

FRactal Analysis of Certain Climatic, Hydrologic and Geomorphologic Parameters Within the Balta Mică of Brăila Natural Park (ROMÂNIA)

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Abstract: The article presents the use of fractal analysis to highlight evolutionary changes upon some climatic, hydrologic and geomorphologic parameters of the Balta Mică of Brăila Natural Park. It has been noted a rise in the fractal dimension of distribution curves of the climatic and hydrological parameters, as well as the emphasis of a positive correlation between the fractal and dimension of the islets' surfaces and the density of the biodiversity.

Keywords: fractal analysis, climatic, hydrologic and geomorphologic parameters, the Balta Mică of Brăila Natural Park

Introduction:

The Balta Brăilei (Wetland of Brăila) along with Balta Borcea (Wetland of Borcea) were the biggest natural aquatic units of the Inferior Danube Meadow. The Balta Brăilei was flanked by the main Danube's arms (the Navigable Danube and Măcin), starting from downstream beyond Gâsca island (next to Hârșova borough, km 243) reaching Brăila (km 175). Once the damming of Balta Brăilei was performed (1964-70), the

parameters of the natural environment, both the geographic and climatic ones, have changed radically. The drainage of the area within Măcin arm and Cremenea arm triggered off the appearance of the widest agricultural area in the country, the Insula Mare of Brăila (The Big Island of Brăila). The other geomorphological entities in Brăila's Danube Meadow which could not have been dammed are presently part of the international RAMSAR site known as the Balta Mică of Brăila Natural Park.

Countless studies concerning the former Danube meadow date back to the first part of the previous century. Hence, Antipa (1910, 1912, 1916) undertake a detailed research of the Danube's mead both in geographically and economically, and Vidrașcu (1921) performs an analysis of the hydrological indices. Hydrological researches on the lakes of Balta Brăilei are to be found with Gâștescu and Breier (1965). With regard to the Balta Mică of Brăila Natural Park the

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studies are of a more recent date especially on the area's biodiversity (Onea 2002; Moisei 2006).

The fractal is a fragmented or lenient geometrical figure which can be divided in items, that each of these be (at least approximately) a miniatural copy of the whole (Mandelbrot 1982). The term fractal was coined by Benoit Mandelbrot in 1975 and comes from the Latin word *fractus* which means "broken" or "fractured". The main properties of the fractal are the: irregular, fragmented form which cannot be described in the traditional geometric Euclidian language; self-similarity; invariant at scaling. Usually, for a fractal the Hausdorff-Besicovitch dimension must be bigger than the topological one.

The fractal dimension is a measure of complexity of the degree/angle in which the fractal "fills" the space, quantifying the degree of irregularity and fragmentation of a geometrical structure or of an object in nature, having most of the times a superior value to the topological dimension. Based on Gray's mathematical relation (1961), $L = 1.4 \times A^{0.568}$ (where L = river's length and A = surface), Mandelbrot indicates that rivers have a fractal dimension of 1.2. The patterns designed a posteriori by Mandelbrot have revealed rivers' fractal character (Tarboton 1988). Rooted in the study of the contributions of Mandelbrot (1982), when studying rivers, many researchers, for instance Hjelmeflt (1988), La Barbera and Rosso (1989), Tarboton (1988), Veltri et al. (1996) and the like, apply the fractal analysis.

Our study is intent on designing a comparative analysis of some climatic, hidrologic and geomorphological parametres registered in-between 1956-2006. Taking into consideration the complexity of the geographical forms of the Balta Mică of Brăila Natural Park, as well as the weather changes appeared after the damming of the Danube's meadow, we alluded to the fractal research of these parameters. The fractal analysis as been indicated following the presence of certain weather conditions

featuring complexity, irregularity, discontinuity, not suiting within the limits of Euclidian geometry and run abiding by non-linear laws. Some aspects regarding the fractal analysis for the Balta Mică of Brăila Natural Park were studied by Andronache (2008).

Materials and methods:

Site description

Geomorphologically speaking, the Balta Mică of Brăila Natural Park is made up of a string of 7 islands and main islets featuring a regime of free flow, with a surface summing up 15.000 ha (Stoiculescu 2000). Each of these islands represents a distinct geomorphological entity made up of sand banks/ banks, flat sectors, streamlets, dams, backwaters, ponds and lakes having in general the aspect of a "saucer", with the higher areas towards the exterior and the hollow ones towards the interior (Nicolau et al. 1961). In the order of their alignment from upstream (km 235, Giurgeni-Vadul Oii bridge) towards downstream (km 172, Brăila County), the 7 main islands are (Fig. 1, Annexes):

- Insula Mică of Brăila (Small Island of Brăila) - 9.714 ha
- Vărsătura Island - 1.176 ha
- Crăcănel Island - 1.081 ha
- Orbului Island - 323 ha
- Calia Island - 717 ha
- Fundu Mare Island - 1.945 ha
- Harapu Island - 252 ha

With an altitudinal difference of only 4 m from the mane of the sand banks till the lake bottom, the microrelief of the Balta Mică of Brăila Natural Park is made up by (high and medium) sand banks, flat sectors, (low, medium and high) protruding backwaters, lakes and ponds.

