FRACTALS, NATURAL DISASTERS AND ECOLOGICAL PROBLEMS OF MALDIVES

Boyko Ranguelov, Fathimath Shadiya

Abstract: A new idea about the fractal nature of Maldives archipelago is under investigation. The origin of this famous Maldivian islands' country is still questionable from geodynamic point of view. The present study is focused to the assessment of the fractal properties and the coefficients of the nonlinearity (fractal dimensions) of the areal spatial distribution of the major atolls of the Maldives. This is the most vulnerable area in the world from point of view of the global warming and the possible negative consequences to the country and population from the ocean level increase. From another side the natural hazards (tsunamis, storms, etc.) are common negative phenomena attacking the country. The strongly developed tourism – more than 30% of the GDP and the increased urbanization is another factor creating ecological problems to the local population. The relationships between the fractal nature and the possible ways to avoid the pollution are also in the focus of this research.

Key words: fractals, Maldives, natural hazards, ecological problems

INTRODUCTION

This paper studied the assessment of the fractal properties and the coefficients of the nonlinearity (fractal dimensions) of the areal spatial distribution of the major atolls of the Maldives. The idea to investigate these properties was inspired by the research of the fractality of other similar objects investigated by different research teams [1, 2, 3, 4]. The results obtained suggested that such fractal properties are rather common in Geosciences [5, 9, 10]. On the other hand the main hazards for Maldives are presented together with the zoning maps as first step of the long term preventive measures and the urban planning of Maldives. The ecological problems are related in general with the global warming and the ocean level rise. The Maldives are low lands (the average elevation of about 1.5 m above the sea level), then the sea level increase is a key factor for the survival of this tourist heaven country.

THEORY AND METHODOLOGY OF FRACTAL APPROACH

The classical example of a fractal object is defined by [7]. If the length of an object P is related to the measuring unit length l by the formula:

$$P \sim l^{1-D} \quad (1)$$

then P is a fractal and D is a parameter defined as the fractal dimension. This definition was given by B. Mandelbrot in the early 60-s of the 20-th century. His ideas support the view that many objects in nature cannot be described by simple geometric forms, and linear dimensions, but they have different levels of geometric fragmentation. It is expressed into the irregularities of the different scales (sizes) – from very small to quite big ones. This makes the measuring unit extremely important parameter, because measuring of the length, the surface or the volume of irregular geometric bodies could be obtained so that the measured size could vary hundred to thousand orders. This fact was first determined when measuring the coastal line length of West England and this gave Mandelbrot the idea to define the concept of a fractal.

In geology and geophysics is accepted that definition of the different "fractals" as real physical objects is most often connected to fragmentation [6]. This reveals that each measurable object has a length, surface or volume, which depends on the measuring unit and the object's form (shape) irregularity. The smaller the measuring unit is, the bigger is the total value for the linear (surface, volume) dimension of the object and vice versa. The same is valid for 2D and 3D objects [8].

Another definition of a fractal dimension is related to the serial number of measurement to each of the measuring units used and the object dimensions. If the number of the concrete measurement with a selected linear unit is bigger than r, then it might be presented by:

$$N \sim r^{-D} \quad (2)$$

and the fractal is completely determined by D as its characteristic fractal dimension. Applying this definition for the elements of faulting and faults fragmentation, some authors use this idea to depict formal models of the earth crust fragmentation, which indicates the level of fracturing of the upper earth layers [2]. Same approach was carried out for the fractal properties of the major elements of the Plate tectonics models [4].

The theoretical approach for the linear case and for the 2D and 3D cases was developed by Turcotte [10] and Hirata [5]. They focused the attention on the relations between the smallest measuring unit and object's size in analyzing linear (1D), 2D and 3D objects (Fig. 1).

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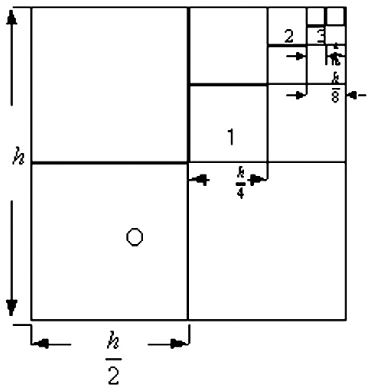

Fig.1. 2D fractal scheme – each linear element is ½ of the larger one

If l is the measuring unit and with m we denote the obtained value for N at each measuring cycle, then the common sum of the lengths N at level m according to [9] is:

$$N_m = (1 - p_c)\left(1 + \frac{n}{m} p_c + \left[\frac{n}{m} p_c\right]^2 \dots \left[\frac{n}{m} p_c\right]^m\right) \quad (3)$$

where p_c denotes the probability for measuring of each length for the corresponding cycle of measuring.

