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Evaluation of Soil Quality and Health Index of Baghdad University Using Geomatics Techniques

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Abstract

The University of Baghdad campus in Jadriya was selected for this study. Jadriya forms a peninsula surrounded by the Tigris River on three sides and is located between longitudes 44.3721116 and 44.387067 East and latitudes 33.266582 and 33.266582 North, with an estimated area of 325 hectares. The study aimed to investigate the soil conditions in this area and assess the quality and health of these soils. Before collecting soil samples, field visits were made to identify surface sampling sites across the entire study area. Thirty surface samples were taken to a depth of 0.3 meters using an auger drill and geolocated using GPS. The GPS coordinates of the study area were also recorded. The samples were brought to the laboratory for analysis and specific measurements. These included physical soil properties such as: particle size distribution, bulk density, hydraulic conductivity, volumetric water content at field capacity, volumetric water content at permanent wilting point, and the difference between the two based on available water. And the chemical properties were electrical conductivity, soil reaction (pH), organic matter, and calcium carbonate. And the biological properties were plant canopy cover, soil respiration, and organic matter. Soil hydraulic conductivity was estimated, and soil respiration was measured in the field, as well as measuring the percentage of plant canopy cover. As for organic matter, it was included in both the chemical and biological properties.

The results indicated that the soil of the University of Baghdad is predominantly of medium texture and has a low bulk density, The salinity levels in the entire study area decreased significantly. Soil respiration was observed to be at a moderate to good level in the overall study region. The percentage of vegetation canopy cover exhibited a range from low to moderate levels, with some areas displaying higher coverage. The analysis revealed that the soil type was predominantly of the second kind, corresponding to a moderate soil health class, constituting 90% of the total. This was followed by the first, or poor, class at 10%, with the third, or good, class being entirely absent.

Keywords: Soil Physical; Soil Chemical; Soil Biological; Soil Quality; Soil Health

Introduction

All applied sciences, especially agriculture, are focused on conserving Earth's natural resources. Soil, as the bedrock of agriculture, is the most critical resource for food and health. Protecting soil aligns with sustainable development and ecological balance, while also improving soil quality and health to meet agricultural sustainability goals, Additionally, it expresses the soil's ability to perform functions within the ecosystem's boundaries during land use, aiming to preserve the ecosystem's quality and enhance its biological productivity. This is achieved through the soil's capacity to provide the necessary requirements for plant growth, sustainability, and increased productivity. As a result, preserving and improving soil quality through sound management practices has become a primary international goal [1-5]. Soil quality reflects the soil's capacity to function within an ecosystem during land use. By providing essential nutrients for plant growth and sustainability, soil quality is crucial for maintaining ecosystem health and boosting productivity. Therefore, preserving and enhancing soil quality through effective management practices has become a primary global objective [6-8]. GIS offers significant advantages for analyzing and assessing soil properties. By providing spatial and environmental data, GIS enables comprehensive analyses that support informed decision-making. This technology allows for the visualization of soil distribution, the analysis of spatial variations, and the identification of areas requiring specific interventions to improve soil quality and health. Additionally, GIS can be used to create detailed soil maps [9-13]. The University of Baghdad is a major university in Iraq with a large campus. This study aims to analyze the soil quality on this campus. By understanding the soil's condition, we can find ways to improve it and make the campus more environmentally friendly. This includes studying how human activities affect the soil and using geographic information systems to create maps of the soil. The goal is to provide recommendations for improving soil health and ensuring a sustainable campus. The study aims to achieve the following:

Determine the type and health of the soil at the University of Baghdad site. Analyze the physical, chemical, and biological properties of the university's soil to serve as an indicator of health and quality.

Map the quality and health of the University of Baghdad's soil using geographic information systems. Provide recommendations based on the results to improve soil quality and health and maintain a sustainable environment within the university.

Material and Methods

Study Area

The University of Baghdad (Al-Jadriya site) was selected as the study area because it is in a vital region. It borders the Tigris River and is fertile land that has historically been characterized by abundant agricultural production because of the constant water supply provided by the river. The University of Baghdad is also one of the largest and most important institutions in the heart of the capital, and its land use is diverse. This study is the first of its kind to assess the quality and health of the soil in this location, which has important vital characteristics. On the other hand, it is exposed to various activities that make the soil in the area susceptible to degradation in its quality and health. The importance of this study in this location is in line with global scientific trends aimed at combating desertification and addressing climate change, as well as the issue of food security, which is directly linked to soil quality and health. The University of Baghdad is located between longitudes 44.3721116 and 44.387067 East and latitudes 33.266582 and 33.266582 North. The area of the University of Baghdad in Al-Jadriya is about 325 hectares or 3.25 km^2. Figure 1 shows a map of Baghdad Governorate, indicating the location of the University of Baghdad in Al-Jadriya.