Fractal analysis

The fractal analysis was undertaken on the following parameters:

- climatic: the temperature of the air, rainfall and potential evaporation-perspiration;
- hydrologic: the minimum, medium and maximum levels of the Danube at the hydrological station;
- geomorphologic: the main and secondary arms of the Danube, as well as on the surface of the 7 islets components of the Balta Mică of Brăila Natural Park.

In carrying out this fractal analysis, we have studied satellite images from Google Maps and Google Earth, climatic data (1931-2011) and hydrological (1965-2011) - annual medium, maximum and minimum data provided by the Romanian Waters' National Administration (RWNA, in Romanian the acronym stands for SGA Braila), as well as observations collected during studying this area.

In processing the data we have used the following soft programs: Open Office 3.4.1 (for climatic and hydrologic data), ArcView 3.1, Quantum GIS 1.7.4, Corel Draw X5 (processing the works and sketches).

In this fractal analysis we have used the topographic works from 1956 and 1996, satellite images of the Balta Mică of Brăila Natural Park taken from the National Institute of Meteorology and Hydrology and the software program XnView 1.93.6 for the binary character of the images; the fractal dimension determination have been undertaken by aid of the program Benoît 1.3.

In determining the fractal dimension the entity is measured with a smaller and smaller set of scales, obtaining a string of approximates of the analysed entity. Following to that, it is under study the convergent of this resulting string, its value (D) being the fractal dimension. It was used the box-counting method, due to its flexibility and reliance for the determination. The box-counting method consists of establishing the number of cells N (l) necessary for covering the structure to be measured, according to the edge of these cells.

For distinct values of the cell's edge l , the cells covering the figure are counted and then it is represented through its logarithmic coordinates $\log N = f(\log l)$. The resulting slope is the fractal dimension:

$$D_f = \frac{\log N}{\log 1/r}$$

where D_f = the fractal dimension; N = the number of little squares covering the structure to be measured, and $1/r$ = scale.

The box-counting method is very-well suited in the cases of a bidimensional heterogenous and disordered structure. This method could have been applied both at determining the Danubes' arms' fractal dimension, as well as that of the islands' surfaces'.

We have undertaken a series of previous tests so as to see the capacity of the box-counting method used by software Benoît 1.3, to determine the fractal dimension with precision. Within the tests, it has been observed whether the fractal dimension obtained is likely to undergo a series of errors of determinations imposed by:

- image resolution which encloses the object to be analysed
- positioning within the image of the object to be analysed.

As regards the part of the image resolution in the reliable determination of the fractal dimension, there have been undertaken a series of determinations upon certain classical fractals, whose fractal dimension is certain (right, Koch curve, Sierpinski triangle), on various resolutions: 512 x 512, 1024 x 1024, 2048 x 2048, 4096 x 4096. Consequently it was noticed that the accurate appreciation of the fractal dimension is done at superior resolutions. It was chosen the second testing stage concerning the resolution 2048 x 2048.

In the second stage, it was sought establishing the role of the fractal's position in the image to be analysed and of the error of determination of the fractal dimension due to the position. Following these tests intent

on the capacity of the box-counting method used by Software Benoit 1.3, there resulted a standard deviation of 0.0022303. Thus, for a more reliable appreciation, to the results obtained through this method it must be applied a correction of ± 0.0022303 .

Results and discussion:

Climatic parameters

The mean annual temperature in Brăila, in natural regime of flow was of 10.6 °C, the annual absolute maximum recorded in 1951 reaching 44.5 °C, the absolute minimum lowering up to - 30 °C in the year 1942 (Figs. 2a, 2b, Annexes) The annual mean temperature recorded by the climatic stations/stands (except the one in Brăila) varies in between 10.3 °C and 10.5 °C. During the period 1931-2011 the annual mean temperature was of over 10 °C, but also with mean which surpassed were over 12 °C in between the years 1936-1938 and 1951.

Concerning the quantity of rainfall fallen there are no major differentiations between the period previous to and after the damming, in both situations alternating wet spells with dry spells. The annual means of rainfall is of 447 mm (Figs. 3a, 3b, Annexes). Being an environment of internal

meadow, the Balta Brăilei, even in conditions of drainage, it does not convey conditions of development of convection clouds, the environment having a descendant character within the meadow, fact which leads to a decrease in the rainfall fallen in the area. From the analysis of the data obtained from the SNFI Brăila (National Society of Improvements Land), concerning the pluviometric determinations in the Balta Mică of Brăila Natural Park, it can be noticed values much lower than those recorded at Brăila station for the same spell (1976-2011): 347.1 mm (Bălaia) and 301.3 mm (Mărașu).

The potential evaporation-perspiration has values of over 700 mm and goes beyond with 200-250 mm annually fact which indicates a deficitary hydric regime (Fig. 4, Annexes).

The fractal analysis of annual and monthly distribution curves of the climatic parameters at Brăila Weather Station before and after the damming reflects the tendency of growth of the fractal dimension posterior to the damming at the level of distribution of the levels throughout a year (Tab. 1; Fig. 5, Annexes). This aspect pinpoints an increment of the complexity (based on certain climatic global changes), the existence of more degrees of freedom which can materialize in the apparition of some jeopardy elements on medium and long term.

