Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 20, Issue 3, 2020
PRINT ISSN 2284-7995, E-ISSN 2285-3952

FRACTAL ANALYSIS IN ESTIMATING THE FRAGMENTATION DEGREE OF AGRICULTURAL LANDS

Florin SALA*, Cosmin Alin POPESCU, Mihai Valentin HERBEI****

Banat University of Agricultural Sciences and Veterinary Medicine "King Michael I of Romania" from Timisoara, *Soil Science and Plant Nutrition, **Remote Sensing and GIS, Timișoara, 300645, Romania; Emails: florin_sala@usab-tm.ro, cosmin_popescu@usab-tm.ro; mihai_herbei@yahoo.com

Corresponding author: mihai_herbei@yahoo.com

Abstract

Fractal analysis was used to evaluate the degree of agricultural lands fragmentation. An area in the Western Plain, Romania was studied. The image was taken with the RapidEye satellite system. From the basic image, 10 polygons with equal resolution of 735 x 840 pixels were selected. For each studied polygon, the total surface (TS), the number of plots (PN), the average plot area (APA), and the fractal dimension (D) were determined. Fractal analysis was performed using the box counting method. The correlation analysis revealed a moderate, negative, correlation between PN and APA (r=-0.776), strong negative correlation between D and PN (r=-0.871), respectively a very strong, positive, correlation between D and APA (r=0.935). APA variation according to PN was most faithfully described by a smoothing spline model. Variation of fractal dimension D according to PN was described by a polynomial equation of degree 2, in conditions of R^2=0.946, p<< 0.01, and the variation of D according to the APA was described by a polynomial equation of degree 2 in conditions of R^2=0.939, p<< 0.01. Based on fractal dimension (D), regression analysis made it possible to estimate PN under conditions of R^2=0.818, p=0.0025, F=15.782, respectively APA variation under conditions of R^2=0.984, p<< 0.001, F=214.86. Based on PCA, PC1 explained 89.441% of variance, and PC2 explained 10.559% of variance. Cluster analysis led to the grouping of the studied cases, in condition of Coph.corr=0.988.

Key words: *fractal analysis, fragmentation, agricultural land, smoothing spline model*

INTRODUCTION

Land cover and land use are intensely studied in relation to environmental aspects [34], administrative aspects [27], [42], resource assessment [5], [8], environmental aspects and management [11], [22], [28], soil resources management [39], agricultural ecosystems [45] etc. Various satellite systems have been developed (Landsat, MODIS, Sentinel 2 etc.) and new generations of satellites have emerged within the same family (ex. Landsat 1 to Landsat 8), for the purpose of providing better service (image resolution, costs, spectral bands, indices etc.) for the study and analysis of natural, agricultural or urban land areas [36].

Studies were carried out to assess the relations between spectral bands and various vegetation indices [14], [15], [2], [24], regarding the development of new models for land cover and land use studies [21]. The number of indices has also increased and diversified in relation to the new satellite systems facilities and the realities of land, agricultural, urban and rural areas, the categories of use that were intended to be studied [32], [46], [26].

Land cower classification has shown particular interest and has been addressed in many studies for the analysis and characterization of natural and anthropogenic areas [13], of forestry and horticultural species in different areas or culture systems [9], of some National Parks and Protected Areas [12], [6], [31], categories of use and agricultural crops [16]. Some studies have evaluated temporal and spatial changes and variability on land use in relation to various factors [38], [19].

With the introduction of fractal geometry, as a vision and approach to nature [25], fractal analysis developed as a method of study and penetrated into more and more fields such as botany, chemistry, fluid mechanics, material science, medicine, biotechnologies, nanomaterials etc. [7], [40]. At the same time,

Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 20, Issue 3, 2020
PRINT ISSN 2284-7995, E-ISSN 2285-3952

fractal analysis was successfully used in the analysis and characterization of natural, agricultural, forestry, and urban areas etc. [33], [37]. Fractal analysis was used in the study and evaluation of spatial and temporal variability in various approaches, such as soil, vegetable cover, crops etc. [44], [43].
This study used fractal analysis to assess the degree of fragmentation of agricultural land by analyzing fractal geometry expressed in satellite imagery.