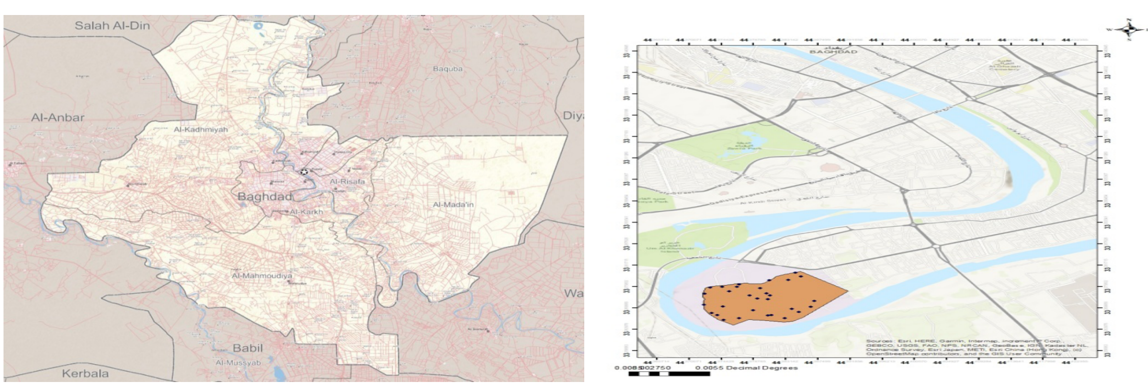


Figure 1: A map of Baghdad with the location and map of the University of Baghdad indicated on it.

Office and Field Procedures

Satellite imagery and geographic maps of the study area were utilized to isolate the location of the University of Baghdad in the Jadriya district. Subsequently, these data were employed within a Geographic Information System (GIS) environment using ArcGIS 10.8 to generate soil attribute maps (soil type and health). Prior to sample collection, a reconnaissance visit to the study area was conducted on October 22, 2023, to identify suitable locations for surface sampling. A total of 30 random, representative surface samples were collected from a depth of 0-0.3 meters using an auger drill. The GPS coordinates of each sampling location were recorded.

Soil Quality Indices and their Health

The soil quality index was calculated based on individual physical (soil texture, bulk density, saturated hydraulic conductivity and available water), chemical (EC, pH, $CaCO_3$ and OM) and biological (Vegetation, CO_2 and OM) properties, considering the measured values of these properties. Additionally, the interactions between physical, chemical, and biological properties were included. The measured property values were classified according to their quality based on globally accepted classifications for specific properties. New values were assigned to properties added in this study to calculate the soil quality index for physical, chemical, and biological properties, as well as their combined three interactions. The calculation method for the indices followed the formula adopted by the United States Department of Agriculture and Natural Resources, which is implemented in a Geographic Information System (GIS). The measured values of the attributes were classified according to their quality into categories, based on internationally accepted classifications for some attributes. Additionally, values were assigned to the attributes added in the current study for the purpose of calculating the soil quality index for physical, biological, and chemical attributes. This calculation was done using specific mathematical formulas, which are indicated by the following equations:

$$SQI_{physical} = (\text{Soil Texture} \times BD \times Ksat \times AW)^{1/4} \quad (1)$$
$$SQI_{chemical} = (EC \times pH \times CaCO_3 \times OM)^{1/4} \quad (2)$$
$$SQI_{biological} = (CO_2 \times OM \times \text{Canopy Cover})^{1/3} \quad (3)$$
$$SQI_{physical—chemical} = (\text{Soil Texture} \times BD \times Ksat \times AW \times EC \times pH \times CaCO_3 \times OM)^{1/8} \quad (4)$$
$$SQI_{physical-biological} = (\text{Soil Texture} \times BD \times Ksat \times AW \times CO_2 \times OM \times \text{Canopy Cover})^{1/7} \quad (5)$$
$$SQI_{Total} = (SQI_{physical} \times SQI_{chemica} \times SQI_{biological})^{1/3} \quad (6)$$

Spatial distribution maps of soil properties and a guide to soil quality and health

Spatial distribution maps of soil properties and a soil quality guide were using the Inverse Distance Weighting (IDW) method, which is used in map drawing in a Geographic Information Systems (GIS) environment, using ArcGIS Desktop 10.8 software according to ESRI [14].

Preliminary measurements and analyses of the field soil were carried out by taking soil samples at a depth of 0.00 - 0.30 m to study the physical, chemical and biological properties of the soil according to the methods mentioned in Black [15].

Results and Dissicussion

The mechanical analysis results of surface soil samples in the study area, as presented in Table 1, revealed a predominance of soils with a medium texture, accounting for 100% of the samples. Loam soil constituted 50% of the total, followed by silt loam soils at 20%. Sandy loam soils made up 16.66%, while clay loam and silty clay loam soils comprised 10% and 3.33%, respectively. All these soil types fall within the medium-textured category, although there are variations in the proportions of sand, silt, and clay components within each type. Figure 2 shows the spatial distribution map of soil content of clay, silt, and sand in the study area. It is observed that the dominant clay content in the soil is less than 200 g/kg, followed by the class between 200-250 g/kg. Next comes the class with clay content greater than 300 g/kg, and finally, the class between 200-250 g/kg. As for the silt fraction, the dominant class was found to be between 350-450 g/kg. This was followed by the class less than 350 g/kg, then the class between 450-550 g/kg, and finally the class greater than 550 g/kg. In the study area, the sand fraction classes showed dominance for the class between 300-500 g/kg with a significant percentage of 70%. This was followed by the class less than 300 g/kg with a percentage of 16.66%. Then came the classes greater than 700 g/kg and the class between 500-700 g/kg, with a percentage of 6.66% for each class.

