Fractal Dimension Calculation for CORINE Land-Cover Evaluation in GIS – A Case Study

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Abstract. Together with rapid development in GI science recent decades, the fractal geometry represents a powerful tool for various geographic analyses and studies. This study points the land-cover areas with extreme values of fractal dimension in Olomouc region. This leads, together with consequent statistical analyses, to result that according to fractal dimension it is possible to distinguish (or at least to assume) the origin of areas. General fractal calculation method is used in the case study. Statistical methods are also applied to test mean values of land-cover areas fractal dimension (Student's t-test and analysis of variance). Using non-integer, fractal dimension, one can analyze complexity of the shape, explore underlying geographic processes and analyze various geographic phenomena in a new and innovative way.

Keywords: fractal geometry, GIS, land-cover, fractal dimension, geocomputation, shape metrics.

1 Introduction

When Weierstrass's continuous nonwhere-differentiable curve appeared in 1875, it was called by other mathematicians as "regrettable evil" and these types of object were known as mathematical "monsters" [8, 18]. Nobody imagined that fundamentals of fractal geometry were just established. However, since Mandelbrot's published its basics in [13], fractal geometry and fractal dimension (non-integer dimension, e.g. 1.32 D) is well known as a valuable tool for describing the shape of objects. It gained great popularity in geosciences [1, 7] (among other disciplines), where the measures of object's shape are essential.

Complex and detailed information about fractal geometry is in [8, 11, 14, 15, 18, 19]. Books provide the broad view of the underlying notions behind fractals and, in addition, show how fractals and chaos theory relate to each other as well as to natural phenomena. Especially introduction of fractals to the reader with the explicit link to

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natural sciences, such as ecology, geography (demography), physical geography, spatio-temporal analyses and others is in [8]. Some papers concerning topics investigated in this paper (land-use/land-cover pattern) were published yet, e.g. Batty and Longley's book [1] as pioneer work. Many other studies, such as [2, 5, 6, 16, 24, 26], applied different fractal methods for description of city morphology and connected issues. Fractal analyses applied especially on land-use/land-cover pattern are described as well, such as in [5, 9, 10, 17, 22, 27, 28].

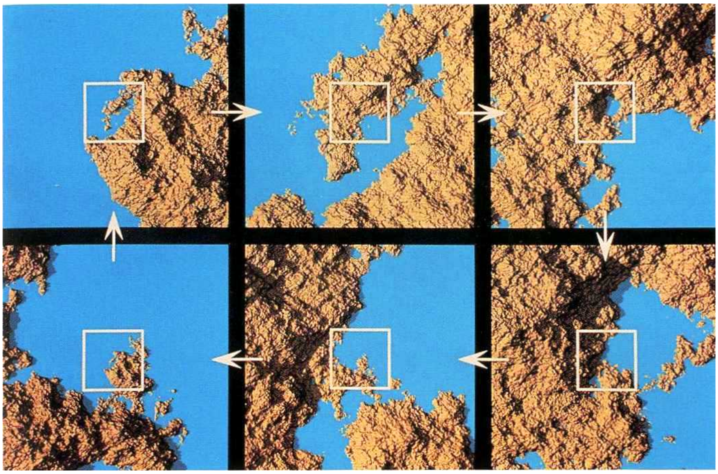

Fig. 1. Example of fractal coast and scale-invariance principle (in six steps/scales) [18].

One of the major principles in chaos theory and descriptive fractal geometry is self-similarity and self-affinity. The most theoretical fractal objects, such as Mandelbrot set, are self-similar – this means that any part of the object is exactly similar to the whole. But these types of fractals are rarely used to approximate objects or shapes from the real world. And thus, another type of fractals is suitable for real-world object description – self-affine ones. These fractals are in fact self-similar too, but transformed via affine transformation (e.g. translation, rotation, scaling, shear mapping) of the whole or the part of fractal object [1, 8, 11, 15, 18, 19]. This observation is closely related to scale-invariance (Fig. 1), which means that object has same properties in any scale, in any detail. In other words, if characteristics of some fractal object are known in certain scale, it is possible to anticipate these characteristics of another fractal object in different scale. The very typical example of this object is land-cover and/or urban forms with theirs dynamics.

