

How Long is Indian Coastline?

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Research Letter

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Abstract

Coastline measurements have no explicit length if they are geometrically self-similar. It is well known that length of self-similar geometrical objects is scale dependent, and hence it is not a fixed number, rather depends on the scale used to measure it. We present a definitive approach based on a fractal method to measure the coastline of India. We propose a method to define optimum scale length, that could be used to measure the coastline. Using our method, the mainland coast measures 7567 km. There are four big inhabited islands in Andaman (North, Middle, South and Little Andaman) which accounts for 687 km of island coast, and Great Nicobar Island has 195 km of coast around it, thus coastal length of inhabited islands is 882 km. Thus the total coast length of India including major 5 inhabited islands from Andaman-Nicobar group of islands is 8391 km. There are several other small islands in Andaman-Nicobar group of islands, we observed 26 of them significant in terms of their size. Indian coast length becomes 9060 km if we account for above mentioned 26 Andaman and Nicobar Islands. According to one of the Wiki articles, there are 572 islands in Andaman-Nicobar group of islands, but many of them are very small and insignificant. This is first ever scientific study about the Indian coast length, which has global significance due to strategic and climate related coastline alterations such as sea level rise due to global warming.

Key Points

- No published scientific study about the Indian coast measurement
- Coast length is strategically important for the government and planners
- Though coast length measurements are paradoxical, we present a definitive and reproducible approach.

Plain Language Summary

We have discussed a simple rule to select optimum measuring scale for the zig-zag curves, which gives best possible measurement of the complex curves. The rule is based on fractal dimension analysis, which has been applied to measure the Indian coastline.

1 Introduction

The term 'fractal' means a geometrical shape independent of scale. This is also termed as 'self-similarity'. In other words, if we take a small portion of a fractal object, then it must look alike the entire object. Some of the popular natural fractal objects are onions (if you peel off, each layer is similar, just size changes), cauliflower, trees, rocks, clouds etc. (Dimri, 2005; Korvin, 1992). Fractal objects have generally irregular geometry, and non-Euclidean dimension (fractional numbers). It can be argued that fractals are everywhere. There are numerous examples of fractal application in earth sciences demonstrating scaling nature of geology (Dimri and Srivastava, 2019; Dimri et al., 2012) and construction of fractals for modelling purposes (Barnsley, 1993). Fractal dimension is used to extend the concept of dimension to

such complex geometrical features. Statistical fractal are the objects having self-similar statistical property, for instance, if mean and variance of a smaller portion of a curve are similar to that of the entire curve, then the curve/ time series is termed as a statistical fractal.

This article aims to address scientific as well as non-scientific reader's inquisitiveness about the coastline length paradox. According to this paradox, the length of geographical curves increases and tends to infinity, as the measuring scale gets smaller and smaller (Richardson, 1961). There is an empirical relation between the length of the curve 'L' as a function of the measuring scale 'S' given by $L(S) = K * S^{(1-D)}$, where K is a positive constant and D is another constant called fractal dimension, which is at least equal to unity for curves. Note that D is always greater than 1 for the non-linear 1D curves, hence 1-D is a negative number, and the equation given above represents an inverse power law. Further, an explanation of the Richardson's observations about the length of the curve and measuring scale was published in a milestone paper (Mandelbrot, 1967).

In most of the cases natural coastlines are pretty involved geological curves and cannot be represented by straight lines (except in few African countries), and they represent a high degree of detail depending on the scale/ level of zoom we look at it. So, it is difficult to accurately measure the length of coastlines using large scales. However, paradoxically if we go on decreasing the measuring scale, the length of coastline increases exponentially and approaches to a large number tending to infinity. The paradox of infinite length holds true for the geometrically self-similar fractals, but not for the statistical fractal.

2 Data Description

The digital coastline data for India has been downloaded from the latest version of Global Self-consistent, Hierarchical, High-resolution Geography (GSHHG) database (Wessel & Smith, 1996). Full resolution data in native binary files of shoreline polygons, rivers, and borders can be downloaded from the following website: <http://www.soest.hawaii.edu/wessel/gshhg/> . After download, data was loaded into Matlab, and the only sea to continent boundary was retained for the further analysis (Fig. 1).

It is obvious from the Fig. 1, that Indian coastline is mostly linear except in western (Gujarat state) and eastern part (West Bengal). Thus, it is an example of statistical fractal, and hence we do not expect self-similar behavior at all scales.