Using formulas 1 and 2 we obtain the following formulas:

$$\frac{N_{m+1}}{N_m} = 2^D \quad (4)$$

for liner elements, and

$$\frac{N_{m+1}}{N_m} = (2^2)^D \quad (5)$$

for any area elements (surfaces).

Using this approach, we studied the area surfaces of the Maldives atolls and calculated the fractal dimensions for these formal areal objects.

Table 1. Areas (in km^2) of the main atolls of Maldives

FRACTAL DISTRIBUTION OF THE MALDIVES' ATOLLS

No	Atolls	Area km^2
1	Thiladhunmathi	4000
2	Huvadhoo	3300
3	Ari	2270
4	Maalhosmadulu Uthuruburi	2000
5	Kolhumadulu	1700
6	Male' Uthuruburi	1580
7	Felidhu	1080
8	Mulaku	970
9	Maalhosmadulu Dhekunuburi	960
10	Haddhunmathi	880
11	Nilandhe Dhekunuburi	730
12	Faadhippolhu	710
13	Nilandhe Uthuruburi	605
14	Male' Dhekunuburi	530
15	Ihavandhippolhu	290
16	Addu	150
17	Fasdhūetherē (Fasdhūtherē)	140
18	Maamakunudhoo	135
19	Goidhu	107
20	Gahaafaru (Gaafaru)	86
21	Rasdhu	60
22	Vattaru (Falhu)	45
23	Kaashidhu	8
24	Fuvahmulah	5.7
25	Thoddu	3.5
26	Etthingili Alifushi	3.2

The total number of atolls taken in consideration is 26. Their surface dimensions vary between 3 and 4000 km^2. The accuracy of the area assessment varies between 1% (for the smaller elements) to the 10% (for the larger ones).

The graphical presentation of the numbers versus areas helps a lot the fractal dimension calculation. Following formula (5) we calculated the fractal dimension from Fig. 2 and it is equal to 2.75.

Thus the graphic representation of the relationship between the size and the respective number of atolls gives the possibility to calculate the fractal dimension of 2.75. This means that the fractality is well defined and the nonlinear relationship between the size (in semi logarithmic scale) and the respective numbers of atolls is very well expressed. Sometimes this reflects to the environmental aspects of the natural hazards and the nonlinearities [11].

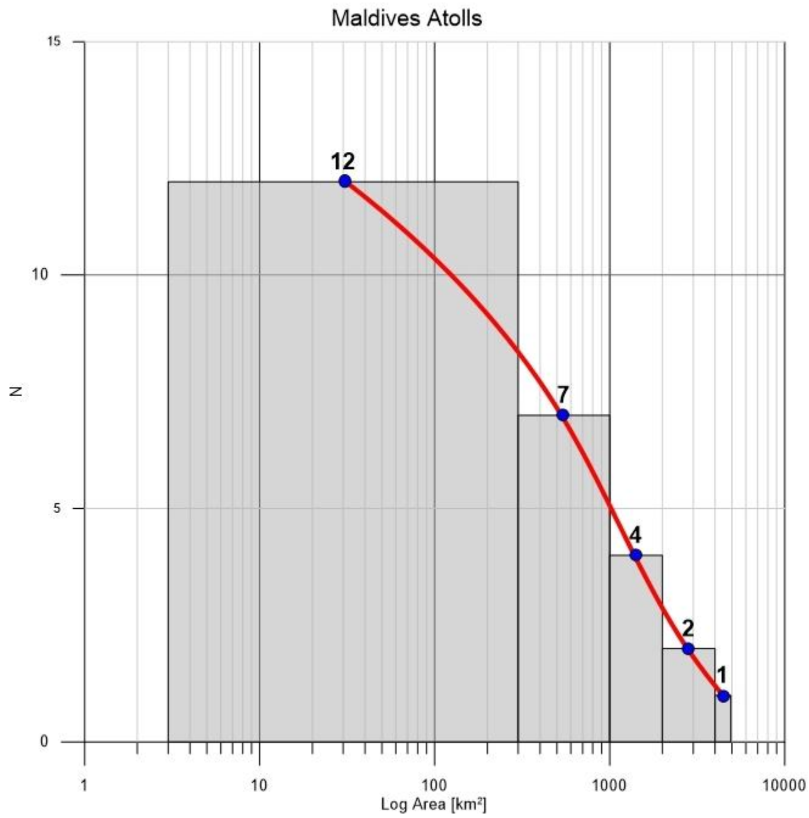

Fig. 2. The semilogarithmic fractal plot of the observed areas and their number for Maldives atolls. The calculated fractal dimension is 2.75.

