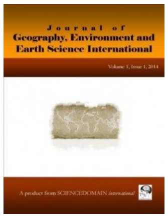

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Environmental Vulnerability Evaluation of the Afro-Alpine Ecosystem Using Remote Sensing and GIS: A Case Study in Mountain Abune Yosefe, Amhara Region, Ethiopia

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Author's contribution

All activities in the preparation of this research paper are only doing by the author.

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ABSTRACT

This study aims to evaluate the environmental vulnerability of the Mt. Abune yosef Afro-alpine ecosystem in the North Highlands of Ethiopia. Remote sensing, Geographic information system (RS,GIS) and Spatial Principal Component Analysis (SPCA) as well as the structure and semi-structured questionnaire interview were employed to evaluate the environmental vulnerability. The Mt. Abune yosef afro-alpine ecosystem, located in the North part of Amhara Region, is characterized by the complex of different fauna and flora. To analyze environmental vulnerability, remote sensing (RS) and geographical information system (GIS) technologies are adopted, and an ecological numerical model is developed using spatial principal component analysis (SPCA) method. The model contains seven factors including altitude, slope, aspect, land use type, vegetation cover, human and livestock population density. According to the numerical results, the

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vulnerability is classified into four levels: potential, light, medial, and massive concentration utilizing the cluster principle. The environmental vulnerability distribution and its dynamic change in the past 30 years from 1985 to 2015 are analyzed and discussed. The results show that the environmental vulnerability in the study area is at an intermediate level, and the Integrated Environmental Vulnerability Index (EVSI) value of 2.856, 3.0698 and 2.925 at 1985, 2000 and 2015 respectively and my study shows the driving forcing of dynamic change are mainly caused by human, social and economic activities. To decrease farmland expansion and livestock grazing, alternative income generating activities such as eco-tourism development is better in the surrounding of Mt. Abune yosef Afro-alpine ecosystem.

Keywords: Environment; vulnerability; Spatial Principal Component Analysis (SPCA); Remote Sensing/RS/; Geographic Information System (GIS).

1. INTRODUCTION

Afro-Alpine mountain ecosystem is widely recognized that mountain regions include many of the world's most sensitive ecosystems. They are mainly vulnerable as a result of their high relief steep-slops, shallow soils, adverse climate conditions and geological variability [1]. Regardless of the high degree of uncertainty, it is clear that the biophysical fragility of mountains ecosystem has direct consequences of the socio-economic vulnerability of mountain people, estimated at 720 million 12% of the world's population. Nearly 90% of the population of the mountain 663 million people live in developing countries and overall, 78% of the land surface in the world’s mountain areas has been classified by the FAO as not suitable or only marginally suitable for agriculture [1].

The most majority of rural mountain people engage in some form of agricultural activities and highly dependent on natural resource and due to environmental constraints such as unfavorable climate conditions, poor quality or shallow soils, and sloping terrain agriculture productivity is low, and harvest output is not competitive in the global market. Pastoral system; however, are becoming increasingly vulnerable due to population growth and the resulting increase in pressure on land [1].

Ethiopia has 70% of all the Afro-tropical lands above 2000 Meter and 80% of all the lands, above 3000 Meter [2]. There are isolated to the northwestern and south-east of the rift valley of mountain blocks that favors the country to have a large number of endemic specious compared to the rest of Africa which make it a key centre of biodiversity and endemism in Africa [3].

The highest Afro-Alpine ecosystem in Ethiopia is the Bale Mountain Nation Park (BMNP) it covers (990 Km^2), and Arsi mountain covers 1000 Km^2 [4]. The coverage of other Afro Areas which found in north Ethiopia are Simene Mountain National Park (SMNP) (960 km^2), south wollo (1220 Km^2), Mt.Guna (960 km^2), Mt.Choke (500 km^2) Guassa-Menz (124 km^2) and Gosh Meda (90 km^2) and the fragmented north wollo areas together cover 1150 Km^2 [5].

The Afro-Alpine potential area of Ethiopia covers about 5000 km^2. However, almost all of the land between 3200 and 3700 meters has been already used for agriculture but leftover only 20% of the estimated potential area [4].

