Studying the Effects of Contamination on Soil Properties Using Remote Sensing

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ABSTRACT

The problem of soil contamination is increased recently due to increasing the industrial wastes such as petroleum hydrocarbon, organic solvents, and heavy metals as well as maximizing the use of agricultural fertilizers. During this period, wide development of data collection methods, using remote sensing techniques in the field of soil and environment applications appear and state the suitable technique for remediation. This study deals with the application of remote sensing techniques in geoenvironmental engineering through a field spectral reflectance measurements at nine spots of naturally hydrocarbons contaminated soil in Al-Daura Refinery Company site which is located to the south west of Baghdad using radiometer device to get standard curves of wavelengths and analyzing the satellite imagery of the site to get the spectral reflectance curves using GIS technique and EARDAS software package which help in producing thematic maps for the spatial distribution and concentration of contaminants. The comparison of results showed a good correlation between the spectral reflectance from field measurements and the spectral reflectance obtained from analyzing the satellite imagery. The study also improves a method to save cost, time, efforts and staff.

Key Words: contaminated soil, remote sensing, spectral reflectance and geoenvironmental engineering.

دراسة تأثير التلوث على خواص التربة بأستخدام طرق التحسس النائي والاستشعار عن بعد

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الخلاصة

ان مشكلة التلوث ازدادت بالوقت الحاضر نتيجة لزيادة المخلفات الصناعية بانواعها, النفطية, المذيبات العضوية, المعادن الثقيلة وكذلك الافراط في استخدام الاسمدة الزراعية. وبعد التطور الواسع, ظهر الاعتماد على طرق جمع البيانات الارضية والتطبيقات البيئية للاستشعار عن بعد في حقول هندسة مكيانيك التربة والبيئة لتحديد مقدار الضرر الناتج من وجود هذه الملوثات على التربة وتحديد طرق المعالجة المناسبة. هذه الدراسة تتعامل تستخدم تقنيات التحسس النائي والاستشعار عن بعد في هندسة التربة الملوثة وذلك من خلال قياس الانعكاسية الطيفية موقعيا لتسعة نقاط من التربة الملوثة طبيعيا بالهيدروكاربونات والرصاص في مصفى الدورة الواقع الى الجنوب الغربي من بغداد باستخدام جهاز الراديوميتر وتحليل الصورة الفضائية للموقع لغرض الحصول على منحيات الانعكاسية الطيفية باستخدام تقنيات نظم المعلومات الجغرافية واستخدام برنامج EARDAS. ربطت النتائج التي تم الحصول عليها من الراديوميتر مع النتائج التي تم الحصول عليها من الحقيبة البرامجية 10 EARDAS , وبينت النتائج وجود ربط جيد بين منحنيات قياس الانعكاسية الطيفية بالموقع والصورة الفضائية والذي بدوره يوفر في الجهد والكلفة والوقت اللازم لدراسة مشاكل تلوث التربة.

1. INTRODUCTION

The rapid growth of industrialization and urbanization has resulted in large quantities of waste gas, waste water, and waste solid being discharged into the environment, thus giving rise to serious environmental pollution problem. The occurrences of contaminants in soil above a certain level causing deterioration or loss some of geotechnical properties of soil , **Huang, 2000**. The most common soil contaminants are petroleum hydrocarbons, fertilizers and pesticides, and heavy metals. Iraq has several thousand contaminated sites resulting from a combination of general industrial activities, military activities and post-conflict damage and looting, **UNEP Report, 2005.**

The great demand for information about properties of surface and sub-surface soil which can be estimated by using spectral responses of surface soil for different bands of radiometer and short time available for the work arises to employ remote sensing techniques in geotechnical engineering which reduce the time, cost, efforts, and staff.

Yousif, 2004, used the remote sensing techniques to classify the soil of Al-Najaf city by comparing the results obtained from remote sensing techniques with those obtained from traditional classification method. **Al-Maliky, 2005.** constructed maps explained the zones of distributions and concentrations of pollutants in air, water and soil depending on an integrated measured and collected data base utilizing from GIS and Arcview software. **Carr et al. 2006,** used PXRF metal analyzer to obtain rabid in-situ elemental analysis for urban soil to produce a spatial maps for the distribution of contaminants in soil. **Nasir , 2008,** used the surface geoelectrical sounding data and remote sensing techniques in the evaluation of geotechnical properties of soil, the results of this study were five contour maps and digital geotechnical maps, as well as five geoelectrical sections to study the soil profile. **Wu et al., 2009,** studied the sensitivity of near-infrared diffuse reflectance sensing (NIRS) to trace metal concentration in (25) soil samples of silt loam soil. Detailed analysis indicates that the NIR spectrum is sensitive to sample handling, including the orientation of the samples in the NIRS instrument.