MATERIALS AND METHODS

The purpose of the study was to assess the degree of fragmentation of agricultural land by fractal analysis. The area studied is part of the Western Plain, Romania, in a perimeter located at N-V, V from Timisoara Municipality, with the following locations Timisoara, Giarmata-Vii, Murani, Satchinez, Săcălaz (Fig. 1).

Satellite system. The images used were taken using the RapidEye teledetection system, which is composed of 5 satellites and it offers images at 5 m resolution on 5 spectral bands: Red, Green, Blue, RedEdge and NIR. The image used was retrieved on 12.08.2017, figure 1. For fractal analysis was used an image resulting from the combination of spectral bands in false colors, namely the NIR-Red-Green combination.
Polygons studied. In the study there are 10 polygons with resolution 735 x 840 pixels, which have as ground representation an area of 102.1373 ha. The polygons studied have been established to include a variable number of plots (Fig. 2).
Parameters and indices studied. For each polygon studied, there were determined the total surface (TS), the number of plots (PN), the average area per plot (APA), and the fractal dimension (D).

Fig. 1. The studied area, Timis County, Romania
Source: original image, based on RapidEye teledetection system

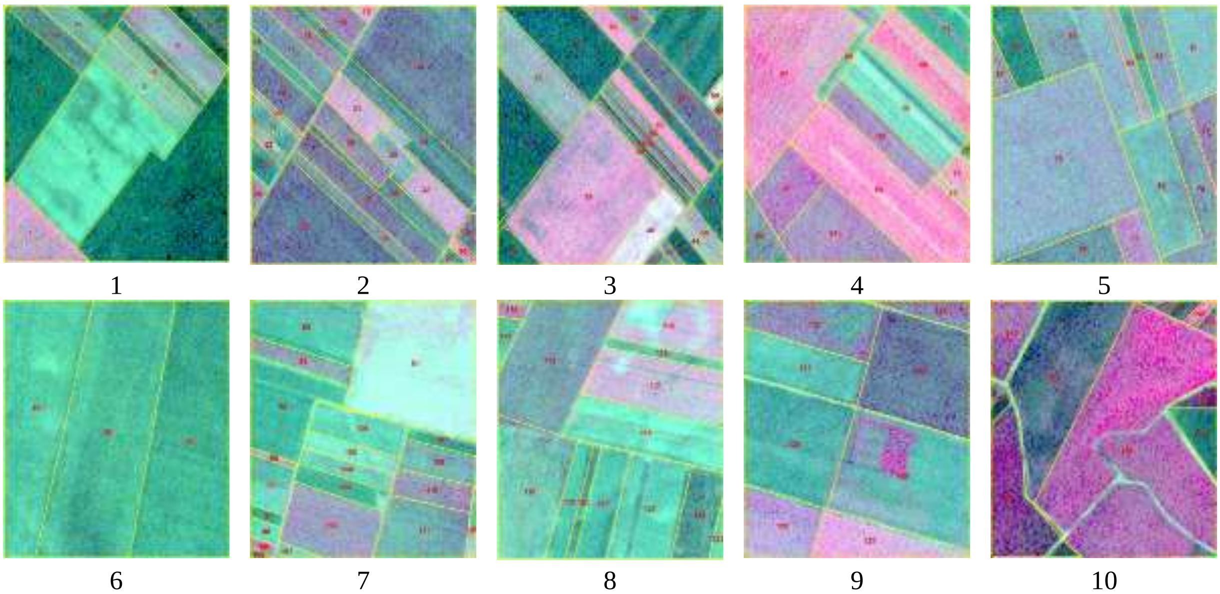

Fig. 2. Perimeters included in the study
Source: original image, extracted by Fig. 1.

