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Quality indicator of a Vertisol dedicated to rice in the Holguín province, Cuba

Indicador de calidad de un Vertisol dedicado al arroz en la provincia Holguín, Cuba

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ABSTRACT: Rice is a product of high national demand and its production needs to be increased. In the province of Holguín, Cuba, a transfer is currently being built that will make it possible to have the water necessary for the cultivation of rice in an area of around 2000 hectares. When there are large areas of soil whose suitability must be evaluated for a crop, indicators are required that are feasible to determine without large costs and experimental campaigns, and that can be estimated indirectly. In this research, a soil quality indicator (SQI) is introduced. The procedure followed is explained for which an experimental campaign was carried out in an area of the aforementioned region in which a total of 14 soil properties commonly used to characterize soil quality were determined. A factor analysis was done in order to determine which of the properties contributed the most to the common variability and, based on their weights and the values of the scoring functions that evaluate the good or bad influence of their values, the values were finally calculated. SQI values that allowed us to find that only 31% of the studied area has moderate to very good suitability, located in the northern part of the studied area. The properties that were most important in the study were total nitrogen, phosphorus, potassium, calcium, magnesium, sodium, organic matter and electrical conductivity.
Keywords: Soil Quality Index, Factor Analysis, Rice.

RESUMEN: El arroz constituye un producto de alta demanda nacional y que se requiere incrementar su producción. En la provincia Holguín, Cuba se construye en estos momentos un trasvase que hará posible disponer del agua necesaria para el cultivo del arroz en una zona de alrededor de 2000 ha. Cuando se dispone de grandes áreas de suelo cuya aptitud debe ser evaluada para un cultivo, se requieren de indicadores que sean factibles de determinar sin grandes costos y campañas experimentales, y que además puedan ser estimados de forma indirecta. En esta investigación se introduce un indicador de calidad del suelo (SQI) por sus siglas en inglés. Se explica el procedimiento seguido para el cual se llevó a cabo una campaña experimental en una zona de la región mencionada en la que se determinaron un total de 14 propiedades del suelo comúnmente empleadas para caracterizar la calidad suelo. Se realizó un análisis factorial con vistas a determinar cuáles de las propiedades eran las que más contribuían a la variabilidad común y a partir de sus pesos y de los valores de las funciones de puntuación que evalúan la buena o mala influencia de sus valores finalmente se calcularon los valores del SQI que permitieron encontrar que sólo un 31% del área estudiada tiene aptitud entre moderada y muy buena, situada en la parte norte del área estudiada. Las propiedades que resultaron de mayor importancia en el estudio fueron el nitrógeno total, el fósforo, potasio, calcio, magnesio, sodio, materia orgánica y la conductividad eléctrica.
Palabras clave: índice de calidad, análisis factorial, arroz.

INTRODUCTION

Soil quality, according to Nasir *et al.* (2024), is defined as its capacity or aptitude to support the growth of crops without this resulting in soil degradation or environmental damage, and is established as a result of associating the condition of the soil with characteristics necessary for a specific use (aptitude). An indicator is a parameter or a value derived from parameters that provides information, describes the properties, processes and characteristics, with the purpose of monitoring the effects of management on the functioning of the soil in a given period, with an extended meaning beyond that directly associated with the parameter value (Vasu *et al.*, 2016).

Prieto *et al.* (2013) point out that these indicators must be limited in number, manageable by various types of users, simple, easy to measure and have a high degree of aggregation. They must contemplate the greatest diversity of situations and have a variation over time such that it is possible to monitor them. Likewise, they should not have a high sensitivity to climatic and/or environmental changes but sufficient to detect the changes produced by the use and management of resources.

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According to the technical instructions for the nutrition and fertilization of rice cultivation in Cuba proposed by Mairura *et al.* (2007), among the chemical elements to take into account to obtain optimal yields are nitrogen, phosphorus, potassium, calcium, magnesium and silicon. Other trace elements such as iron, manganese and zinc are considered present at a micro level in the soil, while sodium is considered a harmful ion due to its dispersing action on soil colloids and toxic to rice.

