*Kuwait J. Sci. Eng.* **31**(1) pp. 135-148, 2004

# Geographic information system and database for the soil survey for the State of Kuwait - design and outputs

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## ABSTRACT

As part of the project 'Soil Survey for the State of Kuwait' a soil information system was designed and implemented to manage the soil survey data generated during the project and to ensure that soil information is readily available to support land development of Kuwait. The soil information system combines the capabilities of a geographic information system that manipulates and displays area, linear and point data with the logical framework of a database to store data for interpretation. This is a significant information source for Kuwait as it is the first database of soil and land resources that provides comprehensive coverage for Kuwait in a flexible digital format. The soil information system, includes all project data, is expandable to accept new data and flexible to allow the data to be reinterpreted. This project was completed in 1999 and the soil information system was fully implemented. This paper describes the design and implementation of the system, shows examples of outputs and highlights areas of future use where the data and soil information system can be used to support investment decisions, policy-making and risk management for land development in Kuwait.

**Keywords:** Environmental data; GIS; land resource; soil information system.

## INTRODUCTION

Traditional soil surveys have been hampered in their usefulness by the difficulty in retrieving information in a flexible way; the information exists in maps and reports or in raw data, all of which had to be processed manually. Modern computer systems now provide the means to store, process, interpret and retrieve vast amounts of data. Work in the natural resource and environmental field has been enhanced by the ability of geographic information systems (GIS) and databases providing essential tools to flexibly and efficiently manage land resource information.

A geographic information system is a software system that allows area, linear and point data that have a geographic reference to be entered, manipulated, modeled, analyzed and displayed. At a basic level, it can be used to digitize line work into the system to produce a map. More sophisticated uses require intelligent rules to be applied to one or more map data sets to produce interpreted outputs in the form of derived maps and/or tabular data listings.

A computer-based relational database is a software system that provides a logical framework to store data so that it can be readily entered and analyzed. Data can be classified as coded/not coded and in the form of numeric or text strings; also, photographic and video pictures and can be linked to other known external data sets.

Bringing together these three developments - computers, GIS and relational databases - releases soil survey information from manual constraints and enables them to realize their potential. Hence, GIS and associated databases are widely used in environmental science, natural resource management, land use planning and development (Adinarayana & Krishna 1995, Machin & Navas 1995, Brown et al. 1998, Gar-on -yeh & Li 1998).

Soil survey information is an essential data set that provides primary resource information on the characteristics, nature and location of soils (and usually associated information on landforms, vegetation, topography, etc.), which is then interpreted for land use planning and management decisions. The type of questions a soil survey are generally asked to answer involve: 1) what soil or soil property occurs for an area of interest; 2) what is the distribution of soils or a soil property; and 3) what is the suitability for a land use based on interpretation of the soil properties?

The volume of information generated in a state-wide soil survey is large, and the information gathered is complex and interrelated. It includes data on the identification and description of the soils and miscellaneous areas (building and industrial areas); their location; and a discussion of their suitability, limitation and management for irrigated agriculture and other land uses. All point, linear and area data are geographically related and displayed on maps to provide information on the location and extent of the soils and their properties.

## Soil survey for the State of Kuwait

An objective of the Soil Survey for the State of Kuwait project (Kuwait Institute for Scientific Research, KISR 1999a, 1999b) was to design and implement a soil information system to manage the soil survey data generated during the project and to ensure that soil information would be readily available to support future land development of Kuwait.

To meet the project requirements, the soil information system had to be able to manage text data (site location, soil profile and landscape description codes, soil classification, interpretative tables and word information) and spatial data (map and geographical located data). The design requirements should be comprehensive to include all project data, expandable to accept new data (of the same types and of new types), and flexible to allow the data to be reinterpreted using alternative methods and to link with other data sets.

The soil survey provided an exciting opportunity for the first time to assemble an interactive soil survey database for a whole country using up-to-date methods for soil survey data retrieval. The purpose of this paper is to describe the design and implementation of the soil information system for Kuwait and provide examples of its use, outputs and interpretations.

