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Using Geometics Technology to Detect Soil Contamination by Sewage and Irrigation Water Within the Urban Area of the City of Almithnab in Qassim Province, Saudi Arabia

Abdulrahman Mohammad Aldukhayil
Assistant Professor of Environmental Applications of RS and GIS
Geography Department- Qassim University

Abstract. This study sought to assess the impact of urban development on the soil environment of Almithneb City (referred to as Almithneb from here on out) to monitor the changes of the soil as a natural component in the City's urban area. The study used a descriptive approach to achieve the main objective in Almithneb's targeted urban area for the year 2028. The study leveraged field work and geomatics technologies such as Remote Sensing, Geographic Information Systems (GIS), and Global Positioning Systems (GPS).

The study is divided into five parts. The first part introduces the study. The second part discusses the literature review. The third part consists of the methodology and procedures used in the study. The fourth part is devoted to the classification and analysis of remote sensing, as well as field and laboratory data. Finally, the fifth part discusses the results, conclusions, and recommendations.

It was found that the urban development and adjacent agricultural area have a clear impact on the soil of Almithneb. This is represented in the soil degradation and pollution. This study made several recommendations aimed at reducing the negative impact of urban development on the soil environment as a natural component of Almithneb. These recommendations are suggestions to address the existing problems and avert potential long-term environment problems that are related to soil.

Research Problem

Almithneb has gone through eight comprehensive development plans between 1970-2010 (Ministry of Municipal and Rural Affairs, 2007), resulting in urban expansion in the North and West. The resulting urban expansion led to visible changes such as deterioration of natural rock area, soil degradation, declining groundwater quality, and flash floods. These environmental problems require a study of their natural history with its relationship to the current situations. Therefore, the study should assess the impact of urban development on the soil environment as a natural component of Almithneb, requiring accurate past and present periodic data of all urban centers to achieve sustainable development (The General Authority of Meteorology and Environmental Protection, 2010). The effort, time and money required for traditional methods, are inadequate to achieve the desired goals since results may not appear until the environmental problem has exacerbated. This study used geomatics applications to avoid those obstacles.

Research Questions

1. Where was Almithneb’s urban area concentrated before the comprehensive development plans?
2. What is the urban area’s growth rate during the four specified periods?
3. How much change is caused by the urban development to Almithneb’s soil as a natural component?
4. Does it help to use some of the geomatics applications to identify changes in Almithneb’s soil environment?

Research Goals

1. Identify the natural and urban conditions of the study area before the comprehensive development stages.
2. Specify the urban area to be studied before the start of the comprehensive development plans in 1970.
3. Measure and record the amount of change caused by urban development on Almithneb's soil over the past fifty years.
4. Identify the best geomatics technologies for assessing the impact of urban development on Almithneb's soil.

Importance of the Study

1. To enable the conceptualization of the urban and environmental status of Almithneb before the comprehensive development plans' stage.
2. To reveal changes on the soil's environment that have occurred in Almithneb as a result of urban growth.
3. To establish a link between the different geographical studies associated with soil change in urban centers.
4. To provide a model for identifying the appropriate remote sensing applications in studying the environmental changes of soil associated with urban development, so that such model can be used in similar studies.
5. To create geodatabases for Almithneb's soil.
6. To reach outcomes that contribute to making development planning decisions that are suitable for the natural conditions.

Focus of the Study

This study covers the urban area of Almithneb up to 2028, ranging between the latitudes 25° 47′ 25″ and 25° 57′ 45″ North, and between the longitudes 44° 06′ 18″ and 44° 11′ 16″ West (Figure 1). The city is located in the center of the Western part of the sedimentary area of the Arabian Peninsula. This urban area is considered a part of the Tethys Sea that had precipitated layers of sand, clay, and limestone, which all resulted in geomorphological diversity.