Indian mainland coastline ranges from gulf of Kuchchh and gulf of Cambay (also known as Khambhat) in a bay of Arabian sea in the western part of country to the Bay of Bengal in the eastern part bordering with Bangladesh. Andaman and Nicobar group of islands consisting of 26 islands of variable size are also part of Indian territory which lies in Andaman sea (Fig. 1).

3 Methods

There are numerous articles and tutorials available about the Fractal dimension calculation methods. However, most suited one for the 1-D object, like coast lines is step-length method which is used in this

study (Napolitano et al., 2012; Turcotte, 1997). The method is briefly described here for the completeness of the paper.

3.1 Step length / Divider method

Divider methods are often used to measure the length of linear features/contours. These methods are based on the notion as if one walks along the object (for instance a coastline) with a measuring scale. These methods are also known as Hand and Divider or Step Length methods.

Length 'L' of an irregular boundary (fractal feature) is approximated by the polygon of given step length 'r', and can be computed by the following equation:

$$L(r) = r n(r), \quad (1)$$

where $n(r)$ is the number of steps needed to complete the walk. Thus, the length of the boundary or fractal feature is estimated by the product of step length (r) and the number of steps needed $n(r)$. The above procedure of walking along the boundary of an object is repeated for several steps of length r_i , giving length/ perimeter of the boundary:

$$L(r_i) = r_i n(r_i), \quad (2)$$

The fractal dimension of the boundary is given by:

$D = 1 - m$, where m is a slope of the plot between $\ln(r_i)$ vs. $\ln(L)$, also known as Richardson's plot.

In practice, a starting point (x_1, y_1) is chosen on the boundary object, and using the step length polygon is constructed to approximate the boundary object. For instance, a next point on the boundary (x_2, y_2) can be selected in a direction following the boundary object using the following criteria:

$d_i = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$, so that $d_i \leq r$, where r is step length. Keep repeating above step to find next point on the curve to approximate it by a polygon until end of the curve or starting point is reached in case of a closed boundary. A nice description and other variants of divider methods are given in (Napolitano et al., 2012) and (Clark, 1986).

Mathematically it is obvious that the length/perimeter of the object will increase to infinity if step length tends to zero. Large step lengths provide a crude approximation of irregular objects and very small step lengths can give a very good estimate of the length/perimeter. However, there is no rule as to what the smallest length of a step should be?

We propose a method to find the smallest value of step length 'r' at which the scaling regime ceases to be constant. This is the optimum 'r' which, we propose to use for the measurement of coast length. There is no need to decrease the length of scale below optimum 'r' because length of the object will not increase

exponentially even if step length is halved than the optimum 'r'. Finally, the coast length is calculated using the optimal value 'r' using Eq. (1).

3.2 Optimum scale length

To find the optimum scale length, authors have chosen middle-Andaman, which is one of the biggest islands from the cluster of Andaman-Nicobar Islands for its boundary length measurement using several scales (Fig. 2). Middle-Andaman has very rugged boundary, and it is ideal for fractal measurement. The log-log plot of perimeter length vs. scale also known as Richardson plot is shown in Fig. 3. It is obvious from Fig. 3 that the scaling regime is no more valid for the scales smaller than $\log(r) = -0.7$, employing that $r = 0.5$ km is the optimum scale, and smaller values than this scale may give slight increase in length of perimeter, but they do not follow scaling behavior. We propose to use above analysis to obtain optimum scale length (Keating, 1993; Srivastava et al., 2007) to measure length/ perimeter of fractal objects. As stated in the introduction that the length/perimeter of fractal object is not absolute rather it depends on the scale of measurement. Hence, we would use the optimum scale length obtained above for mainland Indian coast and all islands in Andaman-Nicobar.

Fractal dimension of the Indian coast is greater than one (1.15), which indicates that the Indian coastline is not a straight line. It is evident from the India map, that western coast along Gujarat state, and Eastern coast near West Bengal is zigzag and presents a high level of detail on a finer scale. Fractal dimension close to 1 signifies that the coastline is mostly linear.

Several step lengths are used for the calculation of Indian coast using divider method (**Fig. 4**). The results are tabulated in Table 1. The mainland coast length corresponding to optimum step length 0.5 km is 7566.92 km, which is closer to the existing coast length estimate found on Google search (7516 km, without islands). It is obvious from **Fig. 4** and Table 1, that halving the step length to 0.25 km from the optimum one (0.5 km) did not increase the coast length significantly. Thus 0.5 km is also an optimum scale to measure the coast length of mainland India.