NATURAL HAZARDS AND ENVIRONMENTAL PROBLEMS

The Maldives frequently experiences high frequency low impact events such as monsoonal flooding, coastal erosion and salt water intrusion. According to United Nation Development Program [13] there are four categories of natural hazards in the Maldives. They are geological hazards which involves earthquakes and coastal erosions, meteorological hazards which involves tropical cyclones and thunder storms, hydrological hazards which involves flooding and storm surges and climate related hazards which involves sea level rise and sea surface temperature rise. Among the categories mentioned, floods induced by tsunamis, abnormal swell waves, heavy rainfall, windstorms, droughts and earthquakes are considered as major natural hazards in the Maldives [14].

The distribution pattern of natural hazards is strictly controlled by their geophysical properties and climatic peculiarities.

The cyclone hazard, wind storms and drought are more frequent in the northern region of the Maldives, while rainfall hazards, swell waves and earthquakes are more frequent in the southern regions of the Maldives.

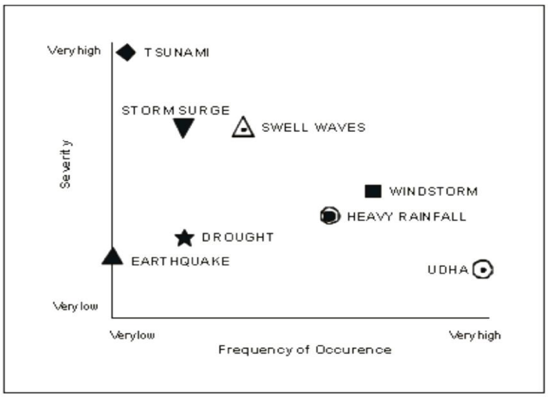

Fig. 3. General patterns of the major natural hazards prevailing in the Maldives (UNDP, 2008)

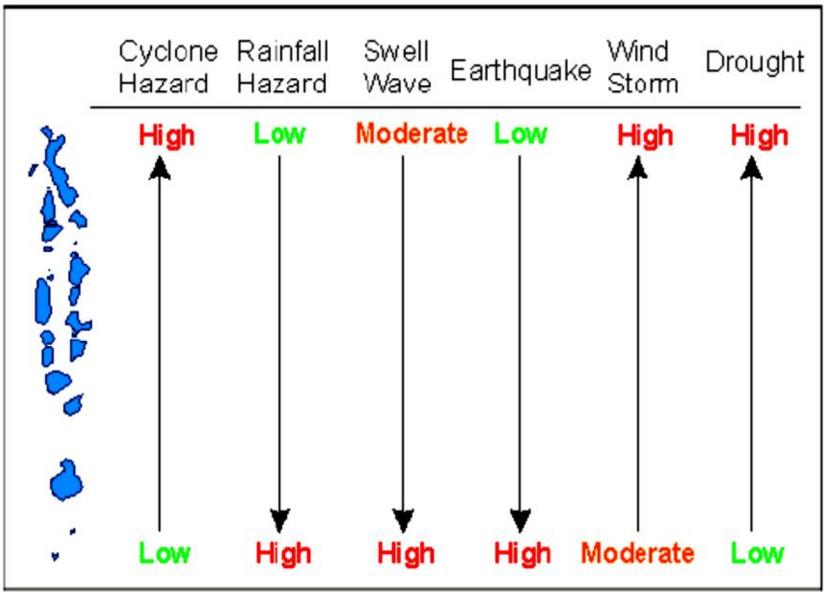

Fig. 4. Latitudinal variations of major natural hazards across the Maldives (UNDP, 2008 [14])