On the other hand, research carried out by Sys (1985); FAO (1991); Horuz & Dengİz (2018); Dengiz (2020); Trigoso *et al.* (2023) raise the need to also know the salt content, texture, pH, cation exchange capacity and organic matter content in the soil. To interpret the condition of the soil in terms of quality, indicators or indices are used that simplify and quantify its properties (Prasad *et al.*, 2017). However, in Cuba no studies have been reported that allow an indicator to evaluate the suitability of soils for rice cultivation.

In the province of Holguín, as a measure to confront climate change to increase food production, the East-West transfer is being developed in the municipality of Mayarí, which will benefit more than 2,000 hectares, mostly dedicated to rice cultivation, so access to water will be guaranteed. Given the extension of the available area and that, it mostly has Vertic soils, it is necessary to have an indicator to know the suitability of the lands in the region to extend this crop. Due to the above, the objective of the research is to introduce a quality indicator in a Vertisol dedicated to rice cultivation that later could be estimated by indirect methods like remote sensing or machine learning.

MATERIALS AND METHODS

The experimental area belongs to the Guatemala Agricultural Company, CCS Tomás Machado of the town of Cosme Herrera located at 20°44'54.601"N and 75°50'43.743"W of the Mayarí municipality in the Holguín province (Figure 1). In it, more than 100 hectares are dedicated to rice cultivation with the prospect of an increase to 2000 hectares due to the potential in this area for irrigation from the supply of water from the East-West Transfer for rice cultivation, as already indicated.

In the study area, according to data from the Guaro meteorological station, located at 20.96 meters above sea level at 20º40'21"N and 75º46'57" W in the municipality of Mayarí, the average annual precipitation is 1067.6 mm and the average annual temperature of 25.6 °C as reported by Villazón *et al.* (2021; 2023).

The characteristic soil of the area is of the chromic Vertisol type Hernández *et al.* (2015) with a slope < 2% so it can be considered flat. In the area of 100 ha, a systematic sampling was carried out at 100 georeferenced points with a GPS with an appreciation of 3 m, at a distance between points of 100 m. The samples were taken in the depth range between 0 to 0.20 m because this depth is where the highest content of radicles and roots of the rice crop is found, capable of absorbing water and the nutritional elements necessary for its growth and development. (Angladette *et al.*, 1969).

Experimentally determined soil properties

The soil properties that were evaluated are shown in Table 1. These properties indicated as important to evaluate the quality of soils, particularly for rice, were determined according to current Cuban standards in the National Network of Soil Laboratories.

Procedure for the determination of Soil Quality Index (SQI)

The SQI determined itself in three separated steps are described in the as Table 2.

The Kaiser-Meyer-Olkin (KMO) index was used to adapt the sampled values, indicating whether they are suitable for carrying out the factor analysis. Values greater than 0.50 indicate the suitability of the data for analysis.

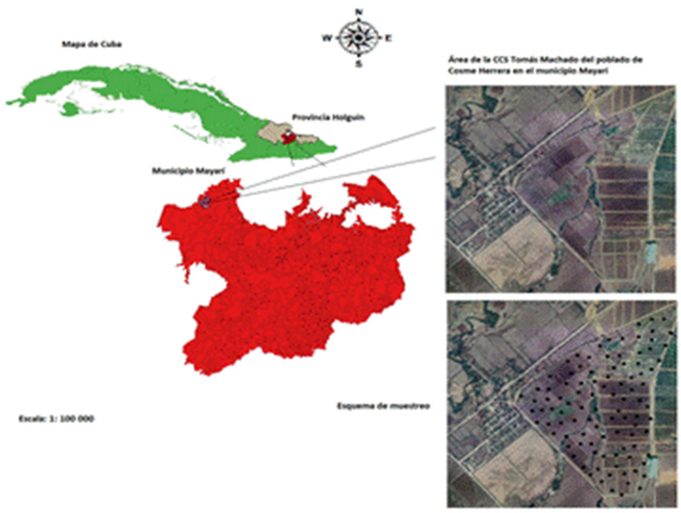

FIGURE 1. Location of the area where the research was carried out, belonging to the Tomás Machado CCS of the town of Cosme Herrera, Mayarí of the Holguín province, Cuba. Image taken from SAS PlanetNightly 200718.10081 (http://www.geojamal.com).