Concept of fractality was described in detail in many publications [4, 7, 15, 18, 23]. Fractal dimension is a measure of complexity of the shape, based on irregularity, scale dependency and self-similarity of objects [2]. The basic property of all fractal structures is their dimension. Although there is no exact definition of fractals, the publicly accepted one, coming from Mandelbrot himself: "A fractal is by definition a set for which the Hausdorff-Besicovitch dimension strictly exceeds the topological dimension" [15]. Hausdorff-Besicovith dimension is therefore a number, which describes the complexity of an object and its value is non-integer. The bigger the value of Hausdorff-Besicovitch dimension, the more complex the shape of object and the more fills the space. In sense of Euclidean geometry, dimension is 1 for straight line, 2 for circle or square and 3 for cube or sphere, all. For real objects in plane, Hausdorff-Besicovitch dimension (fractal dimension) has values greater than 1 and less than 2. It obvious that Euclidean, integer, dimension is extreme case of fractal, non-integer, dimension. So it is claimed that regions with regular and less complex shape has lower fractal dimension (approaching to 1) and vice versa – the more irregular and complex shapes, the higher fractal dimension (approaching to 2). Values of fractal dimension of land-cover regions vary between 1 and 2 because of the fact that area represented in the plane space without vertical extend is in fact enclosed curves. And fractal dimension of curves lies between 1 and 2.

As depicted in mentioned publications, fractals provide tool for better understanding the shape of given object. Furthermore, fractal geometry brings very effective apparatus to measure object’s dimension and shape metrics in order to supply or even substitute other measurable characteristics of the object.

Next paragraphs do not intent to completely identify socio-economical, demographical and geographical aspects of land-cover current state in Olomouc region. The case study demonstrates the opportunity and power of fractal analyses of geographical data. Particularly, objectives are: land-cover pattern and its geometric representation in GIS. Land-cover pattern fractal analyses, among others, identify areas with maximal and minimal fractal dimension to evaluate complexity of such areas.

2 Methods, Data and Study Region

There is a number of methods for estimating fractal dimension and as [20] shows, results obtained by different methods often differ significantly. Also not only the method itself, but also the software, which calculates the fractal dimension may contribute to the differences [20]. In this case, ESRI ArcGIS 9.x software was used.

It has to be mentioned that in the case study statistical testing was accomplished. For this purpose, R-project statistical software was used. Because of the well-known formulas and characteristics, detailed description of the methods is not stated, excluding the program code in R-project environment. The methods were, namely, analysis of variance (hereafter as ANOVA) and Tukey's honest significant difference test and t-test.

2.1 General Calculation of Fractal Dimension

As mentioned above, there exists a plenty of methods to calculate fractal dimension [3, 6, 8, 18, 25]. For this purpose, one of the most general fractal dimension formula is used:

$$D = \frac{2 \cdot \log P}{\log A} \quad . \tag{0}$$

Where *P* is the perimeter of the space being studied at a particular length scale, and *A* is the two-dimensional area of the space under investigation [26]. Formula (**1**) was used to calculate fractal dimension for land-cover regions classified by Level 1 of the hierarchy. Formula (**1**) can be easily computable directly within GIS, thus ESRI ArcGIS 9.x was used in order to obtain fractal dimension values.

2.2 Statistical Evaluation of Fractal Dimension

After the fractal dimensions of land-cover shapes were calculated, the statistical evaluation was done. Firstly, the differences of fractal dimension among objects of various origins were testing using ANOVA. A null hypothesis, stated as ”there are no differences among mean values of the classes”, was formulated. In the case that null hypothesis was denied, the differences among groups were statistically significant and Tukey's honest significant difference test (hereafter as TukeyHSD) was performed. Although TukeyHSD is weaker test than ANOVA [21], it allowed multiple comparison procedure and statistical testing for finding particular differences among class couples. Thus, it could be helpful in the evaluation of fractal analysis [12]. If the criterion of TukeyHSD was on the boundary between a distinction and non-distinction, the t-test was also performed.

