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Evaluation of the forest quantity, quality and management through gray relational analysis method

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Abstract

Forests cover 30 per cent of the Earth's land surface, almost four billion hectares. They are necessary to sustain human health, economic growth and the environment. Also, approximately 25 per cent of the global population depends on forests for food and work. The world population is expected to reach 9.6 billion by 2050. Therefore, there needs to be quick action at all levels to make sure that forests are managed in a way that is good for the environment and our way of life in the future. The Sustainable Forest Management Goals are included in the major headings of Sustainable Development Goals and the United Nations Strategic Plan for Forests 2017–2030. The data for the worldwide and six geographical areas were assessed using the Gray Relational Analysis (GRA) approach, which is one of the Multi-Criteria Decision Making methodologies. The major goal of the study is to use the GRA mathematical approach to assess data from 6 geographical areas, totaling 245 regions and nations, and 236 countries and regions worldwide. The second purpose is to contribute to the existing literature by expanding the geographical scope, number of indicators, and the time period covered by the study. The study also aims to provide information on new forest quality and management technologies, as well as the change of geographical areas over 30 years. South America consistently comes out on top in interregional comparisons. On the other hand, Oceania ranks last in the rankings. While the scores for 1990 increased markedly for all regions and worldwide in 2000, the performance values for the years 2000, 2010 and 2020 are fairly close to each other. The findings and methods of this study are aimed to be a useful resource for future researchers and policymakers.

Keywords: monitoring and reporting, sustainable ecosystem, sustainable development goals, forest management, gray relational analysis, global forest goals, MCDM

Introduction

Forests are undoubtedly the richest biological diversity among terrestrial ecosystems. Forests not only serve people in economic, ecological, social and cultural aspects but also are the natural environments of plants, animals and other living creatures, which are essential part of the natural life. Forests supply fundamental ecosystem services, such as wood, food, non-wood goods and house, as well as soil and water protection and clean air. Forests stop soil degradation and desertification and decrease the danger of floods, landslides and snow slide, shortage of water, dust and sand storms and other disasters. Forests are home to almost 80 per cent of all terrestrial species. Forests mainly reduce climate change and ensure acclimatization and biodiversity (FAO, 2018). Although the factors that negatively affect the natural environment are generally considered as regional or local problems, the great effects of these factors are experienced globally. Therefore, forests and each tree need to be monitored and managed in a sustainable manner, in order to reach the Sustainable Development Goals (SDGs) and especially goals of SDG 15, which is particularly relevant for the sustainable management of forests. In order to emphasize that the forests are of great importance for people and all other living things, the UN General Assembly has determined March 21 as the International Forest Day, which is celebrated worldwide every year to create awareness and action plan on forest issues (Assembly, 2012).

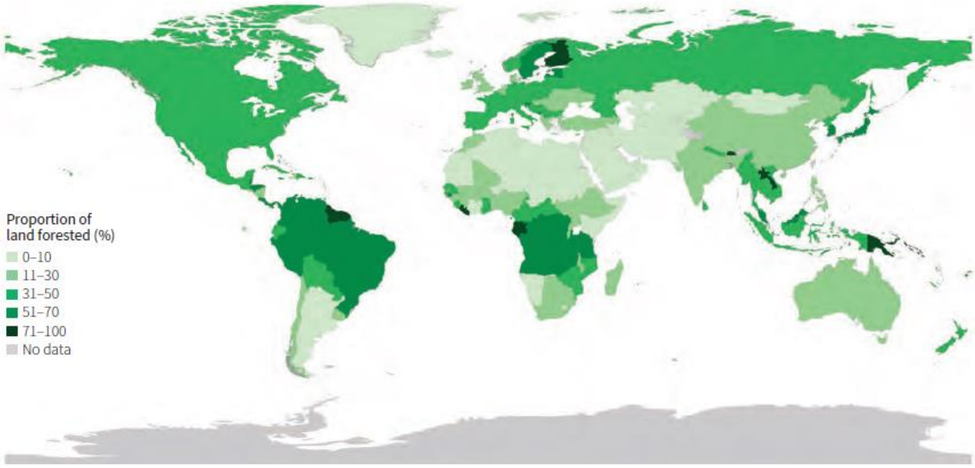

Figure 1. Forest area as a percentage of total land area, 2020 (FAO, 2020).

In recent years many agreements have been made such as the New York Declaration on Forests (NYDF), the Paris Agreement, the 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs), and the UN Strategic Plan for Forests 2017-2030 (UNSPF) and its Global Forest Goals (GFGs). On the other hand, no significant progress has been made in solving global environmental issues despite all the efforts of international organizations, particularly the United Nations. The United Nations Strategic Plan for Forests 2017-2030 (UNSPF) presents a global plan for operations at all levels to sustainably manage all kinds of forests and trees and prevent forest degradation. The plan considers all forest-related frameworks and agreements for a sustainable environment and its vision is to supply economic, social, environmental and cultural benefits for present and future generations. UNSPF, in addition to 6 Global Forest Goals, has set 26 more goals planned to be reached by 2030 (Nations, 2017).

