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Application of GIS and Remote Sensing for Land Use Planning in the Arid Areas of Jordan

PhD Thesis

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Abstract

Land suitability analysis formed part of a land use planning exercise in a development project aimed at improving agricultural productivity in the transitional Badia region of Jordan. Soil observations and soil maps were available at three levels of detail with differing coverage: level one (1:250,000 scale –complete cover), level two (1:50,000 scale – part cover) and level three (1:10,000 scale very limited cover). The development project selected the FAO Framework for Land Evaluation as the basis for land suitability analysis. This research investigated seven different calculation approaches for the processing of soil observations within soil map polygons using a GIS to derive land suitability ratings. These methods either use the soil observations to calculate the suitability of each soil mapping polygon or an interpolation technique (Voronoi diagram or Triangulated Irregular Network) between observation points. The overall map purity and homogeneity with respect to land characteristics were used to evaluate these methods. The quality of suitability maps varied according to the level of soil mapping and the method of processing the soil observations. The relative performance of the processing methods is discussed and recommendations for each level of mapping are proposed. The results showed that the purity of suitability maps was between 60 and 70% at the highest level of detail. Thus they should be used with caution for site specific analyses. Statements of map quality should be appended to suitability maps.

The soil maps and observation points were derived and collected in a previous soil survey programme and georeferenced by map reading before the widespread availability of the Global Positioning System (GPS). When the data were integrated and overlaid on a satellite image within a GIS, a number of inconsistencies in georeferencing the data and in the attributes attached to them were revealed. Investigation and correction of these evolved into a major component of this work.

Systematic errors caused by the use of different datums to georeference soil maps and observation points in the Jordan Soil and Climate Information System (JOSCIS) were detected. The map reading procedure also caused unsystematic errors in the locations of soil observations, which were re-measured at a sample of original observation sites using GPS. The correction of the unsystematic errors was not feasible due to the difficulty and cost of relocating all observation points. Errors in the attributes attached to the observation points were caused by survey recording procedures, highlighting the need for an examination of the data before analysis. The systematic and attribute errors were corrected and the implication for suitability analysis examined. The areas and spatial distribution of different suitability classes were affected increasingly as the level of mapping became more detailed. The presence of all these errors was sufficient to create errors in the derived land suitability maps, which could lead to incorrect land use planning decisions. The integration of satellite imagery, soil observations and soil mapping polygons within a GIS was indispensable for quality control of the data.

The highest purities of suitability maps using existing soil mapping polygons were between 60% to 70% at level three but they only covered very limited areas. This indicated the need to extend mapping at this detail for site-specific planning and if possible, to increase the purity of soil mapping units. This was investigated by integrating satellite imagery and topographic data in a GIS.

A 3-D perspective view of a Landsat TM image using an air photo-derived DEM was the most promising way of using the available data. Further research is needed to investigate the interactive use of air photo-derived DEMs and Landsat images, with more focus applied to site specific planning and field verification of the technique.

Although this work was necessarily focussed on the issues and problems particular to one data set used in a Jordanian context, a number of general lessons have been learned. Firstly, careful examination of all input data is necessary to eliminate georeferencing and attribute errors. Secondly, overlay of input data onto a geocoded satellite image is extremely useful for detecting potential sources of input data errors and is recommended. And thirdly, GIS is indispensable for investigating existing data for errors and exploring new methods of analysis.

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This thesis is dedicated to the memory of Dr. Chris Bird

CONTENTS

Chapter One

Introduction

Background

Agricultural production in Jordan is heavily dependent on rainfall distribution. The total area of the country is about 9 million hectares, of which less than 10% receives more than 200 mm average annual rainfall. This is the limit of rainfall below which stable rainfed crop production cannot be expected. The result is an imbalance between agricultural production and food demand, forcing the country to import more than 70% of its food requirements (FAO 1985). The high average increase in population (over 3% per annum) and the limited area suitable for food production, increases the significance of this problem with time (Jaradat 1988).

Rainfed agriculture is considered an important part of Jordan's agricultural sector. However, the suitable area for this use has limited land and water resources. To improve the agricultural production, an expansion in cropped land is required. This expansion has to include the marginal areas which receive 100–200 mm of annual rainfall, and occupy about 13% of the total area of the country, defined as the arid to semi–arid zone. These areas support grassland and brush species, and are traditionally considered as a grazing area. Cereals and legumes are planted in some years, but with a low production capacity, about 10 kg barley/donum (100 kg barley/ha) (Tadrus 1984, MoA 1995). The area is characterised by a very low average annual rainfall with variable distribution and a degraded vegetation cover, which promotes the erosion of surface soil layers (Taimeh 1989). There is an urgent need to improve the productivity of land in these areas and at the same time to sustain the limited land and water resources. This requires comprehensive land use planning that is based upon a scientific assessment of the limited and fragile resources in the area (JAZPP 1997).

Jordan Arid Zone Productivity Project (JAZPP)

To cope with these challenges and problems, the Jordan Arid Zone Productivity Project (JAZPP) started in October 1994. The main objective of the project is to provide a basis for optimal use of the limited resources of land and water in the arid to semi–arid zone of

Jordan. This will contribute to the sustainable development of the region, through the promotion of improved techniques for producing crops and livestock, the formulation of land use recommendations that optimise the low rainfall amounts, and finally, transfer of technology. The project is structured into four broad areas of activity: land use planning; water utilisation techniques; farming system improvement; and technology transfer. These activities are subdivided into 12 components (Figure 1), which start with the evaluation and compilation of available land and water resources data and the understanding of catchment hydrology. The JAZPP area has been divided into hydrological catchments considered as the basic units for land use planning. These catchments need to be characterised in terms of land and water resources as well as socio–economic conditions. Cost/benefit analysis for some proposed interventions is obtained from two components: better water utilisation and more productive farming systems. The environmental impact and socio–economic acceptability components are designed to assess these interventions. An implementation of any promising interventions validated by the above components will be considered when finalising the outcome of the project, land use planning recommendations and technology transfer (JAZPP 1997).

This thesis contributes to the land use planning activities of JAZPP, mainly through two of the components: the Natural Resources Database and GIS, and the Land Use Planning Recommendations. The objectives of the former are to combine the available natural resources data into a suitable format and make them ready for use by the other components of the project, especially the land use planning recommendations component. The natural resources data are available in different format and collected from different sources. The integration of this data in a useful database needs a critical evaluation of the data.

The land use recommendations component models the physical and socio–economic resources of the area at three levels:

- the whole project area; to assist strategic planning
- individual catchments; to recommend the best use of land and water resources
- individual land holdings; to develop rational land use plans in consultation with the owners.

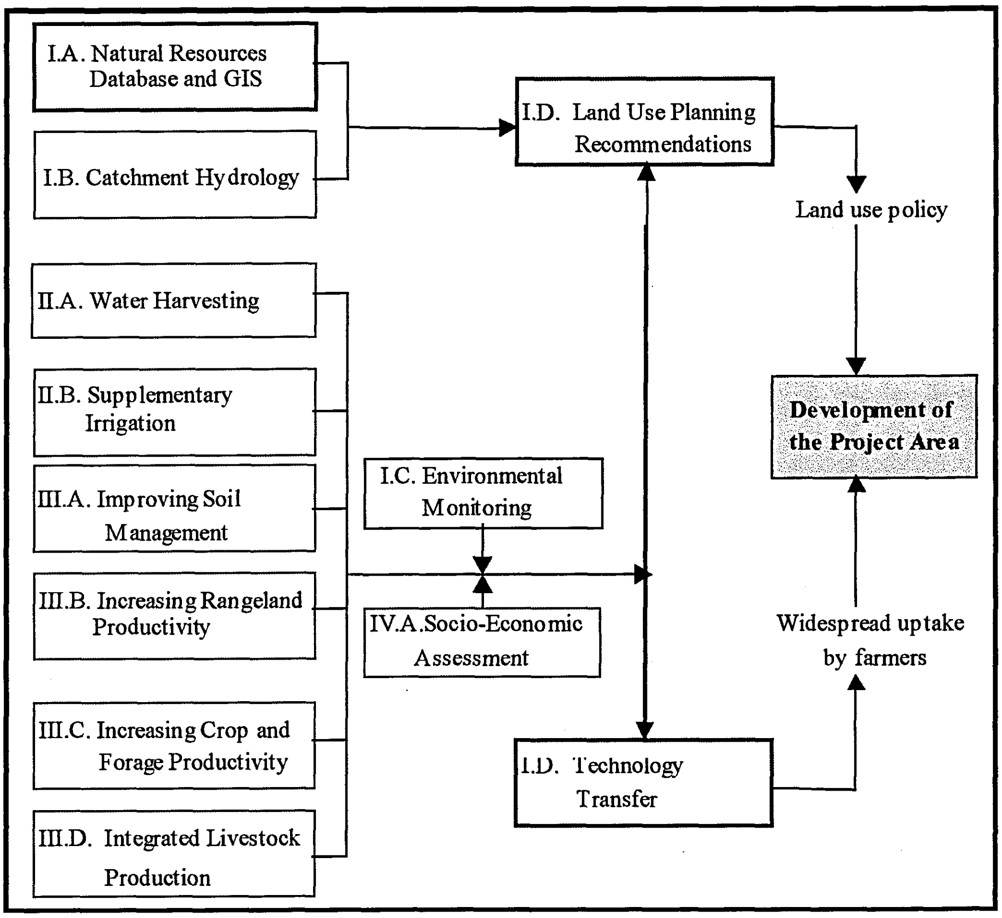

Figure 1 Flowchart of the main components of JAZPP and the ultimate objective. Principle interests of the research are components IA and ID (highlighted).

The starting point for these plans is to assess the land suitability at different scales, using the available information, and undertaking field surveys to collect additional information. This thesis investigates appropriate land suitability methods using the available data. The land use recommendations component within JAZPP developed the land suitability details, including the application of the FAO approach of land evaluation in the project area, which will be discussed later. This research is concerned with the application of this analysis within a GIS context, and the consequences of data integration and management using this technique.

The following sections discuss the selection of an appropriate land evaluation approach, taking into consideration the limitation of data availability and the suitability of the results for land use planning. The nature and limitations of the available data are also discussed to identify the requirements of land evaluation in a Geographic Information System (GIS) context for land use planning.

Land use planning and land evaluation

Decision–makers and planners require information about natural resources that is easily interpreted for the purposes of land use planning. The absence of such information may be the reason for the absence of appropriate land use plans in some countries, including Jordan (Qudah 1983). Soil survey maps and reports along with other natural resources data exist in Jordan, but these do not provide direct guidance on land use planning (FAO 1989, Theocharopoulos et al. 1995). Land use planning tries to make the best utilisation of limited land, water and economic resources, but becomes more difficult when there are region–specific problems, which may have agronomic, economic, social, and political dimensions (Dent 1988, Van Diepen et al. 1991).

Land evaluation represents the first step in the preparation of a comprehensive land use plan. It provides information on the suitability of land for the present and potential uses, which serves as a basis for making decisions about land use and its management, and contributes to the solution of land use problems (Smit et al 1986, Van De Putte 1989, Bronsveld et al. 1994). The land suitability map produced as a result of land evaluation is combined with an assessment of economic, social and environmental factors, to produce a powerful and essential tool for the land use planner and decision–maker (FAO 1989, Van Lanen et al. 1992). This reduces the diversity and complexity of information that the decision–makers have to deal with, improving their effectiveness in the land use planning process (FAO 1993).

The selection of an appropriate land evaluation approach is an important step for the success of the whole planning process. This is because the selected approach has to optimise the use of the available land resources data to produce the best land suitability maps, and at the same time, produce land suitability maps that are easily integrated with the assessment of socio–economic and environmental factors. A review of different land evaluation approaches is presented in the next section, in addition to the rationale for selecting the FAO approach.

Land evaluation approaches

Most of the evaluation approaches can be differentiated as qualitative or quantitative.

Quantitative evaluation depends on detailed technical procedures, which use numerical economic values. Qualitative evaluation is based on simple concepts, that is, an expert's or farmers' knowledge (Sys 1985, Van Lanen et al. 1992). The most important factor in selecting one of these approaches is the availability of data and the possibility of collecting new data. When detailed data is not available, it is more realistic to use the qualitative approach for land evaluation (Goldschmidt and Jones 1988, Rossiter 1996).

One evaluation approach is the Land Capability Classification (Klingebiel and Montgomery 1961). The main objective of this approach is to classify soil mapping units according to the limitations imposed by soil and other physical factors. Hence, it is not related to a particular kind of land use (Rossiter 1994). The final classification of land using this method is based on integrated soil factors, and therefore, the effect of each separate soil factor is not provided. The system considers the capability of the area for a particular use as the most important factor, ignoring other socio–economic factors affecting the use of land (Flaherty and Smit 1982, Van Diepen et al. 1991).

Another example of the qualitative approach is the Soil Survey Interpretation (Aandahl 1958). This method simplifies the information included in a soil map, in order to identify the opportunities and alternatives for the use and management of soil. The disadvantages of this method are that soil maps are based on physical characteristics, which do not incorporate social or economic factors, and the fact that in most cases the way of rating the map unit is not indicated, which makes it difficult to reproduce (Flaherty and Smit 1982). A further example is the Parametric Indices approach (Sys 1985), which requires that each soil characteristic is given a numeric value. These values are combined by adding or multiplying to reach a final rating of the land. For example, the final rating in the case of the Storie Index (Storie 1976) is a ratio scale that goes from 0 (useless) to 100 (excellent land). The reliability of the results is highly dependent on the factor determinants and their weighting. This might lead to misleading accuracy because of the arbitrariness in factor choice and the flexibility allowed when assigning numerical values to soil characteristics. Furthermore, the number of factors that can be incorporated for analysis is limited. These analyses do not allow for the incorporation of social or economic factors (Van Diepen et al. 1991, Rossiter 1994).

The last example is the FAO Framework for Land Evaluation (FAO 1976), which sets out basic concepts, principles and procedures for land evaluation. These are universally valid, applicable in any part of the world and at any level. The framework was developed to help establish the tools for land evaluation. The use of this framework has proved to be beneficial even when there is limited available data about yields and insufficient detailed soil information (Sys 1985, Goldschmidt and Jones 1988, Kassam et al. 1991). The results of land evaluation using this approach were validated by FAO using yield data drawn from many studies, and it was able to predict yield in more than 80% of all crop suitability classes (Hennebert et al. 1996). The framework is distinguished from other land evaluation approaches by the following three points (Van Diepen et al. 1991, Chinene 1992, Rossiter 1994):

1. It evaluates the land separately for each use and then compares the results, while other systems consider the general ability of land.
2. It defines the land utilisation type with a detailed description that is suitable for the level of analysis, which also includes the production system and social aspects. It can identify which land quality is the limiting one, which provides a basis for advising farmers on land management.
3. It considers both qualitative and quantitative evaluation based on the availability of data.

There are other evaluation systems which are a development of the FAO Framework; the international framework for evaluating sustainable land management (FESLM) and the automated land evaluation system (ALES). The FESLM seeks to connect all aspects of the land use under investigation with the multitude of interacting conditions; environmental, economic and social, which collectively determine whether that form of land management is sustainable. The framework provides a systematic basis for a generalised approach to sustainability investigation, achieved by selecting and conceptualising the more significant influences on environmental change. Sustainability in this context can be considered as an extension in time of the concept of suitability. The framework includes two main stages. The first stage, with two levels (objectives and means), defines the purpose of the evaluation or what is to be evaluated. The second stage, with three levels (evaluation factors, diagnostic criteria and indicators and thresholds), defines the process of analysis or how the evaluation is done. Land evaluation results of the FAO framework form a starting point for the sustainability evaluation within this framework (Smyth et al. 1993).

ALES is a computer program that allows land evaluators to build their own knowledge-based systems with which they can compute the physical and economic suitability of land map unit in accordance with the FAO's Framework for Land Evaluation. The system includes three steps; model building, decision tree and economic analysis. In the model building, the evaluators compute and display evaluation matrices, which show five kinds of ratings, namely: physical suitability subclasses, economic suitability subclasses, predicted gross margin, expected yield or other outputs, and ratings for single land qualities. The model facilitates the easy alteration of parameters to enable the preliminary model to be refined iteratively. The model builder constructs the decision trees, and they are traversed by the program to compute an evaluation using actual land data for each map unit. The advantage of the decision trees is that both the model builder and the user have an explicit representation of the reasoning process used to reach a decision. In the economic analysis, ALES compares land use options by gross margin analysis. Predicted yields are multiplied by output prices to determine cash values. Outputs can have negative values, so that, for example, loss of topsoil could be reflected in the economic calculation (Rossiter 1990).

Selection of the FAO approach

The selection of the FAO approach for land evaluation in this research was based on the following rationale:

1. The FAO framework considers it necessary to make a description of all land utilisation types relevant to the area. This includes all the characteristics of the production system and social context that influence suitability. This description is very important for the completion of the socio–economic analysis aspect of the JAZPP, which will follow the physical assessment in order to produce suitable land use planning recommendations. The framework facilitates the application of either the FESLM or ALES in later stages in order to produce comprehensive land use plans, as and when the additional data needed for these models becomes available.

2. The method places land resources inventories at the centre of the evaluation process.

This is very important because it requires a comprehensive integration and compilation of different data in a natural resources database.