Table no. 1 The fractal dimension of the distribution curves of the monthly averages values for the main climatic parameters (Brăila Weather Station)

Fractal dimension of air temperature		Fractal dimension of rainfall		Fractal dimension of potential evaporation-perspiration	
before damming	after damming	before damming	after damming	before damming	after damming
1.100	1.109	1.128	1.131	1.104	1.109

Hydrologic and hydrogeologic characteristics

The damming of the Danube's course caused the diminishing of the flowing section which

imposed a higher level than the previous situation. Hence, at the flow of 6300 mc/s registered in Braila, the level increased 39 cm (from 286 cm to 325 cm) following the damming. In Braila the multiannual means of

the levels increased 33 cm (from 273 cm previous to the damming to 306 cm post-damming as consequence of the damming: 0 level in Braila is of 1.076 m). This thing is highlighted also by the extreme levels: the minimum level anterior to the damming was of -61 cm in January 1954, and the one after the damming was of -1 cm in September 2003; the post-damming maximum level of 699 cm registered on 27th April and of 713 cm on 6th July 2010, was 6 cm, respectively 20 cm above the value of the maximum level in the post-damming period during the 1897 floods (693 cm) (Figs. 6 and 7, Annexes).

The fractal analysis undertaken highlights the incremental tendency of the fractal dimension post-damming, both at the level of annual means and of the distribution of the levels throughout a year (Tab. 2). This aspect indicates a growth of the complexity, the existence of more degrees of freedom which can materialise in the apparition of some jeopardy elements on medium and long term. Following the analysis of the distribution of the annual means of the levels, there can be noticed a positive tend due to the river’s constraint by dams.

Table no. 2 The fractal dimension (D_f) of the distribution curves of the annual and monthly variation of Danube water levels (Hydrological Station of Brăila)

	minim level D_f		average level D_f		maxim level D_f	
	before damming	after damming	before damming	after damming	before damming	after damming
annual	1.219	1.307	1.220	1.249	1.213	1.249
monthly	1.130	1.136	1.117	1.119	1.112	1.106

The damming has determined that this natural reservoir of flowing be disused and as consequence there appears a new distribution of the flows in the upstream sector, where the maximum flows convey in these situations higher values. The damming of Balta Brăilei eliminated the alleviation of the flows, determining at the end of the upstream of the dammed sector (Brăila) the rise of the flows with difference form the period previous to the damming: as multiannual means before the damming the increase was of 209 mc/s (the multiannual means before the damming was of 5980 mc/s and after the damming it reached 6280 mc/s). The maximum medium anterior flow of the damming of 10170 mc/s grew to 11030 mc/s as a consequence of the damming. The maximum medium anterior flow occurred on 28th May and on 27th April 2006 and was of 15000 mc/s.

The solid flow being in suspension at Brăila following the damming is of 846 kg/s

the multiannual mean. The average value of solid flow in suspension for Braila is of 3365 kg/s.

The meadow’s area is subdued to flooding with a frequency of 1-3 years, when the overflowing quota is surpassed and it reached 7-8 hydrograde. Total floods occurred when the threshold of 8.5 hydrograde was exceeded. The waters enter the Balta Mică of Brăila Natural Park through the upstream dams starting with the second half of February and stayed there till the first half of May. After this date the waters withdraw through the upstream dams till July-August.

After the waters’ withdrawal, in ponds there remains a part of the water due to the thresholds corresponding with the level of 3 hydrograde, ath the mouth of streamlets, though the ponds have a superior level to that of the indicated stage.

Geomorphologic parameters

The fractal dimension was formerly determined on the main and secondary Danube's arms, and afterwards on the islands' surfaces existing in the Balta Mică of Brăila Natural Park (Tab. 3):

The resulting fractal dimension fell within the scope of four value classes, according to stability or complexity. The I interval conveys the best degree of stability, whereas IV interval with the highest complexity degree (Tab. 4).

The increase of the degree of complexity imprints the apparition of more degrees of liberty within the frame of the system, highlighting itself in a more accentuated dynamics and a decrease in the degree of predictability.

Table no. 3 The fractal dimension (D_f) of the main and secondary Danube's arms and the surfaces of islands

	1956	1996	2006
Arm's length			
Calia	1.2116	1.2278	1.2281
Cravia	1.2381	1.2380	1.2340
Cremenea	1.2156	1.2244	1.2278
Navigable Dunube	1.2378	1.2424	1.2486
Harapu	1.1974	1.2062	1.2064
Măcin	1.2175	1.2252	1.2306
Mănușoaia	1.2317	1.2267	1.2267
Vâlcui	1.2323	1.2451	1.2495
Islands' surface			
Calia			1.8026
Cracanel			1.8916
Fundu Mare			1.8889
Harapu			1.9341
Orbului			1.8674
Vărsătura			1.9021
Insula Mică of Brăila			1.7884

Table no. 4 The value classes of fractal dimension

	Value classes			
	I (< 1.22)	II (1.221 - 1.23)	III (1.231 - 1.24)	IV (> 1.241)
Main and secondary Danube's Arms	Harapu	Orbu Cremenea Calia Mănușoaia	Cravia	Vâlcui Navigable Danube
	I (> 1.921)	II (1.901 - 1.92)	II (1.881 - 1.90)	IV (< 1.88)
Islands surface	Harapu	Vărsătura	Fundu Mare Crăcanel	Chiciu Orbului Insula Mică of Brăila

The analysis of the fractal dimension of the main and secondary arms of the Danube from the sector of the Balta Mică of Brăila Natural Park

After the comparative analysis (1956, 1996, 2006) of the fractal dimension of the main and secondary arms of the Danube in the sector of the Balta Mică of Brăila Natural Park, result the following:

- only regarding the Cravia and Mănușoaia arms the fractal dimension features a decrease, showing a tendency of steadiness of

these arms on long term. Hence, the fractal dimension of Cravia arm lowered from 1.2381 in 1956 to 1.2380 in 1996 and to 1.2340 in 2006. The fractal dimension for Mănușoaia arm lowered from 1.2317 in 1956 to 1.2267 in 1996 and to 1.2267 in 2006.