## DESIGNING THE SYSTEM

Specifications for the soil information system required it to allow geographic data (maps, images, thematic interpretations) and text data (site and soil profile data, soil descriptions, map unit descriptions, interpretation tables) generated by the soil survey to be entered, stored, processed and reported. It also had to be able to accept into and use other digital maps and text information in the database for future interpretations.

The main option available to meet the design requirements was to combine the spatial information management capabilities of a geographic information system (GIS) with the text information management of a relational database management system (RDBMS). The GIS is used for the storage, manipulation, analysis and presentation of spatial data. The RDBMS has similar functions for text site, soil profile, soil class and map unit information. The two information types are integrated through a relational interface system (RIS).

The system was commissioned in 1996 at Kuwait Institute for Scientific Research. At this time, a number of software solutions were available. Intergraph GIS software was selected because the software provides easy data capture and manipulation via standard menus. The software had features to cartographical present maps for publication and was compatibility with other Kuwait agencies that had topographic and cadastre digital data in Intergraph GIS format. The Oracle database management system was selected because it provided the flexibility required for complex dataset storage and retrieval and the software can be updated and modified to meet future requirements and can operate as a server to a number of users.

A schematic representation of the data flows and hardware configuration is shown in Fig. 1. At the time of commissioning the system between 1996 and 1999 the following was used: Personal computers (PCs) running Windows 95 operating systems and two Intergraph technical desktop workstation computers

(TD30) running Windows NT operating systems. Connected to the system is a large format Calcomp digitizer for map data capture, HP Laser Jet 4 Plus printer and HP755cm Design jet plotter for paper printouts, and an Exabyte tape driver for system and data backup.

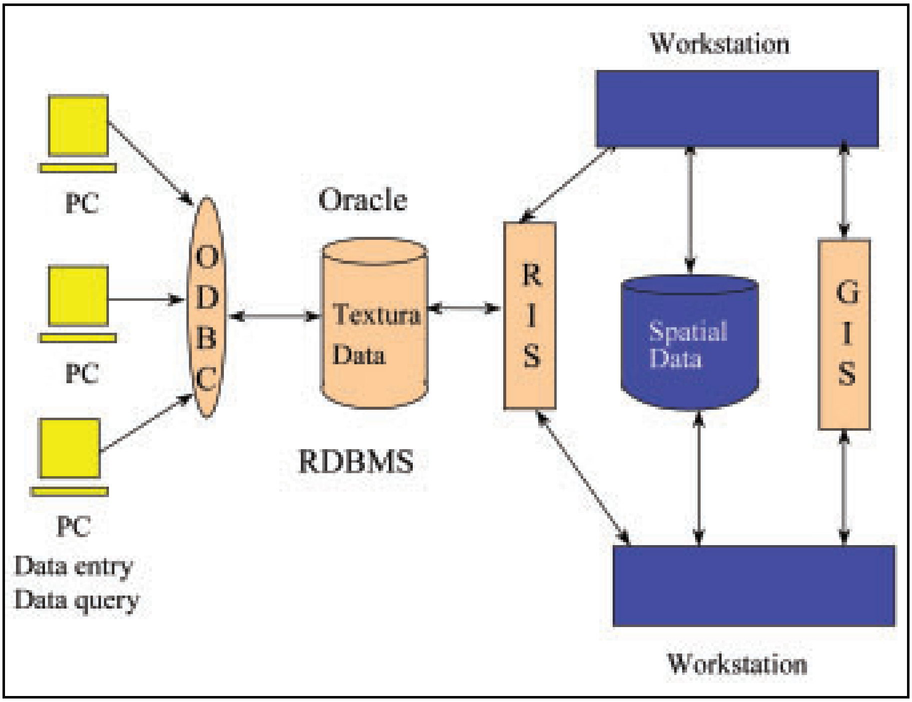


**Figure 1:** Schematic representation of data flows in the soil information system.

GIS operations are conducted on the workstations, which have components of Intergraph's Modular GIS Environment (MGE) software suite installed based on the functional use of the workstation. One workstation also has Oracle installed for database operation and acts as the server to the other workstations and personal computers. Database connectivity between the MGE system and the database requires the RIS client product for all machines and RIS Oracle data server on the workstation where Oracle is installed. The GIS software installed includes Microstation, CAD script, MGE Nucleus, MGE Base Mapper, MGE Administrator, MGE Analyst, MGE ASCII Loader, MGE Base Imager, MGE Modeler, and MGE Projection Manager.