When making a selection, it's normal practice to look at a number of possibilities and choose the best one. It is necessary to choose the criteria that are relevant to the present situation. As a result, multi-criteria decision making (MCDM) is a technique that is extensively employed in forest management planning today (Kangas & Kangas, 2005). MCDM is used to tackle complex forest management difficulties because it combines the intuitive judgment operations of policymakers with logical knowledge management procedures (Ananda & Herath, 2009). When it comes to reviewing the forestry system, high-level decision-making procedures are required (Ok, Okan, & Yilmaz, 2011). Sustainability Forest Management (SFM) decisions are expected to be taken in order to meet the demands of society, the economy, and the environment. Efforts to employ GRA in forest management field have not applied in a global level. Çağlayan, Koç, and Demirel have a research on forest management in Turkey in collaboration with the Gray Relational Analysis (GRA). There are other city-country-specific analyses carried out using different methodologies within the MCDM framework. Many MCDM approaches, such as ELECTRE (Ok et al., 2011), TOPSIS (Stanujkic, Nikolic, & Stanujkic) AHP (Daşdemir & Güngör, 2010; Feng & Wang, 2000), AHP&TOPSIS (Nilsson, Nordström, & Öhman, 2016), GRA method (Çağlayan, Koç, & Demirel, 2017; Chan & Tong, 2007; Gai, Weng, & Yuan, 2011; P. Wang, Zhu, & Wang, 2016; Y. Wang et al., 2020; Zuxing & Dian, 2020) have been carried out in order to better understand the dynamics of forest management, quality and ecosystems. The fundamental objective of the research is to present the GRA mathematical approach in this field. The GRA's purpose is to assess the relationship between components based on the degree to which development patterns among these aspects are similar or different (Feng & Wang, 2000). The GRA technique has many significant benefits, the most important of which are that the conclusions are based on the original data and that the computations are basic and uncomplicated (Chan & Tong, 2007; Zhai, Khoo, & Zhong, 2009). In the study, a 30-year period analysis covering the past and present situations of the world and different geographical regions was conducted in achieving the sustainable forest management goals, which are included in the main headings of Sustainable Development Goals and the United Nations Strategic Plan for Forests 2017–2030.

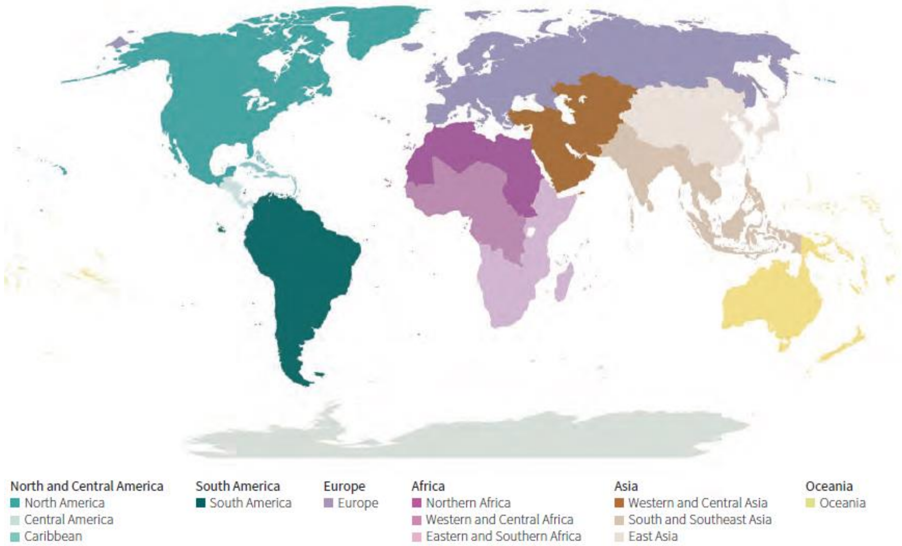

Figure 2. Regional and sub regional breakdown used in the Global Forest Resources Assessment 2020 (FAO, 2020).

In this study, the data of the World and 6 geographical regions were evaluated with the Gray Relational Analysis (GRA) method using 18 indicators related to forest quantity, quality and management in the Global Forest Resources Assessment 2020 Main Report. One of the primary aims of this study to evaluate the data of 6 geographical regions, including 245 regions and countries, with world-wide data belonging to 236 countries and regions, by using the GRA mathematical method. Also, performance assessment in models where many indicators have a positive and negative correlation with each other is evaluated using multi-criteria decision making approaches (Hasan, 2019; Hasan, Koçak, & Doğan, 2016). The reason of using this method is that, in GRA technique has been used for the assessment of forest quality and management in a variety of different geographical areas. The second goal of the research is to contribute to the literature by broadening the geographical scope, increasing the number of indicators, and extending the time period covered by the study. Providing information on new technologies for forest quality and management, as well as the evolution of the world's regions over a 30-year period, is another goal of the project.

The remaining of the study is organized as follows: Section 2 provides the research materials and methods. Section 3 summarizes the results, while Section 4 outlines the conclusions drawn from them.

2. Material and methods

The methodologies that were used in the research are described in this section.

2.1. Equal Weights Method

In order to determine the weighting method, it is necessary to have knowledge about the distributions of the actual weights. Sometimes there are situations where there is insufficient information to determine the weights. In such conditions, real weights can be explained as a uniform distribution on the n-unit simplex through the set {0≤ wj ≤1 and $\sum_{j=1}^{n} w$; j=1,2,...n} (Jia, Dyer, 1998, 87-92). Therefore, within the framework of the hypothesis of insufficient or no knowledge about the weights, the distributions of the weights and their expected values are explained by the equal weights vector defined by Dawes and Corrigan as follows (Dawes, Corrigan, 1975, 95-106): wj = 1/n j = 1,2....,n (n: number of qualifications). In line with this information, the method of equal weighting has been applied to the qualifications in the study.

2.2. Gray Relational Analysis (GRA) Method

The gray relational analysis (GRA) method was proposed by Ju-Long (1982) in 1982. GRA is a useful method for solving problems where there are many criteria and complex and contradictory relationships between criteria. It is also a recommended method for solving complex relationships between variables. Depending on the degree of these associations, it considers the differences or similarities between two sequences in the form of a measure of varying correlation, which involves a comparison of data sets rather than the distance between two points (Lee & Lin, 2011; Tang & Young, 2013).

