Chapter

River Plume in Sediment-Laden Rivers

Levent Yilmaz

Abstract

Fractal dimension, which is a measure for the degree of complexity or that of fractals, is given for the erosion and sedimentation of fluvial beds. An alternative to fractal dimension is ht-index, which quantifies complexity in a unique way while sediment particles begin to move if a situation is eventually reached when the hydrodynamic force exceeds a certain critical value. Back to question, the physical meaning of fractal dimension is that many natural and social phenomena are nonlinear rather than linear, and are fractal rather than Euclidean. We need a new paradigm for studying our surrounding phenomena, not Newtonian physics for simple systems, but complexity theory for complex systems, not linear mathematics such as calculus, Gaussian statistics, and Euclidean geometry, but online mathematics including fractal geometry, chaos theory, and complexity science in general.

Keywords: natural dimensions, nonlinearity, fractals, meanders, plume

1. Introduction

The conflicting definition of the braided pattern raises the issues concerning (a) the difference between midchannel bars and islands, (b) the precise nature of the interaction between flow stage and bars or islands, and (c) the differences between the mechanisms of channel divergence that lead to river patterns termed as "braided" and those defined as "anastomosing." Consideration is given to the factors involved in determining the shear stress distribution at the flow boundary layer. The experimental results are presented in two parts. Experimental observations of meander evolution are described qualitatively. The most important parameter is the shear stress distribution, because of the inhomogeneous distribution of boundary layer meander features. At the wavy boundary layer, the shear stress distribution, measured with WTG-50 hot – film –anemometer is given graphically and theoretically.

Bankfull discharge is generally considered to be the dominant steady flow that would generate the same regime channel shape and dimensions as the natural sequences of flows would. This is because investigation on the magnitude and frequency of sediment transport has determined that for stable rivers the flow that transports most materials in the longer term has the same frequency of occurrence as bankfull flow. For stable gravel-bed rivers, this is considered to be the 1.5-year flood [1].

The objective of regime theory is to predict the size, shape, and slope of a stable alluvial channel under given conditions. The distribution parameter at the boundary layer is a meander feature curvature with the scope of inhomogeneous shear stress. A channel is characterized by its width, depth, and slope. The regime theory relates these characteristics to the water and sediment discharge transported by the channel empirically. Empirical measurements are taken on channels and attempts are made to fit empirical equations to the observed data. The channel characteristics are related primarily to the discharge, but allowance is also made for variations in other variables, such as sediment size.

For practical purposes, rivers are preserved to be in equilibrium (in regime) or in quasi-equilibrium with these characteristics, which have not changed over a long period of time. Canals usually maintain constant discharge, and regime relations may, therefore, be established using field data. However, field measurements for rivers are not usually suitable for establishing laws for rivers in regime.

If you use a ruler of k = 1000 m, you will need K rulers to run the entire river meander curvature. If you use a ruler of l = 500 m, you need L rulers and successively. What is the physical meaning of fractal dimension?

The number of rulers necessary to measure a meander curvature line M is proportional to the length of ruler m with an exponent D, where D is a constant that defines the dependence between the number of rules and the length of ruler and is known as a fractal dimension for measuring a river meander curvature.

It is intended to calculate fractal dimension slightly undulating line. It is found one code from net on boxcounting method (by [2]) and used for slightly undulating surface that is not given correct answer. Having x and z value of corresponding line. Is it possible to calculate from these values by any software/code [2]?

A characteristic feature of fractals is their fine structure. An object is known to have fine structure if it has irregularities at arbitrarily small scale. 'Fractal dimension' attempts to quantify the fine structure by measuring the rate at which the increased detail becomes apparent as we examine a fractal ever more closely. Fractal dimension indicates the complexity of the fractal and of the amount of space it occupies when viewed at high resolution. All definitions of dimension depend on measuring fractals in some way at increasingly fine scales.

A fractal, strictly speaking, has no "physical meaning." It is like asking about some curve we see on some Cartesian 2D coordinate frame-"what is its physical meaning? Or the curve, the function which we may have available to help us understand it and the frame of reference are all constructs of what we can now say... for purposes of brevity...is our intuition and our urge to express ourselves in ways that somehow help us deal with or cope with actions we have to take either now or in the future.