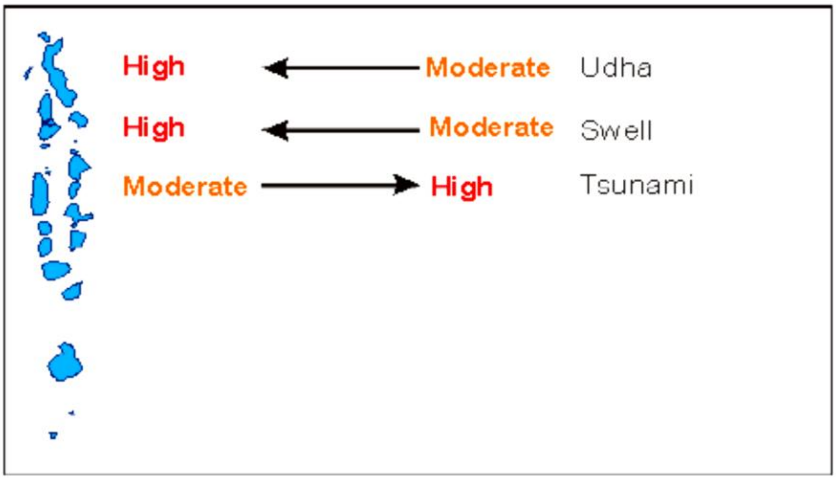

Fig. 5. Longitudinal variations of the major natural hazards across the Maldives (UNDP, 2008 [14])

The eastern rim islands are subjected to tsunamis and waves of higher intensity compared to islands in the western rim which are protected from high intensity waves. The island morphology and size also plays an important role in protection against coastal hazards [14].

According to Ministry of Environment and Energy [15], three major types of swells exist in the Maldives, they are 1) "Udha" waves, which are known as gravity waves caused by high tides and strong winds; 2) swell waves, which are known as tidal waves and 3) Tsunami waves, which are low frequency high impact waves caused by earthquakes and other bottom phenomena. Wave swells can cause significant flooding that can damage key infrastructures such as homes, harbors, schools, mosques, and jetties in the islands. Other hazards such as monsoon strong winds can cause high tides, which can increase coastal flooding events. In 2008, strong surface winds, combined with heavy rainfall, caused significant damage to roofs and the uprooting of trees in many islands of the Maldives. Hazardous weather events which regularly affect Maldives include tropical cyclones and sever local storms. Tropical cyclones are considered destructive if they are associated with strong winds exceeding 150 km per hour with rain fall above 30 to 40 centimeters within a 24-hour period and storm tides exceed four to five meters. Northern atolls have a greater risk of cyclonic winds and storm surges compared to the southern atolls however, the cyclones that affect northern islands of the country are weak cyclones that are formed in the southern part of the Bay of Bengal and the Arabian Sea [14]. Islands located within close proximity to the equator, are largely free from storms. The northern region of the Maldives is more prone to wind hazards from cyclones compared to southern region of the Maldives. Strong winds can damage vegetation, houses, communication systems, roads, while heavy rainfall can cause flooding and cyclonic winds sometimes can cause sudden rise in the sea-level along the coast leading to storm surges [14].

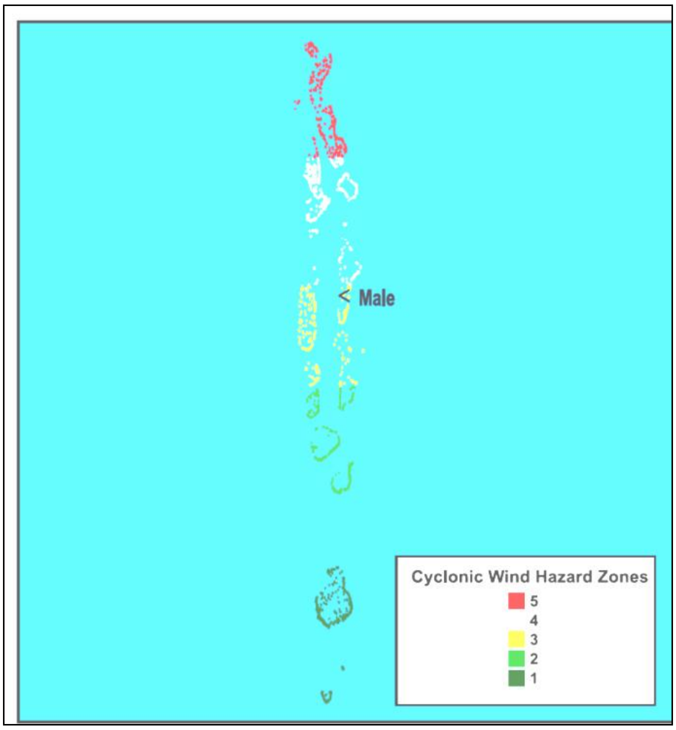

Fig. 6. Cyclonic wind hazards map of the Maldives (UNDP, 2008 [14])

Seismic hazard is low and only few expectations are related to the south. The threats from sea level rise due to climate change are a uniform hazard throughout the whole country (Fig. 7).