Gray relational Analysis method consists of seven steps (Karaatlı, Ömürbek, Budak, & Dağ, 2015; 2011):

Step 1: As a first step, the decision matrix is created. In the mxn-dimensional decision matrix, which consists of m number of alternatives and n number of criteria, the value of the ith alternative according to the j[th] first criterion is expressed as x_{ij}.

$$X = \begin{bmatrix} x_1(1) & x_1(2) & \cdots & x_1(n) \\ x_2(1) & x_2(2) & \cdots & x_2(n) \\ \vdots & \vdots & \ddots & \vdots \\ x_m(1) & x_m(2) & \cdots & x_m(n) \end{bmatrix} \tag{1}$$

Step 2: In the next step, the data is normalized. With the normalization process, the decision matrix elements defined by different units are free from their units. Thus, it is possible to evaluate the criteria together. The normalization process is applied by using formula 2 when the criterion is a benefit criterion, and using formula 3 when it is a cost-oriented criterion.

$$x_i'(j) = \frac{x_i(j) - min\, x_i(j)}{max\, x_i(j) - min\, x_i(j)} \quad i = 1,2,\dots,m \quad j = 1,2,\dots,n \tag{2}$$

$$x_i'(j) = \frac{max\, x_i(j) - x_i(j)}{max\, x_i(j) - min\, x_i(j)} \quad i = 1,2,\dots,m \quad j = 1,2,\dots,n \tag{3}$$

Step 3: In this step, the difference of each value of the reference value determined by considering the maximization (benefit) or minimization (cost) criteria of the criteria is calculated, and the absolute value of these differences and the absolute value table of the distances to the reference values are obtained. Since the values of each criterion in the transformed decision matrix have values in the [0,1] value range, the reference value for the benefit criteria is determined as 1, while the reference value for the cost criteria is determined as zero.

$$x_i'(j) = 1 - \frac{|x_i(j) - x_0(j)|}{max\, x_i(j) - x_0(j)} \quad i = 1,2,\dots,m \quad j = 1,2,\dots,n \tag{4}$$

Step 4: In the matrix created in the previous step, the largest (Δmax) and smallest (Δmin) values for each criterion are determined.

Step 5: Gray relational coefficient values are calculated.

$$\varepsilon\,(x_0(j), x_i(j)) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{0i}(j) + \xi\Delta_{max}} \tag{5}$$

In the formula Δi(j); Δi represents the jth value in the difference data set. The coefficient ξ is used to eliminate the possibility of being the extreme value in the Δmax data set and is usually treated as 0.5 in the literature.

Step 6: Gray relational degrees (GRD) matrix is created by multiplying the gray relational coefficient values with the weights of the criteria.

$$\gamma(x_0, x_i) = \sum_{j=1}^{n} \varepsilon(x_0(j), x_i(j) * w_i(j)) \tag{6}$$

The $w_i(j)$ in the formula represents the weight for the *j*th data point.

Step 7: In the last step, GRD values are ordered from largest to smallest to obtain the ranking of the compared alternatives by GRA method. The alternative with the greatest value is defined as the best alternative in terms of the evaluated criteria.

The application consists of 18 quantitative indicators. Indicator codes and definitions are shown in Table 1.

Table 1. Indicator codes and definitions

Indicator Codes	Indicator Definitions	Indicator Codes	Indicator Definitions
C1	Forest area (million ha)	**C10**	Planted forest (million ha)
C2	Forest area (% of land area)	**C11**	… of which plantation forest (million ha)
C3	Growing stock (billion m3)	**C12**	Primary forest (million ha)
C4	Growing stock (m3/ha)	**C13**	Mangroves (million ha)
C5	Carbon stock in biomass (Gt)	**C14**	Forest in protected areas (million ha)
C6	Carbon stock in biomass (t/ha)	**C15**	Forest area with management plans (million ha)
C7	Total carbon stock (Gt)	**C16.1**	Protection of soil and water (million ha)
C8	Total carbon stock (t/ha)	**C16.2**	Conservation (million ha)
C9	Naturally regenerating forest (million ha)	**C16.3**	Social services (million ha)

3. Results

In the study, a total of 7 alternatives representing 6 regions and one for the whole world were evaluated in terms of forest quantity, quality and management using 18 indicators. Values for assessment indicators consist of 1990, 2000, 2010 and 2020 data in the Global Forest Resources Assessment 2020 Main Report. The GRA approach was used to evaluate the data from each of these years independently. The tables of the processing stages of the GRA technique for the year 2020 are presented in this part just to serve as an example of how the method works. To begin, using the GRA technique, a decision matrix consisting of indicator weights and indicator values for each alternative was built, as shown in Table 2. The equal weighting approach was used to determine the values of the weights.

After creating the decision matrices, the appropriate computations were performed using the procedures to get the normalized decision matrix shown in Table 3.

In the matrix created in the previous step, the largest (Δ_{max}) and smallest (Δ_{min}) values for each criterion were determined. The following matrix was created by calculating the absolute value of the difference ($\Delta_i(j)$) between the value of the alternative in the normalized matrix and the largest value (reference value) in the relevant column.