- the fractal dimension of the other arms increased during the period of 1956-2006, based on a more accentuated dynamics of Balta Brăilei as a result of anthropic pressure, the highest increment being

on the Calia arm (from 1.2116 in 1956 to 1.2340 in 2006) and Măcin arm (from 1.2175 in 1956 to 1.2306 in 2006). The general tendency is of increment of the fractal dimension of the Danube's arms in the analysed sector which conveys a highlight of the dynamics which can be mirrored in the increase of unsteadiness. It is necessary that the anthropic intervention be intensely monitored so as not to stress the increase of unsteadiness, which may affect a valuable biodiversity. Thanks the fractal analysis on the rivers, and implicitly on the arms, the more the fractal dimension heads for 2, the more increases the its complexity (in terms of unsteadiness), the arm filling the room more. The values closer to 1 indicate a better steadiness of the arm.

From the analysis of the 2006 results, it can be noticed that the smallest fractal dimension is featured by Harapu arm (1.2064), situated in the upstream segment of the balta Mică of Brăila Natural Park.

The Orbu, Cremenea, Calia and Mănușoia arms which enclose the islets in the central and southern segments of the Balta Mică of Brăila Natural Park have fractal dimensions ranging in-between 1.23 and 1.24. These have a moderate steadiness, imposed also by the fact that these arms take over reduced quantities of water and silt. At a more thorough analysis, there can also be distinguished more complex sectors, where the value of the fractal dimension is higher and the bank and meadow processes are more accelerated:

- the northern sector of Orbu arm: 1.2846
- the southern sector of Mănușoia arm: 1.2652

Cravia arm and Măcin arm have a fractal dimension ranging in-between 1.23 and 1.24 having thus a higher degree of complexity.

Between Smârdan and Turcoaia arms, the fractal dimension is of 1.2851. In this sector, during rainfall, there is a huge risk of

flooding. As regards Cravia arm, the relatively high discharge for this river makes that the dynamics of bank processes be more shaped. In the southern part of Cravia arm the fractal dimension is higher, being of 1.2703, superimposing itself with an area featuring a more shaped dynamics.

The arms with the biggest fractal dimension are Vâlcui and the navigable Danube, arms which take over the biggest part of the liquid, solid and soluble flows, a fact which affects the formation of the microrelief in that area.

Analysis of the fractal dimension of the islands' areas

In the fractal analysis of the areas, the fractal dimension is almost rather closer to 3, in addition, the steadiness of the islets is bigger and vice versa. Analysing the fractal dimension of the surfaces of islets it could be deduced that Harapu Island has the biggest fractal dimension, this being of 1.927, conveying very good steadiness of this island (just like Harapu arm). The low dimension of this island shows that there are not conditions for the development of some bigger colonies as in Fundu Mare Island and the Insula Mică of Brăila.

Vărsătura Island and the Insula Mare of Brăila have higher values of the fractal dimension ranging between 1.90 and 1.92, indicating better steadiness of these. The Balta Brăilei till 1964, in natural flowing conditions, allowed the existence of a real biodiversity paradise. The fractal dimension of Vărsătura Island is of 1.9627, fact which confirms a relationship between the fractal dimension and favourable conditions in maintaining the biodiversity.

The areas of Crăcănel and Fundu Mare islands have low fractal dimension values. A cause could be their great fragility imposed by the lengthening of these islands. For Fundu Mare island the fractal dimension of the area is quite superior (1.911).

The smallest values of the fractal dimension of the area are specific to Chiciu Orbului Island, the Insula Mică of Brăila and

Calia Island. These islands are elongated and presenting a complexity of the form which ensures many degrees of freedom. For example, on the Insula Mică of Brăila, in the Egret's area where biodiversity and ecosystems are most complex from the wet area of Balta Mică of Brăila Natural Park, the fractal dimension is superior (1.8944).

This high value may ensure greater steadiness in the area so that it allows self-restoration opportunities because of certain strictly controlled activities. The reduced steadiness of Calia Island, mirrored in the 1.8026 fractal dimension indicates intense processes especially in the southern area, where there is a possibility of unification with the Insula Mică of Brăila.

Conclusions:

We have made an analysis from the geographical viewpoint of all the characteristics of the wet area of the Island. I have also noticed that the climatic, biological and hydrological parameters influence the entire geographic environment. The most important aspect of the article is represented by the fractal analysis of a wet area of Balta Brăilei.