The purpose of the present work is to measure the reflectance ratio for nine naturally contaminated soil samples designated N1 to N9 by using three bands radiometer and compare with those data obtained from satellite image analysis using Arch GIS and ERDAS10 software.

2. EXPERIMENTAL WORK

2.1. Study Area

The study area is Al-Daura refinery company site which is located at Al-Daura district in the south-west of Baghdad governorate. Nine spots are selected in this site according to the advice of environmental staff in the Midland Refineries Company/Daura Refinery Company as well as the natural ground surface color. The soil profile of site is formed of top layer of very stiff to hard cohesive material about (8m) thick, overlying cohesion less layer of dense silty sand (6 to 8) m thick. The third layer at a depth of 16 m from ground surface consists of hard brown clayey silt. Groundwater table varied from (1.45 to 2.85) m below the ground surface (NCCL Report) as cited by , **Abdul Rasool , 1999**. Disturbed soil samples were obtained from ground surface to a depth of 15cm for chemical test and particle size analysis.

2.2. GPS Measurements

Soil samples location from the study area are determined by using global positioning system (GPS) receiver. The spatial position of target can be determined by the GPS receiver for soil samples location which are located on topographic map using the Universal Transverse Mercator (UTM) system which is a global spatial system based on the transverse Mercator projection , **Clarke, 1997**. The coordinates of position are referred to as Easting and Northing, being distances East and North of an origin. They usually expressed in meters. Under the UTM system, each East and North coordinate pair can refer to one of sixty points on Earth, one point in each of the sixty zones (World Geodetic System, WGS 84). The geo-referencing data of these locations are listed in **Table 1**. and the locations of these points are specified on the satellite imagery as shown in **Plate 1.**

2.3. Chemical Tests

The hydrocarbons and lead content of soil samples are determined in Ibn Sina State Company to measure the effects of hydrocarbons and lead on the reflectance ratio. The results of tests are given in **Table 2**.

2.4. Particle Size Analysis

The soil samples are collected from the surface layer of Al-Daura site to determine the particle-size distribution according to ASTM (D422). The results of particle size distributions are given in **Table 3.**

3. SPECTRAL REFLECTANCE MEASUREMENT

3.1 Radiometer

Radiometer is a device used for measuring the spectral reflectance of an object as a function of wavelength. It is used to measure the reflectance for different targets, which is reflected, scattered, transmitted, or emitted by an object , **Joseph and Simonett, 1976**. Any earth target receives solar radiation directly (irradiance E) by unit (Watt/m^2), otherwise, reflectance radiation from the same target (radiance L), with same unit radiometer records. This radiation as electrical signal must be transferred to radiation (Watt/m^2) by using the following equation:

$$L=C_1V_1 \tag{1}$$

where

C_1: constant transfer factor for each spectral band, each constant has two values: the first is used for radiance radiation and the second is used for the irradiance radiation.

V_1: electromagnetic radiation that is recorded by radiometer, similarly, the irradiance radiation (E) is given by:

$$E= C_2V_2 \tag{2}$$

In the present study, the radiometer (EXOTH, 1000BX) with three filters of spectral reflectance bands ranged from (0.45 to 0.7) micrometer as given in **Table 4** has been used to measure the intensity of the reflected waves that come from the soil in vertical direction. The measurements of radiometer are unit less and can be expressed as percentage between the reflectance of falling waves from the sun and their reflected intensity from the soil , **Manual of Radiometer, 1983**.

The spectral reflectance of soils can be useful in their identification and characterization. The reflectance data from carefully selected wavelength bands radiometer can be used to extract information from bare soil areas that can be related to levels of organic matter, soil moisture, iron oxide content, particle size content, or used as an indicator of potential productivity such as: cation exchangeable capacity (CEC) for certain specified climatic areas. The soil contrast is often found in the wavelength interval from 0.6 to 0.7 µm , **Colwell, 1983**.

3.2 Conditions of Test

To use the radiometer device in measuring the reflectance ratio of surface soil, the following conditions must be satisfied:-

i. The target sample should be well represented to region in order to get more occurrences in measurement;

ii. Readings should be taken for several points closed from the target in the same soil specimen and calculate their average for more occurrences;

iii. The radiometer should be fixed on the target in order to get constant distance between the radiometer and soil sample surface. That is required to ensure no movement of the radiometer during reflectance testing;

iv. All readings are carried out in a sunny weather.