Table 2. GRA Decision matrix for 2020

w_i	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
Regions	Max	Max	Max	Max	Max	Max	Max	Max	Max
World	4059	31.1	557	137.1	295	72.6	662	163.1	3737
Africa	637	21.3	76	120.0	51	79.4	81	127.1	625
Asia	623	20.0	63	100.4	38	60.3	85	136.1	487
Europe	1017	46.0	116	114.2	55	53.6	172	169.5	915
North and Central America	753	35.3	95	126.3	42	55.3	146	194.1	706
Oceania	185	21.8	19	101.8	14	74.9	33	178.5	180
South America	844	48.3	187	222.1	96	114.1	145	171.6	824
w_i	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556
	C10	**C11**	**C12**	**C13**	**C14**	**C15**	**C16.1**	**C16.2**	**C16.3**
Regions	Max	Max	Max	Max	Max	Max	Max	Max	Max
World	293	131	825	14.7	629	1991	390	422	182
Africa	11	8	123	3.2	131	118	36	107	3
Asia	135	79	86	5.6	135	353	132	89	6
Europe	74	4	1	0.0	46	942	171	39	19
North and Central America	47	15	313	2.6	73	432	17	74	15
Oceania	5	4	3	1.3	28	12	1	31	0
South America	20	20	299	2.1	216	134	34	83	140

Table 3. GRA Normalized decision matrix

Wi	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
Regions	Max	Max	Max	Max	Max	Max	Max	Max	Max
World	1	0.39222615	1	0.301561	1	0.31405	1	0.537313	1
Africa	0.116675	0.0459364	0.105948	0.161052	0.131673	0.426446	0.076312	1E-08	0.125105
Asia	0.113061	0.00000001	0.081784	1E-08	0.085409	0.110744	0.082671	0.134328	0.086309
Europe	0.214765	0.91872792	0.180297	0.113394	0.145907	1E-08	0.220986	0.632836	0.206635
North and Central America	0.146618	0.54063604	0.141264	0.212818	0.099644	0.028099	0.17965	1	0.147877
Oceania	1E-08	0.06360424	1E-08	0.011504	1E-08	0.352066	1E-08	0.767164	1E-08
South America	0.170108	1	0.312268	1	0.291815	1	0.17806	0.664179	0.181051
Reference Value	1	1	1	1	1	1	1	1	1
Wi	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556
	C10	**C11**	**C12**	**C13**	**C14**	**C15**	**C16.1**	**C16.2**	**C16.3**
Regions	Max	Max	Max	Max	Max	Max	Max	Max	Max
World	1	1	1	1	1	1	1	1	1
Africa	0.022901	0.02913386	0.147634	0.220408	0.171381	0.053562	0.089506	0.194373	0.016484
Asia	0.45177	0.59055118	0.102709	0.377551	0.178037	0.172309	0.33642	0.148338	0.031319
Europe	0.240111	0.00000001	1E-08	1E-08	0.02995	0.469934	0.436728	0.02046	0.104396
North and Central America	0.146426	0.08818898	0.378331	0.173469	0.074875	0.212228	0.040638	0.109974	0.082418
Oceania	1E-08	0.00314961	0.001931	0.085714	1E-08	1E-08	1E-08	1E-08	1E-08
South America	0.053435	0.12677165	0.361333	0.144218	0.312812	0.061647	0.084362	0.132992	0.769231
Reference Value	1	1	1	1	1	1	1	1	1

Table 4. Distances and Absolute Value Matrix

Regions	C1	C2	C3	C4	C5	C6	C7	C8	C9
World	0.00000	0.60777	0.00000	0.69844	0.00000	0.68595	0.00000	0.46269	0.00000
Africa	0.88332	0.95406	0.89405	0.83895	0.86833	0.57355	0.92369	1.00000	0.87489
Asia	0.88694	1.00000	0.91822	1.00000	0.91459	0.88926	0.91733	0.86567	0.91369
Europe	0.78523	0.08127	0.81970	0.88661	0.85409	1.00000	0.77901	0.36716	0.79337
North and Central America	0.85338	0.45936	0.85874	0.78718	0.90036	0.97190	0.82035	0.00000	0.85212
Oceania	1.00000	0.93640	1.00000	0.98850	1.00000	0.64793	1.00000	0.23284	1.00000
South America	0.82989	0.00000	0.68773	0.00000	0.70819	0.00000	0.82194	0.33582	0.81895
Δmax	1	1	1	1	1	1	1	1	1
Δmin	0	0	0	0	0	0	0	0	0
ξ	0.5								
Regions	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16.1**	**C16.2**	**C16.3**
World	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Africa	0.97710	0.97087	0.85237	0.77959	0.82862	0.94644	0.91049	0.80563	0.98352
Asia	0.54823	0.40945	0.89729	0.62245	0.82196	0.82769	0.66358	0.85166	0.96868
Europe	0.75989	1.00000	1.00000	1.00000	0.97005	0.53007	0.56327	0.97954	0.89560
North and Central America	0.85357	0.91181	0.62167	0.82653	0.92512	0.78777	0.95936	0.89003	0.91758
Oceania	1.00000	0.99685	0.99807	0.91429	1.00000	1.00000	1.00000	1.00000	1.00000
South America	0.94656	0.87323	0.63867	0.85578	0.68719	0.93835	0.91564	0.86701	0.23077
Δmax	1	1	1	1	1	1	1	1	1
Δmin	0	0	0	0	0	0	0	0	0
ξ	0.5								

Then Gray Relational Coefficient values were calculated (ξ= 0.5), and Gray Relational Coefficient Matrix (K_j) values are shown in Table 5.