The connected PCs were used for data entry, database queries, and reporting within a local Microsoft ACCESS environment. The PC's communicated with the Oracle RDBMS across a network using TCP/IP protocols and via an ODBC interface to the database tables. The PCs had the installation of Oracle products for Windows to provide client capability through Microsoft ACCESS via

ODBC interface, and Microsoft Office Professional to provide word processing and data manipulation capability. The Oracle database acts as the attribute database for the Intergraph GIS software and as the database for the soil survey site profile data and the soil/map unit data accessed using Microsoft ACCESS 'front ends' and a SITES (Soil Information Transfer and Evaluation System) data model.

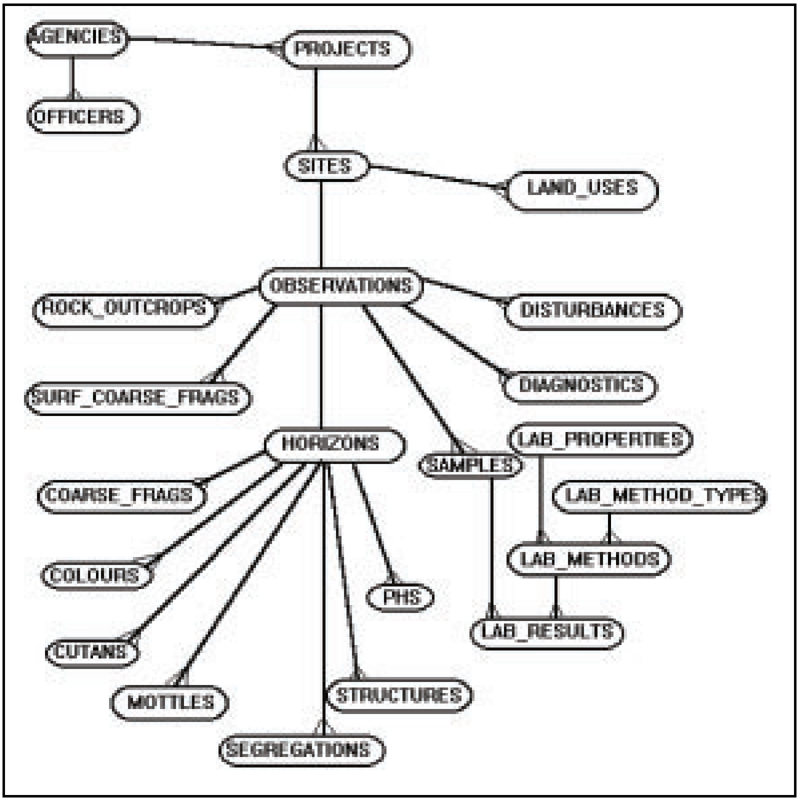


**Figure 2:** Schematic structure showing the relationship between the main tables in the site profile database. These tables are related to soil description categories, for further information on these technical terms refer to KISR 1999c.

The SITES data model provides an interface to enable the data entry of field-recorded data. The model is a PC application that uses ACCESS as an interface to the relevant tables in the Oracle database. The software provides data entry, query and reporting capabilities. It is based on the SITES data model described by Peluso & McDonald (1995) and produced by the Australian Collaborative Land Evaluation Program. Modifications have been made to codes and additional data fields added to cater for the United States Department of Agriculture system (Soil Survey Division Staff, 1993) and Kuwait characteristics; the details are in KISR (1999c). Within the Oracle database, tables hold the base data in columns; the relationship between the main tables for the site and soil profile data is shown in Fig. 2 and for the soil/map unit data in Fig. 3.