3. It allows the possibility of choosing either qualitative or quantitative evaluation. This is important because data may not be available to implement a quantitative evaluation, especially at the regional level.

4. The matching process in this approach has an iterative nature; presenting the evaluation results to an expert for field validation reveals whether the results are in agreement with what is expected of the land. This is vitally important since the ratings of different land qualities are mainly based on experience and judgement in the project area. This is considered a quality control measure for the whole evaluation process.

The basic requirements of applying the FAO framework are the selection and definition of land utilisation types for which the land is to be evaluated. The requirements of the land utilisation types are then compared with the land resources represented in the land qualities and land characteristics. The following two sections discuss these requirements in detail, and how the FAO framework has been applied within JAZPP.

Selecting land utilisation types, land qualities, and land characteristics

The land utilisation type (LUT) is land use defined in more detail than generic land use categories, according to a set of technical specifications in a given physical, economic and social setting (FAO 1983). The selection of LUTs is a very important part of the land evaluation process using the FAO framework. The results of land evaluation will be determined by the relevance of this selection as measured against the expectations. It seems that there is no structured methodology to select LUTs for a certain area. The guidelines offered are the different factors that determine alternative land uses, namely: existing land use, the prevailing rainfall and other climatic elements, physical and chemical characteristics of soil, the wishes and preferences of farmers, and other social and economic conditions necessary for their success (Rondal 1985, Van De Putte 1989).

In the FAO framework the requirements of each land utilisation type should be matched with the available land resources. In this matching process, land resources are described as land qualities, for example, water availability and rooting conditions. Land qualities are the result of interaction between a series of land properties which have a direct influence on land capability for a specific use (FAO 1975). Land qualities are derived from land characteristics which are discussed below. The advantage of using land qualities is that they have a distinct influence on a specific kind of land use. This is independent from other qualities, i.e. there is no interaction between different qualities, which allows each quality to be related to an economic value in the case of economic evaluation (FAO 1976, Van Diepen et al. 1991, Rossiter 1995).

Land characteristics are measured or estimated attributes of land that are used directly in the matching process. However, they can be difficult to use due to the interactions between land characteristics and the fact that their number will often be large (FAO 1976, Van Diepen et al. 1991). Usually, there are no published references to aid selection of land characteristics or to identify limits between factor ratings; this largely depends on the specific setting of the area, as well as the crops to be grown. National or regional manuals, local experience, and professional judgement should be consulted in carrying out this exercise (FAO 1983, FAO 1989).

Application of the FAO Framework within JAZPP

Land use planning within JAZPP utilises a model which seeks to optimise the land, water and economic resources. There are three basic requirements of this optimisation model:

1. The identification of the maximum available/suitable area for each land utilisation type, or simply a land suitability map
2. Economic assessment (cost modelling)
3. Hydrology (catchment parameters).

The selection of the land evaluation approach which satisfies these requirements, forms an important part of the land use planning process within JAZPP. The proposed approach should start with an evaluation that classifies the land based on its physical suitability for the proposed land utilisation types, which will provide estimates of the maximum available/ suitable area for each type. This should also provide a description of the relevant land utilisation types in terms of socio-economic requirements. The next step is the socio–economic analysis of these land utilisation types, based on the above description and the existing socio–economic situation within the project area. The integration of socio–economic analysis with the physical evaluation will be the main activity of the land use planning recommendations component of JAZPP. However, the methodology and details of this integration have yet to be fully developed within the project.

Selection of land utilisation types

There are a number of constraints that should be kept in mind regarding the use of land in the project area, when new land utilisation types are proposed. The most important of these are: low rainfall, high rainfall variability, land degradation and social and economic acceptability (JAZPP 1997). The low rainfall within the project area is not able to sustain any kind of normal rainfed cultivation. Therefore, specific management practices have to be introduced to improve the productivity in the area; the management of water resources is one of the most important practices. The area in general is suitable for crop production if water is available. This is evident from crop production data in some areas where runoff is naturally concentrated, and from research results in the Al–Muwaqqar project (JAZPP 1997, Hatten 1998). Water harvesting has been recognised as one promising tool for supplying and managing the water resources (Makhamreh 1996). This should be coupled with extension and back–up activities for the farmers, provided by the Ministry of Agriculture. Based on the above assumptions, nine land utilisation types were defined as being applicable in the project area (Appendix A). The basic factors in defining these land utilisation types were the method of water harvesting, method of water spreading or application and type of crop to be grown (Hatten 1998).

Selection and rating of land qualities and land characteristics

The selection of land qualities and rating of criteria for land suitability classification were based on agronomic experience at experimental stations and existing farms within the project area. The important consideration in this selection was the effect of these qualities on the use of land within the project area. Based on these considerations, six land qualities were determined to be matched with the requirements of the ten land utilisation types, these are climate (c), soil (s), erosion (e), topography (t), rock outcrop/stones (r), and infiltration (i). Past experience in selecting and rating land characteristics in Jordan, within the National

Soil Map project (MoA 1995), was utilised to select fifteen land characteristics. These were used to characterise and measure the effect of the six land qualities on the use of land. The primary source of information for these land characteristics is the Jordan Soil and Climate Information System (JOSCIS), a relational database containing detailed soil survey data that forms the basis of soil mapping for the whole of Jordan.

The socio–economic requirements of these LUTs are described in Appendix A. The requirements for each LUT were used to cost the agricultural and field operation, which was then added to the capital costs of infrastructure (dam, weir and irrigation) to derive the total capital cost. The calculations are based on an interest rate ranging from 5 to 15%. The gross value of production is calculated from the estimated mean production benefits. It is assumed in JAZPP that the approximate yield of the moderately and marginally suitable land is 65% and 40% of the highly suitable land, respectively. The gross margin of each LUT is then calculated after considering the costs of labour (Hatten 1998).

Jordan Soil and Climate Information System (JOSCIS)

For the purposes of land suitability calculation in Jordan, there is a large quantity of data available from the National Soil Map and Land Use Project (MoA 1995). This data exists as original paper maps, tables and digitised information entered into the JOSCIS database, which was completed in 1995. The most important data in this database, for this research, are the soil maps, at three different levels of detail, and the soil observations associated with this mapping. The three levels of soil mapping are (Figure 2):

1. Level one reconnaissance (land system/land unit) mapping (scale 1:250 000), available for the whole JAZPP area.

2. Level two semi–detailed mapping (scale 1:50 000), available for about 16% of the JAZPP area.

3. Level three detailed mapping (scale 1:10 000), available for a small area in the northern part of the JAZPP (Mafraq area).

The database also contains a record of some 41 613 soil/site observations, collected during the three levels of soil survey. For each site a comprehensive list of attributes is recorded, including important variables regarding soil survey (MoA 1995). These observation points can be related to soil and topography maps, since each data point has geographic coordinates recorded in the database. However, this data was collected and georeferenced using traditional methods of identifying points on the base maps. The use of this data within a GIS environment requires critical consideration of certain aspects, for example the accuracy, scale and currency. More discussion on these considerations, and the role of GIS in land use planning, is presented later.

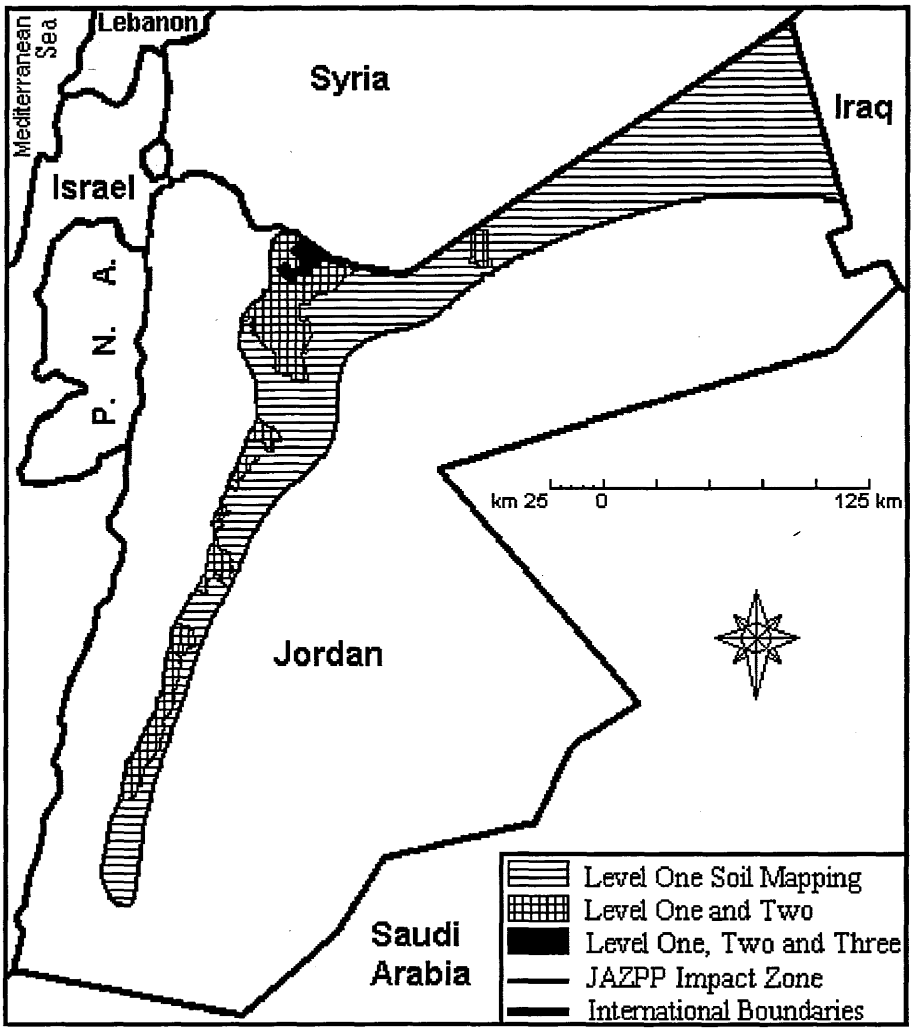

Figure 2 Extent of three soil mapping levels within the JAZPP impact zone.

Other available land resources data

The preparation of the suitability maps as well as the other steps needed to characterise the water and socio–economic resources, require the integration of all relevant data about the natural resources in the area. This data comprises a wide range of land resources information from various sources. Soil data exists as soil maps in digital and paper formats, at different scales, together with field observation points used to characterise the soil mapping units. Climatic data are supplied as maps, for example rainfall maps, and as tabulated data from meteorological stations. Other important data are also available, such as groundwater data, geology, present land use and ownership. As this data is provided from different sources and were collected for different purposes, there are a number of important differences between them. Of particular importance, is the scale of each dataset, the georeferencing parameters (projection system), and the date of collection. These considerations are particularly important when the data are to be integrated with each other for land use planning purposes.

GIS provides a powerful tool for integrating and analysing this data (Goodchild 1993). However, there are some problems associated with this approach, for example, the use of data collected before the development of GIS which may not be in a suitable form for GIS analysis. This data was used mainly for tactical planning, and for most of the time was handled as separate layers of information (Hardy 1987, Bolstad and Smith 1992). It was difficult to overlay paper maps and consequently the accuracy of that data was often considered acceptable. When this data is integrated with other data in a computer, considerations of accuracy become more crucial (Zhou et al. 1991, Brunsdon and Openshaw 1993).

Geographic Information Systems and land use planning

Geographic Information Systems (GIS) are becoming a very important tool for land use planning. This is due to the capability of these systems to provide different functions, which benefit land use planning activities. Of these functions, the most important are the database management (data integration), cartographic analysis and modelling functions. The ability to integrate data within a GIS is one of the most important features, bringing together data from different sources, formats and scales, and making them compatible with each other (Flowerdew 1991). One striking feature of integrated data is the ability to present different layers of information at the same time, which can help planners and decision makers (FAO 1989, Brunsdon and Openshaw 1993). This facility for integrating data is also supposed to eliminate the problems caused by differences in georeferencing between datasets. However, the question of the compatibility of the original datasets should always be kept in mind, because the quality of the integrated dataset depends, in the first instance, on this compatibility (Zhou et al. 1991, Bronsveld et al. 1994).

The other unique function provided by GIS is the cartographic analysis of different data layers. Once these layers have been integrated in a GIS environment, overlay analysis to produce new layers of information, is a relatively easy task. This facility can improve the accuracy and reduce the time required to undertake these analyses, compared to traditional methods (Hammer et al. 1991). An example of using this function is the overlay of different layers representing land characteristics to produce a land suitability map for each land utilisation type. Furthermore, these land suitability maps can be overlaid with each other to produce a suitability map which shows the best use of each area of land (Shankarnarayan et al. 1983, Theocharopoulos et al. 1995). Again, the accuracy of these overlay analyses is dependent upon the accuracy of each of the original layers and the compatibility of these layers with each other (Kiiveri 1997).

The modelling functions provided within GIS can benefit land use planning by providing the ability to analyse and model data layers by automatic means. Once a model has been constructed and validated, the repetition of the analysis, as assumptions and/or conditions change, is a quick and easy task. This function also provides an interface between GIS and other modelling software which can integrate non–spatial data (Hammer et al. 1991, Burrough and McDonnell 1998). For example, suitability maps can be integrated with non-spatial data, such as socio–economic data, to model the effect of these data on the land use. This link between the physical and socio–economic data of an area can be modelled more accurately within GIS, compared to traditional methods of analysis.

These functions of a GIS can save time and cost in the evaluation of land use options, data management and presentation, when compared with conventional means (Hammer et al. 1991). To illustrate the possible role of GIS for updating and manipulating land evaluation results, an example can be used from Jordan. Land suitability evaluation for different land utilisation types was carried out in Jordan as a part of the National Soil Map and Landuse Project (MoA 1995). The land suitability maps of these analyses are presented as hardcopy attached to the soil survey albums. This information as such can only be used at the published scales, and for the same selected land utilisation types and suitability ratings.

Updating or manipulating this data in this form is a very difficult task, and the correction of any errors is impossible or very costly (Theocharopoulos et al. 1995). Furthermore, the integration of data in this format with hydrological or socio–economic data is very difficult.

Data integration within a Geographic Information System

When data are to be integrated for land suitability analysis, there are two important issues to consider: the quality of each input dataset, and the compatibility of different datasets with each other. Compatibility issues to be considered include: geometric accuracy and the accuracy of attributes attached to each geographic entity. The geometric accuracy is a measure of how well the position of an entity in the map is located with respect to its position on the ground. Despite the importance of this issue, it has received little attention in the analysis and characterisation of errors in GIS. This may be because the process is complicated and the definition of ground truth per se is sometimes uncertain. However, the recent advances in the use of Global Positioning Systems (GPS) facilitate the characterisation of these kinds of errors (Dodson and Hains–Young 1993, Burrough 1995).

The accuracy of each dataset is important, but the most important element is the compatibility of different datasets with each other, i.e. the relative location of each layer with respect to other layers. One fundamental feature of compatibility between datasets is the specification of the projection system used to georeference each layer (Flowerdew 1991, Congalton and Green 1992, Iliffe 1995). The consequences of ignoring these kinds of errors in GIS can be very serious. Analysis based on such information produces poor quality results, which might give rise to doubts about the accuracy of the whole model. The most important point to stress is the validity of any decision made by interpreting these results, because if errors are made it might be very costly or impossible to change the decision (Burrough 1995, Lewis and Hutchinson 1996). In some cases where certain errors (especially unsystematic ones) are difficult to correct, the reporting of this error is still necessary. This will help planners to make decisions with the necessary precautions and knowledge of the amount and significance of errors in the analysis (Chrisman 1991, Bernhardsen 1992). This requires preknowledge and user awareness of these issues. However, there is still little attention in the literature to the practical implications of such errors in spatial data (Fernandez and Lozano–Garcia 1991, Kiiveri 1997). In addition to the effect of data integration problems on the quality of suitability maps, there are some limitations imposed by the use of soil maps to generate land suitability maps. These limitations and possible ways to improve the quality of suitability maps, using the available soil survey data, are discussed in the next section.

Use of soil maps to generate land suitability maps

It is well known that a soil mapping unit at any scale will contain some impurities. This impurity depends on the mapping scale, intensity of sampling and the quality of soil description (Burrough 1993). When data from many observation points are summarised to give one value for each mapping unit, the resultant suitability map will contain the impurities that the original soil mapping units contained. This might produce suitability maps with significant amounts of error. Since these suitability maps are a basic component of the land use planning exercise, the accuracy of these maps will determine the reliability of the recommended plan.

There are different approaches to the use of observation points and the soil mapping units to summarise the land characteristics within each mapping unit. These approaches include the use of different methods to calculate the suitability from many observation points within soil mapping units, and calculating the suitability from a sample of observation points using GIS interpolation capabilities. The objective of examining these approaches is to improve the reliability of the land evaluation results, by accounting for variability of land characteristics within soil mapping units at different scales. The reliability of a map can be estimated by calculating the map purity and homogeneity (Western 1978, Bregt et al 1992).

Detailed soil mapping for land use planning

Land use planning is usually undertaken at three levels: national, district and village. These three levels frequently use the reconnaissance, semi–detailed and detailed levels of soil survey, respectively. The first level is to contribute to a resource inventory and to identify development possibilities, which often contributes to a national plan. The second level deals with more specific objectives, such as project selection, while the third level is used for farm planning and formulating farmer advice (FAO 1976, Bronsveld et al. 1994). The JAZPP project is applying the third level (catchment level, scale 1:10 000 and 1:30 000) to undertake the actual planning and advisory work with farmers (MoA 1995, JAZPP 1997).