Tablo 5. Gray Relational Coefficient Matrix (K_j)

Regions	C1	C2	C3	C4	C5	C6	C7	C8	C9
World	1	0.45135566	1	0.417209	1	0.421603	1	0.51938	1
Africa	0.361448	0.34386391	0.358667	0.373427	0.36541	0.465743	0.3512	0.333333	0.363664
Asia	0.360506	0.33333334	0.352556	0.333333	0.353459	0.359905	0.352776	0.36612	0.353684
Europe	0.389034	0.86018237	0.378873	0.360593	0.369251	0.333333	0.390926	0.576592	0.386588
North and Central America	0.369445	0.52117864	0.367989	0.388446	0.357052	0.339697	0.378688	1	0.369789
Oceania	0.333333	0.34809348	0.333333	0.335909	0.333333	0.435565	0.333333	0.682281	0.333333
South America	0.37597	1	0.42097	1	0.413844	1	0.378232	0.598214	0.37909
Regions	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16.1**	**C16.2**	**C16.3**
World	1	1	1	1	1	1	1	1	1
Africa	0.338501	0.33993576	0.369722	0.39075	0.376331	0.345677	0.354486	0.382958	0.337037
Asia	0.476994	0.54978355	0.357835	0.445455	0.378225	0.376594	0.429708	0.369915	0.340441
Europe	0.39686	0.33333334	0.333333	0.333333	0.340125	0.485406	0.470247	0.337943	0.358268
North and Central America	0.369392	0.35415505	0.445764	0.376923	0.350846	0.388268	0.342615	0.359706	0.352713
Oceania	0.333333	0.33403472	0.333763	0.353535	0.333333	0.333333	0.333333	0.333333	0.333333
South America	0.345646	0.3641055	0.43911	0.368791	0.421163	0.34762	0.353198	0.365762	0.684211

Table 6 contains the Gray Relational Degrees calculation matrix and its values.

Table 6. Gray relational degrees and grades

Regions	C1	C2	C3	C4	C5	C6	C7	C8	C9
World	0.056	0.025	0.056	0.023	0.056	0.023	0.056	0.029	0.056
Africa	0.020	0.019	0.020	0.021	0.020	0.026	0.020	0.019	0.020
Asia	0.020	0.019	0.020	0.019	0.020	0.020	0.020	0.020	0.020
Europe	0.022	0.048	0.021	0.020	0.021	0.019	0.022	0.032	0.021
North and Central America	0.021	0.029	0.020	0.022	0.020	0.019	0.021	0.056	0.021
Oceania	0.019	0.019	0.019	0.019	0.019	0.024	0.019	0.038	0.019
South America	0.021	0.056	0.023	0.056	0.023	0.056	0.021	0.033	0.021

Regions	C10	C11	C12	C13	C14	C15	C16.1	C16.2	C16.3	Gray Relational Grades (GRG)
World	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.878
Africa	0.019	0.019	0.021	0.022	0.021	0.019	0.020	0.021	0.019	0.364
Asia	0.026	0.031	0.020	0.025	0.021	0.021	0.024	0.021	0.019	0.383
Europe	0.022	0.019	0.019	0.019	0.019	0.027	0.026	0.019	0.020	0.413
North and Central America	0.021	0.020	0.025	0.021	0.019	0.022	0.019	0.020	0.020	0.413
Oceania	0.019	0.019	0.019	0.020	0.019	0.019	0.019	0.019	0.019	0.361
South America	0.019	0.020	0.024	0.020	0.023	0.019	0.020	0.020	0.038	0.514

The Gray Relational Grades (GRG) values in Table 7 were obtained by analyzing the values related to the other 10-year periods with the above-mentioned process steps.

Table 7. Gray Relational Grades (GRG) for 6 regions and the world in 10-year periods

Regions	1990	2000	2010	2020
World	0.823470	0.878920	0.878556	0.878211
Africa	0.355830	0.371020	0.367361	0.364011
Asia	0.364240	0.385420	0.384648	0.382784
Europe	0.365640	0.398750	0.405895	0.413052
North and Central America	0.387910	0.411040	0.412711	0.412961
Oceania	0.351240	0.367140	0.367082	0.360567
South America	0.495790	0.515280	0.514287	0.514295

In Figure 3, these values of the regions are shown graphically.

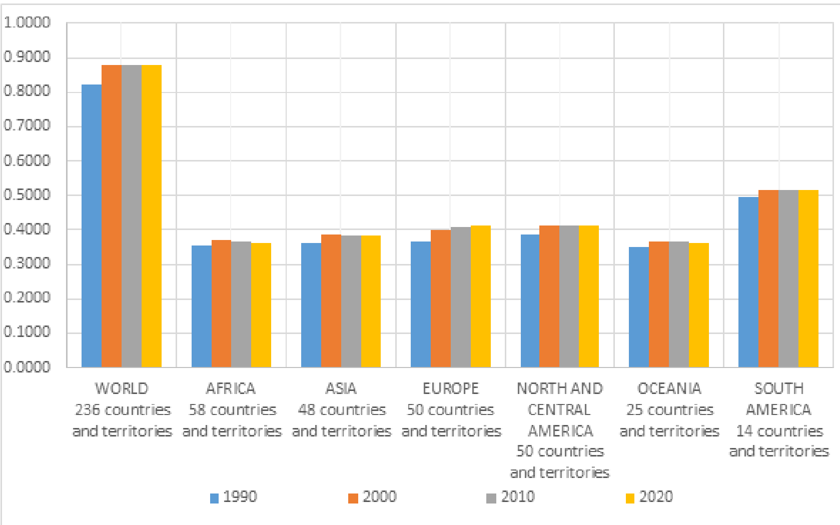

Figure 3. GRA scores of forest performance of the world in general and continents at 10-year intervals

It is necessary to mention some key statistics and inferences that should be emphasized globally and regionally in terms of the indicators included in the study in order to better understand the importance of forest management and the point reached in the field of forest in the last 30 years, both globally and regionally.