Table 1
Step length vs. coast length using divider method. From Fig. 4 it is obvious that scales larger than 50 km are not appropriate and do not measure the coast adequately.

Step length (km)	Indian coast length (km)
0.25	7568.83
0.50	7566.92
1.0	7547.26
2.0	7489.5
4.0	7359.84
8.0	7033.40
16.0	6385.80
32.0	5702.88
64.0	5336.60
128.0	4599.22
256.0	4128.01

Same optimum scale length (0.5 km) is used to measure the coastal boundary of the Andaman-Nicobar group of islands. Length of all the Andaman-Nicobar Islands using different scales is tabulated in Table 2. It is worth mentioning that some of the islands are so small that it is not possible to measure their perimeter using 1 km scale. Hence, it was possible to use only following three scales (0.25, 0.5 and 0.75 km) for all the islands as shown in Table 2. We consider coastal boundary of Andaman-Nicobar Islands equal to 1493 km which corresponds to optimum scale length of 0.5 km. Please note that in this case also halving the scale to 0.25 km does not give significant change in Andaman-Nicobar boundary length.

Table 2
Step length vs coast length of Andaman-Nicobar islands using divider method.

Step length (km)	Andaman-Nicobar islands coastal boundary (km)
0.25	1494.62
0.50	1493.35
0.75	1484.13

4 Results

We have demonstrated use of optimum scale length concept for finding length of complex geometrical shapes using fractal dimension analysis. The method is robust and repeatable without ambiguity, and it provides a reliable length estimate of complex shapes, which is usually very difficult due to high dependence on measuring scale.

Length of Indian mainland coast is shown in Table 1, which is chosen to be 7566.92 km corresponding to scale length of 0.5 km, similarly coast length of Andman-Nicobar islands is shown in Table 2 which is 1493.35 km corresponding to same scale length. The optimum scale length 0.5 km has been chosen based on the analysis shown in Fig. 3.

5 Conclusions

Our calculations which can be easily reproduced using our Matlab code and the data available in public domain demonstrate that the mainland Indian coast is 7566.92 km. Coastal length of biggest inhabited islands is 882 km. Thus, the total coast length of India including major 5 inhabited islands from Andaman-Nicobar group of islands is 8391 km. In our calculations we used 26 islands in Andaman-Nicobar group of islands which are significant. Sum of their coastal lengths is 1493.35 km when measured with a scale of 0.5 km. Thus, another estimate of coastal length of India amounts to 9060.27 km with a 0.5 km scale considering all the significant islands in Andama-Nicobar group of islands. We believe that our study could be used as a base case measurement for the other studies which may focus on studying coast length variation due to sea level changes for instance.

Declarations

Availability of data and material

Data and Matlab code is uploaded at the site (<https://doi.org/10.5281/zenodo.3405572>) and has open access for everyone. There are two zip files uploaded on the above site, one is Mainland, which contains Indian coastline and Matlab code, another file called Andaman contains 26 data files representing each Island in Andaman and a Matlab code to measure its boundary.

Competing Interests

Authors declare that there is no financial and affiliation related conflict of interest which influences results of this paper.

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Author contributions

Author R.P.S has compiled and reformatted data for computational purpose. He also wrote Matlab code to generate results and contributed in writing of the research paper. Author V.P.D came up with the idea of the problem. He has quality checked results and contributed in writing.