The most devastating natural event affected Maldives is the tsunami in Indian Ocean of 26 December 2004. This unexpected event affected 3 continents, 11 countries and was the most deadly natural disaster occurred during the human history. More then 300 000 deaths, 1.5 million homeless and damages over 100 billions US$ were reported. Significant damages were registered as well as in Maldives. After this disastrous event an extensive program of tsunami hazard investigations and measures about people protection have been developed (Fig. 8).

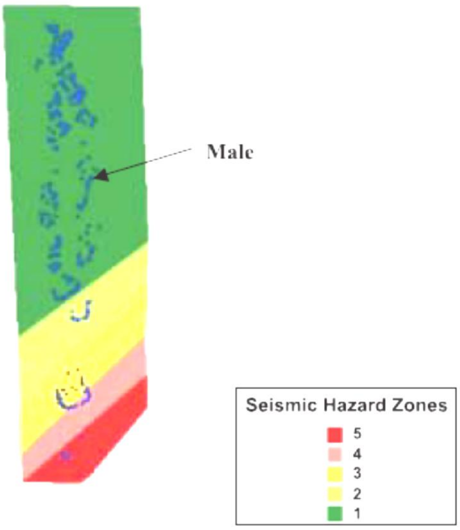

Fig. 7. Maldives seismic hazards zones (UNDP, 2008 [14])

Hazard Zone	Range of Probable Maximum Wave Height (centimeters)
1	less than 30
2	30-80
3	80-250
4	250-320
5	320-450

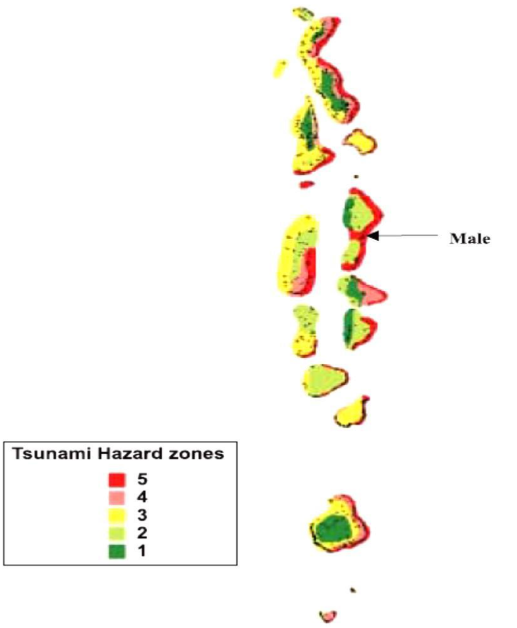

Fig. 8. Tsunami hazard map for Maldives (UNDP, 2008 [14])

The analysis of the natural hazards observed for Maldives, shows that the islands are prone to the natural disasters in their full complexity described earlier. This needs special attention the disasters mapping and the assessment of complex hazards [12]. As a first step the natural hazards mapping can serve as a long term preventive measure, giving to the decision-makers a tool for urban and territorial planning. The stormy expansion of tourism creates another problem. The huge waste quantities are deposited in the Ocean which threatens with pollution the waters and the land. The low level of the Ocean is another disastrous fact. The global warming is a factor which can lead to the Ocean level increase. Having in mind that the country has an average sea level elevation about 1.5-1.6 meters above the seal level rise is a critical issue.