Thus, the lines we see on the graph paper have no physical meaning, per se. But that does not mean they have no "use." In fact, "use" is perhaps the best notion of "meaning." Their use if those who may be able to co further with those constructs and incorporate them into models they might work with in regard to various inquiries in science. Unfortunately, there has been little inquiry into just how and in which way and why fractals may be of use. We only tend to "look at the computer screens" and think that we "are seeing" something beyond some interesting calculations in complex number space.

In the end, complex numbers and their spaces are of far more use than real numbers and Euclidean-style geometries. Hopefully, we will be able to hone our intuitions to make use of them and of fractals in a wide range of pursuits, and, among them would be those understandings of ourselves and matters of human engagement that cannot begin to be approached with real number spaces and Euclidean assumptions about "reality."

"Reality" itself is an entirely flawed concept, which is rooted in our intuitions and imaginations being locked into a limited "real number/Euclidean/Cartesian" model for thinking and expressing ourselves. When we then speak of "reality," we expressly bring up the intrinsic nonsense and paradox of Cartesian coordinates and the real numbers. Fractals are the first message or signal to us that we can, in the long run, learn more about the universe and about ourselves via the creative "use; of complex numbers and indeed of complex number spaces and those number spaces further down the road of honing of intuitions such as quaternions and octonions… as well. Their beauty is a great lure and clue that there is much more than meets the eyes in our numbers…and that complex numbers can enable us and our mind's eye to see what real numbers cannot [3].

That is then the first step to using them and using fractal awareness within our other engagements with the so-called physical world.

2. Method

The body is where most of the objects found in nature possess irregular shapes that cannot be quantified with the help of standard Euclidian geometry. In many cases, these objects have a peculiar character of self-similarity where a part of the object looks like the whole [4]. Such objects are known as fractals and the associated degree of complexity of shape, structure, and texture is quantified in terms of fractal dimension (**Figure 1**). Natural fractals do exhibit self-similarity and scale invariance; however, this is present to a limited extent [5]. For example, a part of a cauliflower may look like the whole, but if further division is made, the resulting part may not resemble much the original cauliflower after several steps. The concept of fractal was first introduced by Mandelbrot in the year 1980; he showed that the concept of fractal can be used to quantify the complexity of shape associated with irregular geometry [2].

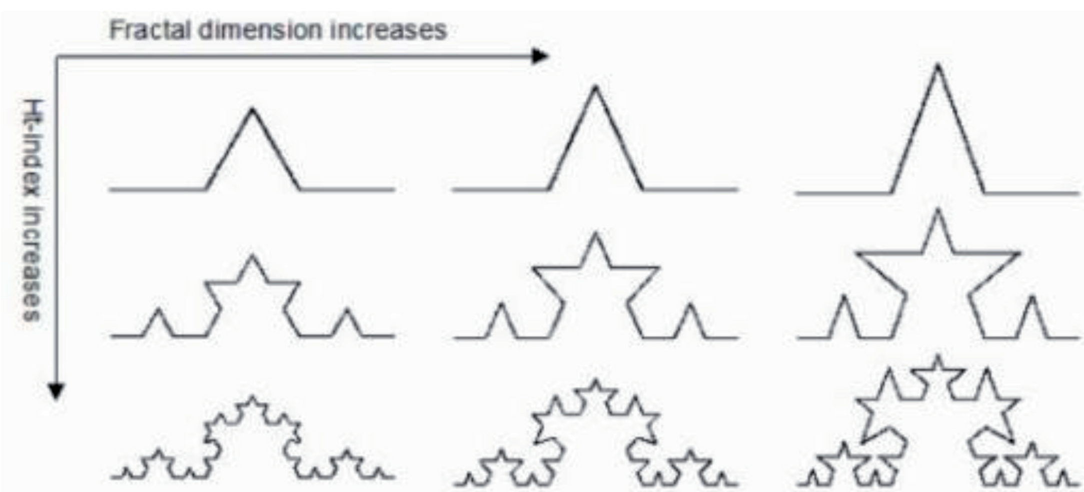

Figure 1.
Examples of naturally occurring fractal patterns in nature [5].

3. River meander curvature fractals

Fractal dimension of the curve is found from the slope of the best fitting straight line to the data (fractal dimension = 1 – m), where m is the slope of the straight lime.

Richardson's plot technique using rulers or segments of different sizes [6].