The bulk density values of the soils in the study area ranged between 0.92 and 1.64 $\mu g/m^3$. The coefficient of variation for the bulk density of the soils in the study area was 14.57, which is relatively high. The reason for this high value is the variation in the proportions of soil separates, which were high as we showed in the presentation of the results of the distribution of soil separates. Figure 3 shows the spatial distribution of the bulk density property in the study area, which shows the appearance of four classes with values ranging from less than 1 to more than 1.37 $\mu g/m^3$. The class with values exceeding 1.37 $\mu g/m^3$ dominated, with a percentage of 40%. This class is considered the worst in terms of bulk density. It was followed by the class between 1.26 and 1.37 $\mu g/m^3$ with a percentage of 23.33%, then the class with values less than 1.12 $\mu g/m^3$ with a percentage of 20%, and finally the class between 1.12 and 1.26 $\mu g/m^3$ with a percentage of 16.66%. The available water content in the soils of the study area ranged between (0.101 – 0.64)

cm^3 cm^{-3} as shown in table (4). The coefficient of variation reached 12.88, and this variation is due to the variation in soil textures in the study area, which is of a medium nature. Figure 4 shows the spatial distribution map of the available water content in the soils of the study area, which recorded the appearance of four classes. The class greater than 0.14 cm^3 cm^{-3} was the most dominant with a percentage of 30%, followed by the class between 0.12 – 0.13 cm^3 cm^{-3} with a percentage of 26.66, then the classes between 0.13 – 0.14 cm^3 cm^{-3} and less than 0.12 cm^3 cm^{-3} with a percentage of 16.66 each. The values of available water in the soil are due to the clay content of the soil, as this content increases with increasing clay content and vice versa. Table 1 presents the hydraulic conductivity values for the soils in the study area, which ranged between 0.28 and 1.81 cm/hour. The coefficient variation for this property was very high, reaching 57.31, due to several factors, most notably the soil texture, its content of different soil separates, and the nature of land use. Figure 5 shows the spatial distribution map of the hydraulic conductivity values for the soils in the study area. The class was less than 0.5 cm/hour and the class between 0.5 and 1.00 cm/hour dominated, each with a percentage of 33.33%. This was followed by the class greater than 1.2 cm/hour with a percentage of 23.33%, and finally, the class between 1.00 and 1.2 cm/hour with a percentage of 10% of the soils in the study area [16,17].

NO	Sand	Clay	Silt	Texture	BD	AW	Ksat
	g kg^{-1} soil				µg m^{-3}	cm3 cm-3	cm h^{-1}
1	180	380	440	SiCL	1.12	0.155	0.47
2	430	220	350	L	0.946	0.146	0.77
3	390	180	430	L	1.22	0.149	0.81
4	750	120	130	SL	1.59	0.111	1.62
5	710	110	180	SL	1.24	0.107	1.64
6	400	170	430	L	1.03	0.132	0.83
7	305	180	515	SiL	1.01	0.164	1.32
8	310	220	470	L	0.92	0.152	1.16
9	270	210	520	SiL	0.94	0.162	0.934
10	260	140	600	SiL	1.34	0.156	1.75
11	350	365	285	CL	1.64	0.127	0.31
12	470	220	310	L	1.34	0.147	0.764
13	625	125	250	SL	1.57	0.121	1.76
14	385	215	400	L	1.41	0.125	1.02
15	785	95	120	SL	1.44	0.101	1.81
16	395	260	345	L	1.34	0.128	0.62
17	460	195	345	L	1.55	0.11	0.46
18	515	170	315	SL	1.51	0.12	1.24
19	360	240	400	L	1.42	0.136	0.67
20	120	165	715	SiL	1.41	0.111	0.34
21	385	215	400	L	1.42	0.123	1.02
22	430	220	350	L	1.25	0.144	0.52
23	375	160	465	L	1.28	0.138	0.48
24	360	170	470	L	1.32	0.146	0.54
25	420	130	450	L	1.42	0.138	0.46
26	330	310	360	CL	1.34	0.122	0.34
27	290	340	370	CL	1.24	0.126	0.28
28	385	210	405	L	1.38	0.164	0.62
29	370	130	500	SiL	1.32	0.136	0.36
30	395	100	505	SiL	1.24	0.142	0.28

Table 1: Physical properties of the soil of the study area.