The spectral reflectance measurements of soil samples are carried out at the day time between 10 and 12 am in order to minimize the effect of the angle of in chiding from the sun.

3.3 Procedures of Test

The procedure of spectral reflectance test can be summarized as follows:-

i. The test is conducted on the surface of natural soil at the field;
ii. The radiometer is applied to the sunlight direction and recorded the reading;
iii. The radiometer is applied vertically above the target by a vertical distance of 15cm;
iv. The reflectance is read and recorded.

3.4 Spectral Reflectance Analysis

The properties of soils that govern their spectral reflectance are color, texture, structure and surface roughness, particle size, mineralogy, organic matter, free carbonates, salinity, moisture and the oxides/hydroxides of iron and manganese, emissivity, polarizing properties and soil normalization. Also, the chemical composition of the soil influences spectral signature of soils through the absorption processes , **Manchanda et al., 2002.**

Radiometer capacity to measure the visible adds a valuable dimension to the use of soil spectra to explain many soil characteristics and to predict soil response to different contaminations, management, and variations in climate , **Colwell, 1983**. Soils can often be distinguished by their photographic tone and/or color characteristics factors which depend on the properties of soil materials themselves.

Also, electromagnetic, radiation can be sensed by detectors that respond in spectral regions beyond those discernible by human eye , **Colwell, 1983**. In order to use remote sensing techniques to produce thematic map explain the zoning of soil contaminants distribution, it's necessary to understand the relationship between soil properties and soil color. The most important factors influencing soil color are mineralogy, chemical composition, moisture content and organic matter content.

4. SATELLITE IMAGE PROCESSING AND ANALYZING

The processing and analysis of satellite imagery can be summarized by the following procedure:

i. Geo-referencing Spatial Data

Geo-referencing is the conversion of spatial information from an existing format (collected data and tested samples) in to a digital format and data structure compatible with a GIS. Geo-referenced data to be encoded include hard copy paper maps and tables of attributes electron files of maps and associated attribute data, scanned aerial photographs and digital satellite remotely sensed data (form GPS device). The traditional digitizing of points is based on the use of Cartesian coordinates such as UTM coordinates , **Jensen, 1996**.

ii. Analyzing Spatial Data

The satellite image for AL-Daura site is analyzed by using software (EARDAS 10) to get the reflectance of geo-referenced data (soil samples locations) depending on the results of radiometer measurements for soil samples in the field. Data not in image form are difficult to reduce or associate with specific ground elements unless simultaneous bore-sighted photography is available.

iii. Classification Process

Multispectral classification is the process of sorting pixels into a finite number of individual classes, or categories of data, based on their data file values. If a pixel satisfies a certain set of criteria, the pixel will be assigned to the class that corresponds to that criterion. This process is also referred to as image segmentation. Depending on the type of information, extracted from the original data, classes can be associated with known features on the ground or can simply represent areas that look different to the computer.

The classification process breaks down into two parts: supervised and unsupervised. In supervised classification the analyst designates a set of “training areas” in the image, each of which is a known surface material that represents a desired spectral class. The classification algorithm computes, the average spectral pattern for each training class, and then assigns the remaining image cells to the most similar class. In unsupervised classification the algorithm derives its own set of spectral classes from an arbitrary sample of the image cells before making the class assignments , **ERDAS Field Guide™, 2008.**

iv. Organization Spatial Data

The organization of spatial data component includes those functions needs to store and retrieve data from the data base. The methods used to implement these functions determine how efficiently the system performs all operations on the data; each variable is archived in a computer-compatible digital format as a geographically referenced plane (often called a GIS layer). Each layer contains features with similar attributes, like type of pollutant and concentration of pollutant that are located in the same geographic extent , **Jensen, 1996**.

5. RESULTS AND DISCUSSION

The results of field spectral ratio for nine locations (N1 to N9) are shown in **Fig. 1**. The suffix R in symbol of sample designations refers to the results obtained from radiometer measurement. From the results shown in Table 2 and **Fig. 1**, it can be noticed that the spectral reflectance ratios are decreased with increasing the hydrocarbons content in the soil samples which makes the color of soil samples darker. While in (N4R) the neutralities may be due to the soil texture or variation in the water content.