The Afro-Alpine highlands of North Wollo are the second largest in Northern Ethiopia including Mt. Abuneyosef(in Lasta woreda), Mt.Abohoy Gara (in Gidan woreda) Mekulet near Kulf Amba between Gubalafto and Delanta woreda. It covers a total area of 189.18 km^2 [4].

Growing barley and grazing is the significant land use practices in the lower altitude but in the upper zone agriculture is limited by frost, and it provides habitat for wildlife such as Ethiopian wolf. Nowadays due to climate change and population growth these land uses are disturbed in all Afro-Alpine ecosystems of the zone and unless measures are taken these specious are vulnerable to extinction [3].

The need for studying the problem in Mt. Abune yosef is great as there is no available database that shows national or regional the environmental vulnerability magnitude of the Afro-Alpine ecosystem.

Therefore this study is carried out using the above mentioned environmental factors that disturb the stability of the Afro-alpine ecosystem are evaluate the trends of environmental vulnerability on the year 1985, 2000 and 2015 using satellite imageries and GIS techniques.

2. MATERIALS AND METHODS

This study is conducted at Mt. Abune yosef during the period from 1985 to 2015 and Remotely sensed satellite image are used for the purpose of land use land cover classification and vegetation change detection.

The LULC/land use and land cover/ classification and vegetation cover map are developed from landsat satellite images were acquired in the year 1985, 2000 and 2015.

The land use land cover maps are used to investigation land use land cover dynamics and vegetation coverage of the study area. DEM/ Digital Elevation Model/ with 90M resolution is used to analysis the Altitude in *meter, aspect* and slope gradient in *degree* of the study area.

Comprehensive questionnaire is designed and used to get the following data: human population density, livestock population density and to identify driving force of environmental vulnerability in the study area.

The EVI/ Environmental Vulnerability Index/ is an indicator-based method for estimating the vulnerability of the environment and state to future shocks. It is reported simultaneously as a single dimensionless index and as a breakdown profile showing the results for each indicator so that in addition to an overall signal of vulnerability, it can be used to identify specific problems. It has been designed to reflect the status of a country's 'environmental vulnerability', where 'vulnerability' refers to the extent to which the natural environment is prone to damage and degradation. It does not address the vulnerability of the social, cultural or economic environment, and not the environment that has become dominated by these same human systems (e.g. cities). The natural environment then includes those biophysical systems that can be sustained without direct and/or continuing human support. In the context of the EVI, 'damage' refers to the loss of diversity, extent, quality and function of ecosystems [6].

The previous investigations have developed many method to evaluate environmental vulnerability, such as the fuzzy valuation method [7] the gray evaluation method [8] and artificial neural-network evaluation method [9]. Combing these technologies cannot only supply a platform to support multi-level and hierarchical integrated analysis on resource and environment, but also integrate the obtained information in a comparative theoretical ecosystem analysis. The principal component analysis (PCA), using coefficients of linear correlation offers the possibility to weight the contribution of factors [7]. Recently, the space technologies, such as remote sensing and GIS, and numerical modeling techniques have been developed as powerful tools for ecological and environment assessment [10].

The study used Spatial Principal Component Analysis, which is an ordination based statistic data exploration tool that converts a number of potentially correlated variables (with some shared attribute, such as points in space or time) into a set of uncorrelated variables that capture the variability in the underlying data. As such, PCA can be used to highlight patterns within multivariable data. PCA is a non-parametric analysis and independent of any hypothesis about data probability distribution [10].

PCA uses orthogonal linear transformation to identify a vector in N-dimensional space that accounts for as much of the total variability in a set of N variables as possible the first principal component (PC) where the total variability within the data is the sum of the variances of the observed variables, when each variable has been transformed so that it has a mean of zero and a variance of one [7]. A second vector (second PC), orthogonal to the first, is then sought that accounts for as much of the remaining variability as possible in the original variables. Each succeeding PC is linearly uncorrelated to the others and accounts for as much of the remaining variability as possible [8].

The study using seven variables which are negatively affect the stability of the environment/ land use land cover, vegetation change, Altitude, Aspect, Slope, Human population density and Livestock population density/ are analyze using ArcGIS spatial principal analysis tool. The results are computed in Table 1.