Fractal analysis. Fractal analysis was carried out using the box counting method [41], relations (1), (2), (3), [35]. This is the most used method for analyzing fractal geometry on binarized images [20], [22].

$$\text{MeanD} = \sum(D)/\text{GRIDS} \quad (1)$$

$$D = m\left[\frac{\ln(F)}{\ln(\varepsilon)}\right] \quad (2)$$

where: D – fractal dimension; m – slope to regression line, in eq. (3); F – number of new part; ε – scale applied.

$$m = \left(n\sum SC - \sum S\sum C\right)/\left(n\sum S^2 - \left(\sum S\right)^2\right) \quad (3)$$

where: m – slope of regression line; S – log of scale or size; C – log of count; n – number of size;

Statistical analysis of data. The resulting experimental data was analyzed by the ANOVA single factor test, correlation analysis, regression analysis, Principal Component Analysis (PCA) and Cluster Analysis (CA).
For estimation the accuracy of the results was used correlation coefficient (r), regression coefficient (R^2), parameter p, average error ($\bar{\varepsilon}$), and Cophenetic coefficient (Coph.corr), as statistical safety parameters. They were used EXCEL mathematical module, and PAST software [10], for the experimental data analysis and processing.

RESULTS AND DISCUSSIONS

The polygons considered in the study were analyzed in terms of the total area, the number of plots and the average area on the plot. Starting from the working resolution, 735 x 840 pixels per polygon, and the field area of each polygon was 102.1373 ha.
With ArcGIS software, there were determined and marked the number of parcels within each perimeter and the surface of the plots was calculated. Variable number of plots were found, between 3 (polygon 6) and 25 (polygon 2).
Based on the total surface (TS) of a polygon, and the number of plots (PN), the average area was calculated on the each plot (APA). The results obtained are presented in Table 1.
Anova Test, single factor, has confirmed the existence of the variance in the experimental data set, and statistical accuracy of results, F>Fcrit, p<<0.01, for Alpha=0.001.
The correlation analysis has revealed a moderate, negative correlation between PN and APA (r=-0.776). Between fractal dimension (D) and PN was recorded a strong, negative correlation (r=-0.871), and between D and APA there was a very strong, positive correlation (r=0.935).

Table 1. Experimental data on field characterization parameters and fractal size (D)

Perimeters studied	TS	PN	APA	D
1	102.1373	12	8.511	1.763
2	102.1373	25	4.085	1.734
3	102.1373	24	4.256	1.754
4	102.1373	13	7.857	1.778
5	102.1373	13	7.857	1.782
6	102.1373	3	34.046	1.881
7	102.1373	21	4.864	1.729
8	102.1373	14	7.296	1.756
9	102.1373	8	12.767	1.810
10	102.1373	11	9.285	1.795

TS – total surface (ha); PN – plots number; APA – average plots area (ha); D – fractal dimension
Source: original data, resulted from the 10 polygons analysis.

Starting from the correlations identified between the parameters studied (PN, APA, D), different models were analyzed that described interdependence relationships in statistical accuracy conditions.
The variation of the average area per plot (APA) by number of plots (PN) was best described by a model called smoothing spline, and the error of estimation over actual values was given by the equation (4). The smoothing spline model dataset is presented in Table 2.

$$\bar{\varepsilon} = \left(\sum_{i=1}^{n} \varepsilon_i\right) / n = \left(\sum_{i=1}^{n} \left|\frac{ys_i - y_i}{y_i}\right|\right) / n \quad (4)$$

Table 2. Statistical data for APA variation in relation to PN, in the case of studied perimeters

Trial	x_i	APA			
		y_i	ys_i	ε_i	$I_{i/1}$
6	3	34.046	32.726	1.32	1
9	8	12.767	14.993	2.226	0.458137
10	11	9.285	9.4771	0.1921	0.289589
1	12	8.511	8.4198	0.0912	0.257282
4	13	7.857	7.6071	0.2499	0.232448
5	13	7.857	7.6071	0.2499	0.232448
8	14	7.296	6.957	0.339	0.212583
7	21	4.864	4.7236	0.1404	0.144338
3	24	4.256	4.2355	0.0205	0.129423
2	25	4.085	4.0776	0.0074	0.124598
				$\bar{\varepsilon} = 0.48364$	

Source: original data obtained based on equation (4).

The graphic distribution of APA values according to PN, based on the smoothing spline model, is presented in Fig. 3.