The satellite imagery of Al-Daura site with four bands was analyzed using EARDAS10 software for nine geo-referenced points and the summary of results is shown after redrawn in **Fig. 2**. The results obtained from radiometer tests as shown in **Fig. 1** are identical and have the same pattern of those obtained from the analysis of satellite imagery by EARDAS software which shown in **Fig. 2**, except (N6). Dealing with the behavior of (N6), the value appear with high different comparing with other values because of the randomly error through the image processing steps. The digital map of the study area can be divided into zones according to the type of contaminants and/or the concentration of contaminants in the surface layer of soil depending on the reflectance measurements, digital imagery and geotechnical properties of soil using GIS techniques. The integration between geotechnical properties of soil and GIS techniques help to generate missing spatial data.

The important application of remote sensing and GIS techniques in geotechnical engineering is production of digital maps with supervised classification operation with nine spectral classes for Al-Daura site; the first one explains the distribution zones and concentration of hydrocarbons as shown in **Plate 2**. While, the second is a digital map explains the distribution zones and concentration of lead as shown in Plate 3. Construction digital maps using GIS techniques are representative, easy to use, and saving time and cost. The predicted and measured (reference) contents and the spatial distributions of hydrocarbons and lead were interpolated by using EARDAS software to produce digital thematic maps of layers for the distribution and concentration of hydrocarbons and lead are shown in **Plate 4** and **Plate 5** respectively. This application of remote sensing and GIS techniques in geotechnical engineering is new and powerful in predicating the geotechnical properties of surface soil layer especially in the field of soil contamination.

6. CONCLUSIONS

The spectral reflectance depends on the soil sample color, so the reflectance ratio for natural contaminated soil with hydrocarbons decreases with increasing of hydrocarbons concentration except (N4R). The field simulation of the spectral reflectance in naturally contaminated soil with hydrocarbons using radiometer measurements corresponding to the bands used in the satellite image analysis using EARDAS software prove that this technique is very useful and powerful for the estimation of contaminants types in the surface layer of soil. Also, the use of satellite images with high resolution and different bands provides a very large amount of qualitative and quantitative information for study area to state the soil contamination states.

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NOMENCLATURE

C_1 and C_2: constant transfer factors for each spectral band.
E: the irradiance radiation (Watt/m^2).

L: reflectance radiation from the target (Watt/m^2).
V_1 and V_2: electromagnetic radiation that is recorded by radiometer.

Table 1. GPS coordinates of soil samples locations.

Sample No.	GPS Coordinates	
	Northing	Easting
N1	0447612	3681802
N2	0447607	3681742
N3	0447247	3681867
N4	0447277	3681886
N5	0446932	3682403
N6	0446836	3682350
N7	0446832	3682340
N8	0446761	3681643
N9	0446757	3681650

Table 2. Hydrocarbons and lead contents and particle-size distribution of soil.samples.

Soil Sample	Hydrocarbons Content %	Lead Content %	Silt %	Clay %
N1	0	0.0025	100	-
N2	0.185	0.0022	40	60
N3	0.285	0.0048	50	50
N4	0.644	0.0034	60	40
N5	22.44	0.0233	100	-
N6	3.629	0.0035	15	85
N7	3.225	0.0027	40	60
N8	0	0.0043	50	50
N9	0	0.0035	30	70

Table 3. Particle-size distribution of soil samples.

Soil Sample	Silt %	Clay %
N1	100	-
N2	40	60
N3	50	50
N4	60	40
N5	100	-
N6	15	85
N7	40	60
N8	50	50
N9	30	70

Table 4. Wavelength of radiometer bands.

Band	Range of Band (μm)	Peak (μm)
Blue	0.45-0.49	0.48
Yellow	0.56-0.59	0.56
Red	0.63-0.70	0.66

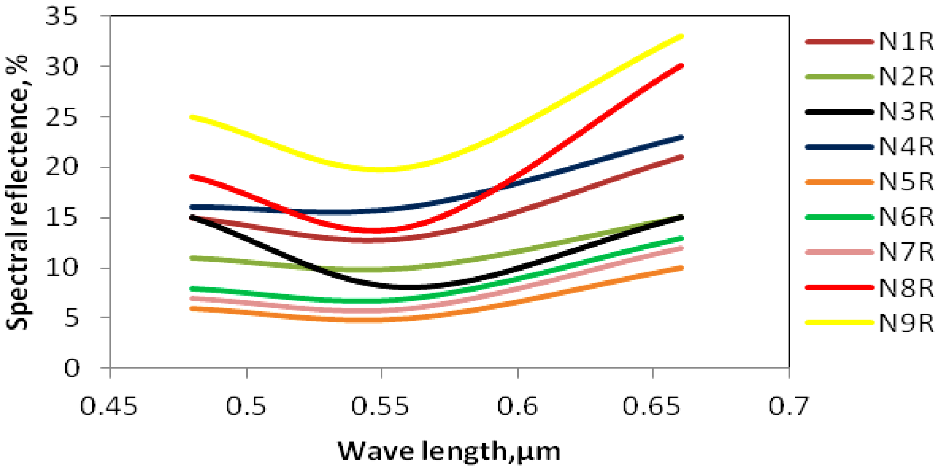

Figure 1. Spectral reflectance curves from radiometer tests.