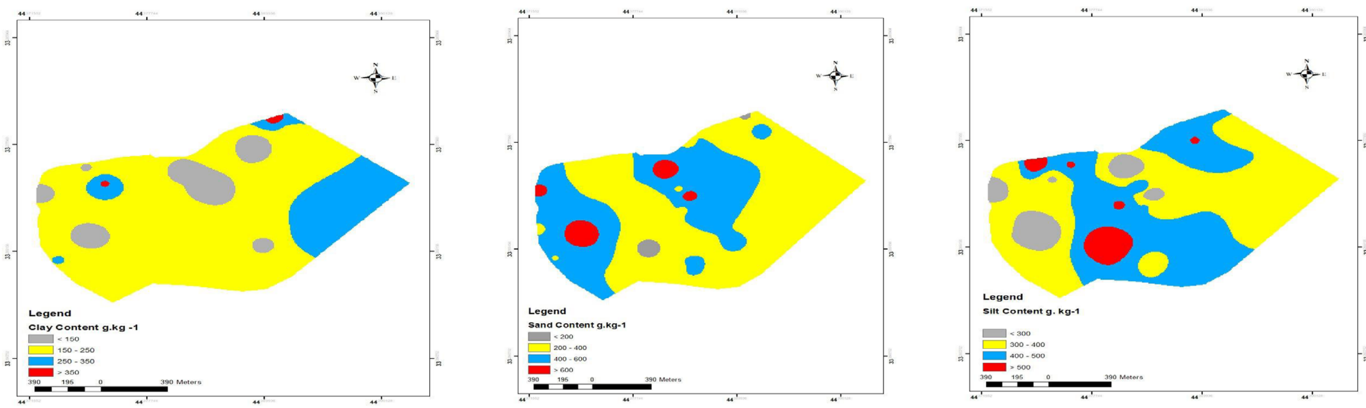
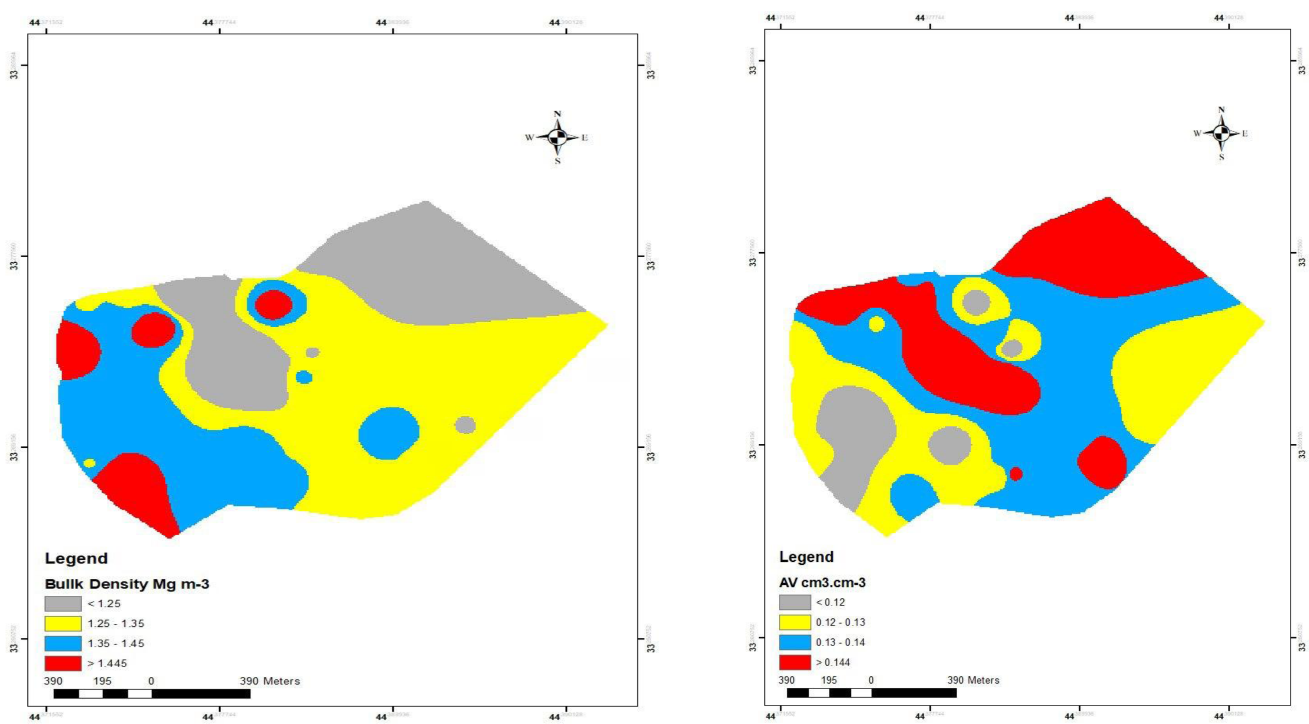


Figure 2: The spatial distribution map of soil content of clay, silt, and sand in the study area.

Table 2 shows the values of the chemical properties of the soils in the study area. The ranges of electrical conductivity values for the saturated soil paste extract showed a narrow range between the maximum and minimum values. The values ranged between 3.25-8.45 dS m^{-1}. Figure 6 shows the spatial distribution of electrical conductivity values, and it is observed that the class of 4-6 dS m^{-1} predominates, representing 43.33% of the total study area. This was followed by the class between 6-8 dS m^{-1} with a percentage of 30%. It is worth noting that although this class falls between 6-8 dS m^{-1}, all its values were within the range of 6 dS m^{-1}. This was followed by the class less than 4 dS m^{-1} with a percentage of 23.33%, and finally, the class greater than 8 dS m^{-1} with a percentage of 3.33% of the total study area.



Figures 3 & 4: The spatial distribution of the & The spatial distribution map of Bulk density in the study area. the available water content in the soils of the study area.

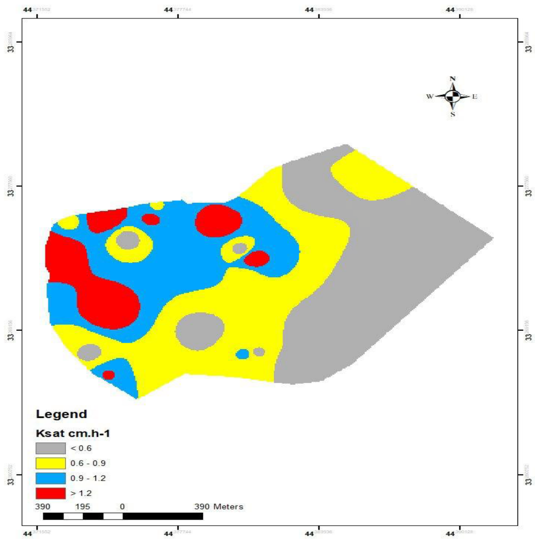


Figure 5: The spatial distribution map of the hydraulic conductivity for the soils in the study area.