To attain effective planning at this detailed level, an accurate and detailed knowledge of land suitability is required. Soil inventory is one of the most important sources of information for planning the use of land in general, and in particular, in such arid areas (Dwivedi 1985, Lillesand and Kiefer 1994). Unfortunately, soil survey data at the detailed level is only available for a very small area within the project impact zone (Figure 2). Soil survey at detailed levels by conventional methods is costly and time consuming. For example, the production of level three soil maps by the National Soil Map and Landuse Project in Jordan required a detailed interpretation of 1:10 000 aerial photography, manual delineation of slope classes from 1:25 000 scale topography maps, and a very high density of field observation points (MoA 1995). In addition, the availability of large scale aerial photography and topography maps, is questionable due to the cost effectiveness of gathering such data in that area. Therefore, the new advances in remote sensing and GIS might provide a good opportunity to assist in soil mapping.

Remote sensing and Geographic Information Systems for detailed soil mapping

The advances and improvements in satellite images, in terms of spatial and spectral resolution, have been reported to be beneficial for soil mapping by many researchers (Asrar 1989, Biswas and Singh 1991, Chagarlamudi and Plunkett 1993). The usefulness of satellite image characteristics for soil mapping is fully explained in Chapter 4. Arid and semi–arid regions are particularly suitable for the application of remote sensing for mapping and characterising the soils (Barrett and Curtis 1992, Dinc 1993, Leone et al. 1995). Landsat imagery alone might not be enough to produce a soil map, but it improves the time and cost requirements for delineating objects necessary to complete the soil survey (Mulders 1987, Biswas and Singh 1991).

An important feature of the satellite data is its availability in digital format. This encourages and facilitates many activities related to soil survey interpretation and subsequent incorporation into a GIS environment. This includes, for example, visual image interpretation and the capability of direct on–screen digitising to delineate soil boundaries (Derenyi and Pollock 1990, Trotter 1991, Lopez–Blanco and Villers–Ruiz 1995). Despite these benefits, aerial photo–interpretation is still the most popular technique used for soil mapping. This is mainly because of the ability to view terrain features 3-dimensionally, which enables better delineation of soils (Mulders 1987). However, advances in computer analytical procedures facilitate the production of Digital Elevation Models (DEMs) for large and small scales at reasonable cost (Green 1992). This enables either the incorporation of DEM–derived maps as ancillary information with satellite data, or the 3–dimensional viewing of satellite images (Su et al. 1989, Hammer et al. 1991). Both applications are expected to increase the information that can be derived from satellite images and DEMs, and improve the understanding of relationships between landscape elements (Florinsky 1998). However, the incorporation of satellite imagery and DEMs in a full operational context is still an open domain for research (Hinton 1996). The integration of these data is also valuable for activities other than soil mapping, such as the visualisation of an area for more comprehensive land use planning (Hammer et al. 1995).

Aims

The aims of this research are the following:

- To investigate different methods of processing the existing soil data in the transitional Badia region of Jordan in order to produce the best suitability maps using a GIS and the FAO framework.

- To critically assess the quality of the data and the consequences of integrating them within a GIS environment.

- To investigate the use of remote sensing and GIS for creating detailed soil maps, and improving their purity, for the purposes of land suitability analysis.

An international panel of experts was tasked with defining the parameters for land suitability analysis within the land use recommendations component of JAZPP. This included the determination of the land utilisation types, land qualities, land characteristics, thresholds between suitability classes and the details of matching land qualities with land utilisation types requirements. The main concern of this research was the application of GIS and remote sensing to facilitate these analyses and improve accuracy.

Thesis Structure

The thesis consists of this introduction followed by four chapters, comprising four papers that deal with three subjects related to the land use planning in the project area and a conclusion. Three of these papers exist in a format suitable for publication in journals. One paper was published in the Proceedings of the 7th International Congress on Computer Technology in Agriculture, where the author of this thesis was co–author of one part of the paper (Problems finding suitable soil in Jordan). The last chapter discusses the links between the findings of these papers.

The research started with the investigation of different calculation procedures for using soil data in the land suitability analysis as reported in chapter two. During this phase, several sources of errors in the soil database were noticed and investigation of these developed into a major component of this thesis. The soil data was investigated thoroughly with the aid of GIS, remote sensing and GPS, as reported in chapter three. The investigations of calculation procedures were then repeated using the error-corrected soil data and the results are reported in chapter two.

Chapter Two:

Application of GIS for optimising the use of soil survey data for land suitability analysis in Jordan: the subject of this paper is the use of available soil survey data (soil maps and observation points) to produce suitability maps. The paper studies the effect of the survey scale and the intensity of observation points on the quality of the suitability maps produced for different land utilization types. This includes methods which use both soil mapping units and observation points or alternatively the observation points only to calculate the suitability of land for different uses. The quality of the suitability maps produced using different methods is assessed by calculating the purity and homogeneity. The results of these analyses are used to select the best method of suitability calculation at different levels of detail.

Chapter Three:

Detection and correction of errors in soil information using satellite images and GIS: a case study in Jordan: The analysis included in Chapter two required the integration of data from different sources, mainly soil maps at different levels, and the observation points. When these data are integrated and displayed at the same time using satellite imagery as a backdrop, there are clear discrepancies and shifts between the layers. This chapter investigates the possible sources of these errors, provides a method for correcting some sources of error, and discusses the significance of the other (uncorrectable) sources for the quality of the data. The effect of these errors on the suitability maps is also investigated in order to provide a measure of the significance of these errors when using different levels of soil mapping detail.

Modelling for land resource management with remote sensing and GIS: living with confusion and error: This paper provides three examples of dealing with errors in thematic maps and GIS layers used in land resources management. The first two examples illustrate the errors in the classification of thematic maps. This is when digital classification of satellite imagery is used to estimate the crop within the EU Monitoring Agriculture with Remote Sensing project (MARS), and when visual classification of air photos is used to measure the changes in landscape within the National Parks of England and Wales. The paper provides a methodology for unbiased estimates of such kinds of errors. The third example discusses errors in locating soil maps and observation points for land use planning within the Jordan Arid Zone Productivity Project (JAZPP). Although these examples are from different areas of interest, they stress one point: the accuracy of the original data and thematic maps produced from it. Also, when these errors are uncorrectable, the significance of errors and their effect on the accuracy of the results should be kept to a minimum and recorded for future use.

Chapter Four:

Merging Landsat TM imagery with topographic data to aid soil mapping in the Badia region of Jordan: The results of the suitability analysis in Chapter two indicate that the best quality land suitability maps were those derived from level three soil survey (scale 1:10 000), with highest values of map purity between 60% to 70%. The land suitability assessments required for detailed land use planning were also best extracted from those maps. Soil survey at this detailed level is available only for a very limited area within the project zone. The possibility of using the available satellite images (Landsat TM) together with some representation of topography to increase the coverage and if possible, improve the purity of soil mapping for site-specific planning is investigated. This includes the selection of the best band combination of the Landsat TM data and the easiest method of incorporating the topography data with these images. Different methods of representing the topography, together with the Landsat TM image, are compared with the existing soil map at level three. The results and findings of these investigations form the starting point for an integration of image processing capability with GIS for soil survey in the arid to semi–arid region of Jordan. This layer of information is a basic requirement for better utilization of land and water resources in Jordan.

Disclosure

This thesis covers a split research programme undertaken by Feras M. Ziadat during the period 1996-1999. The period was divided between Cranfield University, where the courses, planning for the research, writing up and some analysis were undertaken, and the University of Jordan, where the major research activities were done. During the period in Jordan, the supervisor Professor John Taylor and Mr. Tim Brewer had many visits during which very useful guidance and supervision was provided.

The thesis includes three papers for peer reviewing, to be submitted for publication, and a fourth paper in Chapter three (Modelling for Land Resource Management with remote sensing and GIS: Living with confusion and error), which was published in the Proceedings of the 7th International Congress on Computer Technology in Agriculture. In the first three papers I am the main author and the responsibility for data collection, analysis and conclusions rests wholly with myself. In all these papers the advice and suggestions of my supervisor, in data analysis and the structure of the papers, were very significant. Therefore, he is the first co-author in all of these papers. Also, Mr. Tim Brewer made a very important contribution on these three papers, in data analysis and reviewing the draft of these papers. Therefore he is a second co-author in these papers.

In the fourth paper, I contributed in writing the section 'Problems finding suitable soil in Jordan', where the responsibility of data analysis and results rests with myself. Therefore, I am the second co-author in this paper.

Chapter Two

This chapter contains one paper for peer-reviewing. The raw data used to derive tables and figures for this chapter are found in the attached CDROM. The data exists under the directory chapter2. This includes three directories for the suitability analysis at the three levels of detail.

Application of GIS for optimising the use of soil survey data for land suitability analysis in Jordan

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Abstract: Land evaluation based on soil survey data is required in a study area, which covers the arid to semi–arid (transitional Badia) area of Jordan. Soil maps are available at three levels of detail, with variable area coverage. The FAO Framework for Land Evaluation was selected for land suitability analysis. GIS was used to determine the best of seven alternative methods for using soil survey data. These methods either use the soil observations to calculate the suitability of each soil mapping unit or an interpolation technique (Voronoi diagram or Triangulated Irregular Network) between observation points. The overall map purity and homogeneity with respect to land characteristics were used to evaluate these methods. The quality of suitability maps varied according to the level of soil mapping and the method of processing the soil observations. The relative performance of the processing methods is discussed and recommendations for each level of mapping are proposed. The results showed that purity of suitability maps was between 60 and 70% at the highest level of detail. Thus they should be used with caution for site specific analyses. Statements of map quality should be appended to suitability maps.

Keywords: Land Suitability Analysis, Map Quality, GIS, Soil Mapping Level

Introduction

The transitional Badia region of Jordan receives on average 100–200 mm of annual rainfall and occupies about 13% of the total area of the country (Figure 1). Limited natural resources in Jordan as a whole necessitate the improvement of agricultural productivity in the transitional Badia but appropriate and sustainable land use schemes are required. The first step in their development is the evaluation of the biophysical land resources for different uses. Jordan is fortunate in having a comprehensive soils database, created as part of the National Soil Map project (MoA 1995), containing data on many biophysical parameters relevant to the process of land use planning. The available soils data in itself does not provide proper guidance for land use planners and decision–makers (FAO 1989, Theocharopoulos et al. 1995). Thus, to improve its value in land planning, the data should be presented in such a way that the potential of land for any use is clear and can be interpreted more easily (Hammer et al. 1991).

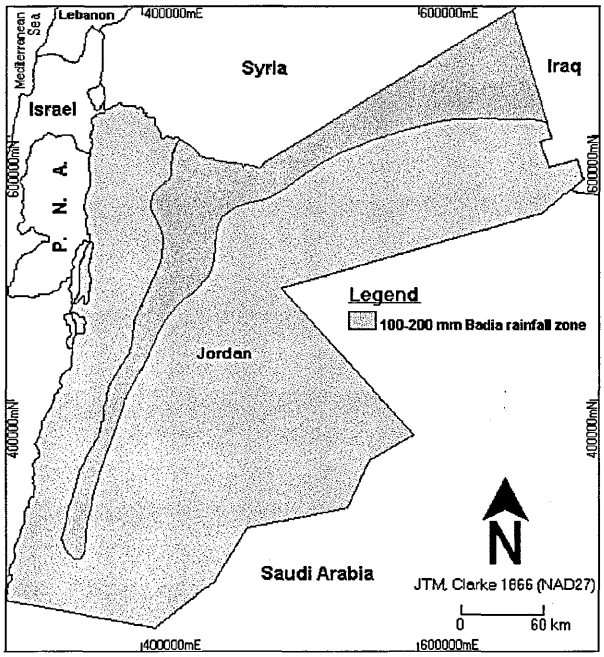


Figure (1) The location of the transitional Badia region in Jordan (100–200mm).

The FAO Framework for Land Evaluation provides a well established method for integrating biophysical and socio–economic data (FAO 1983). The framework states that land use requirements should be matched with land resources important for the use of the land (land characteristics). The structure of the Jordan soils database allows this matching to be done using different approaches in order to produce land suitability maps. There are two broad concepts that can be used. The soil mapping unit can act as a basic subdivision of land, the suitability being assigned to the unit on the basis of the soil parameters at each of several observation points. This raises the question as to what is the best way of aggregating these observations to represent the mapping unit. Secondly, field observation data can be used with spatial interpolation techniques to create suitability maps. In both approaches, the process will benefit from the use of a geographic information system (GIS) through three fundamental processes: database management, computer cartography, and spatial analysis (FAO 1989, Zhou et al. 1991, Theocharopoulos et al. 1995).

The objectives of this study are:

- to suggest different methods of using the existing soil survey data available for the transitional Badia to produce the optimum grading of land suitability;
- to compare the output suitability maps of each method at different scales;
- to recommend the appropriate method(s) for land evaluation in Jordan.

Land evaluation in Jordan

One aim of land evaluation is to provide information on the suitability of land for present and potential uses, which serves as a basis for making decisions about land use and its management (Van De Putte 1989). The FAO Framework for Land Evaluation sets out basic concepts, principles, and procedures for land evaluation. These are universally valid and can be applied at any scale (FAO 1976, FAO 1983, Sys 1985).

The FAO framework has been applied in Jordan in two previous projects. Land suitability evaluation was carried out as part of the National Soil Map (NSM) project. The suitability of land for 5 land utilisation types (LUTs) was evaluated (rainfed arable cultivation, rainfed perennial cultivation, drip-irrigated vegetables, rangeland/grazing, forestry/reafforestation). These analyses are presented as hardcopy maps and tables attached to the published soil survey albums and monographs (MoA 1995). The information, as presented, is only valid for use at the mapping scale provided and for the selected land utilisation types. Updating or manipulating this data requires the manual production of new hardcopy maps each time, which is a difficult task. Furthermore, the correction of any errors in this data is impossible or very costly (Theocharopoulos et al. 1995). The second project, the Jordan Rift Valley (JRV) project, used a similar methodology to the NSM project but concentrated on GIS techniques to undertake the evaluation. The advantage of GIS compared with the database approach is the ability to display and tabulate selected data items within a defined region of interest (MoA 1995, JRV 1998).

The Jordan Arid Zone Productivity Project (JAZPP) is applying the FAO Framework for Land Evaluation in Jordan. The main objective is to provide a basis for optimal use of the limited resources of land and water in the transitional Badia region. One of the major outputs is to provide sustainable land use recommendations. GIS technology is implemented to facilitate the land suitability analysis and the establishment of a land resources database.

Land suitability analysis and soil variation

A common method of assigning land suitability ratings to soil mapping units is to calculate the average and/or modal values of relevant land characteristics from several observation points (Khalil et al. 1995, MoA 1995, Mazahreh 1998, Al-Shoubaki 1999, Rashdan 1999). In general, the rationale for using a soil map for this approach is that the mapping units are considered to be homogenous. In fact, many of the land characteristics vary over a short distance within any mapping unit. For example, Zhou et al. (1991) found a very low agreement (36%) between two basic soil properties (soil development and mode of deposition) when comparing site data and map data. The simplification of this variability into one representative value for the mapping unit may reduce the accuracy of the suitability map and raise questions about the reliability of such maps (Riezebos 1989). A common concept in soil survey is the association of different taxonomic units within one mapping unit. This tends to reduce the agreement between individual site observations and mapped information (Zhou et al. 1991, Burrough 1992). Hence, it seems that the generalisation of information within mapping units is not recommended, especially for large scale mapping (Davidson 1992). However, this generalisation might be appropriate for small scale mapping, because it avoids the presentation and analysis of complex maps. In addition, the detail required at small scale becomes less compared with large scale mapping.

This variability has implications when soil survey data are used for land evaluation purposes. Soil mapping units are classified into suitability classes based on many land characteristics, with a suitability class assigned to each mapping unit. However, this can present a problem. For example, assuming that the purity of characteristic A is 70% and the purity of characteristic B is 80% within a single mapping unit, there is a 50% chance of finding a mis–classified point within the soil mapping unit, if the incorrect points of characteristic A and characteristic B, respectively, coincide (Davidson 1992). This raises the question of how the reliability of the land evaluation can be improved, given the variability of land characteristics within soil mapping units (Riezebos 1989, Burrough 1992, Burrough 1993, Oberthur et al. 1996,).

An alternative approach is systematic, high density sampling to cope with the spatial variability, and the subsequent use of spatial interpolation techniques to map suitability classes. This approach is expensive (Van Kuilenburg et al. 1982, Riezebos 1989). However, this technique will be compared with the alternative of classifying soil mapping units.

Methodology

Soil maps of Jordan are available at three levels of detail: 1) reconnaissance level (level one) at 1:250 000 scale for the whole country; 2) semi–detailed level (level two) at 1:50 000 scale covering about 16% of the transitional Badia; and, 3) detailed level (level three) at 1:10 000 scale for a small area in the northern part of the transitional Badia. The attribute data of soil properties and site characteristics are stored in the Jordan Soil and Climate Information System (JOSCIS), derived from field observations collected during soil survey. The observation points are georeferenced, linking the field data to the digitised soil maps.