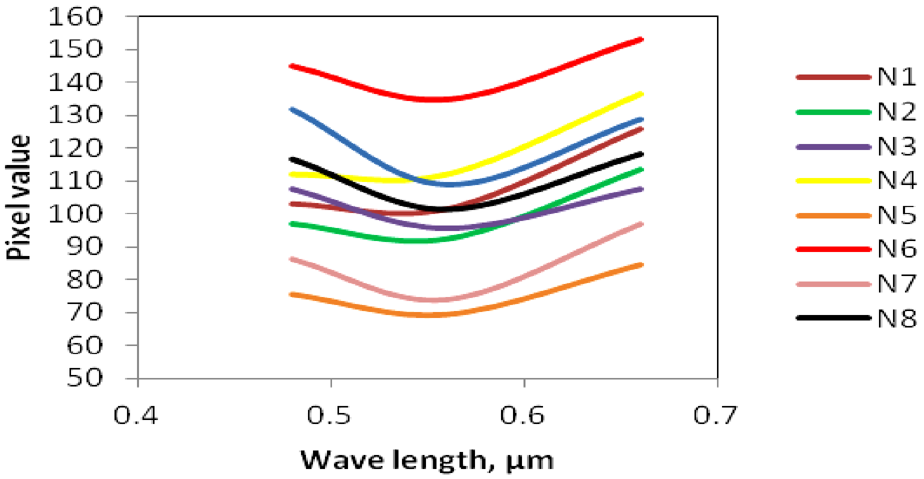

Figure 2. Spectral reflectance curves from satellite image.

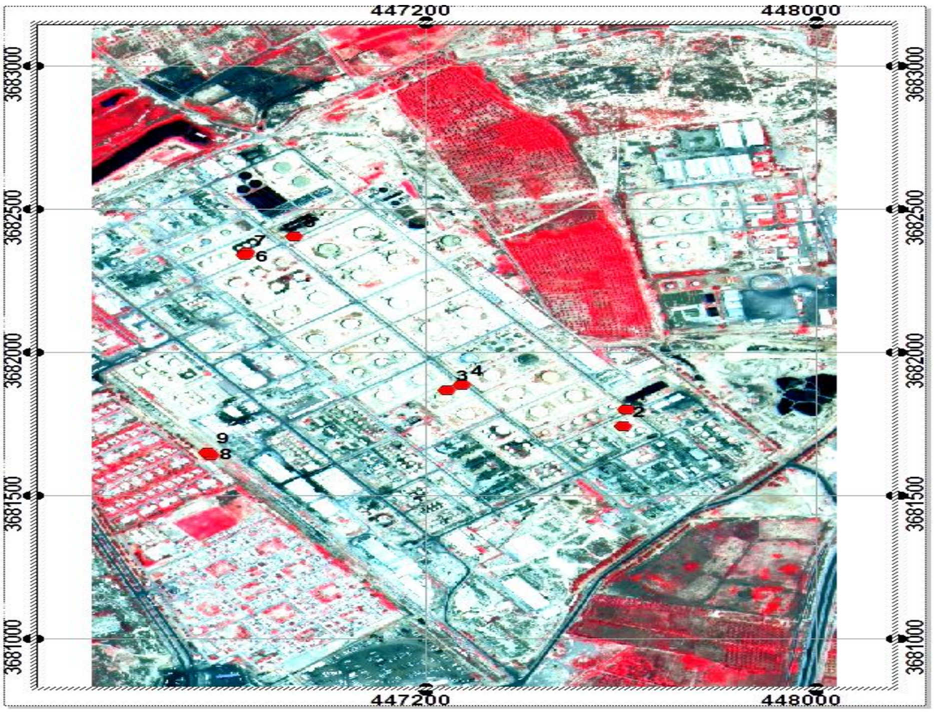

Plate 1. Locations of nine spots on satellite image.