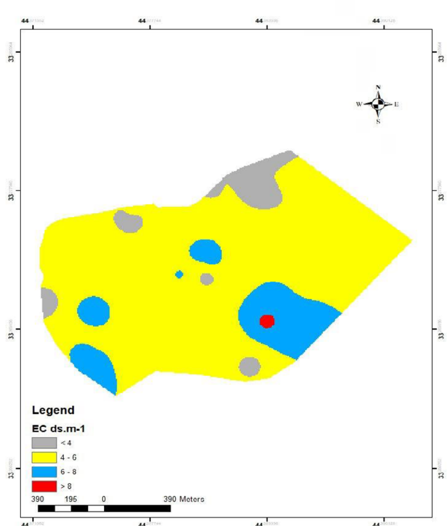
NO.	EC	pH	OM	CaCO3
	dS m-1		g kg-1 soil	
1	4	7	8.4	226
2	5	7	8.7	235
3	4	8	10	238
4	6	8	8.5	223
5	6	8	8.3	235
6	4	7	10	245
7	3	8	10	236
8	4	8	9.2	235
9	6	8	6.4	255
10	4	8	9.3	225
11	5	8	7.1	254
12	5	8	9.3	245
13	5	8	9.2	255
14	3	8	10	245
15	7	8	12	245
16	4	8	10	225
17	7	8	8.3	255
18	7	8	7.1	235
19	6	8	8.5	235
20	5	8	8.1	225
21	5	8	9.3	245
22	4	8	7.6	255
23	4	7	6.9	246
24	6	8	7.6	265
25	9	8	9.5	245
26	4	8	7.7	225

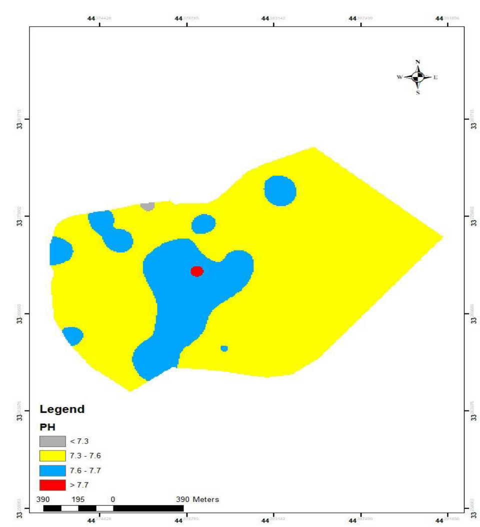
27	7	7	7.9	255
28	4	8	9.5	238
29	7	8	8.5	285
30	4	8	11	225

Table 2: Chemical properties of the soil of the study area.

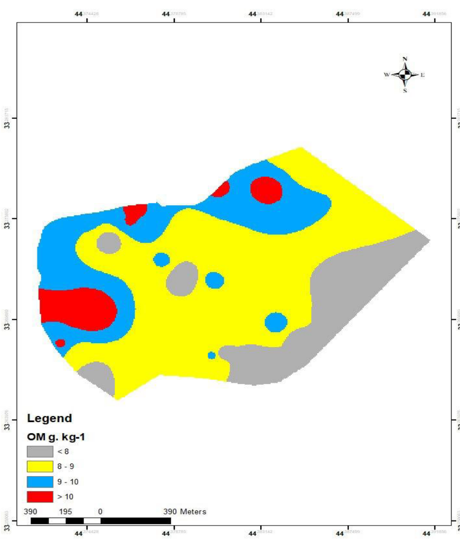
Table 2 indicates that the soil pH values in the study area ranged between 7.23 and 7.72. The coefficient of variation for soil pH was 1.5, a low value suggesting that this property remains within the normal range or typical limits of soil pH for calcareous soils. This is due to the availability of calcium compounds that continuously supply the soil solution with bases, the most important of which is calcium carbonate. Figure 7 shows the spatial distribution of soil pH in the study area. It shows that there were four classes, with the class between 7.3 and 7.6 being the most dominant at 53.33%, followed by the class between 7.6 and 7.7 at 40%. The classes below 7.2 and above 7.7 were the least common, each representing 3.33%. Table 2 presents the organic matter content values of the study area soil. These values ranged from 6.43 to 11.55 g/kg, with a coefficient of variation of 13.9. It is observed that the range of soil organic matter content remained within narrow limits and did not exhibit wide variations, which is attributed to the homogeneity of other soil properties, including electrical conductivity values, whose ranges were like those of organic matter, as well as the nature of land use. Figure 8 shows the spatial distribution map of organic matter content of soil in the study area. Four classes were recorded, with the two classes of less than 8 g/kg and between 8-9 g/kg being the most dominant, each representing 26.66%. This was followed by the classes between 9-10 g/kg and greater than 10 g/kg, each representing 23.33%. Figure 9 shows a spatial distribution map of the calcium carbonate content in the soil of the study area. Four classes were recorded, with the class ranging between 225-250 g kg^{-1} being the most dominant, accounting for 70%. This was followed by the class between 250-275 g kg^{-1}, representing 23.33%. The classes below 225 g kg^{-1} and above 275 g kg^{-1} were the least common, each accounting for only 3.33%.