The fractal dimension may constitute a very important element in analysing the evolution of some exemption of the degree of steadiness, stability and complexity but also the continuation of some local differences. It can be also noticed a tight bond between the fractal dimension and the distribution per arms, the solid and liquid flow, but also with the arms' coefficient of sinuosity. Hence, the arms have the greatest fractal dimension, the highest sinuosity coefficient and transport most of the liquid and solid flow in suspension. The highest fractal dimension in area is held by the Insula Mare of Brăila, which now undergoes some intense processes of clogging from the wet area of the Insula Mică of Brăila, except the region of Egreta-Vulpașu colonies where the fractal dimension is lower, ensuring

conditions for better steadiness and revival of the ecosystems.

Rezumat:

ANALIZA FRACTALĂ A UNOR PARAMETRI CLIMATICI, HIDROLOGICI ȘI GEOMORFOLOGICI DIN PARCUL NATURAL BALTA MICĂ A BRĂILEI (ROMÂNIA)

Articolul prezintă utilizarea analizei fractale în evidențierea de modificări evolutive asupra unor parametri climatici, hidrologici și geomorfologici din Parcul Natural Balta Mică a Brăilei. S-a remarcat o creștere a dimensiunii fractale a curbelor de distribuție a parametrilor climatici și hidrologici, precum și evidențierea unei corelații pozitive între dimensiunea fractală a suprafețelor insulelor și densitatea biodiversității.

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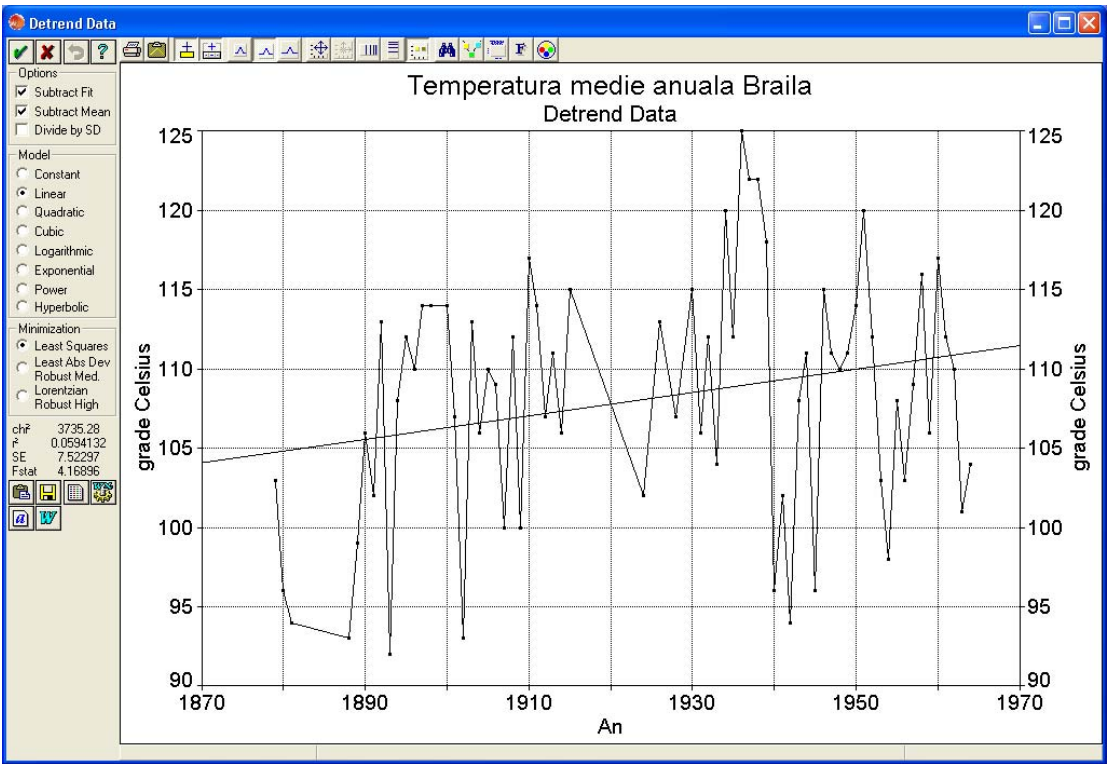
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Annexes:

Figure no. 1 The map of Balta Mică of Brăila Natural Park (source: Onea 2002)