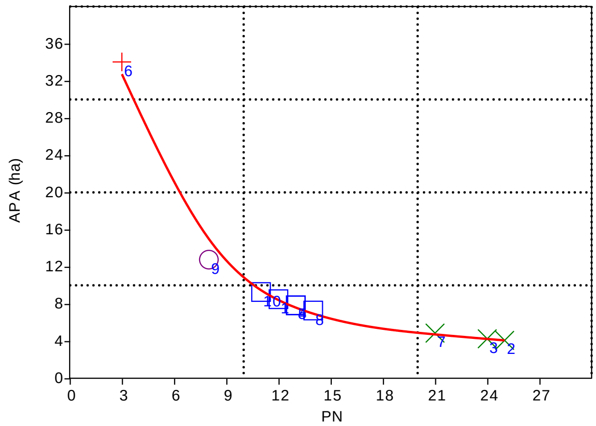

Fig. 3. APA values distribution according to PN, based on the smoothing spline model
Source: original graph based on data from Table 2.

The analysis of the fractal geometry of the perimeters taken in the study led to the obtaining of fractal dimensions (D) that ranged between D=1.729 (perimeter 7) and D=1.881 (perimeter 6).
As the fractal geometry of the images of the studied perimeters was given by the constituent elements, (i.e. plots by shape, surface, and number), consequently was analyzed how the two components of the perimeters (PN and APA) have contributed to the variation of fractal dimension (D).
Variation of D depending on the PN was described using polynomial equation of 2nd degree, relation (5), under conditions of R^2=0.946, p<<0.01. The variation in fractal dimension D depending on APA was described using a polynomial equation of 2nd degree, relation (6), under conditions of R^2=0.939, p<<0.01.

$$D_{PN} = 0.0003932\, x^2 - 0.01732\, x + 1.929 \quad (5)$$

$$D_{APA} = -0.0001778\, x^2 + 0.01162\, x + 1.692 \quad (6)$$

The multiple regression analysis on determining the fractal dimension (D) according to PN and APA, analyzed as a simultaneous contribution, led to equation (7), under conditions of R^2=0.927, p<0.01.
The analysis of the statistical parameters resulting from the regression analysis showed

that the two variables PN and APA had a different contribution to the fractal geometry of the images of the perimeters studied and implicitly to the formation of D value.

Based on the value of the coefficient according to the two variables, the result was that APA had a higher contribution to the generation of D value ($Coef_{APA}$=0.003326), under statistical accuracy conditions (SE=0.000806, p=0.00491), compared to PN whose contribution was lower ($Coef_{PN}$ = 0.00231), under statistical accuracy conditions (SE=0.001016, p=0.05693).

Also parameter p, confirmed a higher degree of statistical accuracy related to variable APA (p=0.00491) compared to the variable PN (p=0.05693).

$$D_{PN,APA} = 1.778714 - 0.00231 \cdot PN + 0.00326 \cdot APA \quad (7)$$

Based on the correlation identified between PN, APA and D, as well as the level of contribution of PN and APA (estimated on the basis of equation coefficients (6) and (7)) when the fractal dimension D is formed, models of estimate of PN and APA were analyzed and tested based on the fractal values D, in order to describe the degree of fragmentation of the land by fractal analysis.

Simple regression analysis for estimating PN according to D has led to the relation (8), under conditions of R^2=0.818, p=0.0025, F=15.782. Simple regression analysis for estimating APA based on fractal dimensions D has led to relation (9), under conditions of R^2=0.984, p<<0.001.

$$PN = 763.8 \cdot D^2 - 2{,}893 \cdot D + 2{,}742 \quad (8)$$

$$APA = 1{,}277 \cdot D^2 - 4{,}419 \cdot D + 3{,}828 \quad (9)$$

PCA led to the distribution of study variants according to the three variables considered, PN, APA and D, according to the graph in Fig. 4. PC1 explained 89.441% of variance, and PC2 explained 10.559% of variance. Cluster analysis led to the grouping of cases studied in high statistical accuracy, Coph.corr=0.988, Fig. 5.

