduction

Since its establishment as the capital city of Greece in 1834, the city of Athens started growing in population. By the end of the 19th century it had developed into a small city situated in the centre of a drainage basin surrounded by mountains. This drainage basin, formed by Mount Parnes on the west, Mount Pentelikon on the northeast and Hymettos on the southeast side, lies in the central part of the Attica peninsula. The old city of Athens was situated around the small hills of Acropolis and Licabetus, with many small villages dispersed throughout the plain in the lower part of the basin.

During that period (at the end of 19th century) the major fluvial processes of the basin were natural without any human intervention. These processes formed the initial drainage network before the urbanization of the plain. The study of this initial drainage network pattern enables us to define its morphometric characteristics and to analyze it quantitatively. The initial drainage network of the basin was plotted with the use of a very detailed mosaic of maps. The 32 maps of this mosaic, with a scale of 1:25,000, were constructed in the two last decades of the 19th century.

2. Methodology

For the plotting of the drainage network of Athens plain, 9 historic maps, with a scale of 1:25,000, were used. German cartographers constructed these maps at the last decades of the 19th century. The cartographer H. Curtius started the project (1862-1868), which was then continued by J.A. Kaupert until the end of the century. The German Archaeological Institute of Athens (Kaiserlich Deutschen Archaeologischen Institut) supervised the whole project. All the maps were included in a volume entitled "Karten von Attica" (Curtius and Kaupert 1900).

All the cartographic and geomorphologic information from the maps was retrieved through the use of Geographical Information Systems (G.I.S.) software. This software consists of MapInfo v.6.0 and Vertical Mapper v.3.1 for the drainage network analysis and for the terrain analysis of the maps respectively.

Old maps cannot be treated just like any other hardcopy printed on paper or other relevant material, because most of them are not well preserved and properly stored. This makes their digital transformation a difficult task since the conventional approach is not appropriate. In addition, these maps were constructed with no processing of aerial photographs and analogue photogrammetry methods. Even though, a new topographic network was established for the needs of the mapping project, map accuracy was still questionable.

The image registration of the scanned maps in a GIS environment was also a problem because we had to identify the coordinate system. It is known that in all German maps of that age the prime meridian was not Greenwich but the meridian of Ferro (Livieratos 2001). With Ferro correction, we established the georeference of the maps. After this image registration, the comparison between these historical maps and the operational maps of the Greek Military Geographical Service showed

a strong resemblance. In addition, the scale of the historical maps (1:25,000) was acceptable for network and terrain analysis in an urban area like the plain of Athens.

3. Drainage Network Patterns

In this article, with the use of the historical maps mosaic of the Attica peninsula, we represent the drainage network of the Athens hydrological basin before the urbanization of the area (Fig. 1). The drainage network of the plain of Athens consists of the drainage network of Kephissos River with its tributaries, and the torrents on the southern foothills of Mount Hemittos at the southeast part of the plain. The most famous tributaries of Kephissos River are the Ilissos River and Iridanos River. Ilissos River is a tributary of Kephissos River on the eastern part of the plain. As referred to the historical maps of Curtious and Kaupert, Iridanos River is a tributary of Ilissos River also flowing from Mount Hemittos.