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Figures

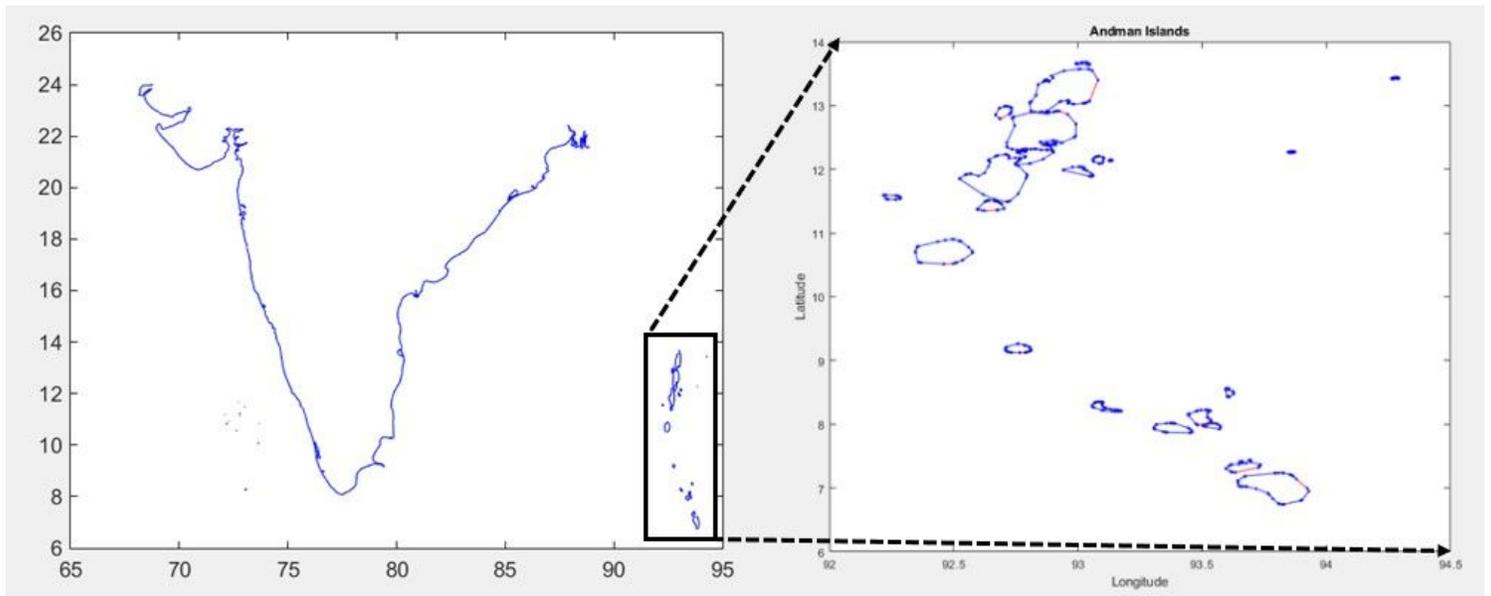


Figure 1

Indian coastline with Andaman-Nicobar Islands. Right part of figure shows zoomed version of Andaman-Nicobar Islands which consists of 26 variable sized islands. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