The tropics, followed by the boreal, temperate, and subtropical regions, has the greatest percentage of the world's forests (45 percent). Only five nations (the Russian Federation, Brazil, Canada, the United States of America, and China) account for more than half of the world's forests. From 7.8 million hectares per year in 1990–2000, net forest loss decreased to 5.2 million hectares per year in the decade 2000–2010 and to 4.7 million hectares per year in the ten years 2010–2020.

Africa, with an annual net loss of forest of 3.9 million ha, and South America, with a loss of 2.6 million ha, experienced the highest rates of net forest loss between 2010 and 2020. Since 1990, the pace of net forest loss in Africa has steadily grown. However, compared to the years 2000–2010, the rate has dropped dramatically in South America, and is now less than half of what it was. Following Oceania and Europe, Asia had the greatest net growth in forest area between 2010 and 2020. Despite this, Europe and Asia had fewer net gains in 2010–2020 than they did in 2000–2010. Oceania had net reductions in forest area between 1990 and 2000 and again between 2000 and 2010.

Deforestation has resulted in the loss of 420 million hectares of forest throughout the world since 1990, however this loss has slowed dramatically since then. During the years 2010–2015, deforestation totaled 12 million hectares; however, between 2015 and 2020, that number reduced to 10 million hectares.

A total of 7% (290 million hectares) of the world's forest land is planted, leaving 93% (3.75 billion ha) is made up of naturally renewing forest. Plantation forests have grown by more than 120 million hectares since 1990, whereas wild forests have shrunk at an ever decreasing pace. Increases in forested land have slowed considerably during the recent decade.

South America has the highest share of planted forest, comprising 99 percent of global planted forest area and 2% of total forest area. In Europe, plantation forest accounts for just 6% of planted national forest and 0.4 percent of forest areas. Worldwide, 44% of plantation forests are composed mostly of imported species. There are considerable geographical differences: for example, whereas plantation forests in North and Central America are dominated by indigenous species, those in South America are mainly dominated by foreign species.

Worldwide, protected areas cover an estimated 726 million hectares of forest. South America, with 31% of its forests in protected areas, has the greatest proportion of forests in protected areas among the six main geographical regions. Globally, the amount of forest in protected areas has expanded by 191 million hectares since 1990, however the yearly growth rate has decreased in the period 2010–2020. Although primary forest cover has decreased by 81 million hectares since 1990, the rate of decline has slowed to less than half in the period 2010–2020.

When the values of the regions in 1990 and 2020 are evaluated in terms of "C3 Growing stock (billion m3)" indicator, a total of 17 (billion m3) growing stock has increased in the world in a 30-year period. While there is an increase of 12 billion m3 in Europe, 5 in North and Central America and 11 billion m3 in Asia, there is a decrease in growing stock value of 12 billion m3 in Africa and 20 billion m3 in South America. Oceania's total volume of 19 billion m3 remained stable. For this metric, South America performs the worst, while Europe performs the best.

The indicator "C4 Growing stock (m3/ha)", in other words, "the average growing stock density" identifies trees of suitable quality for timber. Woodland trees that fall under this definition are generally larger, healthier trees, with long, straight trunks and low-growing branches. When the values of the regions between 1990 and 2020 are evaluated in terms of this indicator, an average of 5 (m3/ha) growing stock has increased in the world in a 30-year period. There are 9.3 (m3/ha) increase in Europe, 6.7 (m3/ha) increase in North and Central America, 20.3 (m3/ha) increase in Asia, 0.6 (m3/ha) increase in Oceania and 2 (m3/ha) increase in Africa, 9.3 (m3/ha) increase in South America ha). In terms of this indicator, Oceania region remained almost at the same level and showed the worst performance, while Asia showed the best performance with the increase it provided.

Biomass is the mass of biological organisms living in an ecosystem in a particular region or at a particular time. Carbon is stored in a variety of locations and forms across the globe. "Stock" refers to the quantity of carbon in a given system. Forests take up carbon through photosynthesis and this carbon is then allocated above and below ground, contributing to the global forest stock. There has been an increase of 3 (Gt) in the carbon stock in biomass (C5 Carbon stock in biomass) indicator values during the last 30 years. According to these indicator values, Europe has seen a rise of 10 (Gt) , Asia by 4 (Gt) , and North and Central America by 3 (Gt) . On the other hand, there is a decrease of 10 (Gt) in South America and 8 (Gt) in Africa. In the Oceania region, there was no change in this indicator value. Therefore, according to carbon stock in biomass (Gt) values, Europe shows the best performance, while South America and Africa show the worst performances.

According to the "C6 Carbon stock in biomass (t/ha)" indicator values, there is an increase of 2.3 (t/ha) worldwide. In this indicator value, there is an increase in the values of all other regions, except for the 0.5 (t/ha) decrease in the Oceania region over a 30-year period. There was an increase of 0.3 (t/ha) in Africa, 2.1 (t/ha) in Asia, 8.2 (t/ha) in Europe, 3.1 (t/ha) in North and Central America and 4.7 (t/ha) in South America. When the values are examined, Europe is clearly ahead of the other regions in this indicator with a significant value, and South America has a very good value.