Using software environment of the GRID module in Geographical Information System software ARC/INFO, the function PRINCOMP is used to transform the data in a stack from the input multivariate attribute space to a new multi-variant attribute space whose axes are rotated with respect to the original space and the result of the analysis have the matrix R of each variable; (1) to compute an Eigen value λi of matrix R and its corresponding eigenvectors αi; (2) to group αi by linear combination and put out *m* principal components,(3) the Eigen value contribution ratio(%) and cumulative contribution(%). And evaluation function can be set up to compute an integrated evaluation index on the basis of selected components.

Index *E* is defined as sum of a couple of weighted principal components shown as below:

$$E = \alpha 1Y1 + \alpha 2Y2 + \cdots + \alpha mYm \quad (1)$$

In the formula, *Yi* is number of *i* principal component, while *αi* is its corresponding contribution of each study year.

The higher the EVI/ Environmental Vulnerability Index/ value, the more vulnerable environment Derived from Table 1 and formula (1), the linear formulas for computing EVI is created as follows:

EVI 1985 = 0.2702 × *A*1 + 0.208337 × *A*2 + 0.204329 ×*A*3 + 0.141079 × *A*4 + 0.086074 ×*A*5

EVI 2000 = 0.235 × *B*1 + 0.219 × *B*2 + 0.178 ×*B*3 + 0.112× *B*4 + 0.0.101 ×*B*5

EVI 2015 = 0.267×*C*1 + 0.228 × *C*2 + 0.195 ×*C*3 + 0.104 × *C*4 + 0.09 ×*C*5

In the formula, EVI is environmental vulnerability index, *A*1–*A*5 are five principal components sorted out from seven initial spatial variables in 1985. Similarly, *B*1–*B*5 five principal components in 2000, and *C*1–*C*5 are the ones in 2015. The cumulative contribution of the five components is 91% (1985a), 84.5% (2000a) and 88.4% (2015a), respectively. Each of them lays in 85–91%, which accord with the convention of choosing factors by PCA method with a high reliability. However, there is still an information loss of about 9-15% when the number of selected components reaches five, which shows that the initial factors have relatively independent function on evaluation.

After the Principal Component Analysis of each study year are accomplished using Iso-cluster and Maximum Likelihood classification method the results are classified and finally all PCA Clustering results are using SpaceStat software each PCA results evaluates using the Histogram distribution and set the histogram four cluster points to classify the vulnerability levels. The classified result (Table 2) as potential, light, medium and heavy vulnerability status of the study area is stated in the following way.

After the EVI classification are completed using histogram graphical tool explore the statistical distribution of the classes and clusters in the attribute space [11]. This study applies the cluster principle to discrete the computed result through analyzing the histogram of index distribution to line out the dividing points between clusters and graded as potential(1), light(2), media(3) and heavy(4) level.

Based on the above mentioned PCA and EVI grade value the total integrated environmental vulnerability index (EVSI) for each year's are calculated using the function given by [11].

$$EVSIj = \sum_{i=1}^{n} Pi \times Ai/Si \quad (2)$$

In this formula,

Ai= the Grade area
Si= total study area
Pi= the graded value which is potential= 1, slight=2, medial=3 and heavy=4.

Table 1. The results of spatial principal component analysis in the study area

1985	**Selected principal components**				
	PC1	**PC2**	**PC3**	**PC4**	**PC5**
Eigen Value	0.50	0.38	0.38	0.26	0.16
Percent of Eigen Value	27.02	20.8337	20.4329	14.1079	8.6074
Accumulative of Eigen Value	27.0	47.9	68.3	82.4	91.0
2000	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Eigen Value	0.42	0.39	0.32	0.20	0.18
Percent of Eigen Value	23.5	21.9	17.8	11.2	10.1
Accumulative of Eigen Value	23.5	45.4	63.1	74.3	84.5
2015	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Eigen Value	0.48	0.41	0.35	0.18	0.16
Percent of Eigen Value	26.7	22.8	19.5	10.4	9.0
Accumulative of Eigen Value	26.7	49.5	69.1	79.4	88.4

Table 2. the result of environmental vulnerability classification in the Mt Abune yosef Afro-alpine ecosystem

Evaluation level	Grade value	EVI	Feature description
Potential vulnerability	1	<3.3	Stable ecosystem, great anti-interference ability, rich soil, and relatively low altitude
Light vulnerability	2	3.3-6.7	Relatively stable ecosystem and anti-interference ability, rich soil, and relatively low altitude
Medial vulnerability	3	6.7-9.38	Unstable ecosystem, poor anti-interference ability, deteriorated soil, and dominated by alpine shrub grassy marshland
Heavy vulnerability	4	>9.38	Extremely unstable ecosystem and poor anti-interference ability, deteriorated soil, and sparse vegetation dominated by extreme- coldness plants ecosystem.