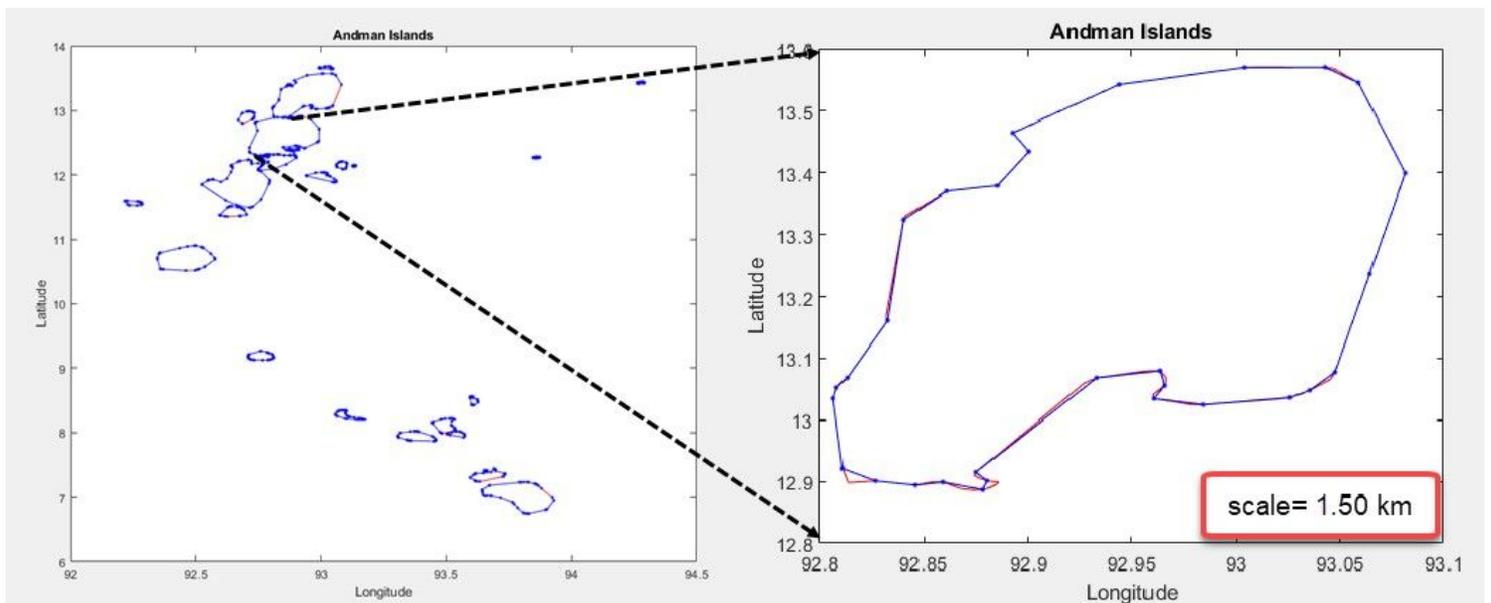


Figure 2

Zoomed version of Andman- Nicobar islands. Right part of the figure shows zoomed version of the island selected for computing optimum scale length. One of the biggest islands allows possibilities to use several scales for measurement, which is needed to create fractal dimension plot for optimum scale

computation as shown in Figure3. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

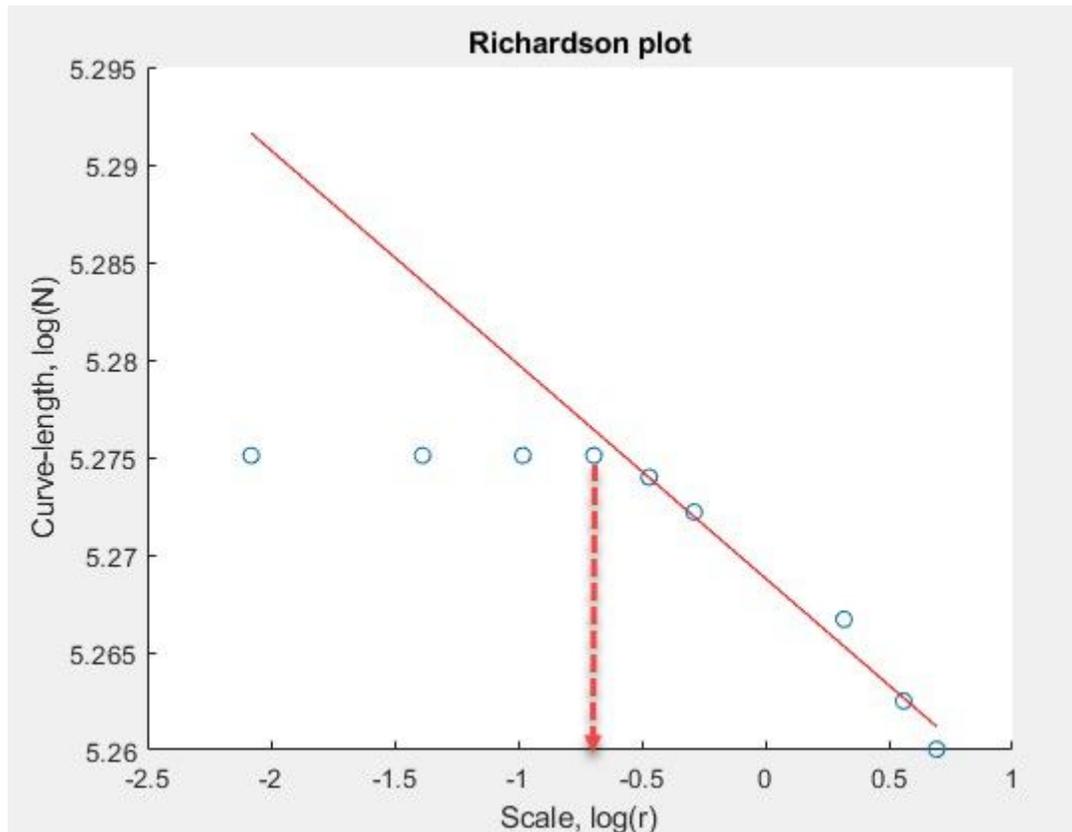


Figure 3

Log-log plot of the scale vs. measured curve length for one of the islands in Andaman. The plot suggests that the scaling regime ends at $\log(r) = -0.7 \Rightarrow r \sim 0.5$ km (shown by the dotted arrow).