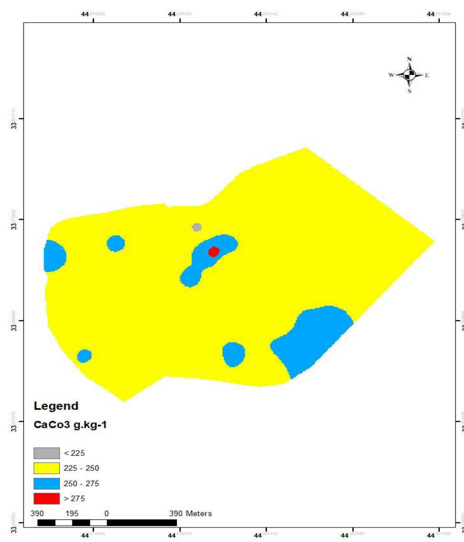
Table 3 presents the soil respiration values or CO_2 concentrations in the soil as recorded by a CDM device for the study area. These values ranged between 234 and 865 parts per million (ppm). The coefficient of variation was 25.74, which is considered a low value when compared to the wide range between the minimum and maximum values. This can be attributed to the dominance of certain classes. As shown in Figure 10, which represents the spatial distribution map of soil respiration in the study area, the class ranging between 400-600 ppm was the most dominant, accounting for 66.66% of the total study area. This was followed by the class at less than 400 ppm and the class between 600-800 ppm, with both accounting for 13.33% of the total area. Finally, the class greater than 800 ppm accounted for 6.66% of the total study area.





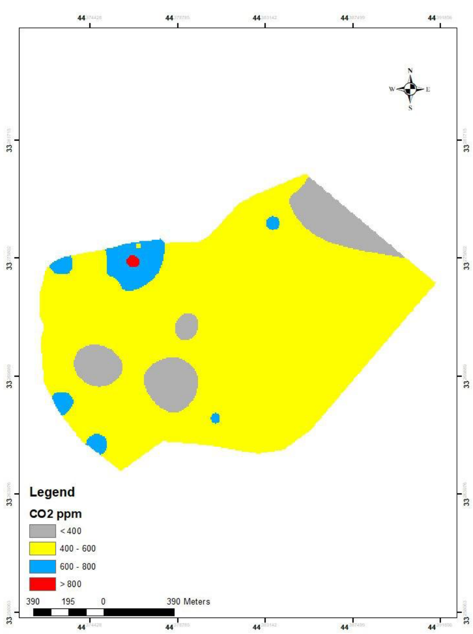
Figures 6 & 7: The spatial distribution of the & The spatial distribution of the map of EC in the study area. the pH in the soils of the study area.

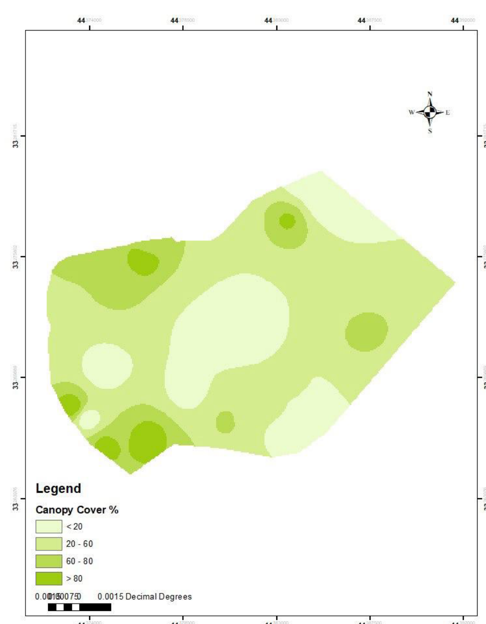




Figures 8 & 9: The spatial distribution of the & The spatial distribution map of OM in the study area. the $CaCO_3$in the soils of the study area.

The variation in vegetation cover (canopy cover) reflects the diversity of the study area. Some areas have high vegetation cover, while others lack such cover to the point of complete absence (0%). Figure 11 shows the spatial distribution of the vegetation cover attribute in the study area. It is clear from the figure that there are four classes, with the class between 20-60% dominating the study area with a percentage of 46.66%. This is followed by the class below 20% with a percentage of 36.66%, then the class between 60-80% with a percentage of 10%, and finally the class above 80% with a percentage of 6.66%.





Figures 10 & 11: The spatial distribution of the & The spatial distribution map of CO_2 in the study area. the canopy cover in the soils of the study area.

NO.	OM	CO2	Canopy Cover
	g kg-1 soil	ppm	%
1	8.41	447	0.16
2	8.71	250	0
3	10.16	480	20
4	8.54	490	40
5	8.34	432	8.1
6	10.34	593	40.5
7	10.11	865	87.21
8	9.21	463	20.2
9	6.43	332	10
10	9.28	545	40.1
11	7.11	592	47.5
12	9.34	626	51
13	9.23	445	20.23
14	10.23	428	28
15	11.55	285	0.02
16	10.11	685	80
17	8.25	426	0.22
18	7.11	625	67
19	8.54	575	72
20	8.12	234	7.19
21	9.25	615	47
22	7.55	565	33
23	6.87	475	15
24	7.58	495	5
25	9.45	515	25
26	7.65	435	45
27	7.855	425	28
28	9.45	525	11
29	8.48	505	9
30	10.45	615	65

Table 3: Biological properties of the soil of the study area.