The first period that the study covered was the ten years that preceded the comprehensive development plans in 1970 up to 2010. The study title identifies three subjects: urban development, which is one of the interests of settlement geography as an independent variable, the soil environment as a dependent variable, and the use of geomatics applications to study the impact of urban development on the City's soil surroundings.

Figure 1: Almithnab's location in Qassim

Literature Review

The study mainly relied on three types of geomatics technologies to assess the impact of urban development on the soil environment as a natural component of the study area. Geomatics technologies include remote sensing, GIS, and GPS.

In a report that compared digital change detection techniques to one another using remote sensing, Peter Deer (1995) concluded that the type of application used determines the appropriate method to detect change. In an empirical study on the city of Mecca and its surroundings, Saad Abu Ras Al-Ghamdi (2002) studied environmental change detection using digital data from satellites. The study concluded the following:

1. The Principal Component Analysis (PCA) method is suitable for detecting change, where it achieved good results in determining the amount and patterns of urban change.
2. The threshold method is the best and easiest method among the ones that were applied.

Ioannis Gitas et al. (2003) used the National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite image to assess vegetation change in the Eastern part of the Mediterranean region between 1989 and 2002. Their study concluded the following:

1. The Normalized Difference Vegetation Index (NDVI) and Soil-Adjusted Vegetation Index (SAVI) can detect changes in the NOAA AVHRR satellite image data for the Eastern Mediterranean region.
2. The Multi-Date Unsupervised Classification (MUC) has the same ability to detect change as the method above.
3. Integration of the two methods above allows demarcation of seasonal and permanent changes.

T.V. Ramachandra and Uttam Kumar (2004) found that the accuracy of supervised classification reached up to 94.6%, while the accuracy decreased to 78% in the unsupervised classification of the land cover in Kolar district, Karnataka, India. In another study, Al-Ghamdi (2005) compared traditional methods to automated methods to create drainage networks for Naaman Mountains near Mecca. The study concluded with the following:

1. The data from the Indian satellite offers high spatial recognition compared to traditional methods and Landsat data.
2. The PCA method cannot be applied.
3. Supervised classification is reliable for the classification of drainage stream network ordering.
4. The Directional Edge Enhancement (DEE) is the best method.

A study by Enton Bedini and Petraq Naço (2008) showed that bi-temporal Landsat data is suitable for studying the mouth of Erzen River in Albania. They also used Canty and Nielsen’s (2006) Multivariate Alteration Detection method, which allowed them to calculate the aggraded and eroded area. Ifeanyi et al. (2010) assessed the environmental degradation in Efon Alaye, Nigeria. The NDVI was applied to perform unsupervised classification of the land cover in two Landsat images for the two years 1986 and 2002. The study concluded that NVDI was able to integrate information from different data sources with theoretical analysis of the ecosystem.

Davidson Alaci et al. (2011) were able to estimate spatial growth and extract distinctive information on environmental changes associated with urban development in central Nigeria using Landsat images for 1987 and 2001, and NigeriaSat-1 image 2005. Such extraction was done by applying the Maximum Likelihood Classifier (MLC) to perform supervised classification.

Mohammad Abdulhamid and Musaad Al-Mosaind (2003) applied four spatial analysis methods in ArcGIS to assess the suitability of Almlqa[1] in Dir'iya province for urban development. The study showed that the network analysis method produces the best results because it provides multiple scenarios that contribute to determining suitability levels. Tahar Ledraa and Ali Al-Ghamdi (2006) applied the Spatial Proximity Analysis (SPA) and Surrounding Area Analysis (SAA) methods. They were able to identify urban sprawl patterns and their association with the road network. Talal Al-awadhi found that the urban area in Muscat, Oman has expanded by 650% during the period covered in the study, an average of 20% annually from 1960 until 2003. This was done using the SLEUTH simulation model to show urban growth there until 2028.