According to the "C7 Total carbon stock (Gt)" indicator values, there is a decrease of 6 (Gt) worldwide in a 30-year period. According to these indicator values, there is an increase of 13 (Gt) in Europe and 3 (Gt) in North and Central America. On the other hand, there is a decrease of 17 (Gt) in South America, 13 (Gt) in Africa and 8 (Gt) in Asia. There is no change in the Oceania region. When this 30-year period is evaluated in terms of the relevant indicator, while Europe has the best indicator value, South America has the worst indicator value. According to the "C8 Total carbon stock (t/ha)" indicator values, there is an increase of 5.3 (t/ha) worldwide in the 30-year period. During this period, according to the relevant indicator, there is an increase of 9.8 (t/ha) in Europe, 4.4 (t/ha) in Asia, 3.5 (t/ha) in North and Central America, 5.5 (t/ha) in South America and 0.2 (t/ha) in Africa. There is a decrease of 1.7 (t/ha) in Oceania. While Europe achieved the best increase, South America and Asia also achieved very good increases.

According to the "C9 Naturally regenerating forest (million ha)" indicator values, there has been a decrease of 301 (million ha) worldwide in a 30-year period. During the same period, Europe was the only region showing an increase of 2 (million ha) among regions. There is a decrease of 109 (million ha) in Africa, 24 (million ha) in Asia, 26 (million ha) in North and Central America, 2 (million ha) in Oceania and 143 (million ha) in South America. Considering these values, Europe diverges positively, while Africa and South America perform quite poorly.

According to the "C10 Planted forest (million ha)" indicator values, there has been an increase of 123 (million ha) planted forests worldwide in a 30-year period. There is an increase of 2 (million ha) in Africa, 61 (million ha) in Asia, 20 (million ha) in Europe, 24 (million ha) in North and Central America, 2 (million ha) in Oceania and 13 (million ha) in South America. In this regard, Asia performed the best by a large margin, while Oceania and Africa performed the worst.

According to the "C11 … of which plantation forest (million ha)" indicator values, there has been an increase of 56 (million ha) worldwide in a 30-year period. There is an increase of 2 (million ha) in Africa, 29 (million ha) in Asia, 1 (million ha) in Europe, 8 (million ha) in North and Central America, 1 (million ha) in Oceania and 13 (million ha) in South America. While Asia is leading in this regard, it performs well in South America and North and Central America. According to the "C12 Primary forest (million ha)" indicator values, there has been an increase of 81 (million ha) worldwide in a 30-year period. There was no change in this period in Europe and Oceania. There is an increase of 20 (million ha) in Africa, 14 (million ha) in Asia and 4 (million ha) in North and Central America. In South America, a decrease of 43 (million ha) occurred. Africa shows the best performance in terms of these indicator values, while South America is the region with the worst value.

Mangrove forests, mangrove thickets, also called mangrove swamps, are fertile wetlands that occur in the tidal zones of the coast. Mangrove forests grow mostly in tropical and subtropical latitudes because mangrove trees cannot withstand freezing temperatures. There are about 80 different types of mangrove trees. All of these trees grow in areas with low-oxygen soils, where slow-moving waters allow fine sediments to build up. According to the "C13 Mangroves (million ha)" indicator values, it has decreased by 1.1 (million ha) worldwide in a 30-year period. While there has been no change in this period in Europe, an increase of 0.2 (million ha) in North and Central America and 0.1 (million ha) in South America. There is a decrease of 0.2 (million ha) in Africa, 0.7 (million ha) in Asia and 0.2 (million ha) in Oceania.

Over a 30-year period, the "C14 Forest in protected areas (million ha)" indicator values show a global increase of 191 (million ha). Over the last three decades, the relevant indicator value has risen for all areas. South America had the largest growth, with 66 million hectares, while Africa had the smallest increase, with 7 million hectares (million ha). North and Central America expanded by 31 (million hectares) and Oceania by 10 million (ha), whereas Asia grew by 50 (million ha) (million ha).

In 1990, there is no value for the indicator "C15 Forest area with management plans (million ha)". Therefore, for this indicator, data for the years 2000 and 2020 have been compared. All regions except Oceania had an increase in the relevant indicator value in this 20-year period. There has been an increase of 233 (million ha) "forest area with management plans" in the world. There was an increase of 39 (million ha) in Africa, 73 (million ha) in Asia, 8 (million ha) in Europe, 55 (million ha) in North and Central America and 69 (million ha) in South America. Increases are most pronounced in Asia, South and Central America, and North and Central America.

Preserving soil, water, and vegetation in regions at risk of degradation is the goal of local soil and water protection operations. These include efforts to reduce soil erosion, compaction, salinity, and water conservation, as well as efforts to preserve or increase soil fertility. According to the "C16.1 Protection of soil and water (million ha)" indicator values, there has been an increase of 94 (million ha) worldwide in a 30-year period. Europe outperforms the rest of the world on this statistic, with 80 (million hectares) in this period. There has been a 15 (million hectare) rise in Asia, a 1 (million hectare) increase in North and Central America, and a 3 (million hectare) increase in South America. The size of the protected area in Oceania has not changed over the last three decades.

The practice of conserving forests for the benefit of present and future generations is known as forest conservation. Forest conservation involves the maintenance of natural resources in a forest that are beneficial to both people and the ecosystem. According to the "C16.2 Conservation (million ha)" indicator values, there has been an increase of 75 (million ha) worldwide in a 30-year period. All areas have seen a rise in this metric. Asia (22 million ha) and North and Central America (21 million ha) are the areas that have had the greatest growth in the amount of conservation since 1990. 10 (million ha) in Africa, 11 (million ha) in Europe, 7 (million ha) in Oceania, and 5 (million ha) in South America have seen a rise.

According to the "C16.3 Social services (million ha)" indicator values, there has been an increase of 2 (million ha) worldwide in the 30-year period. Forest areas designated for social services are the most common kind of land in this category. In this 30-year period, while there has been an increase of 1 (million ha) in Africa, 2 (million ha) in Asia, 2 (million ha) in Europe, there has been no change in North and Central America and Oceania. In South America, there has been a decrease of 3 (million ha).