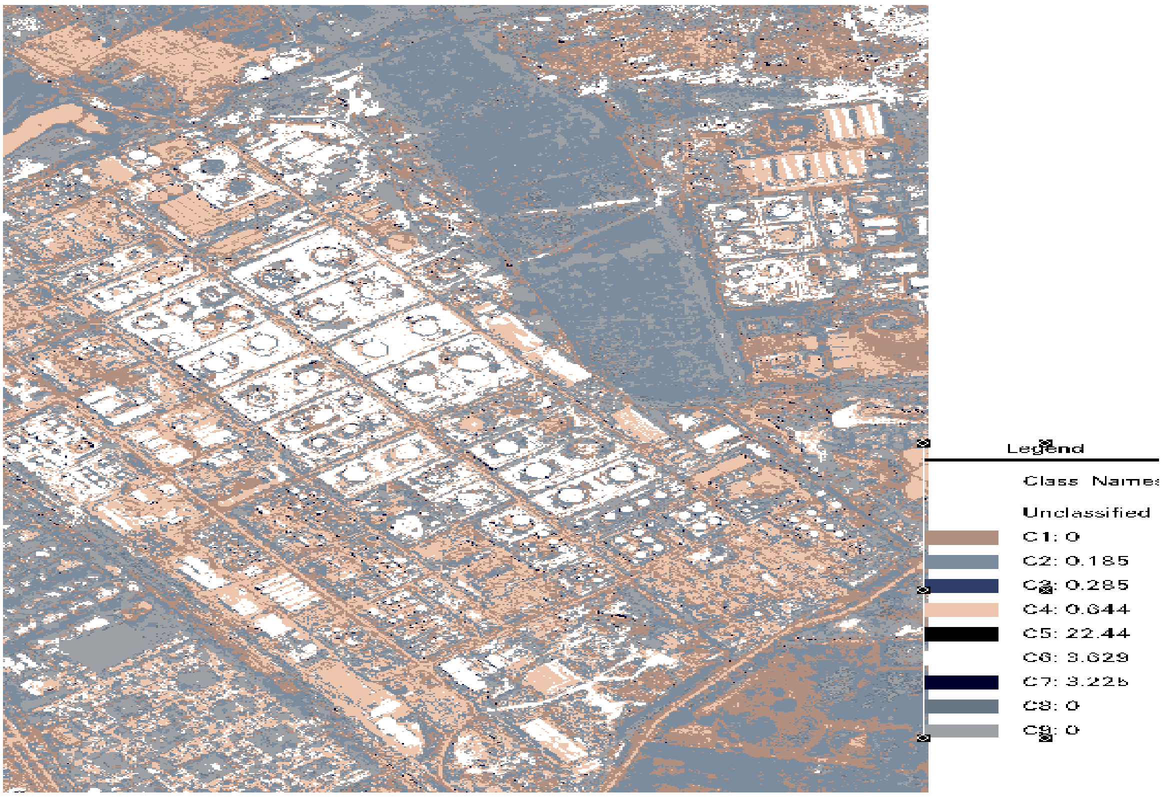

Plate 2. Distribution and concentration of hydrocarbons.