Many of the aforementioned studies were applied in regions with moist or semi-moist environments such as India, Nigeria, China, Thailand, and North America. All these regions have abundant vegetation, which is the most important change detection indicator. They are completely different from Almithneb's dry environment, which is botanically poor. While Al-Ghamdi's (2002) empirical study was conducted on a similar environment to Almithneb, it only detects change in vegetation. Moreover, Al-Ghamdi’s study covers only six years starting from 1992, while this study covers five decades (1960-2010). In addition, the natural, human, and functional structure of the two cities are different. As for Al-Awadhi’s (2008) study, which is similar in terms of the natural dry environment and the periods covered, it is limited to assessing, predicting, and modeling urban sprawl. It does not address any environmental change and urban development’s role in making it happen.

Methodology and Procedures

The study adopted an analytical descriptive approach as recommended. It also utilized geomatics technologies because of their high capabilities, which allow scientifically accurate conceptualization of the studied area’s condition and the suitable solutions for its soil environment. The data has been collected and processed from different sources, which are explained below:

1. Fieldwork

a. Field Visits:

Several visits were arranged —accompanied by some specialists from inside and outside of the region— to identify the characteristics of the study area. These

[1] An area near Riyadh, Saudi Arabia

visits were done in different periods in the month of September 2014. In addition, soil samples were collected (15 September 2014) to be analyzed in a laboratory.

b. Field Measurements:

Several attempts to create a Digital Elevation Model (DEM) using GPS were made. However, the soil of Alsifala Meadow's depression in the Eastern part of the studied area was saturated with subsurface water. Therefore, the study used a DEM with 30m. accuracy, which was obtained from the Space and Aeronautics Research Institute in Riyadh. The old town area was demarcated using GPS since it cannot be done via remote sensing. The study also used GPS in determining the coordinates of selected points to measure the degree of classification accuracy. In addition, Ground Control Points (GCP) were established, which are required for the satellite image correcting process.

2. Office work

a. Obtaining maps, pictures, and satellite image from various government agencies.

b. Preliminary Process (Data Preparation):

The preliminary process included the data import and integration of different formats and sources. Then, the spectral band layers of each image were merged together into one layer. Next, the studied area was extracted from the maps and images. Finally, geometric correction was done to the images, while georeferencing was done to the maps.

c. Final Process:

ERDAS 9.1 was used, which is considered the best remote sensing program since it is widely used for the following:

1. Data preparation steps.
2. Supervised classification of satellite data.

While ArcGis 10.1 was used to execute the following tasks:

1. Creation of a soil geodatabase for the city.
2. Organization and classification of processed data in accordance with the requirements of this study's stages.
3. Analysis of descriptive and quantitative data.
4. Production of digital maps that represent the change in soil's environment that the region went through in each period of the study.

3. GPS Applications

The GPS technology, known as Leica-1200, was used to execute the following tasks:

1. Identification of survey markers placed earlier by Almithneb Municipality to rely on as geodetic datums and use them as GCPs to adjust aerial photographs and satellite images that need a coordinate system or geometric correction.

2. Placement of GCPs for places that do not have geodetic survey markers for the same purpose.

3. Cadastral survey of some parts of the study area that are difficult to identify from remote sensing data, such as the locations in which the old city originated.

4. Identification of natural vegetation areas that are difficult to distinguish from cultivated plants.

5. Identification of the study area's levels in order to create a DEM.

Satellite Image Classification Assessment

The supervised classification method was applied in this study. Several points were selected from the satellite image for each class based on samples or known sites in the studied area’s environment. Based on those selected points, the computer extracted all cells that are similar to the selected points from the rest of the satellite image.

The MLC was applied to obtain the best classification results for remote sensing data (Dewidar, 2002), which would lead to the production of classified digital images (CDI). In addition, the spectral signature accuracy in the classification of the satellite images that represented three periods was assessed by applying the contingency feature. The results showed the following:

1. Assessment of Classification Accuracy in Landsat-1's Image 1972:

According to the accuracy assessment table, the actual number of cells that represented all classes was 9981 cells (91%) out of 11,011 cells, while kappa index reached 80%.