TABLE 1. Determined soil properties

No.	Name of soil property	Symbol	Unit	Analytic Technic
1	pH in water	pH $_{H2O}$	unit	(NC 2001.2015)
2	Assimilable phosphorus	P_2O_5	mg kg^{-1}	(NC 52.1999)
3	Assimilable potassium	K_2O	mg kg^{-1}	
4	Total nitrogen	Nt	%	(NC 11261: 2009)
5	Organic Matter	OM	%	(NC 1043.2014)
6	Calcium	Ca	cmol kg^{-1}	(NC 209:2002)
7	Assimilable magnesium	Mg	cmol kg^{-1}	(NC 209:2002)
8	Assimilable sodium	Na	cmol kg^{-1}	
9	Cation Exchange Capacity	CIC	cmol kg^{-1}	
10	Coarse sand	CS	%	(NC 11508: 2000)
11	Fine sand	FS		
12	Lime	L		
13	Clay	Clay		
14	Electric Conductivity	EC	dS m $^{-1}$	(NC 776: 2010)

*NC: Cuban standard

TABLE 2. Procedure for the SQI determination

No.	Procedure	Method	Description	Equations
1	Selection of the minimum data set (MDS)	Factor analysis	Reduce the number of soil properties. It also identifies the relationship between the variables and their influence on the investigated samples. The factor loadings represent the correlations between the original variables and the extracted factors. To simplify the results of the factor analysis and interpret them more clearly, the Varimax with Kaiser normalization rotation is used (Aiuppa *et al.*, 2003; Behera y Das, 2018).	
2	MDS Indicator Rating for	Standard Scoring Functions (SSF)	Used based on the importance of the soil property for crop development and growth. Each indicator was converted using SSF, normalized to a value between 0.1 and 1 depending on the characteristics of the soil indicators. Equation 1 was used when "lower is better" (LB) which expresses a lower value of The variable is required by the crop to a lesser extent the element or property of the soil. Equation 2 when "more is better" (MB) where a higher value of the variable is better and equation 3 was used when the range of the indicator is optimal (optimum, RO) (Nabiollahi *et al.*, 2017; Jiang *et al.*, 2020).	$SSF_2 = 0{,}1 + \frac{0.9*(x-L)}{(U-L)}$ $0{,}1,\ x < L$; $L \leq x \leq U$; $1{,}0,\ x > U$ (1) $SSF_3 = 0{,}1 + \frac{0.9*(x-L_1)}{(U_1-L_1)}$ $0{,}1,\ x(L_1,x)U_2$; $L_1 \leq x \leq U_1$ $SSF_3 = 0{,}1 + \frac{0.9*(U_2-x)}{(U_2-L_2)}$ $0{,}1,\ x(U_1,x)L_2$; $L_2 \leq x \leq U_2$ (2) $SSF_4 = 0{,}1 + \frac{0.9*(U-x)}{(U-L)}$ $0{,}1,\ x < L$; $L \leq x \leq U$; $1{,}0,\ x > U$ (3) Where x is the value of the soil indicator at a sampled point, U2 and L1 are the upper and lower critical values of the soil indicator, L2 and U1 are the left and right ends of the optimal range which represent the optimal levels and of indicator deficiency in the soil respectively (Yuan *et al.*, 2020).
3	Comparative soil quality index	Soil Quality Index	The indicator scores were integrated into a comparative soil quality index using a simple weighted additive approach (Andrews *et al.*, 2002).	$SQI = \sum_{1}^{n} Wi*Si$ Where: Wi is the weight of indicator i; If is the score of indicator i, which was calculated according to SSF; n is the MDS indicator number.