Figure no. 2 (a) Variation of annual mean temperature in Brăila during 1879-1964



(b) Variation of annual mean temperature in Brăila during 1965-2011

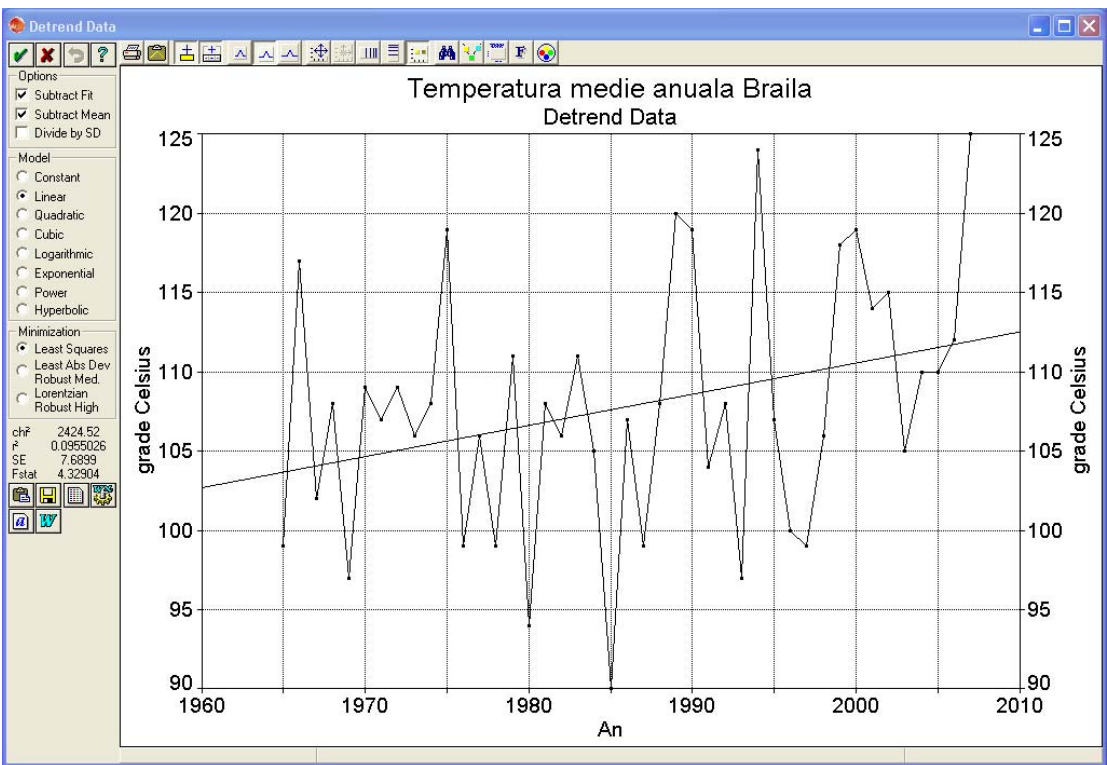
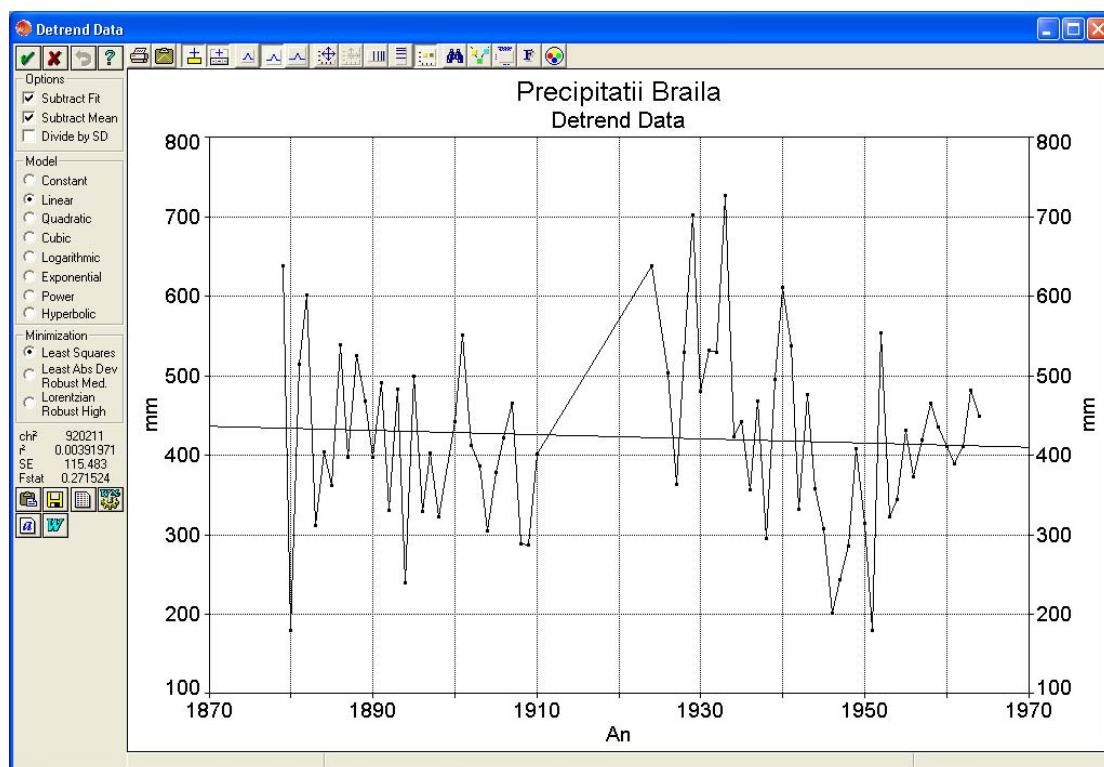


Figure no. 3 (a) Variation of annual mean precipitation at Brăila during 1879-1964