Level one mapping was based upon land systems identified by the National Soil Map project, and derived from interpretation of 1:250 000 Landsat MSS imagery and 1:100 000 scale aerial photography. The soil map legend provides the name and mapping code, the soil subgroups which occupy at least 80–85% of the unit (as determined from the observation sites), and, where possible, the distribution of land facets. Level two soil mapping was derived from Landsat TM imagery merged with SPOT PAN where boundaries could be clearly delineated. In areas where delineation was not clear, an overlay of slope units mapped from 1:25 000 topographic maps aided soil boundary identification. A separate overlay showing observation points with the four most important diagnostic criteria for soil mapping (USDA subgroup, particle size class, soil depth, and slope) was also used (MoA 1995). Detailed air photo interpretation was carried out on 1:10 000 scale panchromatic photographs for level three mapping. This was based on topographic features, rock outcrops, and obvious tonal patterns. Slope maps were prepared to aid the delineation of soil mapping units (MoA 1995).

Field observations were collected at different densities for all three levels of soil survey. The type of observation was either a full profile pit description and analysis, or an auger bore as a supplement to the pit data. For each site, a detailed list of attributes was recorded in JOSCIS, including the most important variables regarding soil survey and land evaluation (MoA 1995).

Three LUTs were selected to test various methodologies for assessing the role of GIS in land suitability classification. The soil survey maps and profile data provided the basis for comparison of the methods investigated. Table 1 presents the definition of each LUT in respect of their land qualities and characteristics. The threshold values for each suitability class were considered to be appropriate for the physical conditions in the transitional Badia region.

Table (1) Rating of land characteristics, grouped by land qualities, for the three selected land utilisation types.

Grouping	Land Quality	Land Characteristic	Unit	Field Crops				Tree Crops				Range Crops			
				S1	S2	S3	NS	S1	S2	S3	NS	S1	S2	S3	NS
Climate	Temperature regime	Winter growth potential	Deg. days	>250	<250	<250	<250	>250	<250	<250	<250	>400	>250	<250	<250
	Moisture regime	Precipitation	mm	>200	>150	>100	<100	>200	>150	>100	<100	>200	>150	>100	<100
Soil	Rooting condition	Total productive available moisture	mm	>150	>110	> 75	< 75	>220	>150	>110	<110	>110	> 75	> 50	< 50
		Soil depth	cm	>130	>100	> 70	< 70	>180	>130	>100	<100	>100	> 70	> 40	< 40
Rock Outcrop	Conditions for germination	Stone at surface*: 1. Boulder, Stone, Gravel	%	< 20	< 40	< 60	> 60	< 20	< 40	< 60	> 60	< 20	< 40	< 60	> 60
		2. Rock Outcrop		< 10	< 20	< 35	> 35	< 10	< 20	< 35	> 35	< 10	< 20	< 35	> 35
Topo-graphy	Topography	Slope steepness	%	< 3	< 5	< 7	> 7	< 3	< 5	< 7	> 7	< 7	< 12	< 20	> 20

* This data exists in one field as classes (ordinal data): 1. Boulders; 2. Stones; 3. Gravel; and 4. Rock.

The study area selected contained mapping from all three levels of survey. This enabled a direct comparison of the effect of observation density and level of mapping detail on the final suitability map created from each methodology investigated.

Suitability calculation approaches

Some variables are physical measurements and are continuous within ranges. In such cases, the mean values are meaningful, as are the mode, median and range. Other variables are ordinal (rankings). In such cases, the mean value is not meaningful whereas the mode, median and range are (Bregt et al. 1992).

Each level of soil survey has increasing densities of field observations. Level three survey contains observations taken at all three levels of field survey whereas level one data only contains observations taken at the level one survey density. The suitability analyses at different levels were first undertaken using all observation points to investigate the influence of mapping detail on the suitability result. These analyses were then repeated using level one observation points for level one and level two observation points for level two analysis, to illustrate the effects of point density on the suitability result. The following methods of suitability calculation were tested:

1. Average and mode calculations: this method calculates the average of continuous variables and the mode of each ordinal variable for the observation points within each mapping unit. This was matched with the land use requirements for each land utilisation type, to calculate the suitability of each soil mapping unit.

2. Average calculations: this is similar to the first method, except that the average was used for all variables. The ordinal values were rescaled as numerical values, by assigning a numerical value for each class. The average values were then calculated and the results were rounded to the nearest integer number. This method was tested because the calculation of modal values often requires much more processing time than the average calculation. Therefore, if the differences between the suitability maps produced by both methods were similar, it would be more efficient to implement the average calculation.

3. Mode calculation: the mode was used for all variables. Before performing this calculation, the continuous variables were converted to ordinal variables by reclassification, following the class limits required by the three land utilisation types (table 1). The aim here was to reduce the variability of continuous variables by imposing class values and testing the effect on the quality of the suitability maps.

4. Mode of suitability classes: in this method the characteristics of each field observation point were matched with the land use requirements for each land utilisation type to calculate the suitability class at each observation point. The modal value of the observation site suitability classes lying within each mapping unit was then calculated. The aim was to give more weight to the observation sites' suitability, and not to the small variations in the characteristics used in methods one, two and three. The rationale for this is that the calculation of suitability from this classification might reduce the effect of extreme land characteristic values.

5. Association of suitability classes: this method is similar to the fourth method, but instead

of calculating the mode, the percentage of points in each suitability class within each mapping unit was calculated. The percentages were used to determine 'associations' of different suitability classes within each mapping unit. The definitions of the associations were as follows:

- Mapping units with more than 80% of observation points classified as a single suitability class were given that class in the final suitability classification;
- Units with two classes, for example, S1 and S2, where neither constituted more than 80%, were given the association S1/S2, where class S1 has the higher percentage;
- Units with three classes and where none were less than 20%, were given an association of three classes, arranged from the highest to the lowest.

These definitions cover all possible combinations of suitability classes within the study area.

6. Layer overlay of different land characteristics: each land characteristic used in the suitability calculation was spatially interpolated to produce separate GIS layers. For continuous variables the Triangulated Irregular Network (TIN) interpolation method was used, while for class variables (ordinal) voronoi interpolation was utilised. Each pixel value in a layer was matched with the land utilisation type to produce a suitability map. The rationale was to build a suitability map, which accounted for the spatial variability of each variable separately.

7. Spatial interpolation between observation sites: this method uses the suitability classes of individual field observation points to produce a suitability map. Since the interpolated variable is ordinal (suitability classes), the voronoi function (Theisen polygon) was used for this interpolation. This procedure assigns the suitability rating of an observation point to the area closest to the point. The shape and extent of this area depends on the proximity of neighbouring points and may bear no relationship to underlying patterns of spatial soil variation. However, this method gives more weight to the suitability of specific sites, and does not consider the soil mapping units as homogenous with respect to land characteristics.

The first five methods use the existing soil mapping units as the basis for suitability mapping. The last two methods use the spatial interpolation of field observation points. All analyses, including calculation of land suitability, map production, spatial interpolation, and between map comparisons were performed using the TYDAC® SPANS GIS software (TYDAC Research Inc. 1997).

Suitability map comparison

The level three mapping had the highest density of observations per unit area and its suitability was compared to the polygon ratings calculated by the different methods defined above, to assess the reliability of the map outputs. This approach has also been used by other researchers such as Van Kuilenburg et al. (1982) and Dalal–Clayton and Robinson (1992). The quality of the suitability map and consequently its usefulness depends on the reliability, relevance, and presentation of the information. Map reliability is characterised by purity and homogeneity defined below (Bregt et al. 1992).

Purity of the suitability maps: Purity indicates the degree to which the suitability classes, as indicated on the map, agree with the suitability of different locations in the field. It provides a numerical measure of map quality and accuracy (Bregt et al. 1992, Dalal–Clayton and Robinson 1992, Davidson 1992, Burrough 1993). Studies show that for soil maps the map purity depends largely on the mapping scale and intensity of sampling (Burrough 1992). In this work, the overall purity of each map was calculated as the percentage of level three point suitability values that agreed with the computed map suitability. The number of points used for these calculations was 2147.

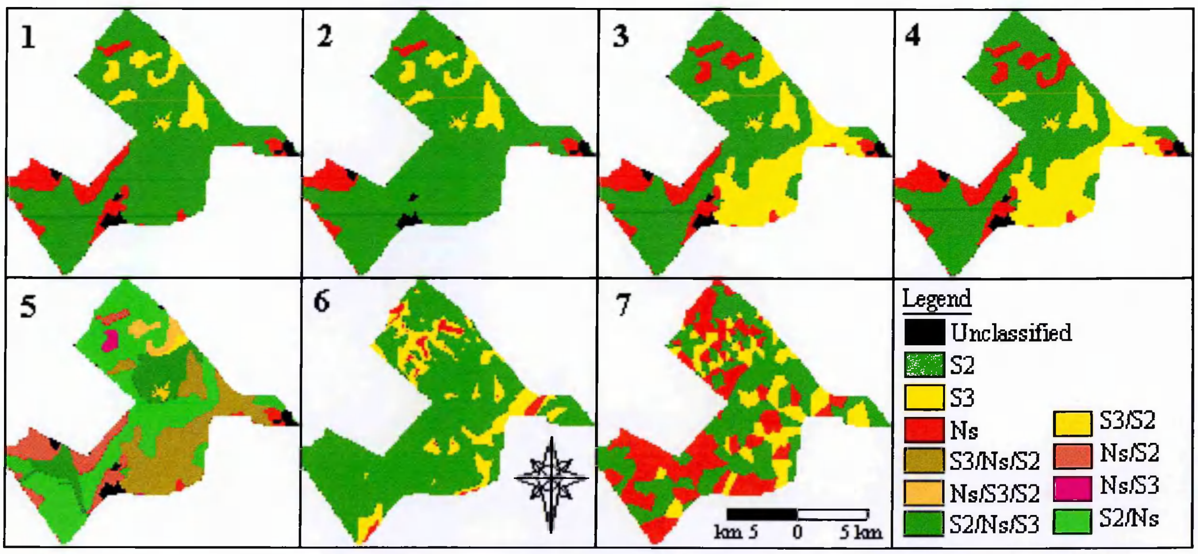
Homogeneity of the suitability maps: The reliability of a suitability map is also a function of the degree of homogeneity of land characteristics within land units (Van Kuilenburg et al. 1982, Riezebos 1989, Bregt et al. 1992). According to Beckett and Webster (1971), homogeneity may be measured using:

$$\text{Relative Variance} = \frac{S^2w}{S^2t}$$

Where: S^2t is the total variance and S^2w is the within–class variance. The within–class variance (S^2w) was obtained by pooling the individual variances for all mapping units. This was calculated from the average of all variances weighted by the degree of freedom of each mapping unit (number of points within each unit minus one). The total variance (S^2t) is simply the variance calculated from all observations in the map, without taking account of the suitability mapping units, and using the whole number of observations minus one as the degree of freedom (Webster and Oliver 1990). The complement of this ratio $1 - (S^2w/S^2t)$ represents the proportion of variance accounted for by different suitability classifications. This reflects the success of the classification in reducing the variance within mapping units. These calculations were only done for continuous land characteristic variables, such as the limiting soil depth and slope steepness.

Results and discussion

Examples of suitability maps derived from the different methods are provided in figure 2. It is evident from visual inspection that the suitability maps in each case are different. This implies that the interpretation and subsequent decisions related to land use planning, might also be different. Hence, it is important to compare these maps analytically in order to evaluate and identify the best method.



Note: Suitability maps represent the following methods: **1** average and mode of points within soil mapping units; **2** average; **3** mode; **4** mode of suitability classes; **5** association of suitability classes; **6** layer overlay of land characteristics; **7** spatial interpolation between points.

Figure (2) Suitability maps for rangelands derived from different calculation methods (level two soil mapping units shown in methods 1-7).

Effect of soil mapping level on suitability map purity

The percentages of agreement between map suitability and point suitability for field and tree crops are presented in figure 3. The pattern of change for range crops was similar to field crops. Methods 1 to 4 have lower purity than the other methods for all levels and land utilisation types. This is because these methods generalise the soil properties' variability within a mapping unit, reducing it to one class. Similar results were reported by Van Kuilenburg et al. (1982), who found that the use of mean values for soil mapping units was less efficient than two spatial interpolation methods for estimating soil moisture capacity.

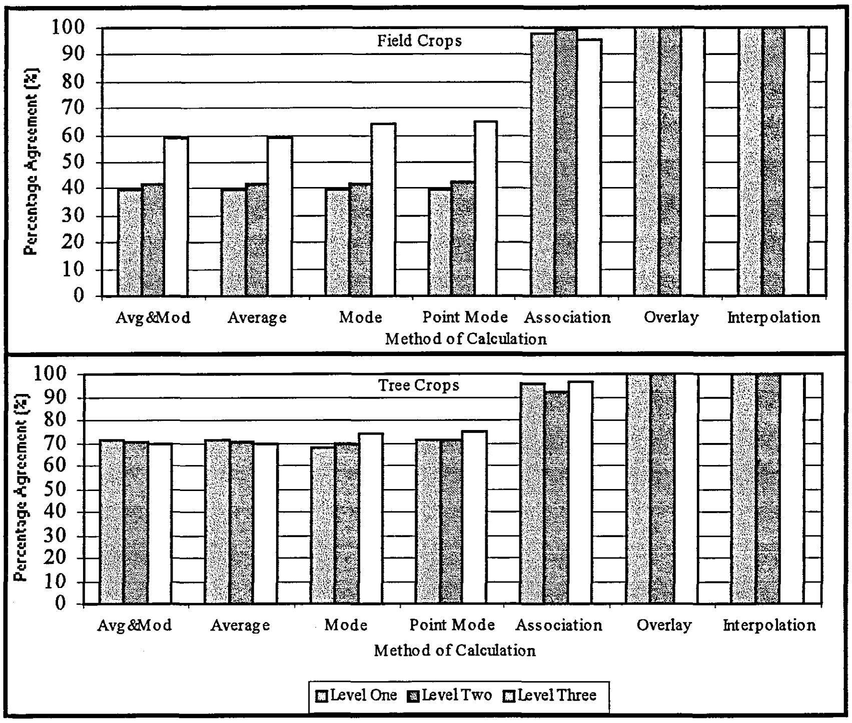


Figure (3) Percentage of agreement between suitability maps derived from the different methods and level three point suitability for two land utilisation types.

The use of associations of suitability classes to classify soil mapping units increased the percentages of agreement to >90% for all mapping levels. The purity of level three mapping was better than levels one and two in methods 1 to 4 for field crops and rangeland. However, the purity of suitability maps for field crops is lower than for tree crops. This is due to the range of values for some land characteristics being wider for tree crops. For example, the tree crops rating of available moisture for class S2 was 220–150mm, while the same rating for field crops was 150–110mm (table 1). Wider ranges tend to group more points within one suitability class and cause the increase in percentage agreement. This factor mostly depends on the adaptation of certain land utilisation types to less stringent land characteristic limits. The purity of level one compared to level two was similar in all methods and LUTs.

Effect of soil observation densities on suitability map purity

The purity of the suitability map derived by the layer overlay method is almost 100%, and for the interpolation method is exactly 100%, by definition of the method (figure 3). Bregt et al. (1992) reported that a suitability map produced by point interpolation was appropriate for selecting potential sites for specific land uses. These methods use the observation points without any reference to the soil map polygons, and so are independent of scale or variability within soil mapping units. However, both methods use level three points, which have a high density of observations per unit area. The average density (point/km^2) within the study area shown in figure 2 is 0.36, 1.82, and 14.95 for levels one, two and three, respectively. This raises the question of whether the high levels of agreement for the association, overlay and interpolation can be sustained if a lower point density is used.

It is more a question of whether the agreement reflects the true accuracy because using a lower point density will cause different boundaries to be produced. Checking with an independent set of points as done later is a more realistic representation of the true accuracy of the map.

Suitability maps at level one and two were derived from level one and two observation points, respectively. Level three observation points were used to compare the purity of these maps. This provides a realistic comparison, especially for the interpolation method (voronoi) because this method, by definition, will be 100% accurate if the same points are used for the interpolation and for the comparison.

The comparison of percentage of agreement for level one suitability maps derived from level one observations with those derived from level three observations is presented in figure 4. The pattern for level two is very similar to that of level one and is not shown. Figure 4 shows a large reduction in the purity of maps derived from the overlay and the interpolation methods using level one points, compared to those derived using level three points. For example, for field crops the reduction was from 100% to 35% and 30% for the overlay and the interpolation methods, respectively. The reduction in purity could be even more if the two sets of observations were truly independent but part of the data set is common. This reduction is due to the artificial nature of the boundaries created by these methods, which becomes more evident when a lower number of observation points are used. From this it can be concluded that these methods are not suitable where the point density is low. The reduction in the purity of maps derived from the association method, using fewer points, was less than the overlay and the interpolation methods, because the same boundaries are used. In the case of field crops for example, it fell from 98% to 65%. In addition, the association method has the highest map purity of the remaining methods for level one and level two, even when the density of points is reduced. For field crops, for example, the purity of the maps derived using the association method is 65%, while for all other methods the purity is less than 40%.