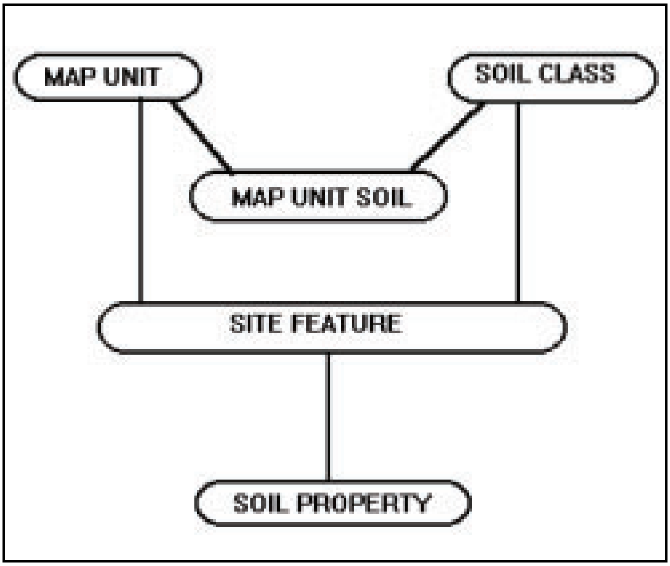


**Figure 3:** Relationship between the tables in the soil / map unit database.

## Soil Survey data linkages in the Soil Information System

To identify, display or interpret survey data, it is important to understand relationships between all the component data fields in the soil information system. In the case of the soil survey for the State of Kuwait, these are portrayed in Fig. 4. There are four main components of data:

- Soil maps
- Soil profile descriptions
- Soil taxonomic description
- Soil map unit descriptions

Within these components, there are data fields that contain large data sets of information. Some of the key data fields and the linkage between them are shown in Fig. 4. An understanding of this data structure and its linkages is essential to fully understanding the interrelations of the information generated by the soil survey. The system also facilitates the use and application of the survey information for land use planning purposes.

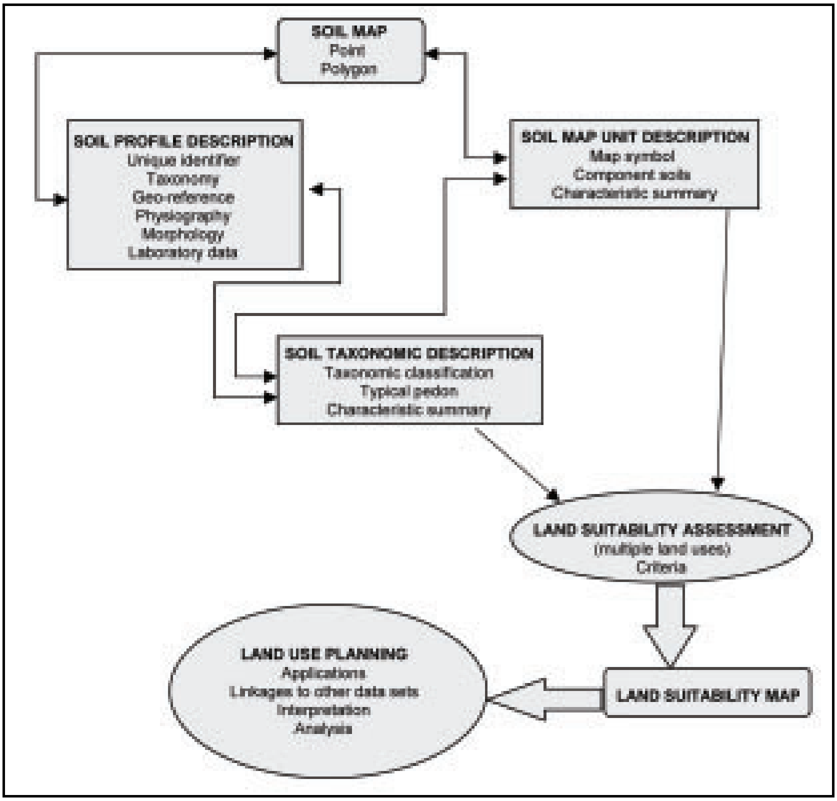


**Figure 4:** Linkages between components of the soil information system and the key data fields. The data flows show how information can be used to produce land suitability assessments and maps for planning purposes.