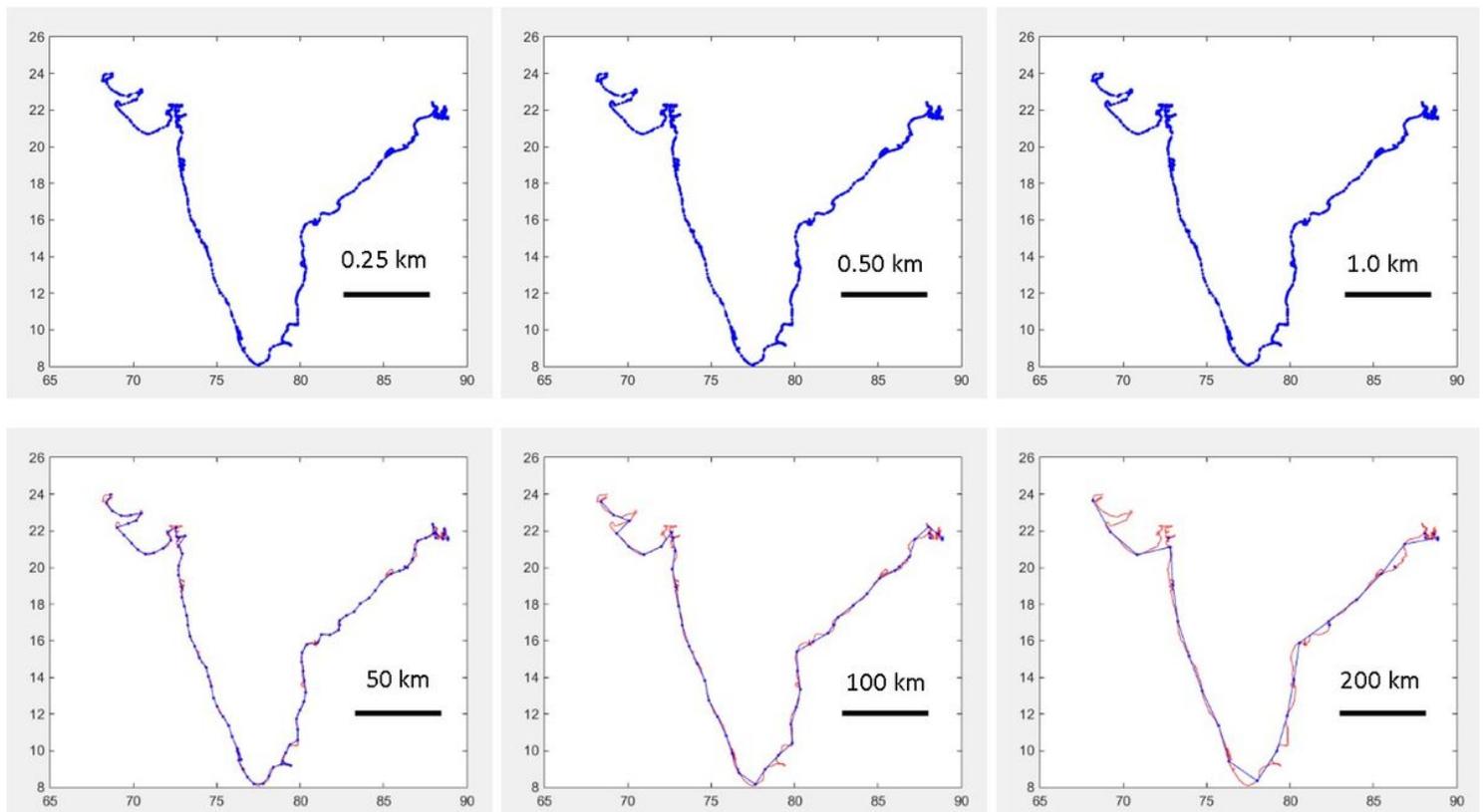


Figure 4

Divider method for length measurement of Indian coast. The original coastline is shown in red color, blue lines are traverses along the coast (as if one walks along the coast with a measuring stick) with the step length shown in the figure. For step lengths smaller than 1 km, both blue and red lines are mostly overlapping in this zoom level. However, with a large zoom, it is observed that some finer details are still not covered with the smallest scale shown above. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.