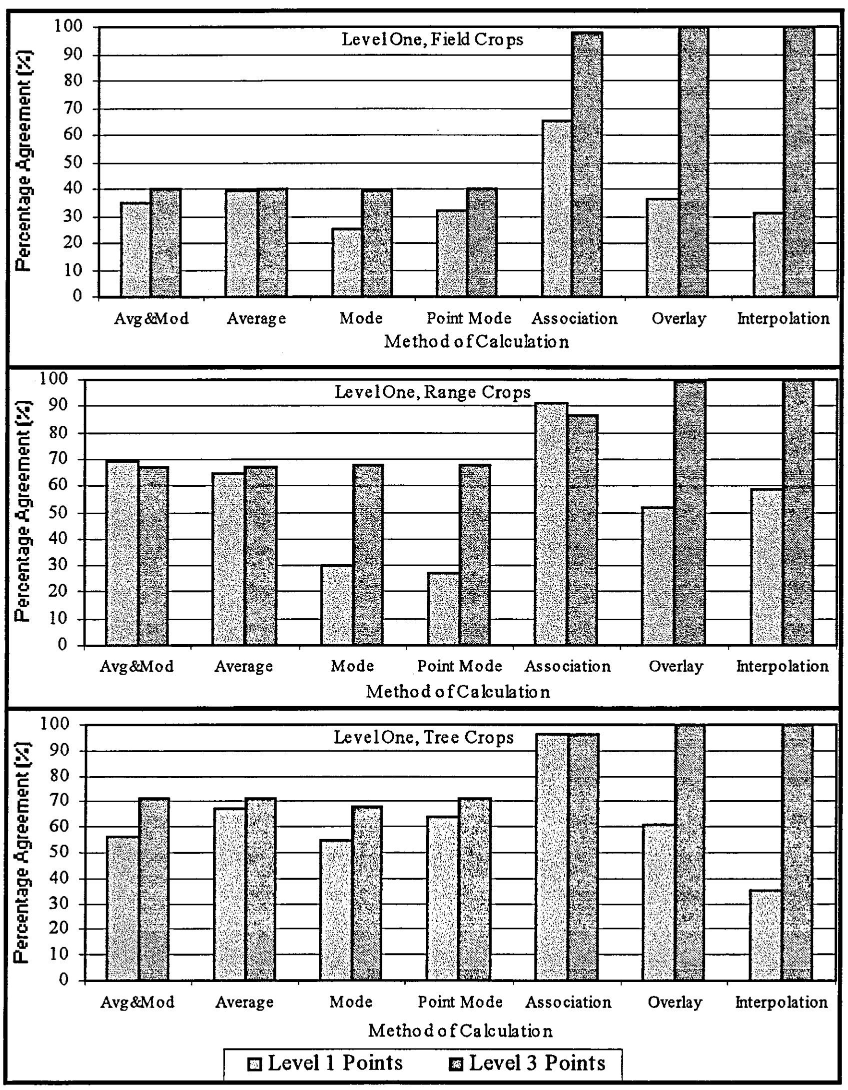


Figure (4) Comparison of percentage of agreement for level one using level one points only against level three points to derive the suitability maps.

The use of soil maps at levels one and two to produce suitability maps is better than the use of point observations only. This is because the soil mapping units were delineated and identified based on the apparent variability of soils, which reduces the soil variability within soil mapping units. This results in a suitability map of good percentage agreement compared to using a low number of observation points at these levels. This result is especially important for most areas of the transitional Badia zone, where only soil maps of level one and/or level two are available.

The results in figure 4 reveal some differences in map purity among the first four methods, which had almost the same purity when level three points were used (figure 3). The maps derived using average calculation methods have higher purities than those derived using the average and mode in the case of field and tree crops, with a very small difference in the case of the range crops. This result indicates that the use of average calculation for all land characteristics could be used instead of calculating the mode for ordinal variables.

Effectiveness of calculation method on reducing the variance within suitability units

Figure 5 presents the proportion of variance accounted for by soil maps at different levels for slope steepness and available soil moisture. Higher values indicate that the soil mapping units contribute more to the reduction in the variance of land characteristics, which gives a better classification. Both level one and level two soil maps contribute less than level three, which reflects the improvement in homogeneity of soil mapping units as the detail of mapping increases. In general, smaller scale maps contain greater grouping of mapping and taxonomic units (Davidson 1992).

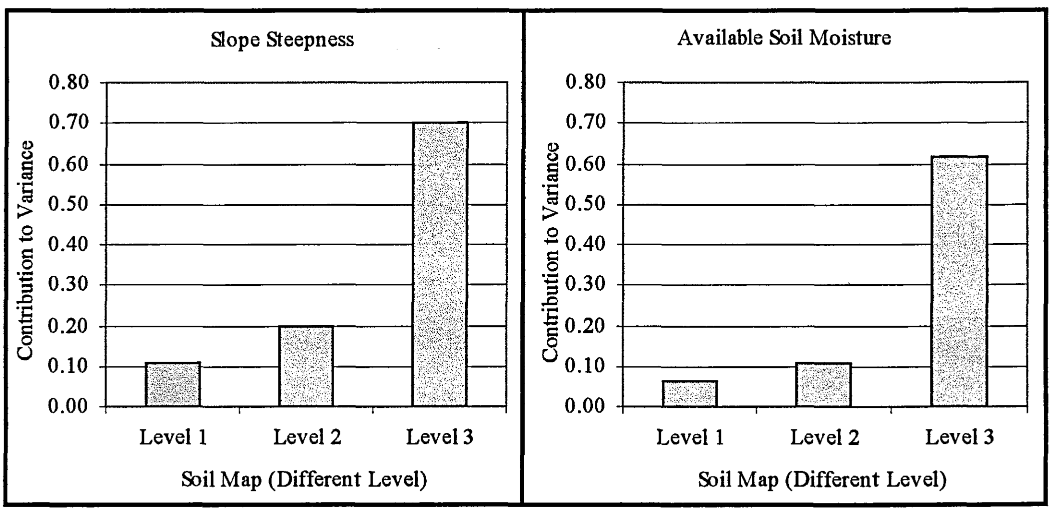


Figure (5) Proportion of variance accounted for by the soil maps for different levels of soil mapping.

Figure 5 also shows only a small improvement when using level two mapping compared to level one. The same pattern is reflected in the purity of suitability maps for field crops derived from these two levels (figure 3), for the first four methods. This leads to the conclusion that soil mapping at level two does not greatly improve the purity of suitability maps compared to level one, but level three mapping does provide improvement. This is because soil mapping units at level two also contain soil associations which tends to reduce the purity of the soil map and hence the suitability maps.

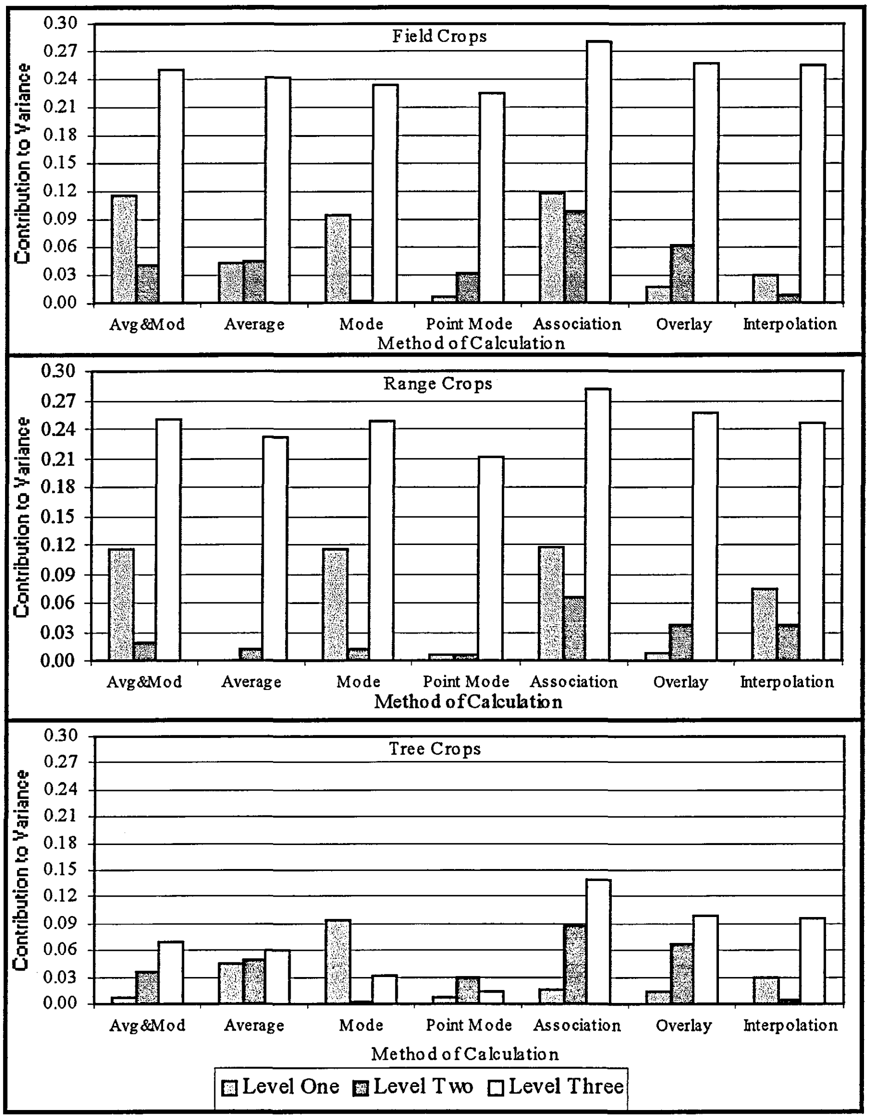


Figure (6) Proportion of variance of slope steepness at levels one, two and three, accounted for by different methods of suitability calculation.

The results of comparing the proportion of variance accounted for by the different methods of deriving suitability maps are presented in figures 6 and 7, for slope steepness and limiting soil depth, respectively. Overall, figures 6 and 7 show no obvious trend for levels one and two but there is generally an increased contribution to variance at level three. One reason for the absence of a trend in the level one and two data is the variation in the suitability class ranges of land characteristics for the different LUTs, which has a similar effect on the map purity as previously mentioned.

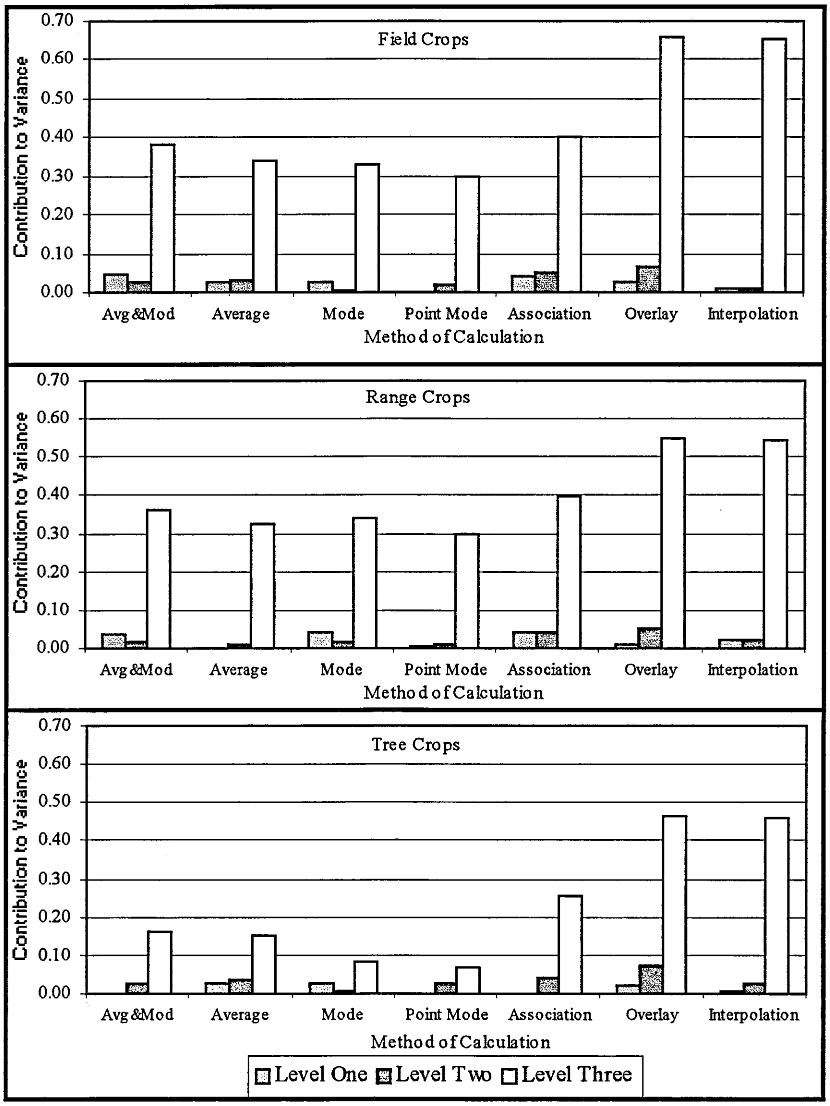


Figure (7) Proportion of variance of limiting soil depth at levels one, two and three, accounted for by different methods of suitability calculation.

Another factor which affects the trend of variations is the use of low point densities to undertake the suitability analysis at levels one and two, while the calculation of variance is undertaken using levels one, two and three point observations. Levels one and two point distributions do not accurately reflect the variability of soil properties within the soil mapping units, but level three points do reflect this.

The association and overlay methods produced maps that have the highest contribution to variance at level two. This can be attributed to the greater number of observation points used to undertake the suitability analysis at level two.

The level three pattern is more obvious than levels one and two, but varies in pattern and magnitude depending on the two land characteristics considered (figures 6 and 7). Suitability maps derived using the layer overlay and interpolation methods contribute more than other methods to the reduction in variance: in the case of limiting soil depth, 0.65 compared to less than 0.40 for field crops. In contrast, suitability maps derived using the association method contribute more than other methods: in the case of slope steepness, 0.28 compared to less than 0.25 for field crops. This is because slope steepness is a basic variable used to delineate soil mapping units, and hence, its variability was reduced when using the soil mapping unit as the basis for suitability grading. On the other hand, limiting soil depth is not a mapped variable, and hence, the overlay and interpolation methods contribute more to the reduction in variability of this characteristic within the suitability units. This is similar to the soil map effect seen in figure 5 where the magnitude of the contribution to variance is greater for slope steepness than available soil moisture.

Conclusions

At all levels, suitability maps derived by calculating the average or the mode of observation points within soil mapping units, only partially reflected the situation on the ground. This was because the methodology does not fully account for the within mapping unit variability and the mapping units are not homogeneous in terms of land suitability. All four methods gave essentially comparable results, however, the method using the averages of land characteristics within polygons is recommended for ease of calculation.

The association method considerably improved the representation of underlying soil variation within the soil mapping units at all levels. This was because the use of associations created a more flexible classification scheme.

Both the layer overlay and interpolation methods apparently produce extremely high levels of map purity. However, the soil boundary information is discarded in favour of interpolation which produces boundaries that are dependent on the spatial distribution of the point observations. Testing the maps produced by these methods at levels one and two with independent observations reveals that their true purity is much lower and no better than when the soil mapping polygons are used. An indication of this is the low purity of suitability maps (35-30%) derived by interpolating level one points and using level three points to estimate the purity.

The association method was considered the best for level one mapping where the aim of land use planning is to select regions which have the highest potential for certain uses. At level two, there is a greater need to be site specific but the results of this work indicate that the level two mapping polygons are no better than those of level one in accounting for the underlying soil variation. However, both the association and layer overlay methods were more effective in reducing variance of land characteristics so both of these methods are recommended at level two for the JOSCIS data.

For level three, the layer overlay and point interpolation methods apparently produced suitability maps with the highest purities. However, it was not possible to say if the real qualities of these were better than using the soil polygons because there were no independent observations. The level three soil mapping polygons were considerably better than those of levels one and two for map purity and reduction in variance and thus the association or average methods used with these are recommended. However, level three suitability maps should be used with caution when site-specific estimates of land suitability are to be made. This is because the purity of level three suitability maps is between 60 and 70%. This points to the need to improve soil mapping and increase the homogeneity of the soil polygons.

The analysis within the transitional Badia, especially on a large scale, requires the selection of land with very specific land characteristics and narrow ranges of land characteristic values. For this reason, and because the results of this study show the map quality varies with the scale of mapping and density of soil observations, it is necessary to append a quality statement to the suitability map. This also emphasises the need for field verification, to validate the assumptions and calculation methods behind the suitability analyses. This is vitally important considering the importance of suitability maps in land use planning and the potential consequences of miscalculation.

Acknowledgements

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References

Al-Shoubaki, A., 1999, Water Harvesting Potential of Different Land Types in Arid to Semi-Arid Region in Jordan. MSc. Thesis, University of Jordan, Amman, Jordan.

Arbia, G., Griffith, D., and Haining, R., 1998, Error Propagation modelling in raster GIS: overlay operations. International Journal of Geographical Information Science, **12**, 145-167.

Beckett, P. H. T., and Webster, R., 1971, Soil variability: a review. Soils and Fertilizers, **34**, 1-15.

Bregt, A. K., Stoorvogel, J. J., Bouma, J., and Stein, A., 1992, Mapping ordinal data in soil survey: a Costa Rican example. Soil Science Society of American Journal, **56**: 525-531.