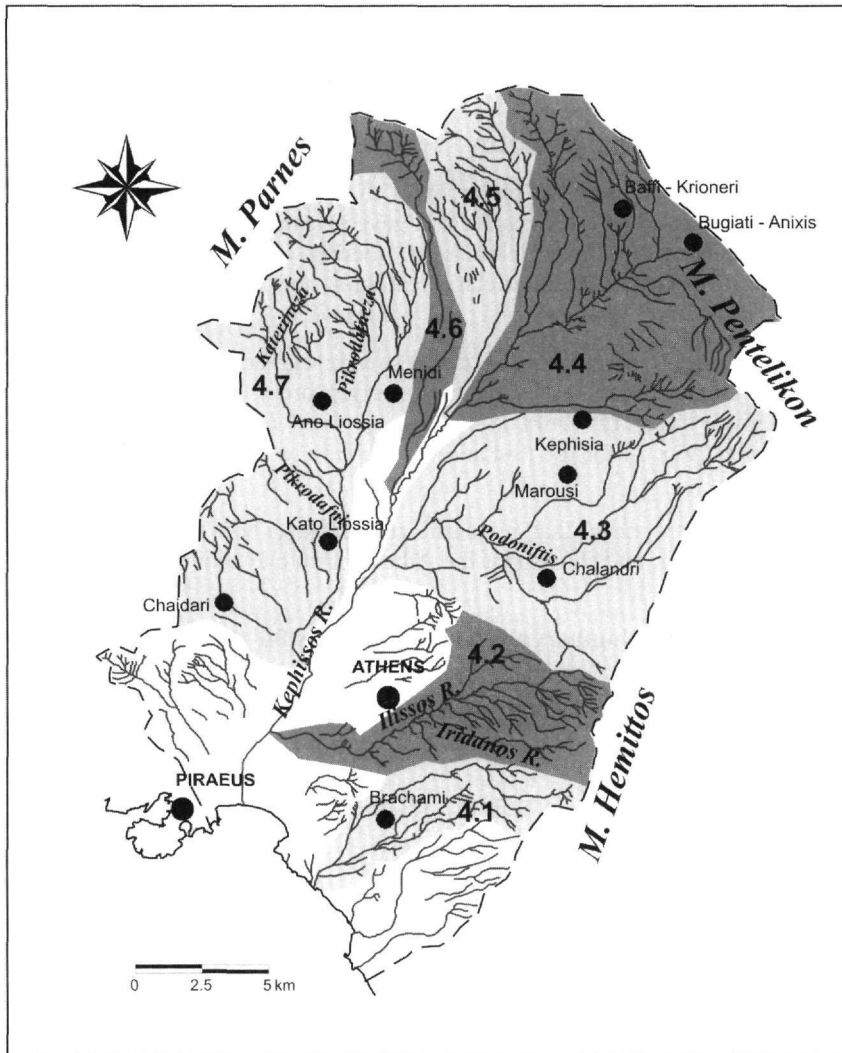


Figure 1 – The drainage network of Athens plain at the end of the 19th century. The major hydrological sub basins (4th order) are marked with the shades of gray. Ilissos River was the main tributary of Kephissos River

The topological arrangement or spatial relationships of stream channels is described as the drainage pattern of a watershed. Patterns describe geometric shapes and arrangements of regional stream networks. They describe the geometric relationships among converging tributaries and they reflect the structural and geologic control of the landscape of the basin. Comparing the drainage network of Athens hydrological basin with the standards (Mitchell 1973) we can say that the dendritic pattern is the dominant one. Of course there are some exceptions, especially on the mid-lower part of the basin, with some elongated streams relatively parallel to each other. These exceptions reveal information about the underlying geological structure.

4. Quantitative Analysis

“Athens Plain” is a term describing a hydrological basin surrounded by mountains, in the central part of Attica peninsula. Mount Parnes on the west, Mount Pentelikon on the northeast and Hymettos on the southeast side form that drainage basin (Fig. 1). The main fluvial system draining Athens plain is Kephissos River. The area of the drainage basin of Kephissos is 411,3 km² corresponding to 88.2 % of the total area. The remaining area of the plain is 55,13 km² (11.2 %), situated on the southeast part of the plain.

4.1. Laws of Drainage Composition

A stream network or drainage basin is a hierarchy of channel segments of differing importance, or order. Horton (1945) established the basis for and gave an impetus to the quantitative analysis of the drainage networks by setting up a hierarchy of ordering. Horton’s method was later modified by Strahler (1957). According to Strahler classification system Kephissos is a 5th order drainage network.

Analysing the morphometric properties of ordered stream segments, Horton derived relationships between order and number of stream segments of a given order (1st law) and between order and stream lengths of given orders (2nd law), known as “*Laws of drainage composition*”. The results (Table 1) and the plots (Fig. 2) for the first and the second law of drainage composition are listed below.

The constant branching ratio means that geometric growth exists between the number of tributaries at successive levels of order, and shows that the Athens basin had achieved equilibrium before the urbanization of the area.