Figure 12 presents a spatial distribution map of soil quality and physical health in the study area. The map demonstrates the dominance of the second soil quality class, which corresponds to the 'moderate' category in the soil health classification. This category constitutes 83.33% of the total study area. Following this, the first soil quality class, corresponding to the 'poor' category in soil health classification, accounted for 13.33%. The third soil quality class, corresponding to the 'good' category in soil health, ranked last with a proportion of 3.33% of the total study area. The soil quality guide for chemical properties has recorded a dominance of the second class, which corresponds to the moderate class in the soil health guide. Neither the first nor the third classes were observed throughout the study area.

Figure 13 illustrates the spatial distribution map of the soil quality guide for chemical properties and their health. The study found that the selected biological indicators (soil respiration, organic matter, and vegetation cover) did not show any soils in the highest quality class. Most soils fell into either the moderate or poor/very poor-quality classes, with each accounting for about 50% of the total.

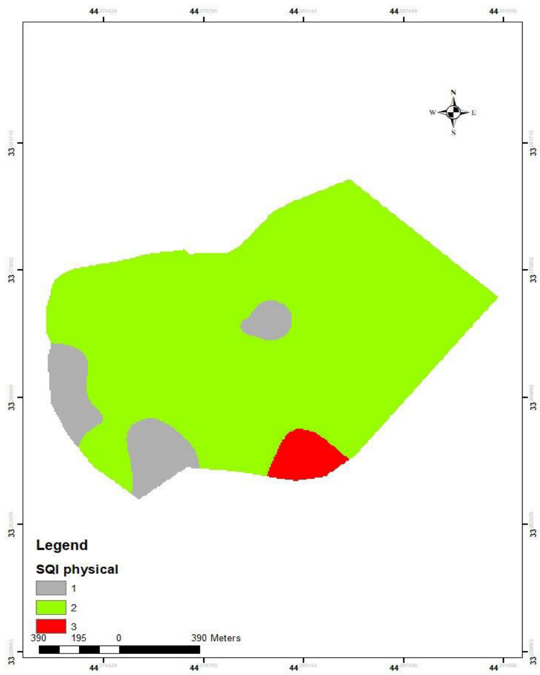
Figure 14 shows the overall quality and health index of the study area soils, resulting from the combined physical, chemical, and biological properties selected in this study. The second soil quality class, corresponding to the moderate health class, was dominant and represented 90% of the area. This was followed by the first soil quality class, which corresponds to the poor health class, with a proportion of 10%. The third or good class of soil quality and overall health was not recorded in the study area.

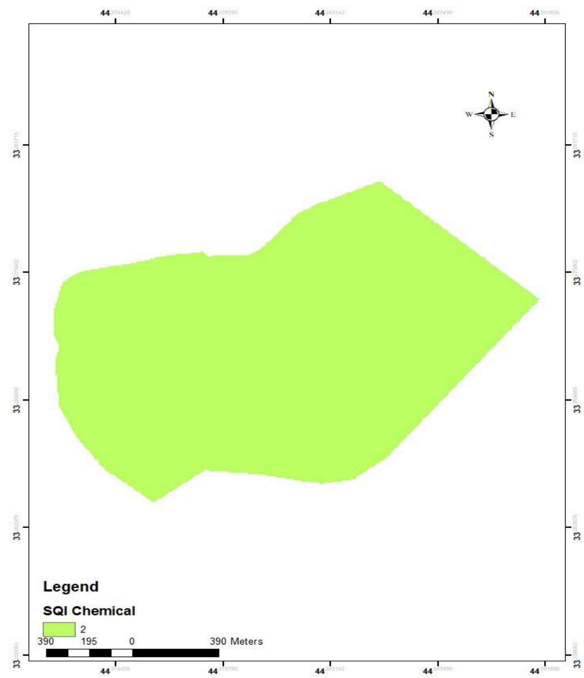
Figure 15 illustrates the spatial distribution of soil type and health indicators resulting from the interaction between physical and chemical properties. The second soil type category, corresponding to a moderate or medium-sized soil health class, accounted for 80% of the study area.

This was followed by the first soil type category, which corresponds to the poor soil health class, with a proportion of 13.33%. Finally, the third soil type category, corresponding to the good soil health class, accounted for 3.33%. The recorded quality indicators were confined to the first and second classes, with the first class being the dominant one.