Burrough, P. A., 1992, Integration of Environmental and Utility Data in GIS: Problems and Opportunities. Geographic Information Systems and the European Challenge: A Solution for Common Problems Across Europe. Proceedings European Conference VIII, Montreux, Switzerland, 7-9 October. AM/FM International, European Division, Basel, Switzerland.

Burrough, P. A., 1993, Soil variability: a late 20th century view. Soils and Fertilizers, **56,** 529-562.

Dalal-Clayton, D. B., and Robinson, D. A., 1992, An assessment of the success of a geomorphologically based reconnaissance soil survey in Eastern Zambia. Geoderma, **45,** 213-230.

Davidson, D. A., 1992, The Evaluation of Land Resources. (Harlow: Longman).

FAO, 1976, Framework for Land Evaluation. Food and Agriculture Organisation, Rome, Italy.

FAO, 1983, Guidelines: Land Evaluation for Rainfed Agriculture. FAO Soils Bulletin No. 52. Rome, Italy.

FAO, 1989, Guidelines for Land Use Planning. Food and Agriculture Organisation, Rome, Italy.

Hammer, R. D., Astroth, J. H., Henderson, G. S., and Young, F. J., 1991, Geographic Information Systems for soil survey and land-use planning. In Spatial Variabilities of Soils and Landforms. Proceedings, International Symposium, Las Vegas, Nevada, 17 Oct. Edited by Mausbach, M. J., and Wilding, L. P., SSSA Special Publication No. 28. Madison, Wisconsin, USA, Soil Science Society of America Inc. pp. 243-270.

JRV (Jordan Rift Valley Project), 1998, Personal communication.

Khalil, K. I., Assal, M. H., and Fahim, M.M., 1995, The application of GIS to soil survey data. Egyptian Journal of Soil Science, **35,** 129-145.

Lodwick, W. A., Monson, W., and Svoboda, L., 1990, Attribute error and sensitivity analysis of map operations in geographical information systems: suitability analysis. International Journal of Geographical Information Systems, **4**, 413-428.

Mazahreh, S., 1998, Alternatives for Land Utilization in Arid to Semi-Arid Region in Jordan. MSc. Thesis, University of Jordan, Amman, Jordan.

MoA (Ministry of Agriculture, Jordan), 1995, The Soils of Jordan. Report of the National Soil Map and Land Use Project, Undertaken by Ministry of Agriculture, Huntings

Technical Services Ltd., and European Commission. Level One, Level Two, Level Three and JOSCIS Manual.

Oberthur, T., Dobermann, A., and Neue, H.U., 1996, How good is a reconnaissance soil map for agronomic purposes. Soil Use and Management, **12,** 33-43.

Rashdan, W., 1999, Potential Utilization of Barley and Rangelands in Arid to Semi-Arid Region in Jordan. MSc. Thesis, University of Jordan, Amman, Jordan.

Riezebos, H. T., 1989, Application of nested analysis of variance in mapping procedure for land evaluation. Soil Use and Management, **5,** 25-30.

Sys, C., 1985, Land Evaluation. Part I, II, and III. (Ghent: State University of Ghent).

Theocharopoulos, S. P., Davidson, D. A., Mcarthur, J. N., and Tsouloucha, F., 1995, GIS as an aid to soil surveys and land evaluation in Greece. Journal of Soil and Water Conservation, **50**, 118-124.

TYDAC Research Inc., 1997, SPANS Manual by TYDAC Research Inc., 2 Gudwara Road, Suite 210, Nepean, Ontario, Canada K2E1A2. Edited by Diane Burke.

Van De Putte, R., 1989, Land evaluation and project planning. ITC Journal, **2,** 139-142.

Van Kuilenburg, J., De Gruijter, J. J., Marsman, B. A., and Bouma, J., 1982. Accuracy of spatial interpolation between point data on soil moisture supply capacity, compared with estimates from mapping units. Geoderma, **27,** 311-325.

Webster, R., and Oliver, M. A., 1990, Statistical Methods in Soil and Land Resource Survey. (Oxford: Oxford University Press).

Zhou, H. Z., Macdonald, H. B., and Moore, A., 1991, Some cautions on the use of geographic information system (GIS) technology to integrate soil site and area data. Canadian Journal of Soil Science, **71,** 389-394.

Chapter Three

This chapter contains two papers. The first is a paper for peer-review that will be submitted to the International Journal of Geographic Information Science. The second has been published in the 7th International Congress on Computer Technology in Agriculture. The raw data used to derive tables and figures for the first paper are found in the attached CDROM. The data exists under the directory chapter3. This includes three directories containing the information about observation points, satellite image and the SPANS study areas.

Detection and correction of errors in soil information using satellite images and GIS: a case study in Jordan

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(Will be submitted to the International Journal of Geographic Information Science)

Abstract: The assessment of land suitability is an important requirement for land use planning in the Badia region of Jordan. Soil maps together with observation points collected by a previous soil survey programme, form the basic data available for analysis. This data was collected and georeferenced by methods available before the widespread availability of the Global Positioning System (GPS). When the data were integrated and overlaid on a satellite image within a GIS, a number of inconsistencies in georeferencing the data and in the attributes attached to them were revealed. Systematic errors caused by the use of different datums to georeference soil maps and observation points in JOSCIS were detected. The map reading procedure caused unsystematic errors in the locations of soil observations, which were measured at a sample of original observation sites using GPS. The correction of the unsystematic errors is not feasible due to the difficulty and cost of relocating all observation points. Errors in the attributes attached to the observation points were caused by survey recording procedures, highlighting the need for examining the data before the analysis. The systematic and attribute errors were corrected and the implication for suitability analysis examined. The areas and spatial distribution of different suitability classes were affected increasingly as the level of mapping became more detailed. This study highlights the need for critical examination of spatial data when GIS is used for spatial analysis. The use of satellite images and GPS facilitated the detection and assessment of errors.

Keywords: Data integration, Land suitability analysis, GIS, remote sensing, GPS

Introduction

Problems of data compatibility often appear when a Geographic Information System (GIS) is introduced as a tool for integrating spatial data from many different sources (Burrough 1995). The data may be in different formats and may not have been collected with the intention of integration with other data sets. In a GIS, it is possible to view and analyse several sets of data at the same time, and hence to examine the spatial relationships between them (Hardy 1987). Prior to the advent of GIS, data was often used separately due to the difficulties of overlaying paper based maps. Consequently, one aspect of data compatibility, that of locational accuracy of common features between maps, was difficult to assess. Mapped features may have been georeferenced to different map projections and/or based on one of several available datums (Iliffe 1995). The consistency in the geodetic datum as well as the map projection used for different data is a primary requirement when GIS is to be used for integrating data (Dodson and Haines–Young 1993). However, information about the projection and datum used to georeference the source data may be lacking, which causes data integration difficulties (Iliffe 1995).

Errors in the attribute data attached to each of the entities in a digital data set are also important in determining the quality of the analysis and results. This consideration is as important as the georeferencing accuracy (Bolstad and Smith 1992). Using data of low quality or poor compatibility can be dangerous. The integration and further manipulation of such data may produce attractive outputs but could lead to erroneous conclusions (Vitek et al. 1984, Fernandez and Lozano-Garcia 1991). Decisions based on these conclusions may be costly or even impossible to correct (Guptill 1992, Burrough 1995).

Land suitability analysis is an established method of integrating physical and human data from a wide range of sources (FAO 1976). In many applications of the technique, soil observations form an important component of the data used. These observations record the physical environment (land resources) of the area under consideration. Land suitability analysis matches the requirements of any type of land use with these land resources. A basic requirement of this matching is that the land resources data should be integrated to produce a natural resources database, which contains all attributes about soil (soil map and observation points), climate and vegetation.

The Jordan Arid Zone Productivity Project (JAZPP) started in 1994 with the main objective of developing the productivity of the arid to semi–arid (transitional Badia) areas of Jordan (100–200 mm average annual rainfall). The project is structured into four broad areas of activity: land use planning; water utilisation techniques; farming system improvement; and technology transfer. The land use planning component requires an assessment of land suitability for all possible uses within the area. The National Soil Map (NSM) project of Jordan (MoA 1995) produced soil maps for the whole country at Level one (1:250,000 scale) and selected areas at levels two and three (1:50,000 and 1:10,000 scales). The project used satellite image–maps for the purposes of soil and land cover mapping. These were prepared by merging SPOT PAN and Landsat TM images, taken within the same month, using the IHS function. This enhanced the spatial resolution of the Landsat imagery without losing the spectral resolution benefits of TM data. A comprehensive soils database accompanies the maps providing data on soil properties at each of 41 613 pit or auger sites described in the field. This data is compiled and presented in the Jordan Soil and Climate Information System (JOSCIS). This database represents an important input for the derivation of land suitability grades within the JAZPP area. JAZPP utilises the field observation data to reclassify soil mapping polygons according to land suitability criteria in order to produce maps showing the suitability of land for land utilisation types based on water harvesting techniques. Commonly, there are several soil observations within each mapping unit. Previous research (Ziadat et al., in press) investigated the options for combining data from the soil observations in order to assign suitability ratings to the soil mapping polygons. It was noticed that there was considerable variation in the individual suitability ratings between point observations within the polygons, whereas it was expected that they would be similar.

Overlaying the soil observation points and soil polygon boundaries onto the satellite imagery within a GIS revealed clear examples of inconsistencies between datasets. For example, one soil observation point was located in the middle of a large reservoir that had been present at the time of field survey. Polygon boundaries in the soil map clearly differed from their true position on the satellite image, exemplified by the polygons defining urban developments. Soil observation points classified as unsuitable for rainfed arable cultivation were located within fields clearly under intensive arable production. This paper reports the subsequent investigation, quantification, and where possible, correction of georeferencing and attribute errors in the JOSCIS soils database.

Inconsistencies in location of field observations

The location of each field observation point was originally recorded in the field by estimating its position on a published 1:50,000 or 1:25,000 scale topographic map and recording the grid coordinates interpolated as necessary with the aid of a ruler. Various projections and datums are used in the published mapping in Jordan (table 1), the major grid depicted varying with the age of publication. A computer program in JOSCIS was used to convert the coordinates from each of the different mapping systems into a uniform system of geographic coordinates (latitude and longitude). However, a review of this program showed that the different datums of the maps were not taken into account in the conversion process.

For the purposes of a regional survey an ellipsoid is defined to approximate the shape of the earth. The datum is a reference system defined from the combination of shape and size of the ellipsoid, and its position given by the location of its origin. This local datum approximates the true shape of the earth in the region better than a global datum. Each local datum has a point of origin off-set from the centre of the earth, which may reach up to 1000m. This is usually expressed in Cartesian coordinates (ΔX, ΔY, ΔZ) plus rotations and scale if necessary. The transformation parameters from any local datum to the World Geodetic System (WGS84) are often unpublished (Iliffe 1995). A point on the earth's surface will have different geographic coordinates when referred to different datums. Thus, if no datum correction is made when reprojecting points, systematic differences in their locations occur (Lee and Walsh 1984, Flowerdew 1991).

Table 1 Datums and projections used in Jordan.

Datum Name	Code (ARC/INFO)	Area Covered	Reference Ellipsoid	Projection System*
European_1950	EUR_M	Mean solution for most European countries	International 1909	Universal Transverse Mercator, Zones 36&37
European_1950	EUR_N (EUR_S)	Mean solution for Jordan and adjacent countries	International 1909	Jordan Transverse Mercator (JTM)
North American Datum 1927	NAD27	Mean solution CONUS	Clarke 1866	Jordan Transverse Mercator (JTM)
Palestine 1928		Palestine	Clarke 1880 (Palestine)	Palestine Grid
World Geodetic System 1984	WGS84	World	WGS84	Not Used in Jordan

* Frequently used projection for these datums in Jordan.

Coordinate transformation between datums

To correct the absence of a datum transformation in the JOSCIS data, the original coordinates from the field observations were transformed to derive new geographic coordinates taking into account the different datums of the maps used in the soil survey. This required knowledge of the original parameters for each of the datums used during data collection. Obtaining this information is not necessarily an easy task. Ordinary use of topographic maps does not require this information and therefore it may not be included in the legend. In addition, datum parameters are sometimes regarded as 'Classified' information in the military sense (Iliffe 1995). Inter–bureau rivalries can also affect the free flow of data about datums (Burrough and McDonnell 1998).

The datum transformations were undertaken using ARC/INFO® software. The datum used for the merged SPOT PAN and Landsat TM imagery (Clarke 1866 spheroid and NAD27 datum) was used as the base for integrating the various data sets, because the imagery provided the best means for visual verification of a feature's location.

Using GPS to verify the coordinate transformation process

The coordinate transformation process was evaluated by comparing differential GPS locations at some of the original observation sites. The location of 26 observation sites were determined in the field using the original soil survey field sheets and help from one of the surveyors who worked on the original mapping project. Relocating these sites was possible because they were left open and have remained untouched. Once found, at least 120 GPS measurements were taken at each site and differential correction applied using the post-processing method. The average coordinates of these measurements were used to estimate the site location and the accuracy was estimated by the standard deviation and by repeating the measurement for some sites on different dates. The average standard deviations were 1.2 m in easting and 1.3 m in northing. The average difference between measurements on different days for 13 sites was 2.2 m in easting and 1.9 m in northing.

The GPS was configured to collect UTM coordinates using the WGS84 datum. These were transformed to JTM coordinates using either the EUR_M or NAD27 datum. These were selected to demonstrate the effect of using different datums because they were used to georeference most of the database. In addition, the parameters defining those two datums are well known. The transformed GPS coordinates were then compared with the equivalent JOSCIS database coordinates as shown in figure 1. This was possible because the JOSCIS database contained the original map coordinates and a code identifying the projection system used.

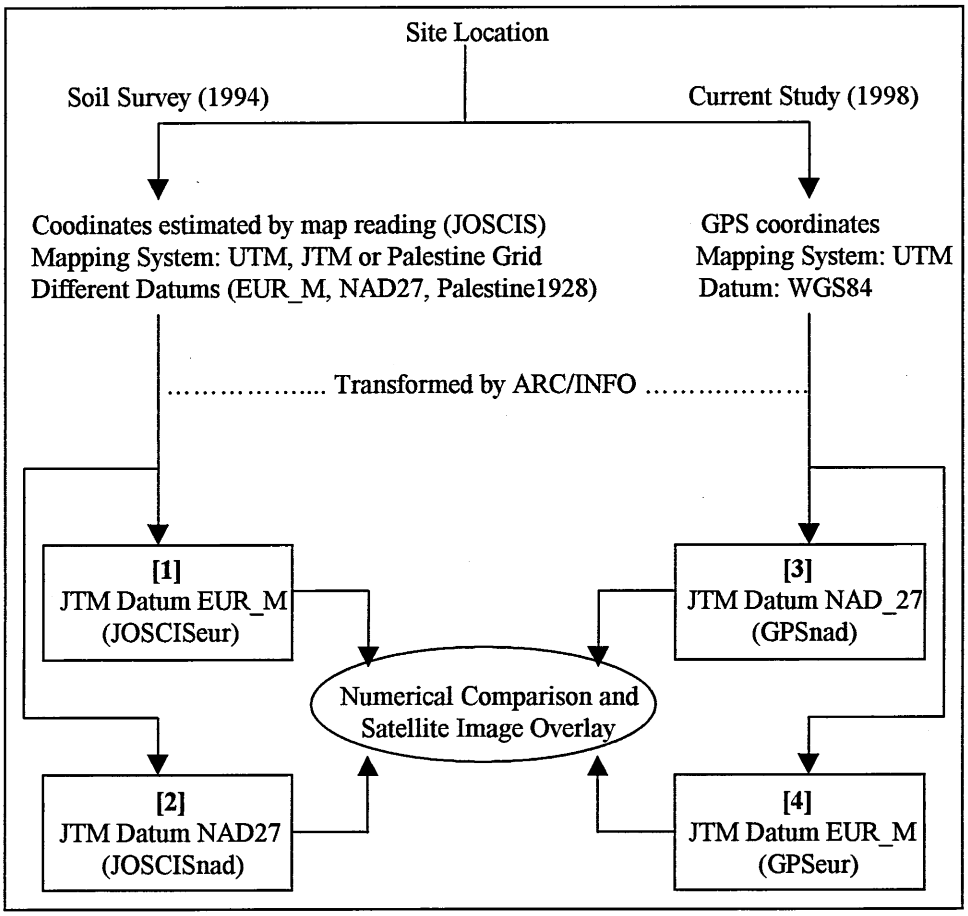

Figure 1 Flowchart of the process of comparison between GPS measurements and JOSCIS coordinates for 26 sites using two datums (The code between brackets is used in the legend in figure 2).

Numerical comparison of the shift between GPS and JOSCIS coordinates

The shifts between JOSCIS and GPS northing coordinates for the example sites is presented in figure 2. The shifts in the eastings follow similar trends, but with different magnitudes. The four point symbols in figure 2 represent the following differences:

1. GPSeur-JOSCISeur: GPS transformed to EUR_M minus JOSCIS transformed to EUR_M;

2. GPSeur-JOSCISnad: GPS transformed to EUR_M minus JOSCIS transformed to NAD27;
3. GPSnad-JOSCISeur: GPS transformed to NAD27 minus JOSCIS transformed to EUR_M;
4. GPSnad-JOSCISnad: GPS transformed to NAD27 minus JOSCIS transformed to NAD27.