Table 1 – Table of Stream Numbers and Stream Lengths for the Kephissos drainage basin

u	Nu	Rb	Lu	Mean Lu	ΣLu	RL
1	523	4.184	292.8	0.560	0.56	
2	125	4.464	171.3	1.370	1.930	3.447
3	28	4.667	96.61	3.450	5.381	2.787
4	6	6.000	58.72	9.787	15.167	2.819
5	1		17.91	17.910	33.077	2.181
	Rbm	4.829			RLm	3.018

where R_b is the branching ratio, u is the stream order, Nu is the number of stream segments of a given order, Lu is the total length, by order, of the streams. R_L is the length ratio

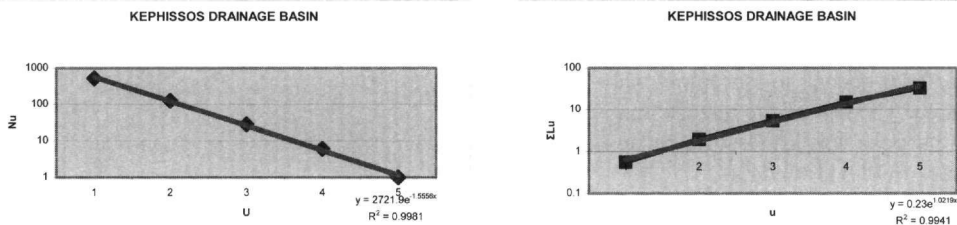


Figure 2 – Diagrams of Stream Numbers (left) and Stream Lengths (right) for the Kephissos drainage basin

4.2. Drainage Density and Frequency

The Drainage Density (D) and the Drainage Frequency (F) are indices used to compare relative erosional activity or channel efficiency between basins (Duckson 1999). The value of the drainage density for the Kephissos River drainage basin is $D = 1.55 \text{ km}^{-1}$. Also the value for the drainage frequency of Kephissos basin is $F = 1.66 \text{ km}^{-2}$. The very low values of both indices determine a coarse-textured network with elongated segments.

In addition, the estimated values of D & F for the 4th order sub basins are also very low (Table 2). A typical example of this coarse-textured network with elongated segments is the Podoniftis torrent basin (No 4.3) (Fig. 1).

Table 2 - Drainage densities and frequencies of the 4th order hydrological basins of Kephissos River

ID No	D Drainage Density	F Drainage Frequency	Area (km^2)	Description and Comments
4.1	2.076	2.408	22.420	Torrents from Hemittos mountain not included in the Kephissos River drainage basin.
4.2	2.018	2.252	36.840	Drainage Basin of Ilissos River and its tributary Iridanos River.
4.3	1.188	0.853	87.840	Drainage basin of Podoniftis Torrent
4.4	1.634	1.939	83.020	The upper most part of the Kephissos drainage basin
4.5	2.197	2.64	28.400	Elongated basin on the sides of Mount Parnes.
4.6	1.893	2.007	15.950	Elongated basin on the sides of Mount Parnes.
4.7	1.549	1.746	93.920	The west part of the Kephissos hydrological basin. The Ano-Liossia plateau is included.

4.3. Kephissos River Basin Morphometry

Morphometry is defined as quantitative measurement of landscape shape (Keller and Pinter 2002). At the simplest level, landforms can be characterized in terms of their size, elevation and slope. Kephissos River is the major hydrological system of Athens plain, and at the end of 19th century its drainage basin area was 411.3 km^2 . For the landscape analysis of Kephissos basin we used the hypsometric curve which describes the distribution of elevations across the basin, and it is

independent of differences in basin size and relief. The calculation of the hypsometric curve (Fig. 3) accomplished with the use of a DEM derived from recent topographic maps of the area. The use of the historic maps for that purpose was impossible because of the lack of elevation data.

The Cycle of erosion describes the theoretical evolution of a landscape. The results of the calculation of the hypsometric curve and the hypsometric integral give us a value of 21 %. This very low value indicates the old-age stage of development. The landscape of the basin is smooth with very gentle slopes in the center, while high mountains (max. elevation 1398 m) with steep slopes surround the basin. Finally, the old-age stage reflects also an achieved equilibrium on the erosional and depositional processes of the basin.