## COLLECTING THE DATA

The general procedures and protocols followed throughout the soil survey project are described elsewhere in standard references: the Soil Survey Manual (Soil Survey Division Staff, 1993), the National Soil Survey Handbook (Soil Survey Staff, Soil Conservation Service, 1993) and Keys to Soil Taxonomy (Soil Survey Staff, 1994). Specific procedures and tailoring of the soil survey for Kuwait conditions are described in KISR (1999c). The net result was that the methods used represent international best practice.

All information relating to the soil profile and surrounding environment was recorded in the field by soil surveyors onto site cards as codes, then later keyed into the project soil information system, followed by systems checks for data integrity. From the field information, map unit descriptions and soil class descriptions were generated and held as text and code fields in the database. The soil surveyors used field and photo interpretation evidence to plot map unit boundaries onto satellite images. The line work delineating map unit areas was digitized and stored on the project GIS for manipulation and presentation.

The soil information system was established and commissioned during the Soil Survey for the State of Kuwait project; results of the data and map interpretations for this project are presented in KISR (1999a & 1999b). For this Kuwait map data all information was compiled on a Universal Transverse Mercator projection for Zones 38 and 39. The soil survey was conducted in two parts: a reconnaissance survey throughout all of the State at a map scale of 1:100,000, and a semi-detailed survey for 200,000 hectares selected as potentially suitable for irrigated agriculture at a map scale of 1:25,000. The soil information system is populated with the survey data and includes about 24,500 sites, and each site contains between 20 and 400 separate fields of information with a total estimate of about five million data records. In addition to the site data, there are 73 reconnaissance scale and 93 semi-detailed map unit descriptions, 24 soil family descriptions, 39 soil series descriptions, and approximately 48,000 laboratory results from 153 sites. The spatial database contains maps produced for soil, vegetation and land use for the State of Kuwait at a scale of 1:100,000, and soil maps at a scale of 1:25,000 for selected areas within Kuwait; a total of 85 maps are cartographically generated for production. Mapped information for more than 30 different land use interpretations at different map scales have also been generated in the GIS.

Additional information has been imported into the soil information system from other sources. These include the Kuwait map grid, cultural features, roads, tracks, water courses, water field locations and topography information such as contour lines and spot high elevations. Satellite imagery from Landsat Thematic Mapper in March 1995 was rectified and enhanced prior to incorporating for use.

## INFORMATION OUTPUTS

A standard report for each of the data components allows information to be retrieved and decoded from the soil information system to provide printouts for the soil profile description, soil taxonomic description and map unit description. All maps have been cartographically prepared and stored, a reduced version for one of the nine reconnaissance maps is shown in Fig. 5.

These standard reports and maps can be modified to provide outputs tailored to the users' needs. User defined queries can also be made via ACCESS query functions using the SITES data model framework.

The value of soil survey data is realized when it is interpreted to provide information to assist with land use decisions. To do this, land suitability assessment is conducted by applying criteria to the soil and map unit