It is seen from **Figure 2** that for a given line with irregular shape, the number of segments or rulers of a given size increases as the size of the ruler is decreased. This results in different measures of the length of the curved line and the complexity of the shape is related to this difference. For a straight line, the measurements made using different sizes of rulers or line segments result in the same length, whereas for complex curves, the measured distance is larger and larger as smaller and smaller ruler sizes are used. The fractal dimension is related to the complexity of shape associated with the curve and a higher fractal dimension stands for a higher degree of complexity of the pattern analyzed.

If the object can be represented by a two-dimensional binary images in a computer screen or a matrix, which can be input from a digital camera or an image scanner, the fractal dimension estimation can be described as follows:

For an object in two-dimensional Euclidean space, the mass-radius (MR) relation is expressed as the mass included is proportional to the square of the circle of radius r or.

$$M(r) = r^2 \tag{1}$$

As an example, the area of a square measured by using circular discs of increasing sizes is directly proportional to the square of the radius of the disc used for the measurement. The power law exponent "2" is therefore the Euclidean dimension (a square is two-dimensional); however, the mass of a fractal object changes with a fractional exponent such that ($1 < D < 2$):

$$D\ M(r) = r \tag{2}$$

From this power law, the fractal dimension "D" of the object can be found as log(r):

$$\log(M(r)) = D'' \tag{3}$$

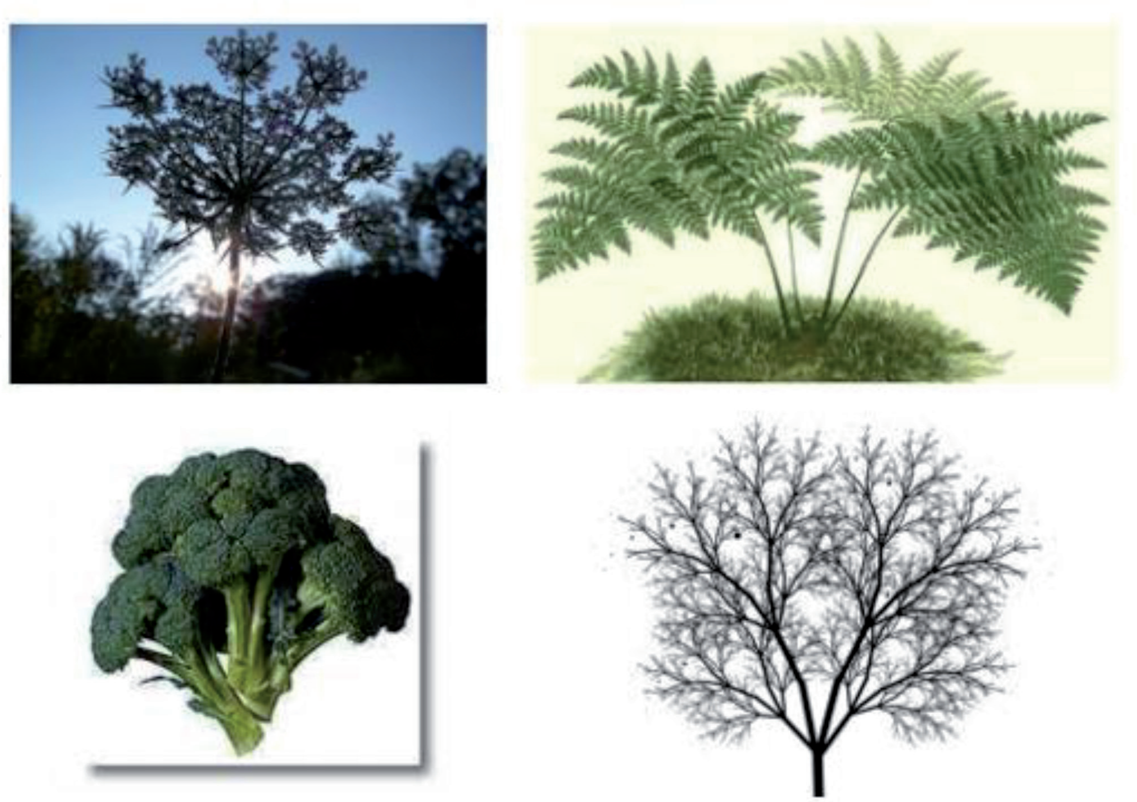

Figure 2.
River meander curvature fractals [1].