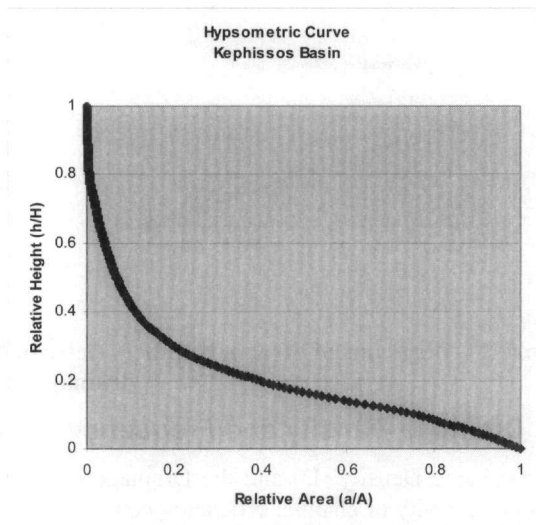


Figure 3 – The hypsometric curve of Kephissos River drainage basin

5. The fluvial system of Kephissos River

Kephissos River was the main fluvial system draining the Athens plain at the end of the 19th century. This fluvial system, as it is obvious from the quantitative analysis, had achieved equilibrium. At this stage the system had reached the maximum elongation of the drainage network (Knighton 1998) and a graded profile of the channel bed. The very low values of D and F indicate the end of the formation of new network segments. The sediment yield was also low because of the low rates of erosion of the basin. In addition, the low values of D & F imply small quantities of fluvial runoff.

The study of the historical maps can reveal information about the fluvial and environmental conditions in Athens plain at that time. This information is very critical because till that time the fluvial system of Kephissos was *natural* without any human intervention. In addition, the urbanization of the area was at its lowest point with only a few villages scattered on the plain and the city of Athens situated, only around the foothills of Acropolis and Licabetus. In the next paragraphs we will try to analyze the natural environment of Kephissos drainage system of Athens Plain starting from the river's mouth in Phaleron Bay extending to the upper part on the North side of the basin.

Until the last decade of the 19th century, there was no deltaic formation of Kephissos River in the bay of Phaleron (Fig. 4). There are three factors which support this hypothesis. First, the shape of the coastline of Phaleron Bay on the maps is continuous, without any headlands. Second, the isobaths of the maps indicate a very gentle bottom of the bay. We know that the old age of the maps is critical for the accuracy of the bathymetric record of the bottom of the bay. However, these isobaths are characteristic and reflect the cartographers' sense of what submarine morphology was like. Third, more inland, from the coastline, there are sand dunes all over Phaleron Bay, which is indicative of a wave-dominated coast without a deltaic depositional process.

In the centre of the lower part of the Kephissos basin, the main channel of Kephissos on these maps is insufficient (Fig. 4). This area is marked with an A and it is located southwards the village

of Kolokyntu. According to the morphology of the depositional features, we have the formation of an inner floodplain. This floodplain was formed by a combination of within-channel and