In addition, the Bartlett sphericity test is also used at a significance of $p < 0.05$, which complements ensuring the viability of the analysis (Mustafa, 2023). Variable loadings represent the weight of the variables on the factors. In general, variables with weights or loadings of 0.60 can be considered for the interpretation of the results, since they are significant for the evaluation of the components. The absolute value of the loading describes the influence of the variable and the principal component, the positive or negative sign shows the direction of the influence. Therefore, a high negative value represents that the factor is highly and negatively influenced by a variable (Lawrence & Upchurch, 1982).

Table 3 shows the upper to lower critical values of the soil for rice cultivation, according to (Guo *et al.*, 2018; Saleh *et al.*, 2021).

To classify the SQI obtained, the proposal by Dengiz (2020) formulated to determine the suitability of a soil for rice cultivation was used based on the analysis of its properties (Table 4).

After the SQI was determined, the soil properties that make up this indicator were taken to a database that contains the necessary information for each sampling point, that is, the value of the soil quality indicator, and were projected into the coordinates of the WGS system. 1984 UTM Zone 18 North in ArcGIS 10.5.

RESULTS AND DISCUSSION

Table 5 shows the results of the Kaiser-Meyer-Olkin (KMO) and Bartlett tests. The value obtained in the KMO test is 0.580, which indicates that the adequacy of the sample for the factor analysis is within the permissible limits to carry out a factor analysis. In the case of Bartlett's test of sphericity, it illustrates an approximate Chi-square value of 1419.299 with 91 degrees of freedom and a significance of 0.000 which indicates that the correlations between the variables are not all zero, which justifies the application of factor analysis. software.

In the study carried out by Mustafa (2023) on the use of soil properties for the development of a GIS of quality indicators, he reports KMO values of 0.78 and Bartlett's sphericity with 141.2, indicating a good suitability of the sample and justifying the use of factor analysis in the identification of key factors such as soil fertility and textural properties.

The communalities indicate the proportion of the variance of each variable that is explained by the common factors extracted (Table 6). In the case of potassium, it has a communality of 0.94 in potassium, which shows that after extraction, 94.0% of the variance of this variable is explained by common factors. This suggests that potassium is well represented in the factor model. A high proportion of communality estimates suggests that a large portion of the variance was explained by the factor; therefore, it would obtain greater preference over a low communality estimate (Shukla *et al.*, 2006).

In contrast, variables such as Coarse Sand, Fine Sand, Silt, and Clay have extremely low communalities after extraction (0.160; 0.026; 0.011; 0.013, respectively), indicating that these components are not well represented in the factor model. The low communality of these variables could be because the main factors extracted are not captured in the dimensions related to soil texture, or that these variables have a different structure in the specific context of the data.

TABLE 3. Upper and Lower critical values for soil in rice cultivation to (Guo *et al.*, 2018; Saleh *et al.*, 2021).

Soil propertie	Standard Scoring Functions	Critical lower value	Critical Major Value
Nt	MB	0,007	0.578
CE	LB	0.09	0.76
Ca	LB	18.2	154.7
OM (%)	MB	0.9	4.12
P_2O_5	MB	1.0	72.1
K_2O	MB	2.0	147.95
Mg	LB	50.0	250
Na	MB	0,1	3,0
pH	Optimum range	8.08	8.22
Clay	MB	12.8	64.9
Sand	LB	6.5	76.2

TABLE 4. Types of soil suitability for rice cultivation based on the analysis of its properties

Classes	Classification	SQI
I	Very low	< 0,40
II	Low	0.40-0.50
III	Moderate	0.50-0.65
IV	High	0.65-0.85
V	Very High	>0.85

TABLA 5. Kaiser-Meyer-Olkin and Bartlett sphericity tests

Kaiser-Meyer-Olkin	KMO	0.58
Bartlett sphericity	Chi-square	1419.29
	gl	91.0
	Significance	0.00