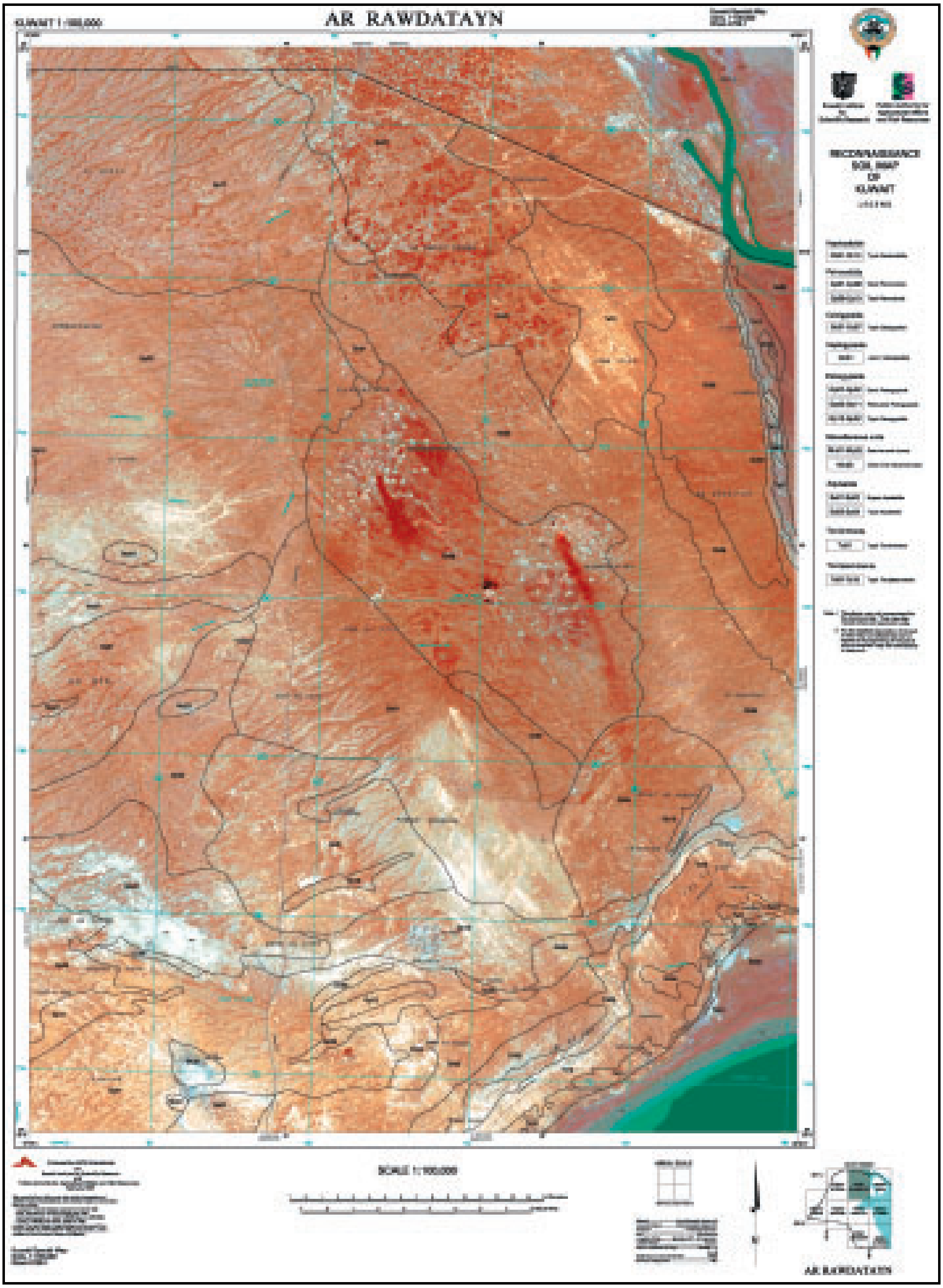


**Figure 5:** An example of a reduced 1:100,000 soil map printed from the GIS.

descriptions. The criteria are usually specified in a tabular format showing relevant soil properties and their suitability ranges. By allocating the suitability rating determined by the criteria for the soil in each map unit, a land suitability map based on the interpretation can be generated.

## Worked example

The linkages of the database components are shown in Fig. 4, which illustrates how data in the soil information system can be compiled to produce interpreted outputs that will assist with land use planning. As an example the land suitability for camping recreational areas in Kuwait is presented here. A criteria table (Table 1) was defined and described in the report Soil Survey for the State of Kuwait (KISR, 1999a). The criteria table was applied to each of the soil property classes to determine the most limiting rating for each soil. Map units are often composed of a number of soils; therefore, the rating applied to the map unit was obtained from the rating of the major soil component. These map unit ratings are allocated to the geographic soil map units in the GIS to produce the suitability for camping recreational areas (Fig. 6).