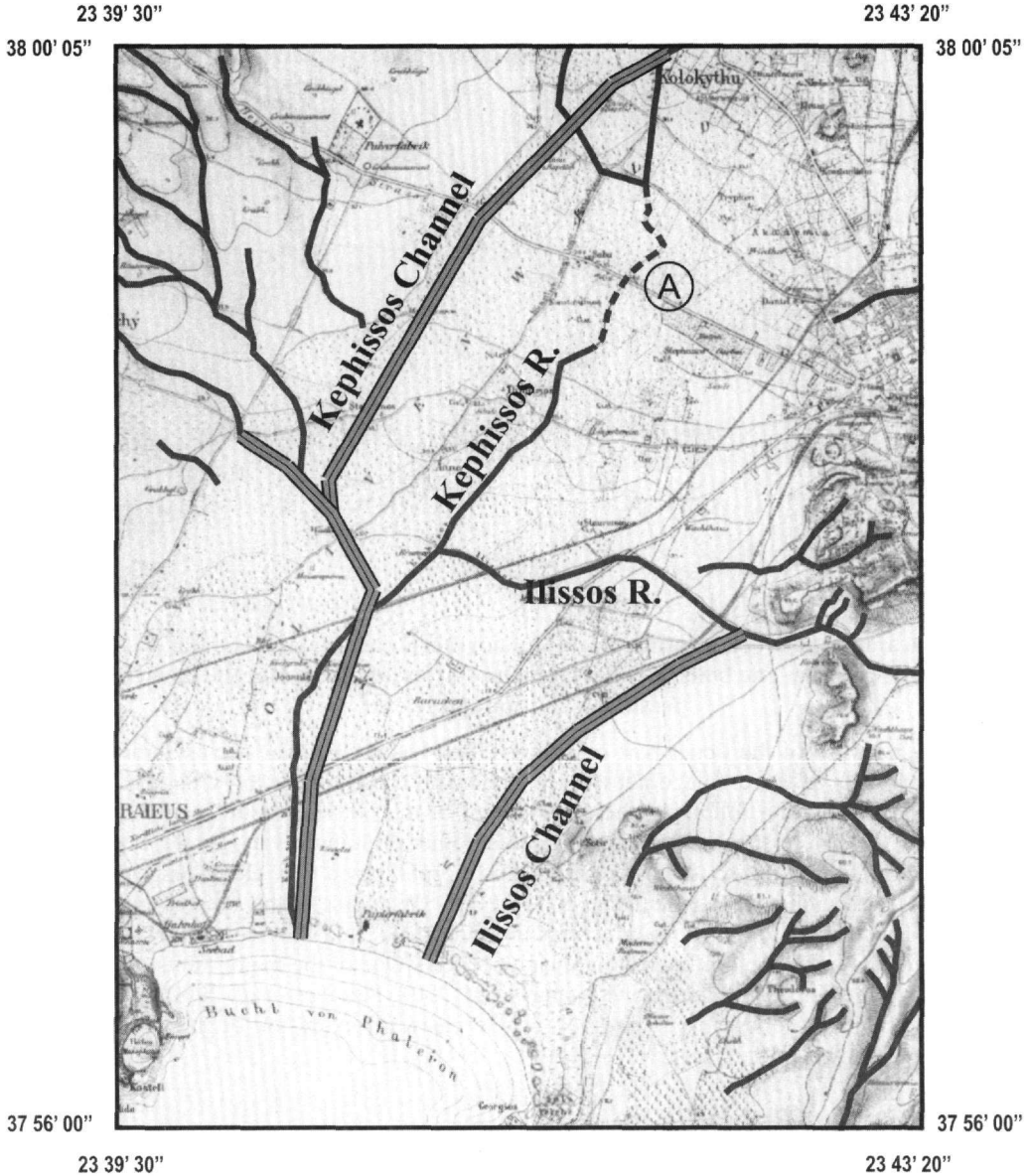


Figure 4 – Topographic map of the lower part of Athens plain

overbank deposits. In the southern part of the floodplain, the junction between the two famous rivers of Antiquity was mapped (Fig. 4). Ilissos River was a tributary of Kephissos River. The junction was situated between the area of what is now the municipality of Tavros and Agios Ioannis Rentis. This floodplain was the main depositional centre of the basin. It was a mature floodplain with relatively flat surfaces as a result of the infilling of the abandoned channels. These channels stopped at the end of the hilly terrain on both sides (east and west).

The floodplain area was problematic even in the last decades of the 20th century (Maroukian *et al.* 2005). Every time we had a flood event in the city of Athens, the most catastrophic events took

place in that lowland area. The most important hydraulic works at the early stages of the 20th century were the new artificial channels of Kephissos and Ilissos Rivers. The new artificial cement bottom channel of Kephissos was on the western side of the initial channel capturing the torrents of the west side hills. An approximately similar cement bottom channel was constructed for Ilissos River, deviating the river's flow to the south before entering the east part of the floodplain area.