TABLA 6. Communality of the analyzed properties

Analyzed properties	Initial	Extraction
pH	0.50	0.43
P2O5	0.52	0.48
K2O	0.84	0.94
OM	0.63	0.60
Ca	0.87	0.96
Mg	0.85	0.74
Na	0.73	0.65
Coarse Sand	0.92	0.16
Fine Sand	0.99	0.02
Lime	0.99	0.01
Clay	0.99	0.01
EC	0.64	0.61
Nt	0.62	0.62
CIC	0.37	0.21

The initial eigenvalues and percentage of explained variance (Table 7) indicate the amount of variance that each factor explains. The first factor has an eigenvalue of 4.75, which represents 33.93% of the total variance. The second and third factors explain 17.10% and 14.25% of the variance, respectively. In total, the three factors explain 65.28% of the accumulated variance, which is a good result.

TABLE 7. Initial eigenvalues and percentage of variance

Factor	Total	% of variance	% cumulative
1	4.750	33.92	33.92
2	2.39	17.10	51.03
3	1.99	14.25	65.28

Mairura *et al.* (2007) obtained 68% of the variation in chemical and physical property data in four factors in determining soil quality indicators under different uses. The rotated factor matrix (Varimax) shows how the factor loadings are distributed after rotation, making interpretation easier.

Figure 2 shows the scree plot of the rotated factors that is used in the factor analysis to determine the appropriate number of axes or factors to retain by interpolating the eigenvalues. On the vertical axis and the number of factors on the horizontal axis, the results show that the eigenvalues, which represent the amount of variance explained by each factor, decrease as the factors increase, and that the first factors explain more variance, with eigenvalues of 4.75 for the first factor; 2.39 for the second factor and 2.0 for the third factor respectively, while as the factors increase, progressively less variability is explained.

As a trend, the point where an inflection takes place is selected to decide the number of axes to consider with a view to carrying out the analysis of major factors that affect the process (Méndez & Sepúlveda, 2012). In this research it seems to be in the transition from the second to the third factor, so the first two factors would be those selected with a view to being able to clearly appreciate the influence of the selected properties on the major factors that affect the process.

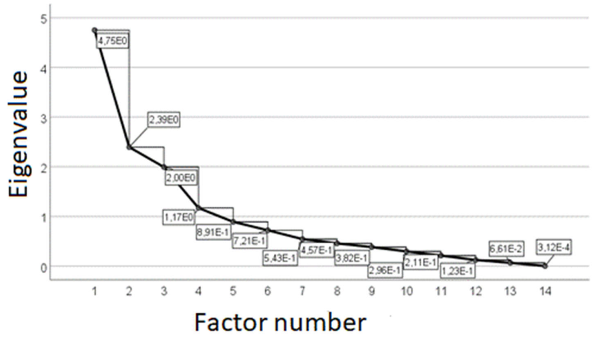

FIGURE 2. Scree plot of factors rotated by Varimax.

Table 8 shows the rotated factor matrix. Factor 1 explains the variables such as potassium (-0.96), organic matter (0.74), total nitrogen (0.78) has high loads, suggesting that in this factor these chemical properties are more correlated with each other. Factor 2 is made up of calcium (0.98) and magnesium (-0.85) with the highest loadings.

TABLE 8. Rotated factor matrix

Analyzed Properties	Factor 1	Factor 2
pH	**-0.65**	0.05
P_2O_5	**0.68**	0.12
K_2O	**-0.96**	-0.04
OM	**0.74**	-0.21
Ca	0.03	**0.98**
Mg	-0.11	**-0.85**
Na	**0.79**	0.11
Coarse Sand	-0.05	-0.39
Fine Sand	-0.14	0.08
Lime	0.10	-0.00
Clay	0.09	-0.06
EC	**0.74**	0.25
Nt	**0.78**	0.07
CIC	-0.29	0.35

Mairura *et al.* (2007) state that pH is one of the soil properties that most affects the development of crops and that in turn is used as an indicator of soil quality. On the other hand, they consider the role that organic matter plays in the availability of water for plants and to reduce the effects of soil degradation.