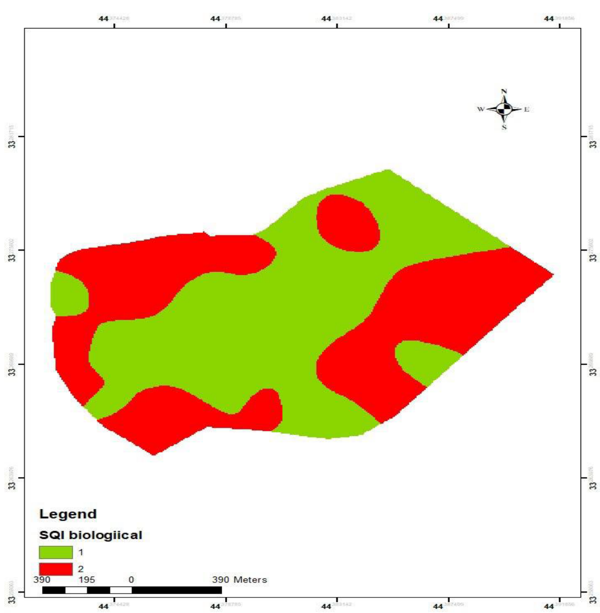
This corresponds to poor soil health, accounting for 56.66% of the total. The second class followed, corresponding to a moderate level of soil health, with a percentage of 43.33%. The third or good class was not recorded in the study area due to the interaction between physical and biological properties (Figure 16).

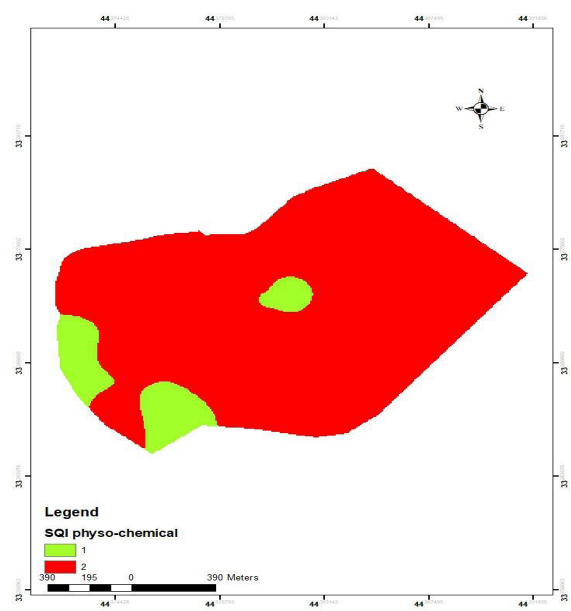
Figure 17 illustrates the overall soil quality and health index of the study area, as derived from the combined physical, chemical, and biological properties examined in this study, the study area was dominated by soils of moderate quality (90%), followed by poor quality soils (10%). No soil was classified as good [18-22].



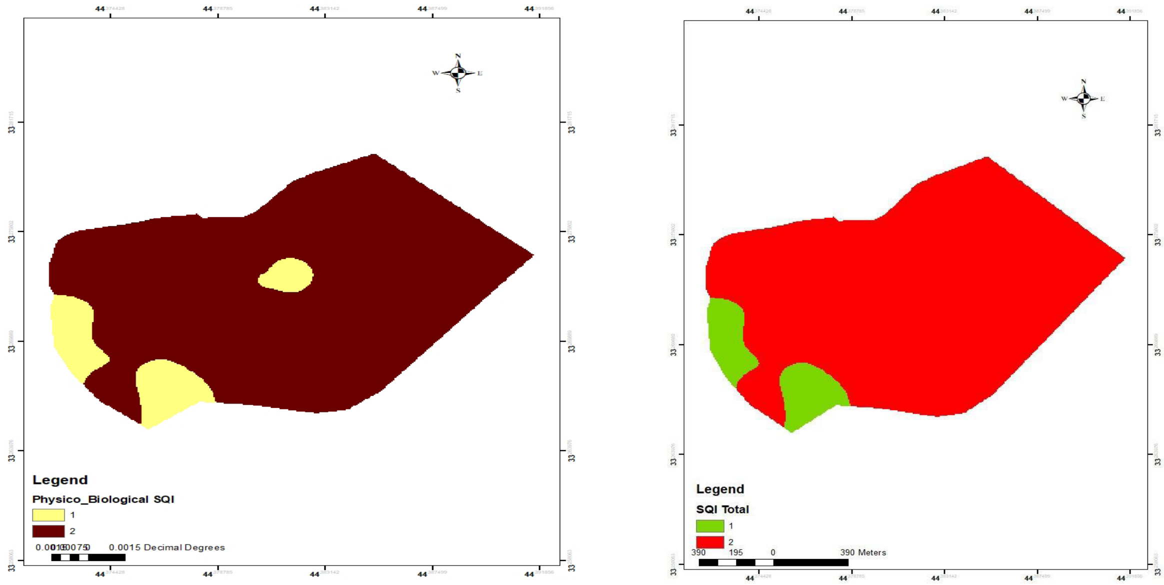


Figures 12 & 13: The spatial distribution of the & The spatial distribution map of SQI physical in the study area. the SQI chemical in the soils of the study area.





Figures 14 & 15: The spatial distribution of the & The spatial distribution map of SQI biology in the study area. the SQI physiochemical in the soils of the study area.



Figures 16 & 17: The spatial distribution of the & The spatial distribution map of SQI physio-biology in the study area. the SQI total in the soils of the study area.

Recommendations

The study revealed that the dominant soil type is the second category, corresponding to the moderate class in the soil health guideline. Due to the university's limited size, it is necessary to implement effective policies to enhance the soil type to the third (good) category by focusing on the attributes that showed reduced levels. Prioritizing the expansion of shaded plant cover across all vacant university land, as well as Implementing essential administrative measures to safeguard soil quality and health as a component of environmental stewardship.

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