Climate change is also a significant issue that needs urgent attention in the Maldives. The UN predicted maximum sea level rise of 59cm by 2100 is expected to make flooding incidents and coastal erosion events more frequent in the future. The expected increase in the sea surface temperature (according different models) will threaten the survival of the coral reef ecosystem [15]. Healthy coral reef ecosystem is a vital natural resource for tourism and fisheries industry. Damage to coral reefs such as coral bleaching due to increase in sea surface temperature will have negative impacts on tourism and fisheries industry Maldives heavily depends on for revenue. The wastes of different origin and materials can also be considered as a future threat to the islands' ecology. The main factor of the global warming influencing the Maldives territory is the ocean level change. The last several thousands years water level changes are result of the global climate change. The graph shows high amplitudes of the sea level oscillations – Fig. 9. They are extracted from the coral growth registered in the boreholes drilled for the petroleum prospecting. The analysis of these oscillations coincide with the global colder are warmer climate changes of the Earth. Even after these phases of the wormer or colder weather the oscillations are relatively small. This is due to the water property to keep the temperature changes in low limits. This means that the recant global change can affect the Maldives in narrow limits.

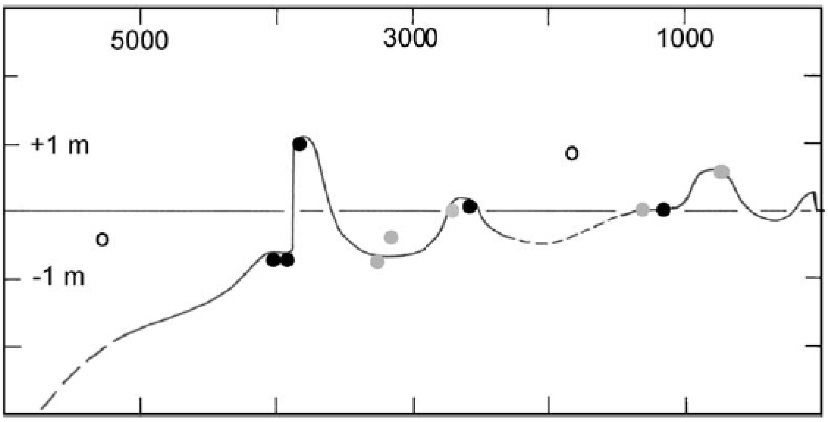

Fig. 9. Sea level change during the last 5000 years

CONCLUSIONS

The fractal analysis is performed to prove the strong nonlinearity concerning the geometry distributions of the areas of Maldives' atolls. The nonlinear behavior of the surface elements of the Maldives' atolls is proved, thus showing that the spatial distribution of the atolls could be investigated using formal approach of the fractal analysis. The discovered fractal properties of the surface elements of the Maldives archipelago, could be suggested that there is a synergy between them and probably have deeper meaning for the Maldives origin.

The principal natural hazards are investigated and the zoning maps are presented as a first step of long term preventive measures for the population of Maldives.

Some ecological problems are described and discussed. The sea level change during the last 5 000 years is presented and shows relatively stable variations. This gives some confidence about the near future development of the Maldives without ignoring the environmental stress to this tourist heaven.

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ФРАКТАЛИ, ПРИРОДНИ БЕДСТВИЯ И ЕКОЛОГИЧНИ ПРОБЛЕМИ НА МАЛДИВИТЕ

Бойко Рангелов, Фатима Шадия

Резюме: Изследвани са фракталните свойства на Малдивския архипелаг по отношение на площите заети от основните атоли, като са използвани класическите определения на „фрактал" и фрактални свойства, като експлицитна изява на нелинейностните свойства на всеки фрактален обект.

Доколкото Малдивите са заплашени от редица природни бедствия (цунами, циклони, дъждове и бури, засушавания и др.) са представени карти на зонирането на страната, като първа, предварителна мярка за защита на населението и туристите. Разгледани са и някои екологични проблеми свързани с глобалното затопляне. Изменението на морското ниво е основна заплаха за Малдивите по няколко причини:

- Страната има много малка средна надморска височена (едва 1.5-1.6 м.) и повдигането на морското ниво може да доведе до драстична загуба на територия.
- Доколкото цялата суша е продукт от растежа на коралите, образуващи кораловите атоли, изменението на нивото, заедно с температурата, може да повлияе негативно върху жизнения цикал на коралите и да доведе до невъзвратими последици.

Друг сериозен екологичен проблем са масивните отпадъци от туристическата индустрия, които няма къде да бъдат депонирани. Към момента това става в акваторията на океана, което в бъдеще може също да доведе до негативни последици.

Ключови думи: Малдивски архипелаг, фрактален анализ, природни бедствия, екологични проблеми

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