Example of a program commands used in R-project for an analysis of variance:

```
setwd("C:/Data/")
fd=read.csv2("fd.txt")
  anova<-aov(fd[,1]~fd[,2])
  summary(anova)
  TukeyHSD(anova)
  plot(TukeyHSD(anova))
```

2.3 Data and Study Region

For the case study, territory of Olomouc region was used (Fig. 2). Its area is approximately 804 km^2 and every single type of LEVEL1 land-cover classification is represented. It is necessary to note that CORINE Land-Cover dataset from year 2000 was examined. Olomouc region is mainly covered by the agricultural areas, but the north-east part is almost completely covered by forests, because of military area occurrence. Despite this fact, Olomouc region is the most typically agricultural region with a great number of dispersed villages (Fig. 3).

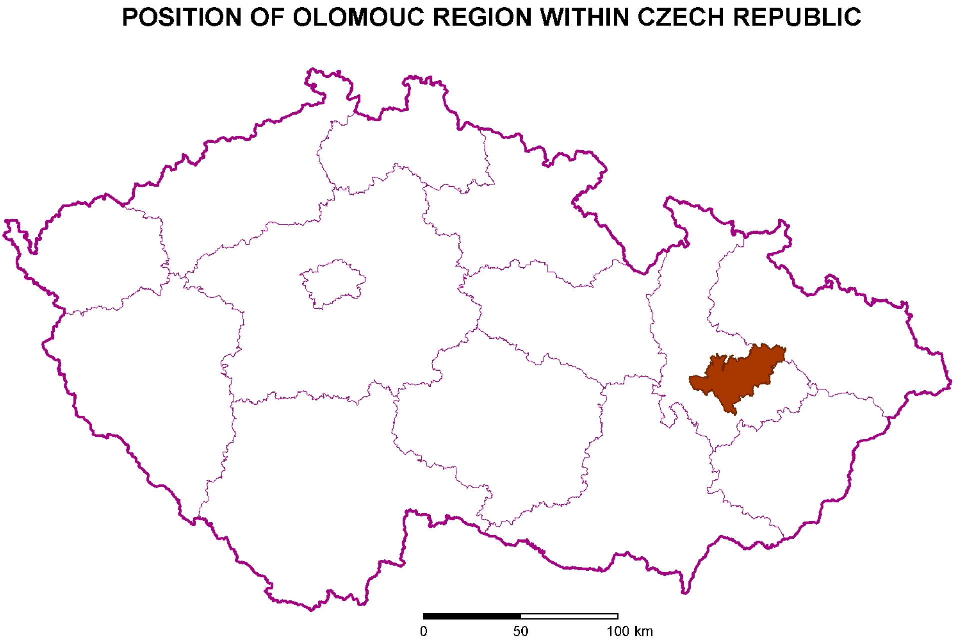

Fig. 2. Position of Olomouc region within Czech Republic (brown filled area).

3 Case Study: Fractal Analysis of Land-Cover within Olomouc Region

Visualization of land-cover in Olomouc region, which has fractal structure typical for landscape, is shown in Fig. 3. Areas with maximal and minimal fractal dimension, both for artificial areas and natural areas, are also outlined. From *Artificial areas*, the maximal fractal dimension (*D=1.393*) has town Hlubočky (Mariánské Údolí) and the minimal value of fractal dimension has part of Bystrovany municipality (*D=1.220*). In the first case, the maximal fractal dimension is caused by the topography of the town. Hlubočky (Mariánské Údolí) was built in steep valley on both sides of the river and thus is forced to follow highly irregular topography, which results into observed fractal dimension.