The study is conducted at Mt. Abune yosef above 3500 Meter in Lasta wereda, North wollo administrative zone of Amhara National Regional State (ANRS). The administrative center of North Wollo zone is Woldia. It has mostly rural population of 1.5 million people living in 13 weredas. Lasta Wereda is one district of North Wollo with its administrative center Lalibela. Mt. Abune yosef lies between 12º8'7" N and 39º 15'7" E. It is one of the long isolated mountains in the Northern massif with a total area of 50 km^2 [12]. The highest peak of North Wollo 4286 Meter and the second peak of ANRS next to Ras-dashen 4620 Meter [13]. The massif is limited to the East by the fault escarpment of the Rift valley depression and separated from the Tigray Plateau to the North and from the Semen-mountains (4,600 Meter of height) to the West by a chain of lower mountain systems (1500-2000 Meter).

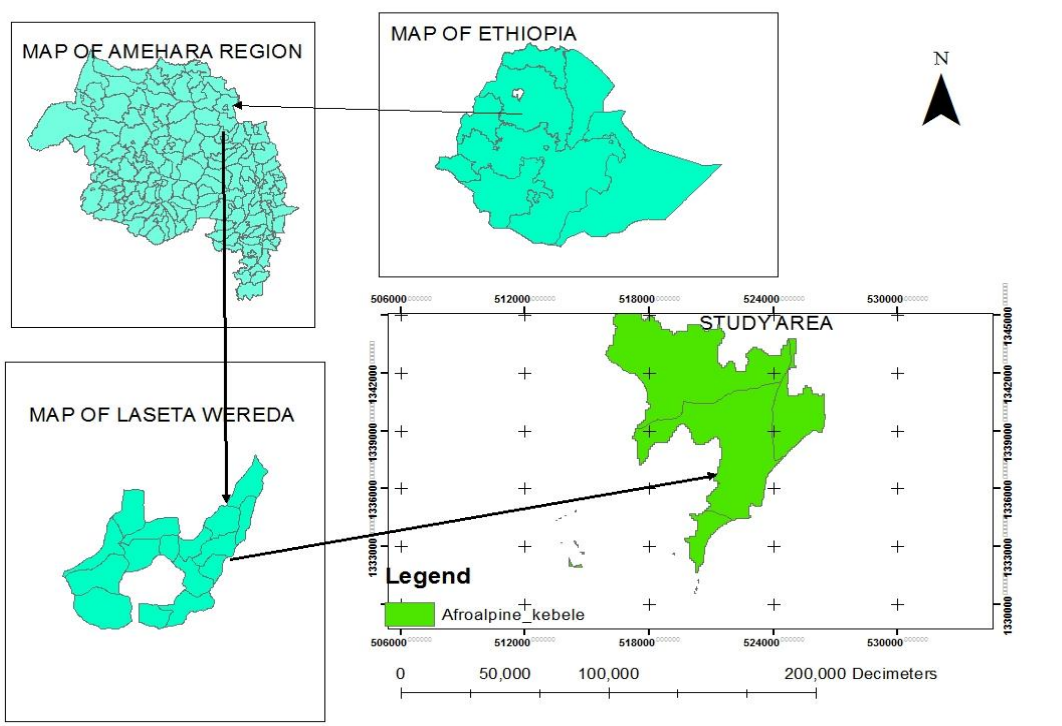

Fig. 1. Location of the study area

3. RESULTS AND DISCUSSION

Using the formula (2), the result of EVSI value in the study area are listed in Table 3 which is the general change trend of environmental vulnerability and its magnitude as potential(1), light(2), medium(3) and heavy(4) vulnerability level are stated in the following way.