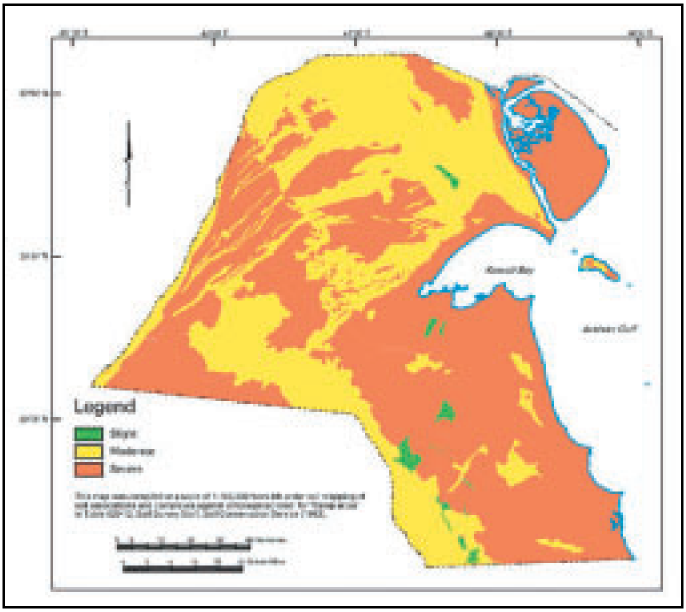


**Figure 6:** Land suitability map for camping recreational areas in Kuwait.

This output is dependant on the criteria used and, if they were modified to test a different scenario or alter the property ratings, then a new map could easily be generated. This is the power and benefit of holding primary data in a computer database that allows the use of the information to be revised and updated with time when new ways of handling or interpreting it become available.

Interpretations for a selected number of land uses have been produced and are in the soil information system. The criteria used, tabular results, explanation of the results and summary maps are in KISR (1999a and 1999b) for: recreation, urban development, construction material, sanitary facilities, and afforestation and range management. Additional interpretations can be produced for any land use if the criteria is defined and the data available.

**Table 1:** Criteria for rating recreational camping areas in Kuwait.

| Rating Criteria* | Slight Limitation | Moderate Limitation | Severe Limitation | Restrictive Feature |
|---|---|---|---|---|
| Texture modifier (surface layer) | -- | 35-60% stones; 35-60% boulders; 0-35% cobbles; 0-35% flagstones | > 60% stones; > 60% boulders; > 35% cobbles; > 35% flagstones; > 60% channers. | Large stones |
| Texture (surface layer) Aridic Suborders, Great Groups and Subgroups | -- | silty clay, clay | -- | Too clayey |
| Texture (surface layer) | loamy fine sand; loamy sand when finer material is < 50cm deep | loamy coarse sand; very fine sand; loamy fine sand; loamy sand. | coarse sand; sand; fine sand. | Too sandy |
| Texture (surface layer) Aridic, Great Groups and Subgroups | -- | silt loam; silt; very fine sandy loam; loam | -- | Dusty |
| Flooding | None | -- | rare, occasional, frequent | Flooding |
| Slope | < 8% | 8-15% | > 15% | Slope |
| Ponding | -- | -- | Yes | Ponding |
| Depth to high water table | > 75 cm | 45-75 cm | < 45 cm | Wetness |
| Stoniness class | stony | very stony | extremely stony, rubbly, rockiness | Too stoney |
| Weight percent 2-75 mm (surface layer) | < 25% | 25-50% | > 50% | Small stones |
| Permeability (0-100cm) Aridic Suborders, Great Groups and Subgroups | ≥1.5 mm/hr | < 1.5 mm/hr | | Percs slowly |
| Unified (USCS) (surface) | -- | -- | peat | Excess humus |
| Depth to Bedrock | -- | -- | < 50 cm | Depth to rock |
| Depth to Cemented Pan | -- | -- | < 50 cm | Cemented pan |
| Sodium Adsorption Ratio | -- | -- | > 13 | Excess sodium |
| Salinity (surface layer) | < 4 dS/m | 4-8 dS/m | > 8 dS/m | Excess salt |
| Soil reaction (pH) | -- | -- | < 3.5 | Too acid |

* Adapted from Tables 620-12, Soil Survey Staff Soil Conservation Staff (1993) for Kuwait conditions.