2. Assessment of Classification Accuracy in Landsat-7's Image 1990:

Based on the assessment of this image, there were 27,900 out of 32,002 classified cells that represented the classified components. Thus, the overall accuracy of this image’s classification assessment was 87%, while kappa index reached 88%.

3. Assessment of Classification Accuracy in SPOT's Image 2010:

The overall accuracy of SPOT's image classification assessment was about 80% of the total classified cells, which in aggregate amounted to 2,676,738 cells, with a Kappa index reached 88%.

Analysis of Satellite Image Data Classification

To extract the soil component's area, identification of other components in the area is required. The purpose of the classification of the study area’s components was to estimate the size of each component in each period of the study. This requires an analysis of the classified data using the geographic information system (GIS) program, ArcGIS 10.1, which contains functions and tasks that allow sufficient flexibility in the production and analysis of digital maps and associated tables and graphs in terms of identifying dimensions and spaces. The classified images' data was analyzed in chronological order.

The classification of Landsat-1's image in 1972 (Figure 2), showed five components, which are sedimentary rock, soil, sand, palm trees, and alfalfa. First, the sedimentary rock covered 17025 acres (ac) (59%) of the urban area, which is 28909 ac. Second, the soil area was 7654 ac (26%). Third, the sand covered 1728 (6%) of the urban area. Fourth, the palm trees covered 1920 ac (6.8%). Finally, the alfalfa covered 492.8 (less than 2%). Since the old town could not be distinguished visually via this image, a cadastral survey was done using GPS. The demarcation of the Almithneb's boundaries up to 1960 was based on experts in the area, where it amounted around 2,246,934 ft2 (1235 ac). The newer images were used to estimate and demarcate the old town's area between 1960 and the first satellite image (1972), which amounted to 6,934,584 ft2 or 0.06% of the area.

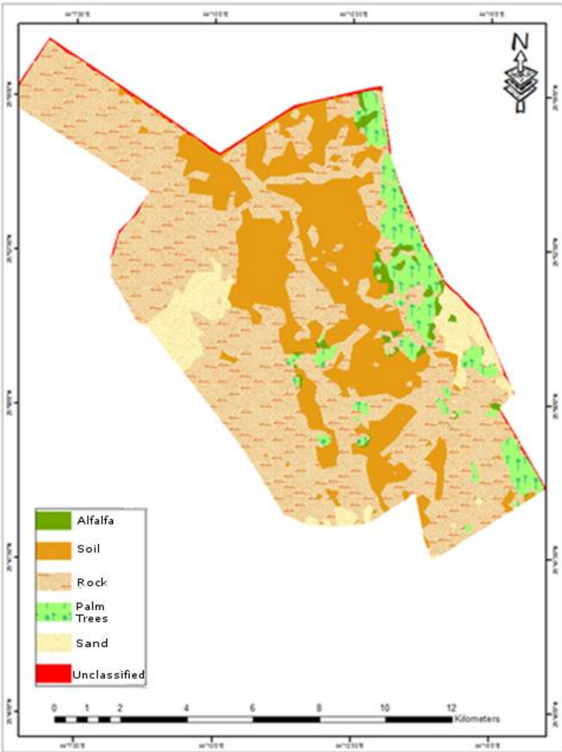

Figure 2: Classification of urban area from Landsat-1 in 1972

The classification of Landsat-7's image in 1990 (Figure 3), showed the following components:

1. Sedimentary rock area was around 8320 ac (29%).
2. Soil area was 7040 ac (25%).
3. Degraded soil area was 1216 ac (4%).
4. Small salt pan area was 243 ac (1%).
5. Sand area was 1107 ac (4%).
6. Built areas covered 640 ac (around 2%).
7. Roads covered 384 ac (1.25%).
8. Palm trees covered 3200 ac (11%) of the urban area.
9. Alfalfa covered 3456 ac (12%).
10. During the visual classification of this image, dark circles around the city were noticed, which suggests that crops residue burning occurred in an area of 2470 ac (about 9%).
11. Unclassified area was 243 ac (around 1%).