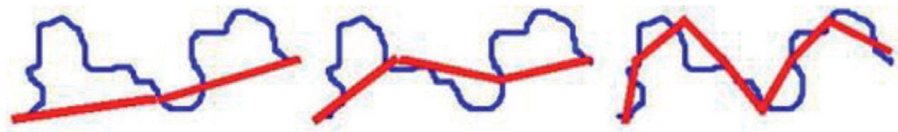

Figure 3.
Irregular shape of a line is analyzed using the ruler method.

Here, D is the slope of the straight line describing the log(M(r)) versus log(r). The two-point correlation function (C(r)) is related to the MR relation that can be used to determine the fractal dimension. For a fractal, C(r) decays as per the power law of a measuring distance (ruler size) r:

$$D\,C(r) = R \tag{4}$$

where D is the fractal dimension.

Since the ruler has a finite length, the details of the curve that are smaller than the ruler get skipped over and therefore the length we measure is normally less than the actual length of the curve. This can be seen in **Figure 3** where three rulers of different lengths are used to determine the length of the curve. The fractal dimension is estimated by measuring the length L of the curve at various scales. Also, it is true that as has been discussed in the use of ruler method the starting point or origin position affects the count or number of boxes required; here too, the estimated value of L may vary depending on the starting position. It is recommended that the same procedure be repeated at different starting positions [6]. This method of determining the fractal dimension of a boundary or a curve is also referred as "structured walk." Longley and Batty [8] discuss number of variants of this basic procedure. Normant and Tricot [3] have described an alternative estimation algorithm, termed the "constant deviation variable step (CDVS) method" that emphasizes the local behavior of the curve.

4. Self-similarity (concept)

The term self-similarity came into existence about 40 years ago that too in a relation to fractals and fractal geometry [6]. Fractal structures are said to be self-similar, when part of the object looks like the whole object under fractal dimension and self-similarity appropriate scaling, that is, the structure looks like a reduced copy of the full set on a different scale of magnification. The beauty of these clusters is that each of these smaller clusters again is composed of still smaller ones, and those again of even smaller ones. The second, third, and all the following generations are essentially scaled down versions of the previous ones. However, this scaling cannot be indefinitely extended; after certain stage, the smaller pieces may not perfectly represent the original shape; and this is the characteristic of natural fractals. In general, this is termed as self-similarity or statistical self-similarity. Thus, natural fractals exhibit self-similarity over a limited range and naturally occurring fractals usually exhibit statistical self-similarity [8], whereas mathematical fractals exhibit self-similarity at all length scales and thus are strictly self-similar.

Fractals are also strictly self-similar if they can be expressed as a union of sets. Geometric fractals may be composed of exact replicas of the whole object with which they are strictly self-similar [3].

Figure 4 exhibits the fractal properties of self-similarity, where MATLAB was used to create a binarized version of the image (**Figure 5**) [2].

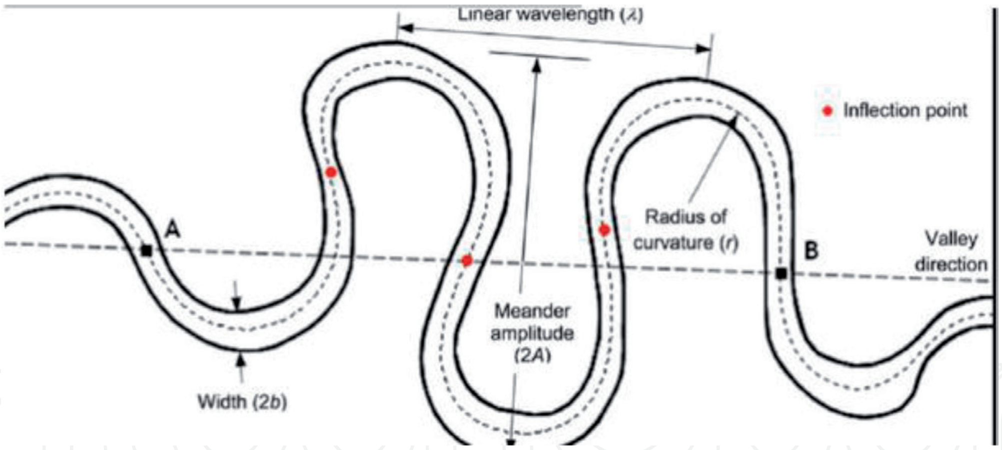

Figure 4.
Both the ht-index and fractal dimensions, characterizing fractals from different perspectives [4].