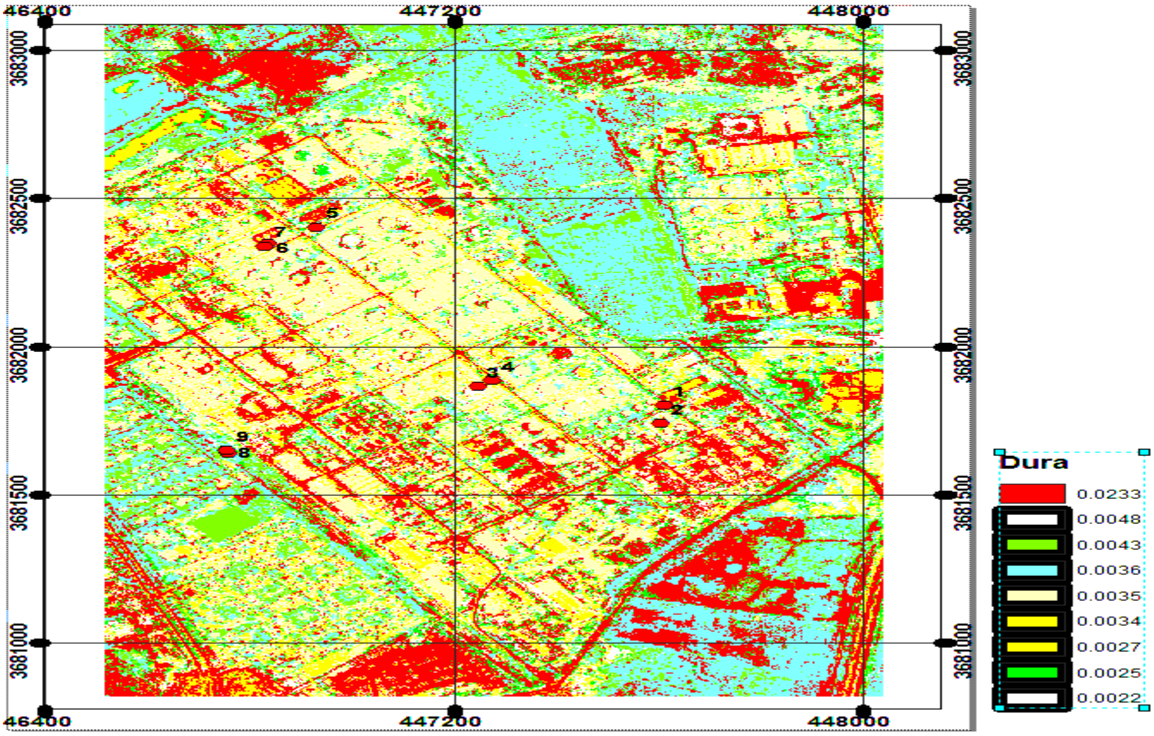

Plate 3. Distribution and concentration of lead.

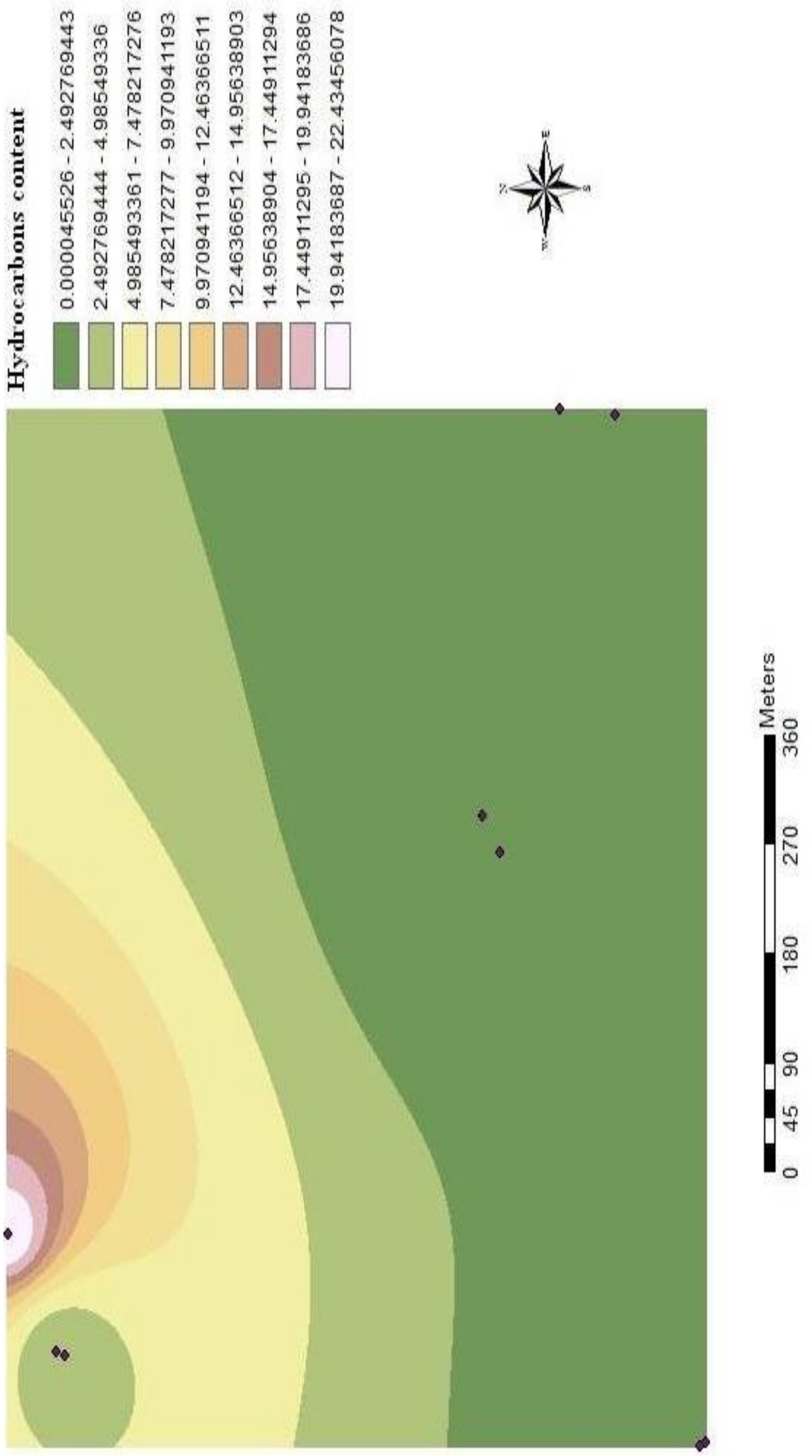

Plate 4. Distribution and concentration of hydrocarbons content in the soil.