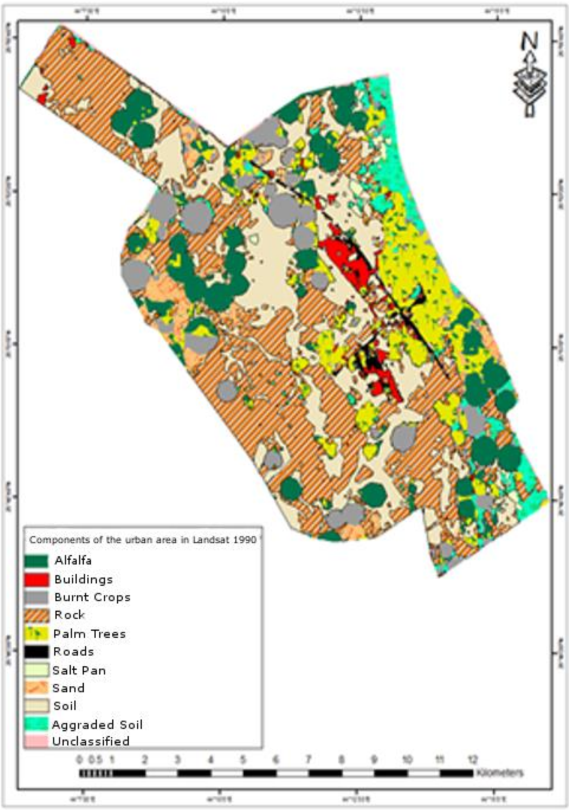

Figure 3: Classification of urban area in Almithneb from Landsat-7 in 1990.

The classification output of SPOTs image in 2010 (Figure 4), showed the following components:

1. Sedimentary rock area covered less than 7040 ac (25%) of the urban area.
2. Soil covered 4928 ac (17%).
3. Degraded soil increased to 3712 ac (17%).
4. Salt pan area reached 2944 ac (around 10%).
5. Sand areas covered 1472 ac (5%).
6. Built areas covered 1280 ac (4%).
7. Paved roads and streets covered 1216 ac (4%).
8. Palm trees covered 1728 ac (6%).
9. Alfalfa covered 1472 ac (5%).
10. Supervised classification showed 1920 ac (7%) of burnt crops residue.
11. Winter crops covered 736 ac (3%).
12. Unclassified area, which is represented in the Eastern and Northeast side, was no more than 243 ac (1%).

The analysis showed that a clear change occurred to the components of the natural environment in Almithneb's urban area. The most significant changes occurred in the rock area, followed by the soil and sand area. During the first period, the rock area (which is the largest component in the region) declined to almost half. In the second period, the decline continued but at a slower pace, where it did not exceed 20% of the first period's remaining rock area. The decline of soil was negligible in the first period. However, it increased by 10% during the second period. The total sand area declined 35% in the first period; however, it increased back to 88%. This indicates sand creep or desertification due to the abandonment of farms falling within the urban area. Most of the decline that occurred in the previous components shifted in favor of other components, where degraded soil and salt pan areas expanded the most, followed by buildings and roads at the expense of rocks, soil, and sand.