Ayoubi *et al.* (2011) in their research on the changes of quality indicators in different land uses due to the effect of soil degradation, based on a factor analysis and the communality values of the properties that explained the greatest proportion of the variance. , included sand content, soil organic matter, total nitrogen and seawater.

The properties with the greatest weight are the most representative indicators in the factor analysis and are used to determine the SQI taking into account the premise of taking values greater than 0.60, which coincides with what was proposed by Mustafa (2023). In this case the properties were: potassium (0.96), calcium (0.98), magnesium (0.855), sodium (0.799), total nitrogen (0.78), organic matter (0.74), electrical conductivity (0.743), phosphorus (0.68) and pH (0.65).

The graph of rotated factors (Figure 3) shows that for factor 1, which is the most important for extracting the greatest variability, once the Varimax rotation was carried out, they presented correlation values or positive loadings above 0.6, as is the case of phosphorus, organic matter, sodium, electrical conductivity and total nitrogen that appear forming a group on the right and positive part of the axis or factor 1, which suggests that increases in some of them induce increases in the same proportion the rest and vice versa.

They appear located on the left or negative part of the axis or factor 1, the variables negatively related to high loading values, this is the case of pH and potassium and indicates that increases in the soil of the positively related variables produce decreases in the negatively related variables. related. For the first factor, calcium and magnesium, coarse and fine sand, silt, clay, and cation exchange capacity do not seem to have important loads.

These results are a sign that factor or axis 1 seems to be more associated with soil fertility and nutrient concentration. Variables with a high load in absolute terms on this factor, such as phosphorus, organic matter, sodium, electrical conductivity, total nitrogen, pH and potassium, constitute indicators of the soil's capacity to support plant growth. Decreases in the pH values of this soil favor increases in nutrients such as phosphorus and nitrogen.

For factor two, with less importance than factor 1, to extract less variability, calcium with a positive charge and magnesium with a negative charge were important because they presented high loadings. With intermediate values for factor two were the cation exchange capacity positively and the coarse sand negatively the rest. The rest of the variables due to the value of their charge are not representative of the axis or factor two, which seems to be more related to the composition of cations such as calcium and magnesium, and suggests that a greater amount of coarse sand reduces the capacity cation exchange.

In the case of rice, the availability of nitrogen, phosphorus and potassium in the soil aligns with grain yield, while influencing plant architecture, which encompasses the number of panicles per unit area and the number of spikes per panicle (Perdomo *et al.*, 1983). EC and OM also contribute significantly to the development and growth of the crop (Coitiño *et al.*, 2015).

In the case of calcium and magnesium, both positioned in the same factor, in contrast they can be attributed to the different functions that these elements play in the soil. On the one hand, calcium actively participates in the formation of soil aggregates, contributing to the general structure of the soil. In contrast, magnesium has been found to reduce the percentage of stable aggregates and decreases the amount of clay that acts as a cementing agent in the soil. Furthermore, the presence of magnesium negatively affects the porosity of the aggregates (Villazón *et al.*, 2017).

Choudhury & Mandal (2021) have used the same soil quality indicators as part of their analysis of the minimum data set. These researchers have recognized the fundamental nature of this analytical approach in the field of precision agriculture, as it facilitates more efficient and targeted soil management practices.

The descriptive statistics of the values obtained in the determination of the SQI for the study area dedicated to rice cultivation are shown below. The calculated value for the SQI-MDS averaged 0.43, with minimum (0.27) and maximum (0.81) values recorded. Regarding the coefficient of variation, the observations showed low values because they were less than 40% (Table 9).