Table 3. EVSI value of each study year and Vulnerability level

Vulnerability level	1985				2000				2015			
	Grid number	%	Each EVSI	EVSI	Grid number	%	Each EVSI	EVSI	Grid number	%	Each EVSI	EVSI
1	2023	3.11	0.03	***2.85***	226	0.3	0.003	***3.06***	921	1.4	0.0141	***2.92***
2	10356	15.92	0.32		3106	4.8	0.095		7100	10.9	0.2176	
3	47594	73.19	2.20		53137	81.7	2.446		52304	80.4	2.4044	
4	5059	7.78	0.31		8563	13.2	0.525		4707	7.2	0.2885	

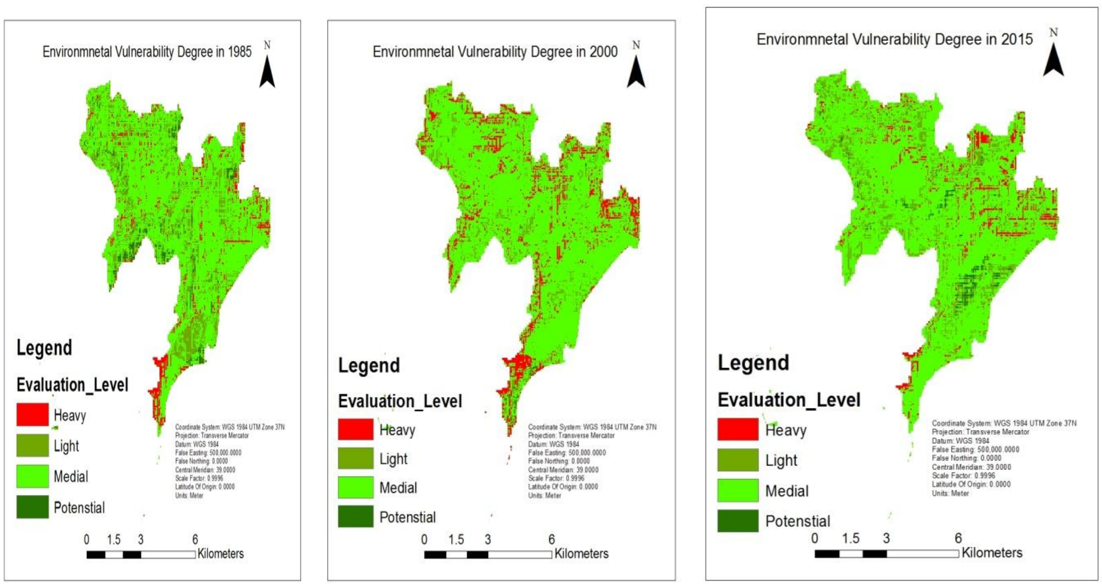

Fig. 2. Distribution and magnitude of environmental vulnerability in the study area

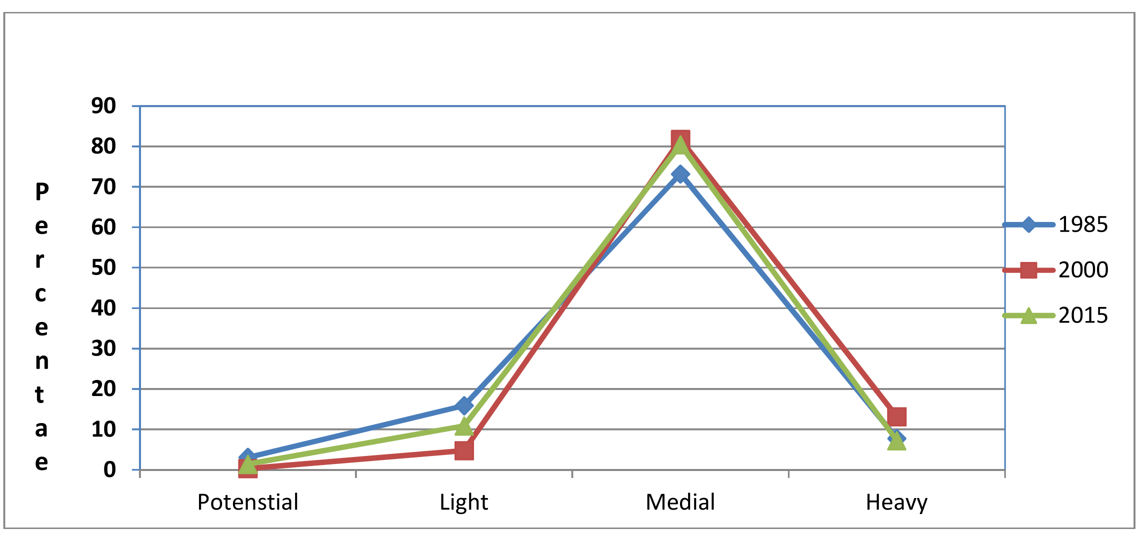

Fig. 3. Environmental vulnerability index profiles in 1985, 2000, and 2015, respectively