The GPS readings were used as the reference, so subtracting the coordinates recorded by JOSCIS from the coordinates recorded by GPS quantifies the shift of the former from the actual coordinates on the ground.

Figure 2 reveals two kinds of shifts. The first are systematic shifts caused by the four datum combinations listed above and the second are non systematic, caused by errors in map reading. When the same datums are used for GPS and JOSCIS coordinates (GPSeur-JOSCISeur and GPSnad-JOSCISnad), the shifts are the same at each point. However, the shifts vary between points and are indicative of the map reading error at each point. When different datums are used (GPSeur-JOSCISnad and GPSeur-JOSCISnad), an additional systematic shift is evident.

The magnitudes of the systematic shifts were 26–29m in easting and 119–121m in northing. The northing shift is represented in figure 2 by the values above and below the middle two values, for each site. Offsets as a result of using different datums have also been reported by Rogowski (1995), where the differences between NAD27 and NAD83 were about 30m easting and 220m northing. The magnitudes of the map reading error ranged from 314m to 10m in easting and 304m to 1m in northing for the 26 sites.

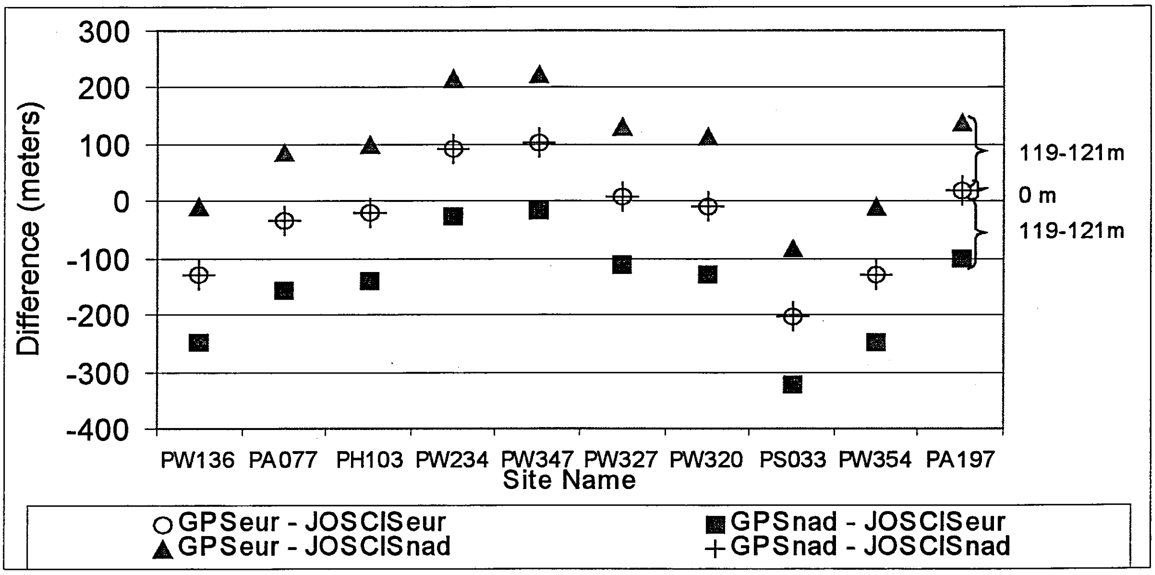

Figure 2 Shifts in northing between GPS coordinates and coordinates recorded by map reading method (JOSCIS coordinates for the same site, using different datums).

Graphical comparison of the shift between GPS and JOSCIS coordinates

The locations of observation sites calculated by the four datum combinations were superimposed on the satellite image (figures 3a, b and c), producing four points for each site. The GPS-measured positions of observation sites, adjusted to the image datum (NAD27), agreed with their expected locations within the limits of the image resolution (10 m), where identifying features existed, and are represented by the yellow crosses. The systematic shift, as a result of using a different datum (EUR_M), is shown by the blue crosses.

The georeferencing method used to obtain the coordinates in JOSCIS was approximate and based on map reading. Each site was located on the topographic map, using the features shown on the map and those recognisable on the ground, as a guide. The surveyors using a millimetre ruler then measured the coordinates of the site. The green crosses represent these. Comparison of the yellow and green crosses in figures 3a, 3b and 3c shows the variable differences between map reading and GPS measurements.

In 12 out of 26 sites, the maximum shift was equivalent to less than one millimetre error in map reading, which is within the expected accuracy of the method. One example is site number J0148 (figure 3a). In six sites the differences between the JOSCIS and the GPS coordinates were up to 100m and 50m at 1:50,000 and 1:25,000 scales, respectively, equating to two millimetre error. Site number PS034 (figure 3a) is an example. This can be accounted for by poor site location on the topographic maps. Insufficient surface features around the site are a causal factor; in some cases contour lines were the only guide to pinpoint an observation site. This magnitude of error agrees with empirical tests undertaken by Bolstad and Smith (1992), who measured errors in hard copy map–derived coordinates ranging from 5 to 279 feet.

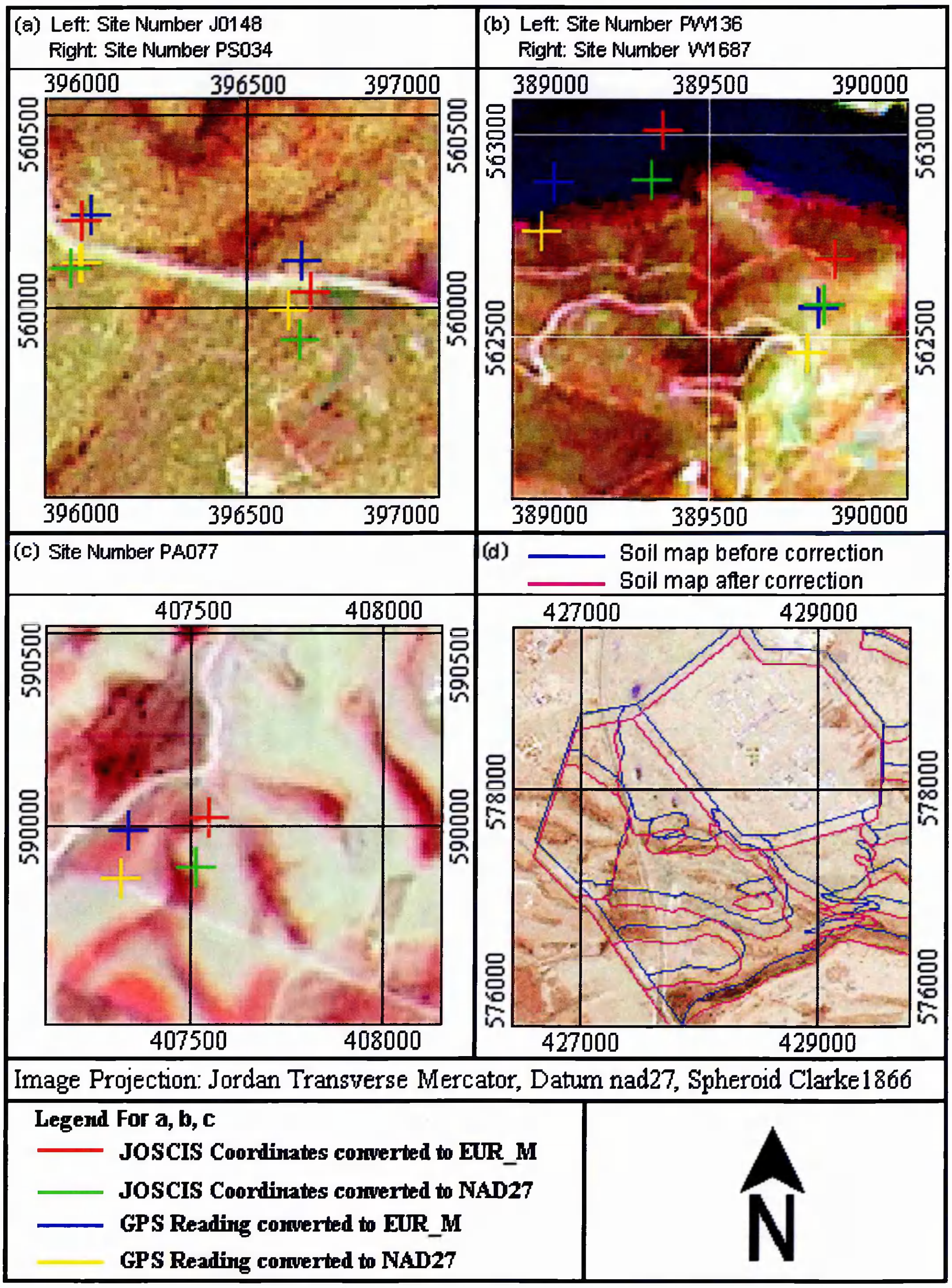

Figure 3 The deviation of observation points and soil map from the original position on the satellite image as a result of datum and map reading errors.

Large shifts between GPS and JOSCIS coordinates were found in five sites, including site numbers PW136 and W1687 (figure 3b). These were thought to be due to one or more of the following reasons:

(1) Major changes on the ground, which were not recorded on the topographic maps published 15-20 years before the soil survey. Hardy (1987) reports a similar problem of using old photographs in field work where many new features existed on the ground that were not on the photographs. A good example is the King Talal Reservoir in figure 3b.

(2) Poor map condition due to continuous use in the field.

(3) Misreading of the map coordinates for the site.

(4) The experience of the surveyor. 17 surveyors, with variable experience undertook the JOSCIS survey. Research recommends that, where possible, point coordinates should be retrieved by the same surveyor to minimise sources of error (Fernandez and Lozano-Garcia 1991).

(5) Some observations were transferred from 1:25,000 scale maps to 1:50,000 scale maps before reading the coordinates. The reasons for this were unclear but this process introduced another potential source of error in three of the sampled points, of which site number PA077 is an example (figure 3c).

Unfortunately, the correction of unsystematic errors is very difficult, or impossible (Walsh et al. 1987, Bolstad et al 1990). Observations from more sites than used in this study are required to gain a full description of these errors in the JOSCIS data. However, data collection is inhibited by the time required to find the exact locations of the original sites in the field. For example, thirty working days were needed to locate the 26 sites.

Inconsistency in geocoding of soil maps

The digitised soil maps were overlaid onto the satellite imagery. This revealed systematic differences attributable to the accidental use of different datums as was the case with the point observations. The level two maps were originally produced by interpretation of the same satellite imagery thus there was a good match with the satellite image features. The level one maps were produced by interpretation of separate satellite images, geocorrected to a different datum. The shift became apparent when the data were examined at international borders. The shift in the level three maps is shown in figure 3d and was the most clearly visible because of the detailed scale of mapping. The differences in datums were identified for each data set and the appropriate corrections were applied resulting in considerable improvements, also shown in figure 3d. The shift between the non-corrected and corrected vectors was approximately 30 m easting and 130 m northing. This represents the shift that results from using two different datums, EUR_N for the soil map versus NAD27 for the satellite imagery.

Close examination of the 1:10,000 scale maps revealed 'steps' in the polygons corresponding to boundaries between individual map sheets. The possible source of error is in the determination of control points to geo-reference the soil maps during digitising when at least two points were required to register each sheet. The magnitude of positional error that results from deriving control points digitised from geographic coordinates on a map has been studied by Bolstad et al. (1990). They found that the difference between locations calculated using the survey data and the graticule data averaged 39 metres. This might complicate the joining of two adjacent map sheets. The level three soil maps were based on the 1:25,000 topographic maps, which contained two mapping grids. Technical limitations at the time of digitising required the use of the minor grid and this meant that control points had to be manually derived by map reading. The measurement of coordinates from control points derived by this method introduces drawing errors (Fernandez and Lozano-Garcia 1991). Although these errors were noticeable in the digital data, they were small and no attempt was made to make corrections.

Inconsistency of attribute data

In this research, the integration of soil observation points with satellite imagery revealed inconsistencies associated with attributes attached to the observations. The suitability of individual point observations was calculated for various land utilisation types, using the land characteristics recorded at each point. These were overlaid onto the satellite imagery and this revealed inconsistencies between the suitability classification of some observation points and the appearance of the surrounding area on the satellite imagery. For example, points classified as not suitable for field crops were found in the middle of groups of cultivated fields large enough to discount any location errors. On reference to the original database, it was clear that this was because of survey recording procedures in 2944 sites out of 30976. This occurred when the surveyor in the field identified two adjacent but similar sites. One of the profiles was described fully, the other was described in part and given a reference site code to refer the user to the remaining attributes. This was not accounted for in the first suitability calculation procedure but was overcome by reprogramming. A further 514 sites were excluded because inconsistencies in the attributes pointed to mistakes in data recording or entry. For example, some sites had water holding capacity values greater than zero, but a soil depth of zero, which is not possible. In other cases, the coarse material size and type were recorded as finite values, but the coarse material percentage was recorded as zero. Also, records for some of the characteristics required for suitability analysis were missing.

These findings emphasise the need for a user of any database to carefully check the database to identify any special processing requirements and mistakes before using it for analysis. The normal output of analysis will not indicate these shortcomings unless a special check, such as overlaying the point suitability calculations onto the satellite imagery, is designed.

Implications of location and attribute errors for land suitability analysis

Soil maps and point data are the basic information used for land suitability analysis. It is worthwhile, therefore, to estimate the effect of georeferencing and attribute errors on the land suitability assessment. Bolstad and Smith (1992) show that the combined effects of spatial and attribute errors may limit the value of model predictions which rely on site specific data from many sources. The effects of the georeferencing and attribute errors on suitability maps were investigated separately and in combination in a 144 km^2 study area around Al-Mafraq containing 2,147 soil observations of which 2,092 were georeferenced to the EUR_M datum and 55 to NAD27. For the level one map (EUR_M) 55 points were in the wrong datum but correction caused no changes from one polygon to another. At level two (NAD27) 2,092 points were in the wrong datum and 106 or 5% changed polygon. At level three (EUR_M), 55 points were in the wrong datum and 47 or 85% changed on correction. This shows the potential increase in importance of geocoding errors as the scale of mapping increases.

The effect of spatial and attribute errors on the suitability analysis in the same study area was investigated. The suitability calculation was based on matching the land characteristics (LCs) of each mapping unit with the land use requirements of different land utilisation types using the FAO method (FAO 1983). The land unit was represented by calculating the average of continuous value LCs and the mode of ordinal value LCs for all observation points within a soil mapping polygon. A comparison of areas of land classified into each suitability class using the uncorrected data and three combinations of corrections is presented in table 2. The derived suitability maps that result from using these datasets for level two mapping is presented in figure 4.

Table 2 Effect of geo-referencing and attribute correction on the area of suitability classes, at three scales

Level of Detail	Suitability Class	Uncorrected	Corrected Georeference	Corrected Attributes	Both Corrected
Level One	S2 Moderately Suitable	96.7	96.7	96.7	96.7
	S3 Marginally Suitable	03.3	03.3	03.3	03.3
Level Two	Unclassified	00.6	00.8	00.6	00.8
	S2 Moderately Suitable	96.0	96.9	95.1	93.9
	S3 Marginally Suitable	03.2	02.2	04.3	05.3
	Ns Not Suitable	00.2	00.0	00.0	00.0
Level Three	Unclassified	12.2	12.2	12.3	04.9
	S2 Moderately Suitable	64.1	64.2	67.3	73.7
	S3 Marginally Suitable	16.0	16.0	14.8	16.2
	Ns Not Suitable	07.6	07.6	05.7	05.3

The effect of the geo-referencing correction is consistent with the findings regarding the number of points that changed location. The areas of different suitability classes remain the same for level one. Few changes in the area of different suitability classes are found for level two but these are higher than those for level three.

The effect of attribute correction shows that at level one, suitability calculations are not affected by attribute discrepancies, but both level two and level three are affected (table 2). This is because level one soil mapping units are much larger than both other levels. This means that at this level a larger number of points are used to classify one polygon, making the classification of that polygon less sensitive to changes in the attributes attached to some of the points. However, this was only investigated for a relatively small area, and might change if a larger area was considered. At levels two and three, the trend was mainly a reduction in the area classified as not suitable land. This is due predominantly to the correction of many points which have zero available water holding capacity and zero soil depth, because of the reference site problem discussed previously. This land was reclassified, either as moderately or marginally suitable when the attributes attached to the observation points were corrected.

The changes in land classified into different suitability classes, as a result of correcting both the georeferencing and attribute discrepancies was greater for level three compared to level two (table 2). The amount of unclassified land was reduced significantly at this level. This is because the points were better distributed with regard to the mapping units as a result of geo-referencing correction and more information is available upon which to base the suitability classification after correcting the attributes.