TABLE 9. Descriptive statistics of the values obtained in the determination of the SQI for the study area dedicated to rice cultivation

Soil Quality Indicator (SQI)	
Medium	0.43
Mínimum	0.27
Maximum	0.81
Variation coefficient (%)	35.99
Standard error	0.02
Standard deviation	0.16

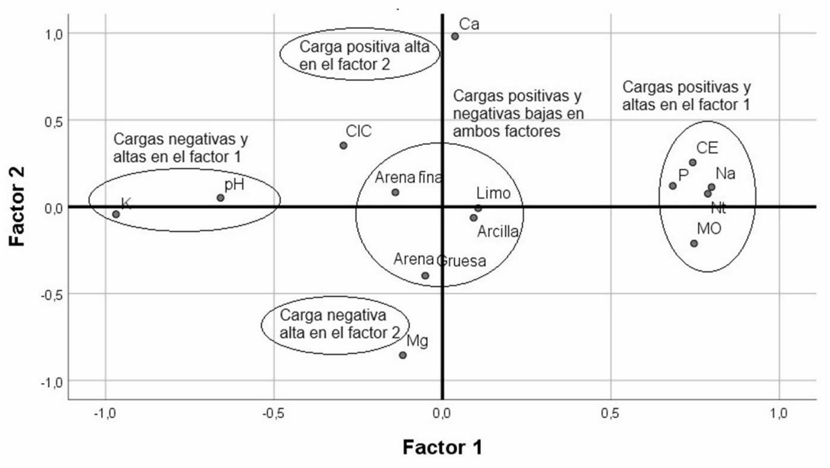

FIGURE 3. Factor plot in rotated factor space.

This result is in line with the results described by Guo *et al.* (2018), who observed a similar range of variation in their research, establishing a benchmark for classifying values that fall within the range of 7.0% > SQI ≥ 55.0%. These results serve to highlight the inherent variability in soil quality that exists in the study area, emphasizing the need for a comprehensive evaluation.

The indicators selected for the SQI-MDS through this tool allow an effective evaluation of soil quality in the study area. These indicators have also been used in other studies, which underlines their importance in precision agriculture (Buji *et al.*, 2022). The calculated SQI-MDS value, together with the observed coefficient of variation, serves to highlight the inherent variability in soil quality within the study area.

On the other hand, the spatial distribution of the soil quality index, which has been determined for evaluating rice cultivation, is illustrated within the specified study region using a minimalist approach to data analysis. Furthermore, this method used a reduced set of data points to obtain complete and reliable information on the soil quality index in a given area.

Figure 4 reveals that a significant part of the region shows a homogeneous characteristic in terms of soil suitability, specifically in the southern section with predominant values between 0.27 and 0.39 of SQI, which are classified as Very Low suitability for 69% of the total area. In the central zone of the area, the greatest variability of SQI values is reflected with classes between Low and Moderate (13% of the area) with an index that ranges from 0.45 to 0.61. Only in the North is there a High class zone, which represents 18% of the area under study. This difference in suitability could be attributed to anthropic action in the study area.

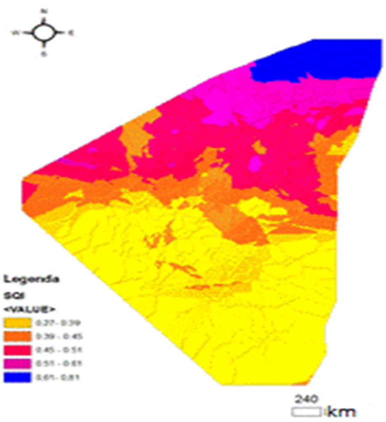

FIGURE 4. Spatial distribution of the SQI obtained for rice cultivation.

CONCLUSIONS

A method is described for obtaining a soil quality index (SQI) using the obtaining of the minimum necessary properties and their relative weights. More than 60% of the area appears with low quality for rice cultivation.

The determination of the soil quality indicator for rice cultivation showed that the most important properties in the study are total nitrogen, phosphorus, potassium, calcium, magnesium, sodium, organic matter and electrical conductivity. Each of the weights of the selected properties are greater than 0.60, which is why their use was superior to the rest of the determined properties

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