(1) From the year 1985 to 2000, levels I–III are increased 3.11, 15.92 and 73.19% at 1985 and 0.35, 4.78 and 81.71% at 2000 respectively, correspondingly, levels IV is increased from 7.78% at 1985 to 13.17% at 2000 respectively; (2) From the year 2000 to 2015, levels I and II are increased from 2000 0.35, 4.78% and at 2015 1.42, 10.92% respectively, while level IV is increased from 1985 7.78% to 13.17% at 2000 and decreased 7.24% at 2015.

Change of area occupied by each evaluation level is surveyed as follows and according to the result showed in Table 3 at 1985 the vulnerability level of the study are is more of medial vulnerability level which is 73.19% , at 2000 81.71% and at 2015 80.43%. The overall vulnerability is medium relative to the other vulnerability level but the heavy vulnerability level is very small at 1985(7.78%) and it increases to 13.17% at 2000 and decreases 7.24% at 2015 respectively which shows the heavy environmental vulnerability level of Mt. Abune yosef Afro-alpine ecosystem is increased between the year 1985 and 2000 slight decreases between the year 2000 and 2015 the past 30 years.

According to [14] In order to analyze environmental vulnerability, RS/remote sensing/ and GIS/ geographical information system/ technologies are very important and useful by adopting an environmental numerical model and SPCA/spatial principle component analysis/ method to evaluate eco-environmental vulnerability of mining cities: a case study of Panzhihua city of Sichuan province in China.

The same phenomena was investigated much of the Ethiopian landscape is 4,000 Meter is altered by agricultural activities and deforestation in order to fit the basic needs of a growing human population. Moreover, overgrazing decreases ground cover density both by consumption and trampling which resulted in reducing infiltration and increasing runoff [13].

Especially Mt. Abune yosef massive of North wollo Afro-alpine ecosystem suffer from diverse level of human intervention mainly from agricultural activities and livestock grazing which dramatically modified the natural landscape and the natural Afro-alpine habitats has contracted over the last decade and currently remain only above 3700 Meter and not more than 5000 hectares covered the future survival of Wolves in North Wollo, especially in Mt. Abune yosef is in question [12].

4. CONCLUSION

This study evaluates the environmental vulnerability status of the Mt. Abune yosef Afro-alpine ecosystem using GIS and Remote sensing technologies from the past 30 years and it also examined the vulnerability magnitude of the Afro-alpine. The result of environmental vulnerability revealed that from 1985 to 2000 seriously increases from EVSI value of *2.856* to *3.0698* and from 2000 to 2015 slight decreases from EVSI value 3.0698 to 2.925 respectively.

In view of the persistent human impact on the immediate massif action is required.

To design sustainable conservation actions research is needed to investigate the current socio-economic and ecological potential of Mt. Abune yosef including its flagship species and evaluate the trend of environmental vulnerability.

The Abune yosef massive Afro-alpine areas are highly degraded by different environmental factors like steep slope, high elevation, population growth, livestock population growth, change in vegetation cover, expansion of agricultural land and overgrazing.

To decrease farmland expansion and livestock grazing alternative income generates such as eco-tourism development should be scaled up in the surrounding of Mt. Abune yosef Afro-alpine ecosystem. Integrated conservation and development activities should be justified on the grounds of increased the sustainable use of natural resources.

Successful planning of ecosystem management and development will require reliable information about environmental vulnerability and factors influencing such changes. Hence, a detailed and long-term study should be conducted as well as continues monitoring of ecosystem health should be an integral part of the afro-alpine ecosystem management and regional development plans.

The results of this study also indicate that the method that integrates the technologies, such as RS and GIS, and the SPCA mathematical approach to evaluating environment vulnerability in Afro-alpine ecosystem areas, cannot only distinctly represent the input subject spatial distribution of the Afro-alpine ecosystem vulnerability feature, but also the magnitude as a whole.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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