4. Discussion and Conclusion

The aims of the study are to contribute to the literature in terms of methodology by using the GRA method, one of the MCDM methods, and to increase awareness about forest quantity, quality and management. Another aim is to examine and compare the changes in the regions in terms of indicators determined over a 30-year period. The study brings a new perspective to the literature since the Gray relational analysis method has not been used to evaluate forest quantity, quality and management in a global context in terms of geographical regions before.

The 18 indicators in the Global Forest Resources Assessment 2020 Main Report used in the study have not assessed by MCDM or other analysis methods. Therefore, this is one of the aims and novelty of the study to the literature. Only a subset of 10 indicators has been frequently used to assess forest ecosystem management strategies, according to a review of the literature. This study was planned and carried out with these key aspects in mind. According to the literature, the most important indicators are "carbon stock," "tree species composition," and "forest degradation." In a research (Bowditch et al., 2020), most of these variables were designated fundamental indicators for evaluating forest and climate. Although Bowditch et al. (2020) indicates that social factors are an important part of the forest management in response to climate change, the opposite is true when it comes to scientific articles: ecological rather than economic factors are commonly discussed. In particular, findings of Santopuoli et al. (2021) show that “forest damage” is the most important indicator deciding the forest management rating. In this study, forest and carbon stock indicators were tried to evaluate the forest damage dimension, while the indicator related to forest social services was included in the analysis and the social dimension was taken into account. Therefore, it has been one of the rare studies evaluating the social aspect in this field.

In interregional comparisons, the South America region has the best values. Oceania, on the other hand, is ranked at the bottom of the list. The main reason for this result is that the forest area (million ha) of the Oceania region is quite less compared to other regions. On the other hand, the ratio of forest area to terrestrial area (21.8%) of the Oceania region is approximately equal to that of Africa and Asia. While the ratio of forest area in South America (48.3%) and Europe (46%) to the total terrestrial area is approximately twice that of Asia, Africa and Oceania, they are approximately 1.5 times that of North and Central America. While the GRA scores for all regions and the world have increased significantly from 1990 to 2000, the performance values for the years 2000, 2010 and 2020 are very close to each other. In all rankings, South America is in the first place, while Oceania is in the last place. Meanwhile, in the 2020 rankings, Europe moved up from third to second place, just a few points ahead of North and Central America.

It's important to note that underutilized forest resources are more sensitive to natural catastrophes and may release more carbon than harvested forest resources in the case of degradation (Jandl, Spathelf, Bolte, & Prescott, 2019). Therefore, the amount of managed forest should increase at a faster pace. When the indicators of the study on this subject are evaluated, the majority of forest areas in Europe have a management action plan; by contrast, fewer than 25% of forests in Africa and less than 20% in South America have implementation strategies. The amount of forest managed under plans is expanding in all areas worldwide, it has expanded by 233 million hectares (ha) since 2000, and reached to almost 2.05 billion hectares in 2020. In 2015, insects, diseases, and severe weather damaged approximately 40 million hectares of forest, mostly in temperate and boreal areas.

Rotation time of forest harvesting operations may increase both the growing stock and the quality of wood products (Jandl et al., 2018; Jandl et al., 2019; Köhl, Ehrhart, Knauf, & Neupane, 2020). An adaptive management plan, which includes increased wood collection, might allow long-term carbon storage in forest products, in addition to the economic benefits already described (Colombo et al., 2012; Jasinevičius, Lindner, Verkerk, & Aleinikovas, 2017; Paletto, De Meo, Grilli, & Nikodinoska, 2017). As a result of these research, it is safe to say that nations and regions with a long-term strategy for managing forest and carbon stock will have a positive impact on their own economy and the environment (Santopuoli et al., 2021). When the analysis in the study is taken into account, Europe under the leadership of Russia and EU; Asia led by China; and North America, led by Canada and the USA, are important actors.

All regions and the majority of subregions are dominated by public ownership. Oceania, North and Central America, and South America have the largest percentage of private forests among the continents. Since 1990, the percentage of publicly held forests has dropped globally, while the amount of privately owned forest has expanded.

A net loss in forest area has reduced the world's total growing supply of trees from 560 billion m^3 in 1990 to 557 billion m3 in 2020. But worldwide and regional growing stock per unit area is rising; it has gone from 132 m^3 per ha per year in 1990 to 137 m^3 per ha in 2020. Most trees are grown per square meter in South and Central America's tropical forests, as well as West and Central Africa's rainforests. About 606 gigatonnes of live biomass (both above and below ground) and 59 gigatonnes of dead wood are available in the world's forests. Biomass as a whole has fallen significantly since 1990, while biomass as a percentage of land area has risen. In addition, carbon storage in forests declined from 668 gigatonnes in 1990 to 662 gigatonnes in 2020; carbon density grew slightly over the same time, from 159 to 163 tonnes per hectare. Around the globe, 186 million hectares of forest are set aside for social activities such as leisure, ecotourism, training, and the protection of spiritual and cultural places. Since 2010, the area allocated for this forest use has expanded by 186 000 hectares each year.

There should be no negative consequences of forest use and management for both the public's health and the environment. Environment-related problems must no longer be ignored or avoided. Policymakers must come up with a common strategy for more effective protection and long-term sustainability of forest resources in order to achieve these goals. Increasing the pace of research and development, education, and public awareness, as well as increasing incentives and investments in the infrastructure of standard data collection systems, will all contribute to the achievement of the Sustainable Development Goals. Global awareness, cooperation, policies, and strategies will bring us closer to a sustainable world in which forest resources are protected and global climate problems can be brought under control as a result of our collective efforts.

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