In a separate position got placed polygon 6, with the lowest number of plots (PN=3) and the highest fractal dimension value (D=1.881). The other polygons were grouped into sub-clusters according to the degree of affinity. Polygons 4, 5, 8 were grouped with very high affinity and formed the subcluster ((4, 5), 8), then polygons 2, 3, and 7 formed the subcluster ((2, 3), 7), followed by polygons 1 and 10, subcluster (1, 10), and in a separate position was placed polygon 9.

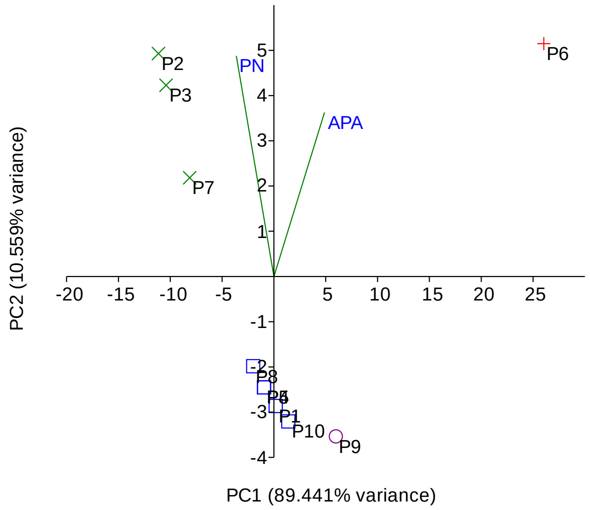

Fig. 4. PCA scatter diagram in relation to PN, APA, and D

Source: original image based on experimental data.

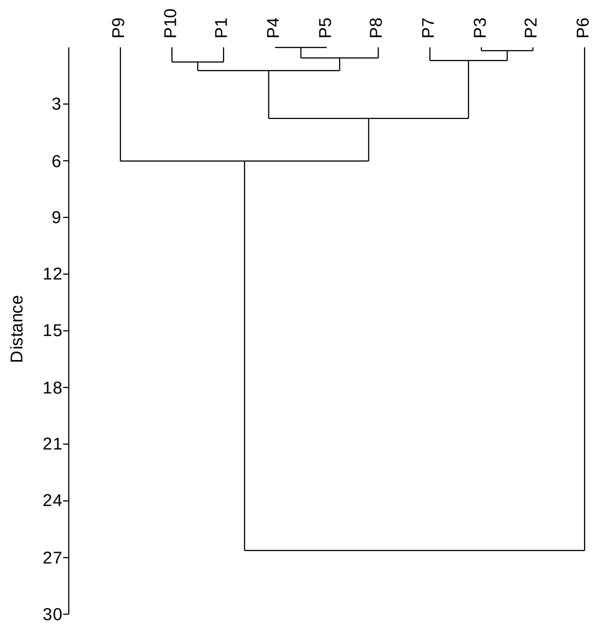

Fig. 5. Dendrogram of cases studied based on Euclidean distances

Source: original image based on experimental data.

Starting from the dendrogram obtained in Fig. 5, the values of Similarity and Distance

Incices (SDI) were analyzed, which confirmed the association and grouping of the 10 cases studied (P1 to P10).
The highest degree of similarity was recorded at the P4 and P5 polygons (SDI = 0.0040), followed by P2 and P3 (SDI = 0.1722), P8 and P4 (SDI = 0.5614), P8 and P5 (SDI = 0.5616), P3 and P7 (SDI = 0.6085) respectively.
An independent position was occupied by the polygon P6 which had the degree of similarity closer to P9 (SDI = 21.2790).