## CONCLUSIONS

The soil information system integrates a geographic information system (GIS) and database to provide a complete compendium of soil resources in Kuwait in a digital format that can be readily used as baseline information for land use planning. The outputs are extendable and re-usable by a wide range of organizations both within and outside Kuwait. The GIS and database of information have many other possible uses, including providing data for environmental assessment, providing information for land use planning, providing the basis for farm planning and irrigation and water management, providing the basis for further research, and for contributing reference data to international protocols and agreements. The worked example for areas suitable for camping identifies the best camping areas

The value of the soil survey information is derived when it is used to generate outputs that can be interrogated to support investment decisions, policy-making and risk management for land development in Kuwait.

The design of the soil information system deliberately allows for incorporation of other environmental and land resource map and text data sets, and for interpreting them (via the information system) to produce interpretations for a wider range of environmental and land use queries. Furthermore, it provides the basis for a general environmental database for Kuwait.

## ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the Public Authority for Agriculture and Fish Resources (PAAFR) who funded the Soil Survey for the State of Kuwait project, Kuwait Institute for Scientific Research (KISR) and AACM International who managed and conducted the work. Also, Les Heinrich Greg Mlodawski, Phil Goulding (from Agriculture Western Australia), and Ruel Dimaculangan (from AACM) who commissioned and operated the soil information system for the State of Kuwait project, and Martin Andrew (from AACM) for providing comments on this paper.

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***Submitted :*** *11/11/2001*
***Revised :*** *2/12/2003*
***Accepted :*** *10/12/2003*

# نظم معلومات جغرافي وقاعدة معلومات حول مسح التربة في دولة الكويت – تصميم ومخرجات

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## خلاصة

تم إعداد وتصميم "نظام معلومات التربة"، كجزء من مشروع مسح التربة في دولة الكويت لإدارة المعلومات المستقاة من المشروع والتأكيد على الاستفادة القصوى من المعلومات المتاحة في مجال تطوير الأراضي لدولة الكويت. ويرتبط نظام معلومات التربة ببرنامج نظم المعلومات الجغرافي القادر على عرض المناطق والبيانات وتحديد مواقعها في نطاق واقعي وتنظيم قاعدة بيانات وتخزينها وتحليلها.

وهذه المعلومات مصدراً هاماً لدولة الكويت حيث تعتبر أول قاعدة بيانات يتم إنشائها عن التربة، كما توفر معلومات تفصيلية عن الأراضي في دولة الكويت تم تطويرها في برامج إلكترونية مبرمجة، ويحتوي نظام معلومات التربة جميع البيانات التي تم الحصول عليها في المشروع، ويمكن التوسع في هذه المعلومات نظراً لمرونة البرنامج وقدرته على تحليل المعلومات. وتم الانتهاء من المشروع واستكمال نظام معلومات التربة في عام 1999. وتحتوي الورقة على معلومات عن هذا النظام وكيفية تصميمه واستخدامه مع عرض بعض الأمثلة لكيفية استعمال المعلومات وتحليلها في تحديد مواقع لاستخدامات مختلفة. كما تعرض الورقة مجال الاستفادة المستقبلية من معلومات التربة لاستخدامها في اتخاذ قرارات ومناقشة إعداد السياسات لإدارة المخاطر المتعقلة باستخدامات الأراضي وتنميتها.

**الكلمات الدالة**: بيانات بيئية، GIS، مصادر أرضية، نظام المعلومات.