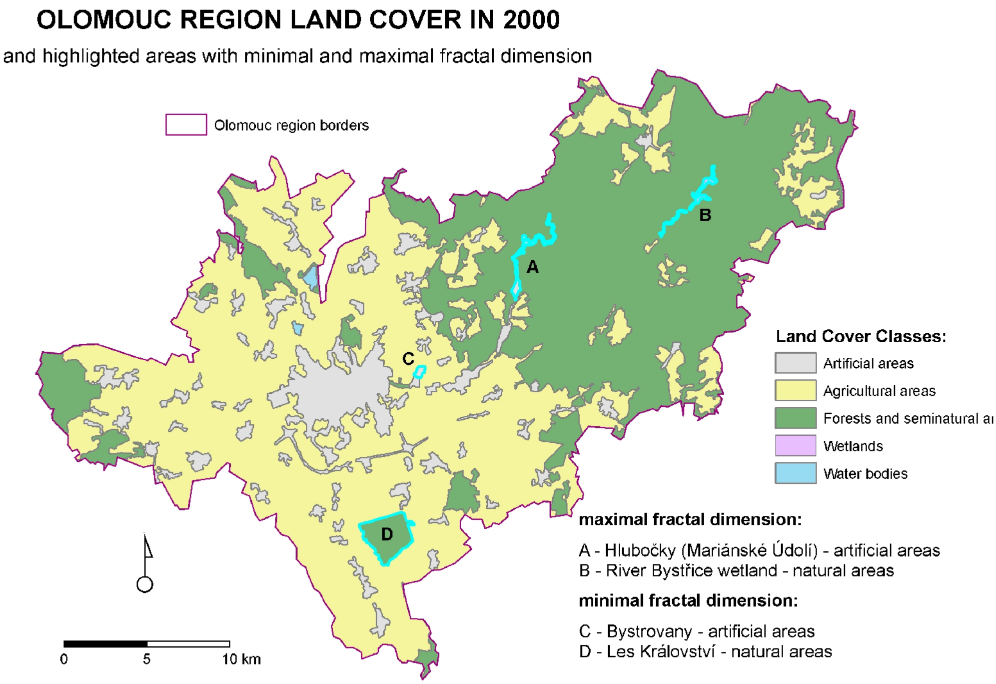

Fig. 3. Olomouc region land-cover in 2000 and highlighted areas with minimal and maximal fractal dimension.

On the contrary, part of Bystrovany municipality represents distinct regular shape – almost square. There were no landscape borders or limitations when the settlement was built and regular fabrication of the build-up area (agricultural facility) was, probably, the most logical one. From natural areas, maximal fractal dimension has the *Wetland area* of Bystřice river (*D=1.396*), which is part of highlands with almost intact landscape. Very regular shape has forest southern from Olomouc called Les Království and its fractal dimension (*D=1.193*) corresponds with that fact.

At last, join of all areas within class was accomplished and overall fractal dimension calculated. Results are shown in Table 1.

Table 1. Overall fractal dimension of particular land-cover classes in Olomouc region.

Class index	Land-Cover Class	Fractal Dimension
A	Artificial areas	1.438574
B	Agricultural areas	1.385772
C	Forests and seminatural areas	1.350355
D	Wetlands	1.395799
E	Water bodies	1.263722

It is clear from Table 1 that highest fractal dimension have *Artificial areas*, which represents in the very most cases man-made build-up areas (villages, towns, various facilities). Although knowledge how to plan and build up the settlement more properly was known long ago, urban sprawl emerged and has great influence on the irregular shape of artificial areas. *Wetlands* are very specific class, which are fully determined by natural processes and its fractal dimension is the highest among natural areas. On the other hand, *Water bodies* have the lowest overall fractal dimension. It is necessary to note that line objects, which would fall into this class (rivers, streams, channels, etc.), are excluded due to CORINE classification methodology. And that is why the water bodies have this overall fractal dimension – only man-made or man-regulated water bodies were identified by the classification process and consequently analyzed.

To objectively prove the significant statistical difference among the land-cover classes, the ANOVA was used. Before that, Shapiro-Wilk test (W=0.98) was performed to check up the normality of data. Normality was confirmed and ANOVA could be used. It was then proven that mean fractal dimension values are significantly different among areas of the various origin and thus the classes are different too. One can then claim that classes (Table 1) originate from diverse processes. To acquire more detailed information, TukeyHSD was performed. This test allowed multiple comparisons among classes and identified particular statistically significant differences. TukeyHSD had two main outputs, tabular output, which mainly contained p-value of difference between two classes, and also the graphical output, which described the differences and is self-explanatory.