(b) Variation of annual mean precipitation at Brăila during 1965-2011

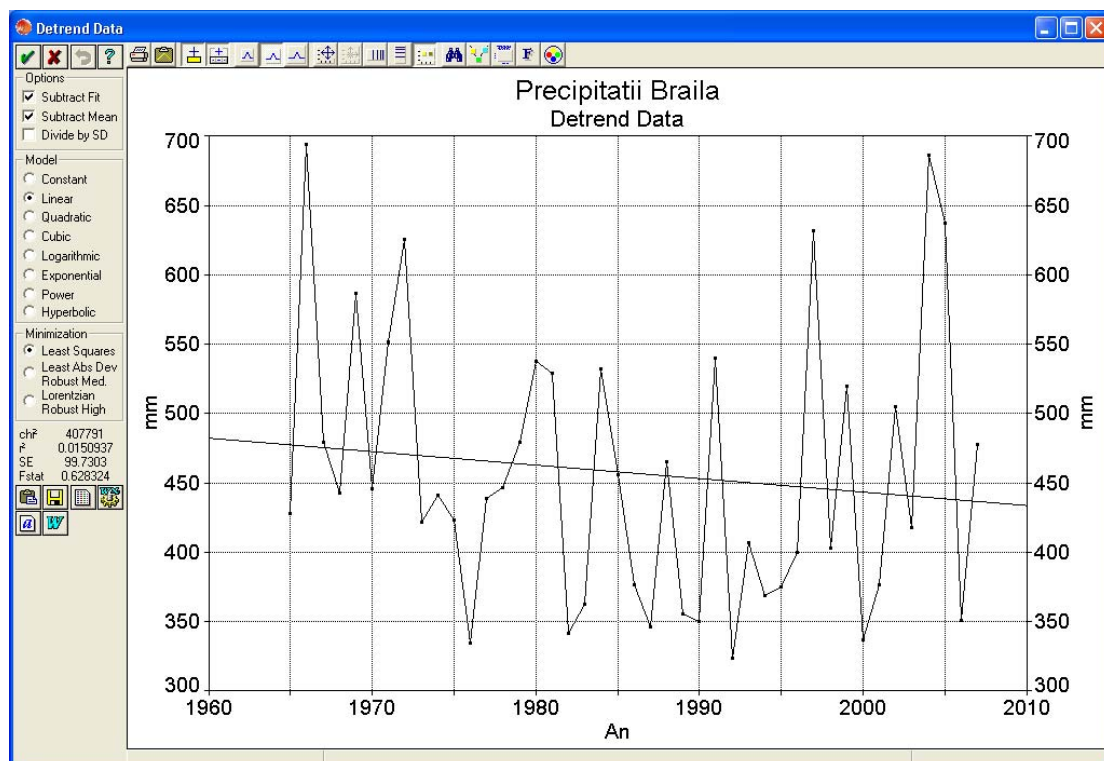


Figure no. 4 Variation of the potential evaporation-perspiration at Brăila during 1931-2011

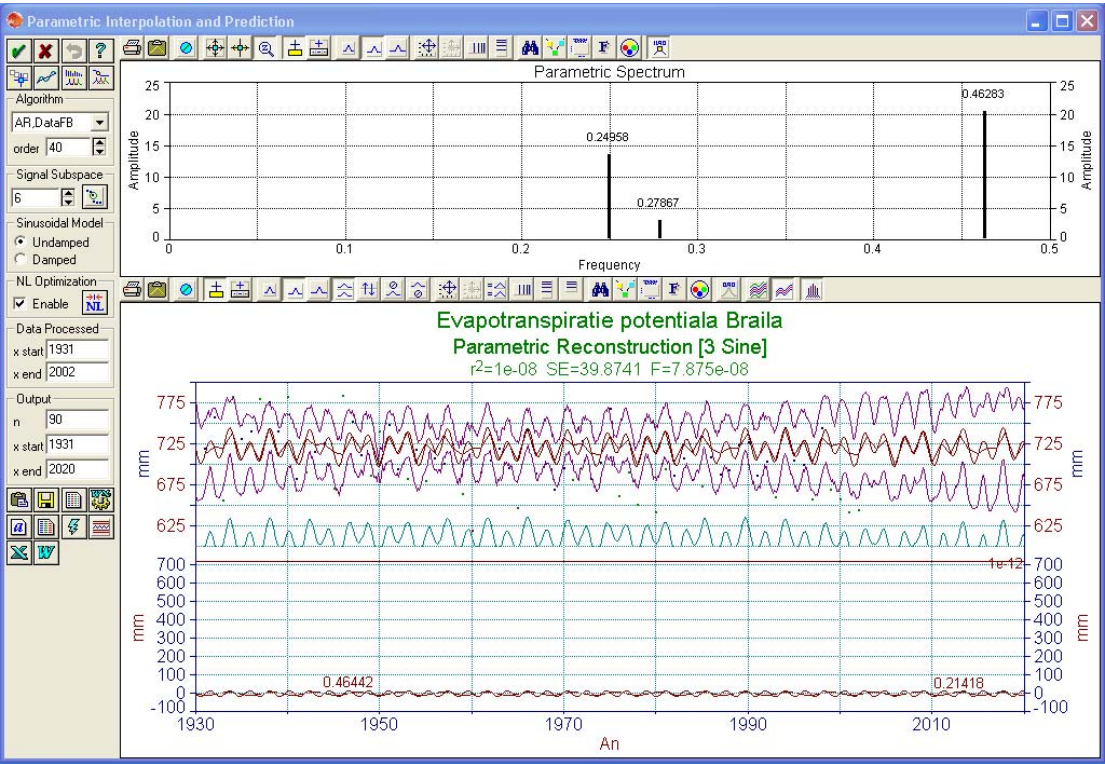


Figure no. 5 The fractal dimension of the distribution curves of medium year temperature of the air (1930-2011) (Braila Weather Station)