Figure 5.
Sierpinski triangles and Koch curve [7].

5. Theoretical study

The increased concern with riverbank erosion has increased the demand for theoretical models that can predict flow and bed features in a meandering alluvial channel where the flow in such a channel is complex than that in a straight channel in the nature.

In order to plan, design, construct, or maintain bank-erosion control structures and river-basin projects in general, the meander characteristics must be quantified by the point bar and deep pool bed topography near the apex of each bend [1]. The relations for depth and depth-averaged mean velocity are developed using standard flow equations with simplifications in the theory of river plume in sediment-laden rivers.

Clouds, shapes of mountains, clouds, trees, stars and the flood of rivers, river meanders were of the old concerns of human which are interested in searching behind the universe and cosmos, motion of planets, ocean waves, the structure and dynamics of the universe by the scientists. Checking behind the seemingly complex and chaotic nature of universe resulted in the emergence of chaos and complexity sciences. Fractal, chaos, catastrophe, and complexity theories are all concerned with the behavior of the complex dynamic theories.

The complex theoretical study of complexity was named edge of chaos that is a middle area between static and chaotic behavior of the natural systems where the complexity science is interested by the dynamic system means that change by time.

It is interested in how disorder gives way to order in reality. This theory studies the interaction between elements of complex system and subsystems, which is not about the sum of its agents but the relationship between parts and how they interact and adapt to the surrounding environment of nature.

With the difficulty of the complexity theory, the notion of nonlinear, feedback, and self-organized universe was introduced by mathematicians.

Here, the bottoms-up concept of organization replaced the machine-oriented ideas: that structure is designed into the system. This new theory was introduced by the mathematician Benoit Mandelbrot in the 1970s to explain the complexity of the systems, which are explained as follows: clouds are not spherical, mountains are not conical, river meanders are not circle and barks are not smooth, etc.

When the development of the nonlinear complex system behavior was given, it will take a geometrical mathematical form whose shape is geometrically fractal "an object that is chaotic in space is called fractal."

This new geometry is an extension of the classical geometry; it's a practical geometric middle ground between the extreme order of Euclidean geometry and the geometric chaos of general scientists. Discrete mathematics is the core foundation of fractal and fractal geometry where algorithms create the magic and simple algorithmic rules generate the fractal-rich structures.

6. Discussion

Theory of emergence, self-organization, evolution, and cosmogenesis rejected the concepts of determination, mechanism, reductivism, and materialism whose shift in thought had been reflected on engineers and architectures as well starting from Venturis' ideas for architects to fractal in architecture.

These views of complexity appear to be contradicting and rejecting modernism concepts in civil engineering, which is refused the plainer, clean, white architecture of modernism; instead, his ideas were directed to the indirect engineering meanings, forms, and compositions that satisfy the mind. Chaotic theory makes one think how things are put together; it takes time to be perceived and decoded. What chaotic theory was aiming for in civil engineers was actually found in the characteristics of fractal whose geometry plays an integral role between natures' complexity and civil engineering.

In civil engineering, starting from design views in 1960s through the postmodernism movement and till the digital age, engineers have started to design iconic cosmo-related works as it is called tending to be esthetically attractive.

The modernism perception of ornament is a crime was changed for the sake of nature. Where thoughts of ornaments as expensive decoration and it is a crime for the economy, waste of raw material and manpower. New thoughts were rejected and postmodernists returned to think about nature where they agreed that nature is the regulator morphology of the universe patterns and of the earth's surface occurrences. Nature is the source of patterns and the most which are complex ones.

In the new area with the use of computers, architects tend to create computer-generated natural occurrences and organizational patterns where the natural designs became much more complex and in the shape of natural ornaments like river plume in sediment-laden rivers. Hydraulics engineers' interest was directed to create natural designs in river curvatures like growing elements of meanders in the plume. The postmodern engineers' goal became esthetic creating complexity by subdividing the elements into billions of smaller units. They thought to create cellular self-generating growing natural ornaments that generate the whole natural body whose work may ripple in river plumes and undulate like frozen vegetation, and it is often based on cellular forms that vary as nature's fractals.

As presented in the previous engineering examples, the use of fractal characteristics transformed from architectural morphology of masses to natural occurrence design where fractal characteristics of scaling are used, and this project was successful in showing it on various dimensions, in the articulation of masses and spaces. This idea of producing the form in different scales to be distributed on the earth's surface of complex phenomena and inside the project, enrich the idea of scaling and emphasize on it.