The graphical output (Fig. 4) clearly shows classes with higher variability or which are more similar in chosen characteristics. Based on the TukeyHSD, it was possible to state that *Wetlands* (D) were the most different from all classes. Furthermore, the second class, which could have been recognizable is *Forests and seminatural areas* (C), which were on the boundary of a distinction with regard to *Artificial areas* (A) and *Agricultural areas* (B). T-tests proved that class *Forests and seminatural areas* really differed from both, *Artificial areas* (p-value=0.006) and *Agricultural areas* (p-value=0.015). Based on previous findings, one can claim that by calculating the fractal dimension of land-cover areas and consequence statistics it is possible to study, evaluate and interpret the processes lying underneath the current land-cover appearance.

According to the CORINE Land-Cover classification system and acquisition of the dataset in reference scale 1: 100.000, influence of generalization on the fractal analysis needs to be taken into account. The more generalized areas in land-cover classes, the more regular their shapes. And the results of fractal analyses are less accurate (in sense of capturing objects as much realistically as it is possible). Furthermore, formula (1) implies that the longer perimeter of the shape, the higher fractal dimension as a result. And this is very important fact, when calculation using formula (1) is used. Fractal analysis results are then influenced by the factors from logic sequence:

reference scale of map/dataset – generalization degree – perimeter of an area – fractal dimension value

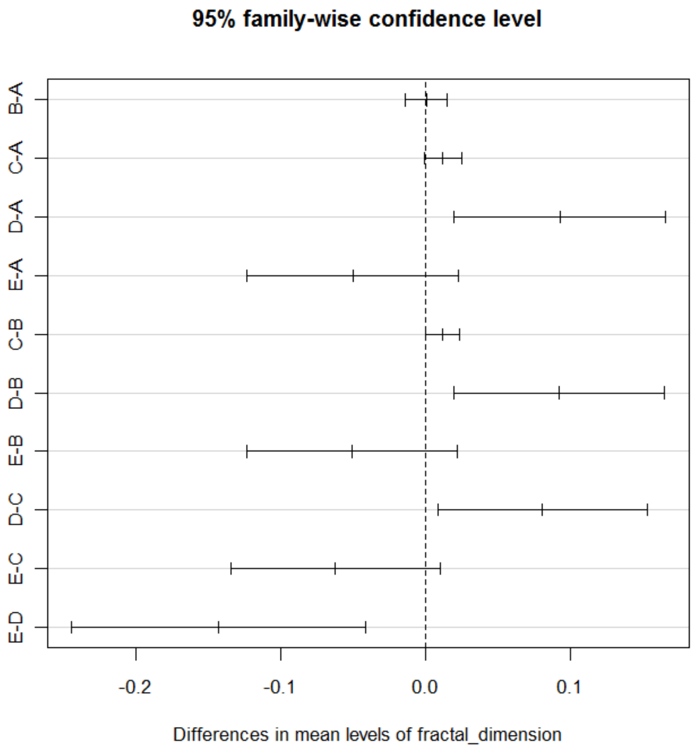

Fig. 4. Graphical output of TukeyHSD. Dotted vertical line is the mean, horizontal lines describe comparison between two classes (meanings of the characters on y-axis are in Table 1).

5 Conclusion

The use of fractal geometry in evaluating land-cover areas was presented. Resulting values of fractal dimension of such areas were commented using expert knowledge of the Olomouc region. Geographical context was mentioned too and proper visualization was made as well. Overall fractal dimension was calculated for comprehension amongst land-cover classes. Finally, some important aspects of generalization influence and CORINE classification system on the results were mentioned.

The paper brings to the reader basics of fractal geometry and its possible usage in geospatial analyses. Brief historical facts are also presented and plenty of publications and papers noted. It is obligatory to introduce methodological frame of fractal geometry apparatus, including formula by which the fractal dimension was calculated. The original case study was carried out to demonstrate practical use of fractal geometry and consequence analyses. As mentioned above, fractal analysis built its stable position in various natural sciences, including geoinformatics and geocomputation

Fractal analyses are very sufficient for measuring complexity or irregularity of various objects, but there are other metric characteristics of the shape (e.g. compactness, convexity, roundness, elongation and others) to evaluate objects, areas in this case, respectively. But the main difference between fractal geometry and this group of metric characteristics is in use of mathematical apparatus and, what is even more important, in concept of fractal geometry and chaos theory. And that is why the fractal geometry built its position in all kind of geospatial analyses.

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