Table 3. SDI values in relation to D and APA values for the studied cases

	P6	P9	P10	P1	P4	P5	P8	P7	P3	P2
P6		21.2790	24.7610	25.5350	26.1890	26.1890	26.7500	29.1820	29.7900	29.9610
P9	21.2790		3.4820	4.2563	4.9101	4.9101	5.4713	7.9034	8.5112	8.6823
P10	24.7610	3.4820		0.7747	1.4281	1.4281	1.9894	4.4215	5.0292	5.2004
P1	25.5350	4.2563	0.7747		0.6542	0.6543	1.2150	3.6472	4.2550	4.4261
P4	26.1890	4.9101	1.4281	0.6542		0.0040	0.5614	2.9934	3.6011	3.7723
P5	26.1890	4.9101	1.4281	0.6543	0.0040		0.5616	2.9935	3.6011	3.7723
P8	26.7500	5.4713	1.9894	1.2150	0.5614	0.5616		2.4321	3.0400	3.2111
P7	29.1820	7.9034	4.4215	3.6472	2.9934	2.9935	2.4321		0.6085	0.7790
P3	29.7900	8.5112	5.0292	4.2550	3.6011	3.6011	3.0400	0.6085		0.1722
P2	29.9610	8.6823	5.2004	4.4261	3.7723	3.7723	3.2111	0.7790	0.1722	

Source: Original data, calculated based on D and APA values obtained from the studied cases.

Fractal analysis has extended to more and more areas as a method and study tool, which ensures a clear decelerating of the reality analyzed and a high degree of accuracy in areas such as nanomaterials [23], biotechnologies [4], medicine [18], and agriculture [1]. Fractal analysis was used in the study and evaluation of the fragmentation degree of green infrastructure in different cities in Romania [30].
Jevric and Romanovich (2016) [17] used fractal analysis as a tool to quantify urban border values for the purpose of space management. Fractal analysis was also used in studies on the evolution and dynamics of forest area fragmentation [3], analysis of cork cambium to some forest arboreal species [29].
The results communicated in this study on the assessment of the degree of fragmentation of agricultural land, are consistent with the studies in which the reporting on the facilities and accuracy provided by fractal analysis was made.

CONCLUSIONS

Fractal analysis facilitated the estimation of the fragmentation degree of the land both in terms of the number of plots (PN) as well as the average area of the parcels (APA), in statistical accuracy conditions.
Polynomial models of 2nd degree described the variation in fractal dimension D depending on the number of plots (PN) and the average area of the plots (APA). Based on the fractal dimension (D) it was possible to estimate the number of plots (PN) and the average area of the parcels (APA) under statistical accuracy conditions. The high degree of fragmentation of agricultural land, expressed by a high number of plots, was associated with low fractal dimension (D=1.734).

ACKNOWLEDGMENTS

The authors thanks to the GEOMATICS Research Laboratory, Banat University of Agricultural Sciences and Veterinary Medicine "King Michael I of Romania" from Timisoara, for the facility of the software use for this study.

REFERENCES

[1]Agüera, F., Nuyttens, D., Carvajal, F., Sánchez-Hermosilla, J., 2012, Fractal analysis of agricultural nozzles spray, Sci. Agric., 69(1):6-12.
[2]Alexander, C., 2020, Normalised difference spectral indices and urban land cover as indicators of land surface temperature (LST), Int. J. Appl. Earth Obs., 86:

102013.
[3]Andronache, I., Marin, M., Fischer, R., Ahammer, H., Radulovic, M., Ciobotaru, A.-M., Jelinek, H.F., Di Ieva, A., Pintilii, R.-D., Drăghici, C.-C., Loghin, I.-V., Diaconu, D.-C., Pepteanu, D., 2019, Dynamics of forest fragmentation and connectivity using particle and fractal analysis, Sci. Rep., 9:12228.
[4]Brouers, F., Sotolongo-Costa, O., 2020, Generalized fractal kinetics in complex systems (application to biophysics and biotechnology), Physica A: Stat. Mech. App., 368(1):165-175.
[5]Chang, Y., Hou, K., Li, X., Zhang, Y., Chen, P., 2018, Review of land use and land cover change research progress, IOP Conf. Series: Earth Environ. Sci., 113:012087.
[6]Duan, P., Wang, Y., Yin, P., 2020, Remote sensing applications in monitoring of protected areas: A bibliometric analysis, Remote Sens., 12:772.
[7]Fernández-Martínez, M., Sánchez-Granero, M.A., Trinidad Segovia, J.E., 2012, Fractal dimension for fractal structures: Applications to the domain of words, Appl. Math. Comput., 219(3):1193-1199.
[8]Garai, D., Narayana, A.C., 2018, Land use/land cover changes in the mining area of Godavari coal fields of southern India, Egyptian J. Remote Sens. Space Sci., 21(3):375-381.
[9]Govedarica, M., Ristic, A., Herbei M.V., Sala, F., 2015, Object oriented image analysis in remote sensing of forest and vineyard areas, Bulletin UASVM Horticulture, 72(2):362-370.
[10]Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001, PAST: Paleontological statistics software package for education and data analysis, Palaeontol. Electron., 4(1):1-9.
[11]Haro-Carrión, X., Southworth, J., 2018, Understanding land cover change in a fragmented forest landscape in a biodiversity hotspot of Coastal Ecuador. Remote Sens., 10(12):1980.
[12]Herbei, M.V., Sala, F., 2014, Using GIS technology in processing and analyzing satellite images–case study Cheile Nerei Beusnița National Park, Romania, J. Hortic. Forestry Biotech., 18(4):113-119.
[13]Herbei, M.V., Sala, F. 2015, Use Landsat image to evaluate vegetation stage in sunflower crops, AgroLife Sci. J., 4(1):79-86.
[14]Herbei, M., Sala, F., Boldea, M. 2015a, Relation of Normalized Difference Vegetation Index with some spectral bands of satellite images, AIP Conf. Proc., 1648:670003-1 – 670003-4.
[15]Herbei, M., Sala, F., Boldea, M. 2015b, Using mathematical algorithms for classification of Landsat 8 satellite images, AIP Conf. Proc., 1648:670004-1 – 670004-4.
[16]Herbei, M., Sala, F. 2016, Biomass prediction model in maize based on satellite images, AIP Conf. Proc., 1738:350009-1 – 350009-4
[17]Jevric, M., Romanovich, M., 2016, Fractal dimensions of urban border as a criterion for space management, Procedia Eng., 165:1478-1482.
[18]Kisan, S., Mishra, S., Rout, S.B., 2017, Fractal dimension in medical imaging: A review, Int. Res. J. Eng. Technol., 04(05):1102-1106.
[19]Li, B., Huang, F., Qin, L., Qi, H., Sun, N., 2019, Spatio-temporal variations of carbon use efficiency in natural terrestrial ecosystems and the relationship with climatic factors in the Songnen Plain, China, Remote Sens., 11:2513.
[20]Li, J., Du, Q., Sun, C., 2009, An improved box-counting method for image fractal dimension estimation, Pattern Recognit., 42:2460-2469.
[21]Liping, C., Yujun, S., Saeed, S., 2018, Monitoring and predicting land use and land cover changes using remote sensing and GIS techniques - A case study of a hilly area, Jiangle, China, PLoS ONE, 13(7):e0200493.
[22]Long, M., Peng, F., 2013, A box-counting method with adaptable box height for measuring the fractal feature of images, Radioengineering, 22(1):208-2013.
[23]Maleki, S., Ghammamy, S., Salehzadeh, J., 2014, A study on fractality properties of nano particles scanning electron microscopy images, Leonardo J. Sci., 25:111-116.
[24]Mancino, G., Ferrara, A., Padula, A., Nolè, A., 2020, Cross-comparison between Landsat 8 (OLI) and Landsat 7 (ETM+) derived vegetation indices in a mediterranean environment, Remote Sens., 12(2):291.
[25]Mandelbrot, B.B., 1983, The fractal geometry of nature - Revised and Enlarged Edition, W.H. Freeman and Co., New York, 495 pp.
[26]Martin-Ortega, P., Garcia-Montero, L.G., Sibelet, N., 2020, Temporal patterns in illumination conditions and its effect on vegetation indices using landsat on google earth engine, Remote Sens., 12(2):211.
[27]Moulds, S., Buytaert, W., Mijic, A., 2018, A spatio-temporal land use and land cover reconstruction for India from 1960-2010, Sci. Data, 5:180159.
[28]Murray, N.J., Keith, D.A., Simpson, D., Wilshire, J.H., Lucas, R.M. 2018, REMAP: An online remote sensing application for land cover classification and monitoring, Methods Ecol. Evol., 9(9):2019-2027.
[29]Nicolin, L.A., Popescu, C.A., Rujescu, I.C., Herbei, V.M., Sala, F., 2019, Fractal characterisation of the cork cambium in *Fraxinus angustifolia* Vahl. depending on image caption distance, AIP Conf. Proc., 2116:370005.
[30]Petrișor, A.-I., Andronache, I.C., Petrișor, L.E., Ciobotaru, A.-M., Peptenatu, D., 2016, Assessing the fragmentation of the green infrastructure in Romanian cities using fractal models and numerical taxonomy, Procedia Environ. Sci. 32:110-123.
[31]Popescu, C.A., Herbei, M.V., Sala, F., 2020, Remote sensing in the analysis and characterization of spatial variability of the territory. A study case in Timis County, Romania, Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 20(1):505-514.
[32]Prince, S.D. 2019, Challenges for remote sensing of the Sustainable Development Goal SDG 15.3.1 productivity indicator, Remote Sens. Environ. 234: 111428.
[33]Purevtseren, M., Tsegmid, B., Indra, M., Sugar, M., 2018, The fractal geometry of urban land use: The