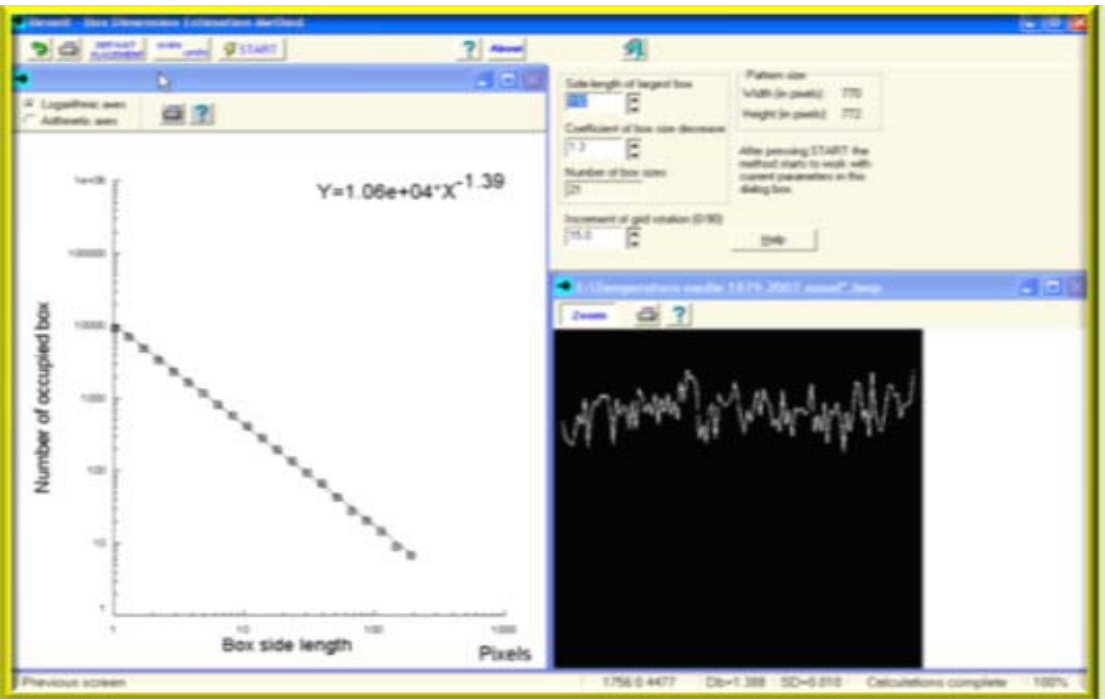


Figure no. 6 Average monthly variation of Danube water levels at Hydrological Station of Brăila between 1937 and 2011

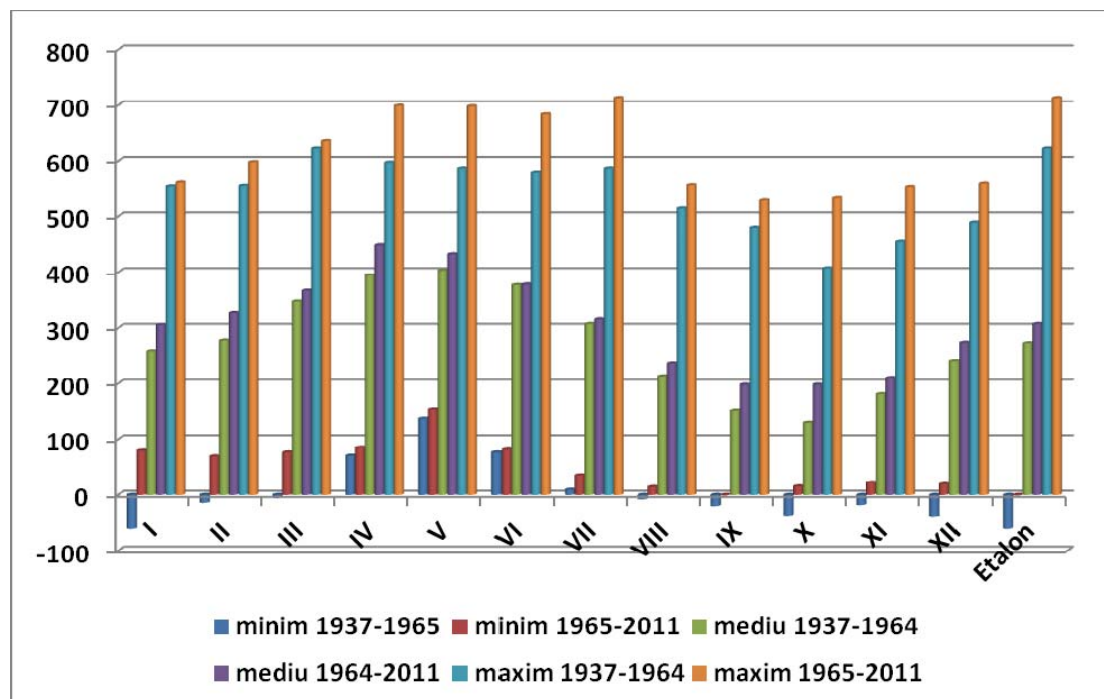


Figure no. 7 Average annual variation of Danube water levels at Hydrological Station of Brăila between 1937 and 2011