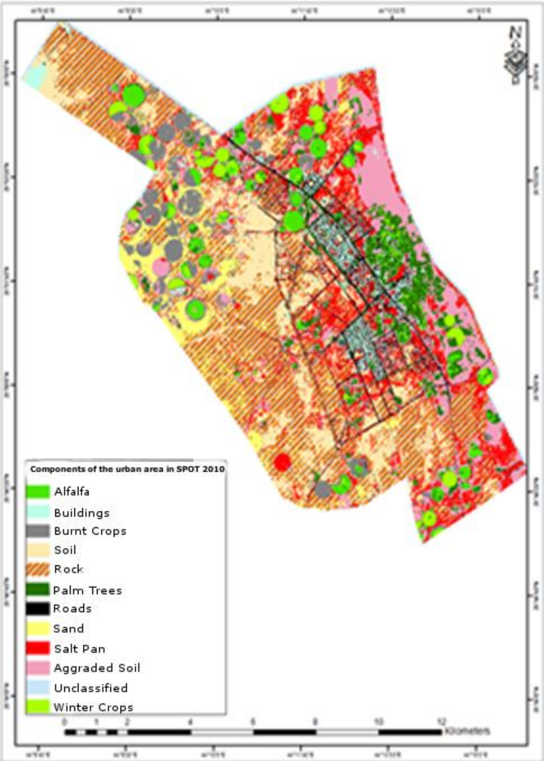

Figure 4: Classification of urban area in Almithneb from SPOT in 2010

Analysis of Field Data

Soil analysis of sixteen different locations' samples was conducted (16 September 2014) in the laboratories of the Department of Soil and Water, College of Food and Agriculture Sciences at King Saud University in Riyadh (Figure 5).

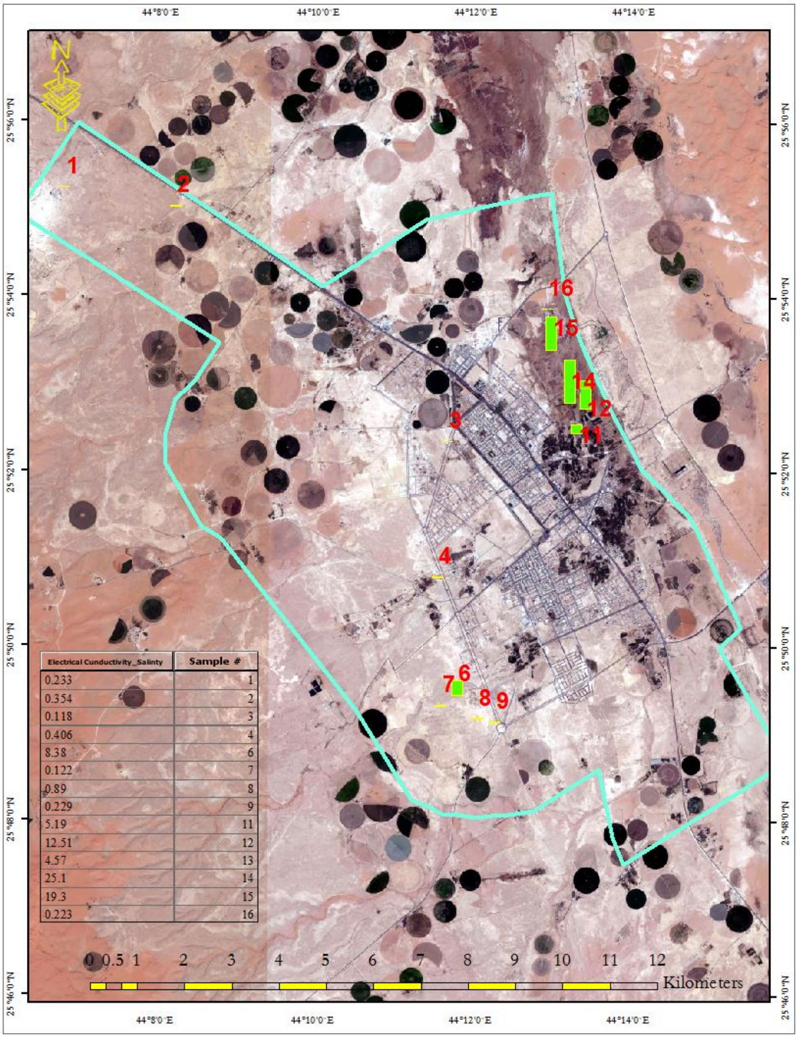

Figure 5: Comparison of soil sample's salinity and alkalinity in Almithneb's urban area