case of Ulaanbaatar City, Mongolia, Land 7:67.
[34]Rafiq, M., Mishra, A.K., Meer, M.S., 2018, On land-use and land-cover changes over Lidder Valley in changing environment, Annals of GIS, 24(4):275-285.
[35]Rasband, W.S., 1997, ImageJ. U. S. National Institutes of Health, Bethesda, Maryland, USA, pp. 1997-2014.
[36]Roy, P.S., Behera, M.D., Srivastav, S.K., 2017, Satellite remote sensing: Sensors, applications and techniques. P. Natl. A. Sci. India Section A: Physical Sciences, 87:465-472.
[37]Sampurno, J., Apriyansyah, Adriat, R., Srigutomo, W., 2018, Fractal analysis of land surface temperature for geothermal and non-geothermal sites characterization, IOP Conf. Series: Journal of Physics: Conf. Series, 1028(2018):012198.
[38]Saparamadu, S., Yi Z., Zongping, Z., 2018, Temporal changes of land use land cover and environmental impacts: A case study in Colombo, Sri Lanka, Int. J. Earth Environ. Sci., 3:150.
[39]Sharma, A., Tiwari, K.N., Bhadoria, P.B.S., 2011, Effect of land use land cover change on soil erosion potential in an agricultural watershed, Environ. Monit. Assess., 173(3-4):789-801.
[40]Swapna, M.S., Sankararaman, S., 2019, Fractal applications in bionanosystems, Advancements Bioequiv Availab., 2(4):OABB.000541.2019.
[41]Voss, R., 1985, Random fractal forgeries. In: Earnshaw R. (Ed.) Fundamental algorithms for computer graphics, Sringer Verlag, Berlin, pp. 805-835.
[42]Wang, Z., Han, Q., de Vries, B., 2018, Land use/land cover and accessibility: Implications of the correlations for land use and transport planning, Appl. Spat. Anal. Policy, 12:923-940.
[43]Zhang, F., Yin, G., Wang, Z., McLaughlin, N., Geng, X., Liu, Z., 2013, Quantifying spatial variability of selected soil trace elements and their scaling relationships using multifractal techniques, PLoS ONE, 8(7):e69326.
[44]Zhang, F.S., Liu, Z.X., 2011, Fractal theory and its application in the analysis of soil spatial variability: a review, Ying Yong Sheng Tai Xue Bao, 22(5):1351-1358.
[45]Zhang, X., Liu, L., Henebry, G.M., 2019, Impacts of land cover and land use change on long-term trend of land surface phenology: a case study in agricultural ecosystems, Environ. Res. Lett., 14(2019):044020.
[46]Zuo, L., Liu, R., Liu, Y., Shang, R., 2019, Effect of mathematical expression of vegetation indices on the estimation of phenology trends from satellite data, Chin. Geogr. Sci., 29:756-767.