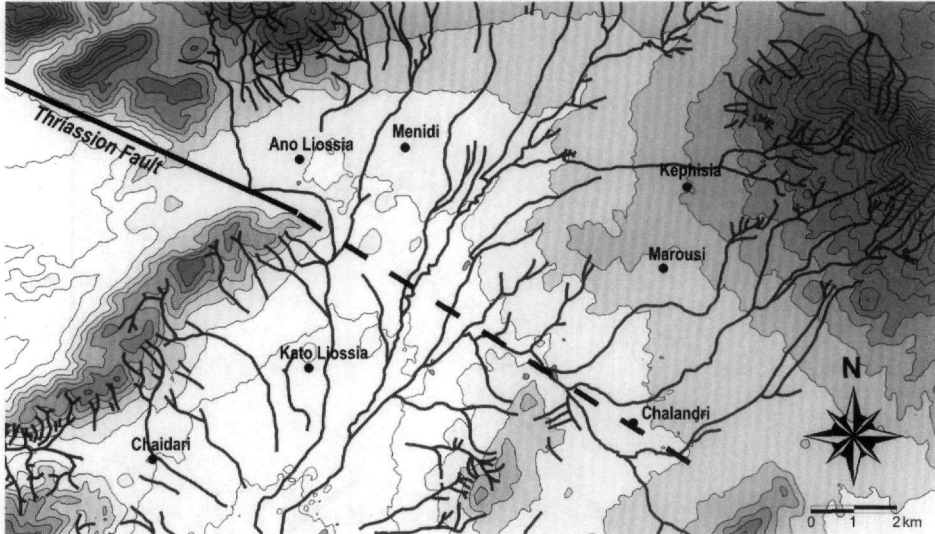


Figure 5 – Drainage network asymmetry on the northern part of Athens plain due to tectonic - geological control. The bold line indicates the Thriassion fault and the dashed line its possible extension to the east

The drainage network of the upper part of Athens Plain has a characteristic asymmetry. All the high order segments of the drainage network of Podoniftis torrent, near the village of Chalandri, have a NE-SW orientation following the morphology of the alluvial foothills of the Pentelikon Mountain (Fig. 5). These streams are parallel to each other draining a very gentle morphology at the east part of Athens plain. At the lower part of this morphology a very elongated segment of the network almost perpendicular to the others, stops the NE-SW course of the streams and turns them to the west. These bends on channel directions are almost 90⁰ and they constitute evidence of a highly tectonic and geological influenced drainage network. One of the major faults of the western part of Attica is the Thriassion fault zone (Ganas *et al.* 2001, Pavlides *et al.* 2002). This drainage network asymmetry may be caused by a non-visible eastward extension of the Thriassion fault zone into the sediments of the basin.

6. Concluding Remarks

In this article we achieved to create a digital database with the major morphological, fluvial and environmental data of the Athens plain. This database is very useful for the study of environmental changes in Athens because of the recent, large scale, urbanization of the plain during the 20th century. In the large cities like Athens, it is very critical to have environmental data before a city's expansion, because all the components of the natural environment of the plain are modified.

For that purpose we used 9 historic maps with the scale of 1:25,000. German cartographers constructed these maps during the last decades of the 19th century. The detailed cartographic records enabled us to reveal and to study the drainage network characteristics of Athens Plain. With this detailed record of the initial drainage network pattern we defined its morphometric characteristics and we analysed it quantitatively. The results of the analysis showed that the Athens basin had achieved equilibrium before the urbanization of the area. The very low values of

Drainage Density (D) and the Drainage Frequency (F) determine a coarse-textured network with elongated segments. This kind of drainage network is susceptible to flood events when we have peaks of fluvial runoff. In addition, the drainage network is in a mature stage without the development of new segments. The absence of non-graded segments of the network decreased the erosional processes on the basin.

The decreased erosional process in combination with the presence of an inner floodplain, at the lower part of the basin, trapped the produced sediment yield in the basin. We believe that this is the most important factor for the absence of a deltaic prolongation at the river's mouth in the Phaleron Bay.

Concluding, the drainage network of Athens was developed on a very gentle morphology of the lower part of the basin. The anisotropy of the network pattern at the northern part of the basin indicates a tectonic – geologic control over the drainage network evolution. The change of the stream's course is the only evidence of tectonic action on the recent sediments of the basin. This is a very important conclusion, because it can be extracted only through the study of the natural network pattern before the urbanization of the plain.

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