The procedure for the analysis is described below:

1. Soil Chemical Analysis

To estimate the total dissolved solids (TDS), electrical conductivity used turned out to be the best measure methods of soil salinity. The analysis showed that the highest rate of soil salinity was represented on site No. 14, at a salinity rate of 25.1 dS-m1, followed by sites 15, 12, 6, 11 and finally 13, while the salinity rate on site no 16 was the lowest. The degree of alkalinity in the soil of sites 1 to 11 was within acceptable limits, with the exception of site 6, which had none. The alkalinity degrees of sites 12 to 16 range between 8.84 and 9.12 (Figure 6), which are a little bit higher than the appropriate alkaline standard as defined by the Food and Agriculture Organization (1989).

2. Soil Physical Analysis

This analysis was designed to determine the studied area's soil texture (See Table 1). The findings are as follows:

1. Sandy loam was found in 40% of the samples.
2. Loam comes second. It prevailed in site 8,14, and15.
3. Loamy sand was found in samples of sites 3 and 16.
4. Silty loam was found in samples of sites 4 and 11.
5. Sand was found in the soil of site 2, which is located in the Western part of the urban area.

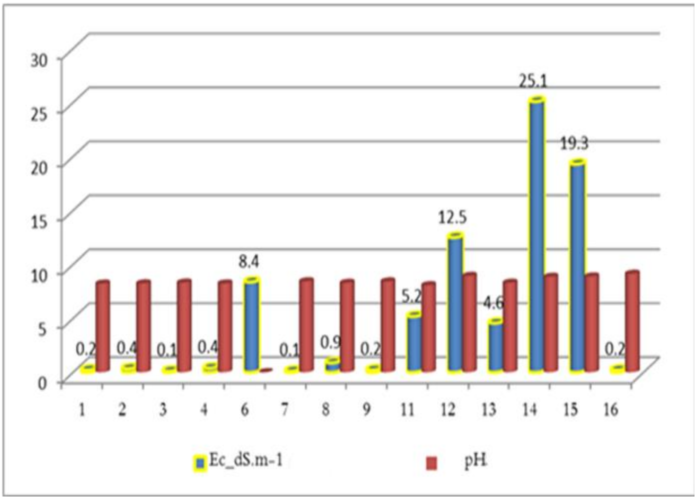

Figure 6: Comparison of soil sample's salinity and alkalinity in Almithneb's urban area

Table 1: Soil Component in the Almithneb's Urban Area

Sample #	Lat	Long	Sands %	Silt %	Clay %	% CaCo3	Texture
1	25.9211	44.1136	60.76	28.17	11.07	45.76	Sandy loam
2	25.9176	44.1371	50.7	36.22	13.08	16.67	Sand
3	25.8729	44.1948	76.86	18.11	5.03	21.99	Loamy Sand
4	25.8469	44.1931	44.67	52.31	3.02	20.83	Silt Loam
5	25.8451	44.1939	NULL	NULL	NULL	NULL	NULL
6	25.8245	44.1968	50.7	46.28	3.02	33.8	Sandy Loam
7	25.8224	44.1938	64.79	32.19	3.02	46.65	Sandy Loam
8	25.8199	44.2015	42.66	48.29	9.05	33.39	Loam
9	25.8193	44.2051	58.75	32.19	9.05	34.99	Sandy Loam
10	25.8172	44.2051	NULL	NULL	NULL	NULL	NULL
11	25.875	44.2221	24.55	56.34	19.11	46.61	Silt Loam
12	25.8793	44.2225	66.8	22.13	11.07	5.32	Sandy Loam
13	25.8799	44.2217	58.75	36.22	5.03	4.07	Sandy Loam
14	25.8804	44.2205	34.61	46.28	19.11	10.09	Loam
15	25.8905	44.2167	44.67	32.19	23.14	6.09	Loam
16	25.8983	44.2157	80.89	10.06	9.05	3.07	Loamy Sand
17	25.8739	44.2361	NULL	NULL	NULL	NULL	NULL
18	25.8797	44.2362	NULL	NULL	NULL	NULL	NULL