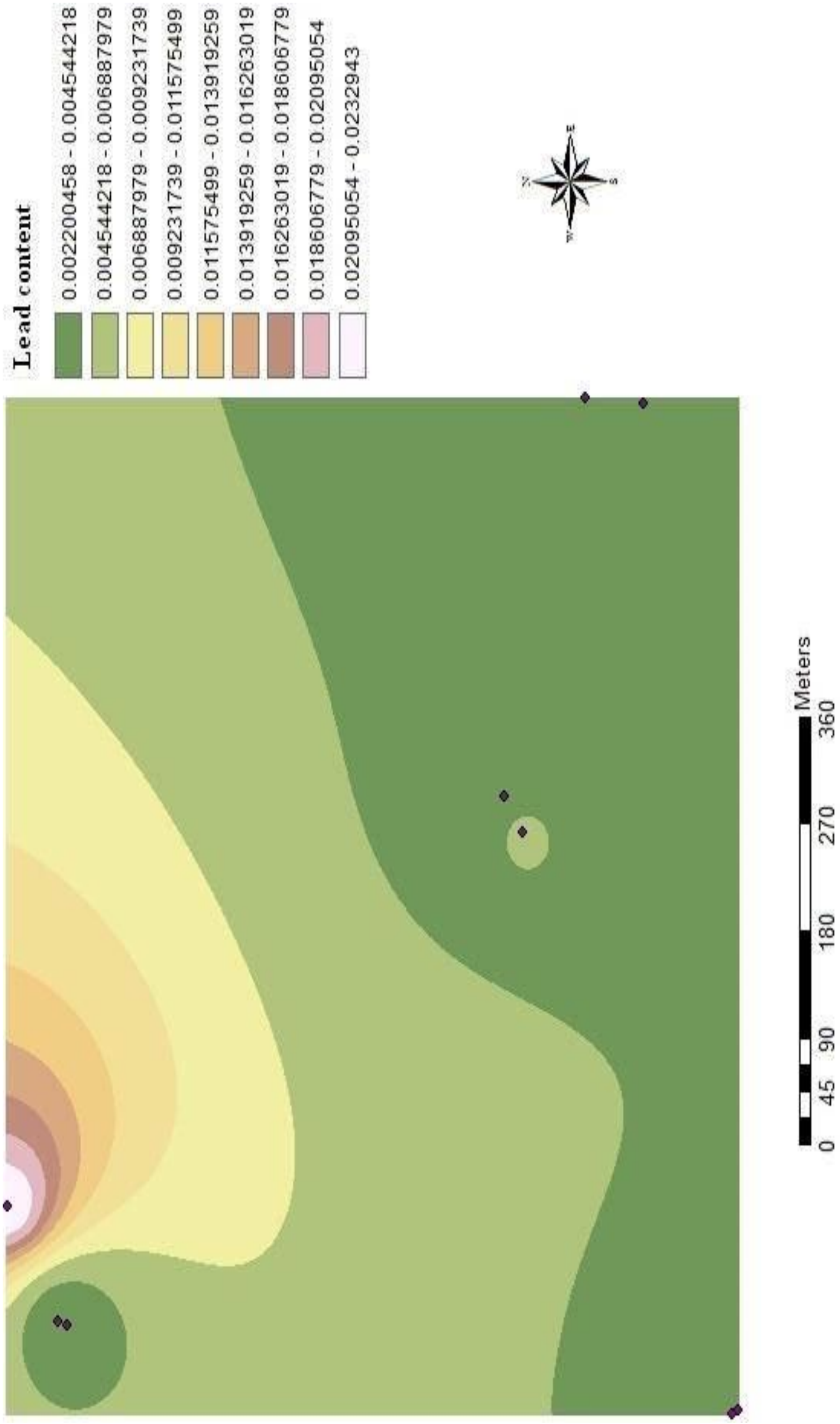

Plate 5. Distribution and concentration of lead content in the soil.