Since the 1990s, the use of fractal geometry has been presented more in geometrical designs and engineering skin as shown in river plumes of different geographical districts.

Civil engineers depended on fractal geometry esthetically, which can be perceived by users and public. The use of fractal geometry in architecture has neither appeared nor has been used in morphology, masses, and spaces. There is a risk of fractal geometry being narrowed to become a tool to create attractive geometrical patterns.

In river meander and plume, the fractal extruded river curvature of the meanders was designed as an environmental solution to cool the space. In nature, we find that the fractal design of river plume was designed functionally as well as esthetically. In natural phenomena, the curvature extension (the spiral), the spiral river design that is covered with fractile, was given as dune design to direct plumes' circulation and create the river boundary layer spaces. In these two examples, the forming of ripples and dunes in hydrodynamics plays a role in the hydraulics engineering where fractal geometry is still fixed on the river plume boundary layers. It works as an ornament, which decorates the bottom of plumes in artificial design, that can be replaced by whatever other motif depending on the engineers' choice in artificial design of boundary layers.

As presented in the examples, the use of fractal geometry in designing of river plume bottoms consists of subripples and dunes that contain elements that have the same shape. This prototyping makes it easy in realizing the natural occurrence of river plume's design.

Which overturns some researchers argument that new theory of chaotic behavior is waste of money, time, and manpower by the use of fractal geometry in civil engineering and skin design became more economically efficient method because of prototyping some new ideas from nature and space.

7. Results

In contrast to river plume fractal dimensions, statistical fractals are self-affine fractals, or statistically self-similar; they are composed of statistically equivalent replicas of the whole object. Examples of strictly self-similar fractals are Sierpinski triangles, Koch flake, etc. as shown in **Figure 6**; the most fractal looking in nature do not display this precise from. The presence of self-similarity in the objects characterizes them as fractal.

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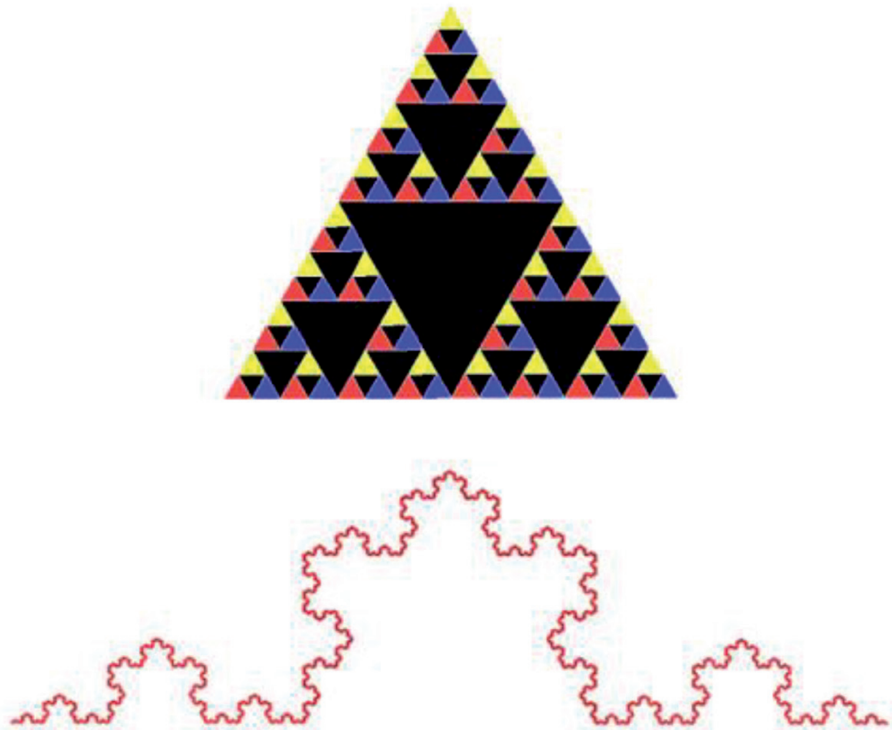

Figure 6.
Meander curvature in nature as defining the fractal dimensions [1].

Author details

Levent Yilmaz
Nisantasi University, Maslak, Turkey

*Address all correspondence to: levent.yilmaz@nisantasi.edu.tr

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