Results

Geomatics applications can provide basic and detailed data on temporal and spatial parameters of geographical phenomena. These applications make collecting spatial data from multiple old periods possible. Such data cannot be obtained by conventional means because of the constant change to the environmental surroundings, resulting in deterioration of many of the area's characteristics and phenomena. The changes in the area can be summarized as follows:

1. Emergence of salt pans that were not present in the soil area, and expansion of the existing salt pan located in the northeast area.
2. Decrease of soil area due to it being converted into residential and commercial lands, or exposed to degradation then salinization.
3. Deterioration of natural vegetation and cultivated area, which were replaced by unwanted plants.

Recommendations

Since this study is concerned with assessing the urban development impact on the soil as a natural component of Almithneb, it can offer recommendations that contribute to resolving some of the problems that have emerged. These recommendations are summarized as follows:

1. Speed up Almithneb's sewer project and extend it to nearby villages.
2. Rehabilitate Alsifala Meadow's depression and surrounding meadows in the following manner:

a. Excavate a primary canal that stretches from the South to the North along the lowest contour line at the Eastern end of the depression. Water can be drawn from the saturated soil via smaller canals, which pour into the primary canal.

b. Apply biological methods to dry the soil using biochemical products.

c. Get rid of salts and other contaminants in the depression's soil, which has been saturated due to sewage and agricultural drainage.

d. Establish a water purification plant to leverage water collected from the depression. That water can be leveraged in cultivation of crops that are not consumed directly, and in afforestation of sand near the Eastern end of the depression.

3. Raise the locals' awareness about risks of pouring sewage and agricultural water into abandoned wells.

Suggestions to Avert Potential Environmental Problems in the Future

1. Prevent any unplanned agricultural expansion on degraded soil areas.
2. Apply biological control and fertilization methods that consist of only organic materials.
3. Prevent establishment of any construction project until an adequate sewage network is confirmed.

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استخدام تقنية الجيوماتكس للكشف عن تلوث التربة بواسطة مياه المجاري ومياه الري داخل المنطقة الحضرية لمدينة المذنب بمقاطعة القصيم، المملكة العربية السعودية

عبدالرحمن بن محمد الدخيّل

أستاذ مساعد، التطبيقات البيئية للاستشعار عن بعد ونظم المعلومات الجغرافية

قسم الجغرافيا، جامعة القصيم

ملخص البحث. تهدف هذه الدراسة إلى تقييم أثر التنمية العمرانية على التربة داخل النطاق العمراني المستهدف لمدينة المذنب حتى عام ٢٠٢٨م، وذلك لمراقبة التغيرات التي طرأت على التربة كأحد العناصر البيئة الطبيعية داخل هذا النطاق، واستخدمت الدراسة المنهج الوصفي لتحقيق الهدف الرئيس لها، وقد استفادت الدراسة من العمل الميداني وتقنيات الجيوماتيك مثل الاستشعار عن بعد ونظم المعلومات الجغرافية ونظم تحديد المواقع العالمية (GPS).

وتنقسم الدراسة إلى خمسة أقسام، حيث يشمل الجزء الأول المشكلة والاهداف والتساؤلات والاهمية، أما الجزء الثاني فيناقش الأدبيات المتعلقة بالدراسة، في حين أن الجزء الثالث تضمن المنهجية والإجراءات المستخدمة في الدراسة، وقد تخصص الجزء الرابع في تصنيف وتحليل الاستشعار عن بعد بالإضافة إلى البيانات الميدانية والتحليلات المخبرية، أما الجزء الخامس فيطرح النتائج والتوصيات التي توصلت لها الدراسة.