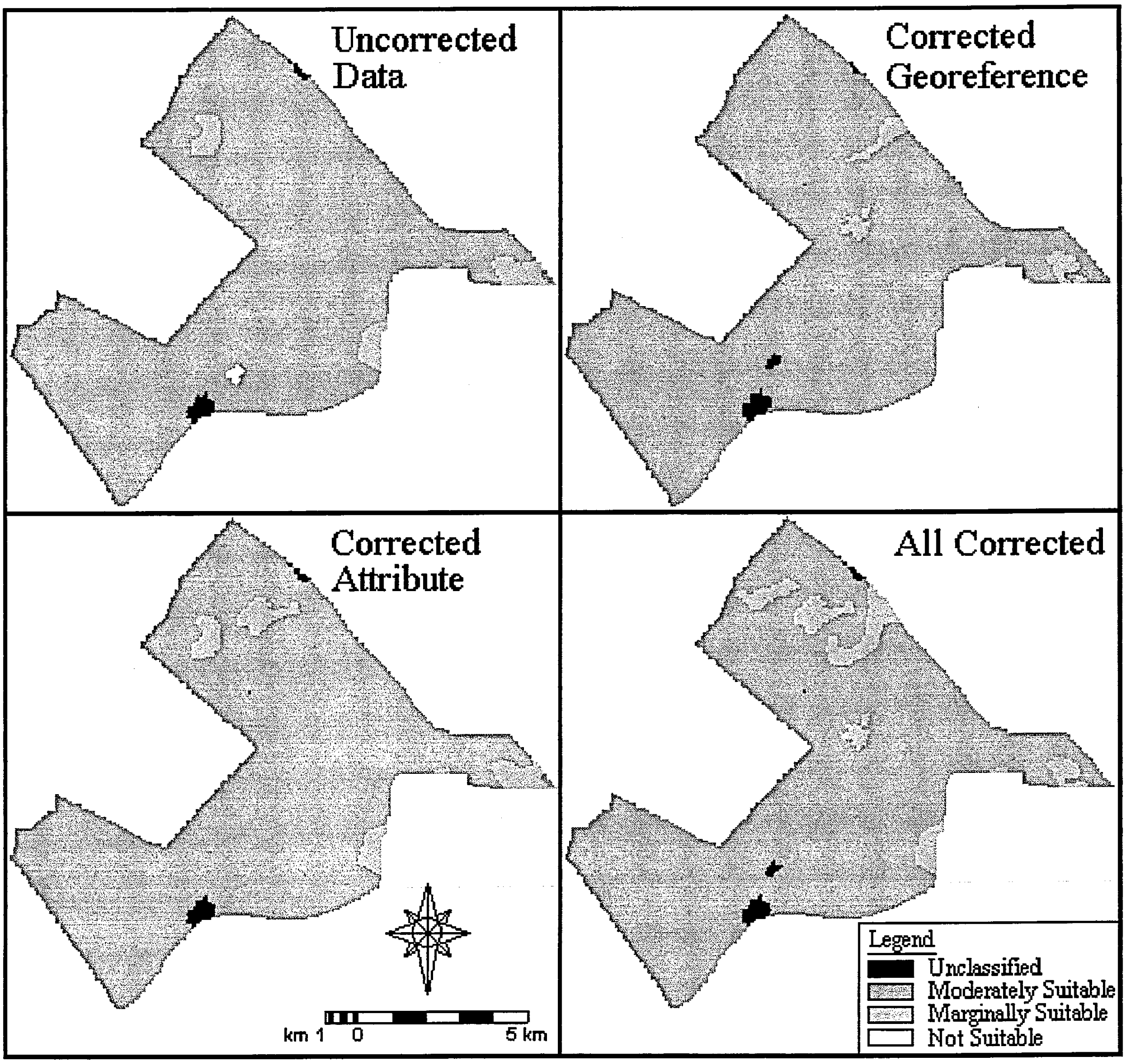

Figure 4 Comparison of level two suitability maps for rangelands derived from the same dataset but using corrected or uncorrected georeference and/or attribute data.

A visual comparison of the suitability maps in figure 4 reveals that each map is different. This implies that any decision taken based on the first three maps will put some land into the wrong use. For example, the map generated after correcting all errors shows greater areas of marginally suitable land in the northern part of the study area. This might lead the decision-maker or the planner to exclude this area from the plan, or to put it for other uses, for which it is more suitable. Whereas the other three maps indicates that this area is moderately suitable, which can be used with less input and therefore the expected yield is greater than the above. If the plan was produced based on the latter scenario, the implementation of the plan will face the problem of having marginally suitable areas instead of moderately suitable land, with much less yield and requiring more inputs than expected.

The implications of discovering this will increase as the implementation of the plan progresses, and might lead to a complete failure of the plan.

Conclusions

This study revealed systematic errors in the JOSCIS soil observations and soil maps. These were 30m in easting and 130m in northing, caused by not accounting for the different datums used in the collection and compilation of the data. Unsystematic errors in locations of soil observations, often larger than the datum shifts were the result of using map reading to determine coordinates in the absence of GPS availability at the time of the survey. The sizes of these errors were dependent on: the existence of some clearly distinguishable features to aid map reading, the experience of the soil surveyor and the age and condition of the field map. The complete correction of unsystematic errors in the JOSCIS data with GPS is not feasible because of the cost and difficulty of relocating all the points. However, the magnitudes of unsystematic errors determined in the work will assist future users in the interpretation of the data when comparing soil observations with other data within a GIS. The overlay of observation points classified according to their suitability on a satellite image revealed errors in the attribute values attached to these observations. These were caused by survey recording procedures, emphasising the need for careful checking of any database before the analysis proceeds.

The implications of datum and attribute errors for land suitability analysis were investigated. The extent and spatial distribution of land with different suitability classes was changed as a result of correcting these errors. Failure to make corrections could adversely influence future land use planning

The effects of datum and attribute errors increased, as the level of mapping became more detailed. At level three, 85% of soil observations, positioned using the wrong datum, shifted into different soil polygons when corrected. Fortunately, these were a small proportion of the total in the case study but nevertheless they caused important errors in the land suitability map.

This study has shown the crucial importance of critical examination and correction of spatial data before analysis within a GIS. The use of geocoded satellite imagery was indispensable in the detection and assessment process.

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References

Bolstad, P. V., and Smith, J. L., 1992, Errors in GIS: assessing spatial data accuracy. Journal of Forestry, **90**, 21-29.

Bolstad, P. V., Gessler, P., and Lillesand, T. M., 1990, Positional uncertainty in manually digitised map data. International Journal of Geographical Information Science, **4**, 399-412.

Burrough, P. A., 1995, Accuracy and error in GIS. In The AGI Source Book for Geographical Information Systems. Green, D. R. (ed.), pp. 87-92.

Burrough, P. A., and McDonnell, R. A., 1998, Principles of Geographical Information Systems, 2nd Ed, (Oxford: Oxford University Press).

Dodson, A. H., and Haines-Young, R. H., 1993, Datum transformation and data integration in a GIS environment. In Geographical Information Handling - Research and Applications. Mather, P. M. (ed.). (New York: John Wiley & Sons), pp. 79-90.

FAO, 1976, Framework for Land Evaluation. Food and Agriculture Organisation, Rome, Italy.

FAO, 1983, Guidelines: Land Evaluation for Rainfed Agriculture. FAO Soils Bulletin No. 52. Rome, Italy.

Fernandez, R. N., and Lozano-Garcia, D. F., 1991, Accuracy assessment of map coordinate retrieval. Photogrammetric Engineering & Remote Sensing, **57**, 1447-1452.

Flowerdew, R., 1991, Spatial data integration. In Geographical Information Systems Principles and Applications. Volume 1: Principles. Maguire, D. J., Goodchild, M. F., and Rhind, D. W. (eds.). (Harlow: Longman), pp. 375-387.

Goodchild, M. F., 1993, Data models and data quality: problems and prospects. In Environmental Modelling with GIS. Goodchild, M. F., Parks, B. O., and Steyaert, L. T. (eds.). (Oxford: Oxford University Press), pp. 94-103.

Guptill, S. C., 1992, Inclusion of accuracy data in a feature based, object-oriented data model. In the Accuracy of Spatial Databases. Goodchild, M., and Gopal, S. (eds.). (London: Taylor & Francis), pp. 91-97.

Hardy, E. E., 1987, Data Preparation for a GIS in a Developing Country Situation. Annual International Conference, Exhibits and Workshops on Geographic Information Systems. Falls Church, Virginia, USA, American Society for Photogrammetry and Remote Sensing, pp. 498-508.

Iliffe, J. C., 1995, Datums and Map Projections for Remote Sensing and GIS. Workshop held at University College London on 18 December 1995.

Lee, J. E., and Walsh, J. M., 1984, Map Projections for Use with the Geographic Information System. Fish and Wildlife Service, U.S. Department of the Interior. Reproduced by National Technical Information Service, U.S. Department of Commerce, Springfield, VA. 22181. Microfiche.

MoA (Ministry of Agriculture, Jordan), 1995, The Soils of Jordan. Report of the National Soil Map and Land Use Project, Undertaken by Ministry of Agriculture, Huntings Technical Services Ltd., and European Commission. Level One, Level Two, Level Three and JOSCIS Manual.

Rogowski, A. S., 1995, Quantification soil variability in GIS applications, I. estimates of position. International Journal of Geographical Information Science, **9**, 81-94.

Vitek, J. D., Walsh, S. J., and Gregory, M. S., 1984, Accuracy in Geographic Information Systems: An Assessment of Inherent and Operational Errors. Proceedings, PECORA IX Symposium, pp. 296-302.

Walsh, S. J., Lightfoot, D. R., and Butler, D. R., 1987, Assessment of Inherent and Operational Errors in Geographic Information Systems. Proceedings, American Society of Photogrammetry and Remote Sensing, American Congress on Surveying and Mapping, Baltimore, Maryland, pp. 24-35.

Ziadat, F.M., Taylor, J.C., and Brewer, T.R., 2000, Application of GIS for optimising the use of soil survey data for land suitability analysis in Jordan. Submitted to the International Journal of Geographic Information Science.

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Modelling for Land Resource Management with remote sensing and GIS: Living with confusion and error

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Abstract: Limitations in spatial data sets have profound implications for modelling in land resource management applications. Increased sophistication in modelling methods may not lead to improved results if the quality of the input data is not sufficiently high. Often little thought is given to the accuracy and integrity of input data and the implications of various sources of error. In this paper we discuss errors in classification of categories in thematic maps. Two cases are considered, digital classification of satellite imagery for area estimates of crops, in the EU Monitoring Agriculture with Remote Sensing project (MARS) and visual classification by Aerial Photograph Interpretation, for measuring landscape change in the National Parks of England and Wales. We demonstrate methodology for making unbiased estimates of category errors using specially designed ground surveys and show ways of minimising category errors and reducing the effects of those which cannot be removed. In our last example, we show how satellite imagery has been used to investigate location errors in existing soil data for land suitability mapping and land use planning in Jordan. These were: non systematic errors of location of soil profile observations caused by the field methodology, which was pre-GPS availability, and systematic errors in location of soil profile observations and map polygons arising from the mixture of projections, datums and spheroids used to collect and digitise the data. We identify the potential problems these errors might cause in applications of the data for land use planning and land suitability mapping.

Introduction

Land resource surveying with remote sensing and Geographical Information Systems (GIS) is a fundamental tool for land resource management. The methodology which has increasing applicability, has been revolutionised by the availability of satellite images and the ability to process them by computer in a GIS. The information systems are used to interpret the image and produce maps of land resources to any desired scale and projection and to calculate statistics. Data sources originating from surveys carried out in the pre-GIS and

GPS era are frequently being converted into digital format for modelling in the GIS environment

The high quality of the computer presentation of outputs produced within a framework of such advanced technology may confer, in the minds of users, a belief that the accuracy is always of equally high quality. But is it?

Assessing the quality of results produced by remote sensing in a GIS is a major problem for users. What levels of accuracy should be expected? Are disappointing results caused by poor work or by inherent shortcomings in the methodology? These are questions frequently asked but not often answered satisfactorily. As with many new areas of technology there are no quality control standards to refer to.

The objective of this paper is to provide users with some guidelines for assessing the quality of land resource surveys carried out with remote sensing and GIS methods. Two of the main sources of errors considered are the incorrect identification of land resource categories and the incorrect spatial location.

Spectral confusion in agriculture

Thematic maps from digital classification of remotely sensed imagery, usually contain category errors i.e. parts of the map have been allocated to the wrong class. Barley has been mistaken for wheat, for example. Such errors can be measured by comparing the thematic map with ground data using a confusion matrix (Story and Congalton, 1986). This is generated by cross-tabulating the frequencies of occurrence of ground data and digital class combinations at a random sample of locations in the study area. Table 1 presents the confusion matrix generated for a regional crop inventory in the UK in 1992 (Taylor and Eva, 1992 and 1993), as an example. The overall agreement between ground observations is the sum of the diagonal elements divided by the total number of observations in the matrix. The off-diagonal row elements represent the mis-classification of ground classes, which are included in the image classification. The diagonal element expressed as a percentage of the row total gives the so-called user or mapping accuracy of the classification for that class. The off-diagonal column elements represent the mis-classification of a ground class into other image classes. The diagonal element expressed as a percentage of the column total gives the accuracy that the producer of the classification has achieved for the class. The agreement between a digital classification and ground survey, given by a confusion matrix, is frequently used to estimate its accuracy, assuming the reference data is accurate.

Table 1. Confusion matrix showing the relationship between ground survey data and the digital classification of SPOT imagery in the 1992, regional crop inventory of Beds., Cambs. and Northants, UK

		Reference Data									
		Woods	Inland Water	Urban	Wheat	Barley	Summer Crops	Grasses	OSR	Other	TOTAL	User Accuracy
Image Data	Woods	15	3	1	2	1		2			24	63%
	Inland Water		4		1						5	80%
	Urban			11			1			1	13	85%
	Wheat	2	1	2	155	8	1	3		1	173	90%
	Barley	8		4	18	16	3	17		3	69	23%
	Summer Crops		1	13		3	43	3	1	5	69	63%
	Grasses			8	6	7	10	37		1	69	54%
	OSR				1				30		31	97%
	Other	2		12	1	3	11	25		16	70	23%
	TOTAL	27	9	51	184	38	69	87	31	27	523	
	Producer Accuracy	56%	44%	22%	84%	42%	63%	42%	97%	59%	Overall Accuracy 63% Kappa 54% Var(kappa)0.000599	

In recent years, considerable experience in the application of remote sensing technology has been gained in the European Union's Monitoring Agriculture with Remote Sensing (MARS) project (Taylor et al, 1997). Digital classifications of Landsat TM and SPOT imagery were carried out over many different parts of the EU and the following observations can be made from this collective experience:

- The results presented in Table 1 are typical for a classification based on a single image. The overall accuracy was usually between 60 and 75% for classifications having between 8 and 12 classes.

- The overall accuracy tends to be lower as the number of classes increases.

- Accuracy of individual classes is very variable - anything between 0 and nearly 100% - depending on spectral separability.

- The accuracy of classifications based on the combination of two or more images is usually improved to about 80 - 85% for the same numbers of classes mentioned above.

There are a number of explanations for the occurrence of misclassification errors: spectral similarity of classes; mixed pixels along parcel boundaries; the classification algorithm used and the land classification scheme being applied.

The above experience confirms that significant misclassification errors usually exist in thematic maps from remote sensing. This poses important problems for the use of the data: 1) Accurate assessment of change by simple cross tabulation of classifications from two dates is not possible because classes are not accurately identified at all locations and errors vary from map to map so. 2) Estimates of class areas, important for agricultural inventory, cannot be accurately measured from pixel counts. A summary of results from the regional inventory reported by Taylor and Eva (1992) in Table 2 illustrates this latter point and also shows the effect of using two different classification procedures. The columns PC-W and PC-UW are the class areas obtained by pixel counts in two separate digital classifications. The columns REG-W and REG-UW are the corresponding areas and their 95% confidence intervals estimated by combining the ground survey data with the respective digital classifications using the regression method described by Taylor and Eva (1993). The MAFF column gives, where available, the areas estimated by a census carried out independently by the Ministry of Agriculture, Fisheries and Food. Comparison of the area estimates for each cover type shows that the pixel counts are widely different, influenced by varying the digital classification algorithm and hence the degree of mis-classification. The regression estimates on the other hand, are similar to each other and to the MAFF census figures. This shows that the differences caused by varying the classification algorithms have been corrected by the regression technique. Experience in the use of thematic classifications for monitoring agriculture in the European Union has shown the general need to measure classification errors and to compensate for them.

The acquisition of an unbiased sample of ground observations of sufficient size is crucial for this so that confusion matrices can be produced or regression estimates made. The effect of bias can easily be illustrated by examining the effect of over-sampling one class. For example, if we had increased the sampling of wheat in Table 1 by a factor of two, we would expect the mis-classifications of the reference data to be in the same proportion. Thus the wheat column of Table 1 would have every element multiplied by two. This would increase the estimate of the user accuracy of wheat to 95%. However the user accuracy's for the other classes will be under estimated because of the increased number of wheat commission errors. For example, the user accuracy of barley would be reduced to 18%.

The confusion matrix will be biased if the samples for each class are not proportional to the class areas. Since these are not known before the classification, a random sample design is used to achieve this. In the MARS project this was done by an area-frame sample, developing methods used by the USDA for crop area estimation in the 1970s (Hanuschak et al, 1979). The requirement for a random sample of locations generally means that access will be very difficult for some sites. The temptation is to ignore these even though it will invalidate the error assessment.

Table 2. Areas (ha) of cover types in the same region of England estimated by different techniques using digital classifications and by agricultural census

CLASS	PC-W[1]	PC-UW[2]	REG-W[3]	REG-UW[4]	MAFF[5]
Woodland	35153	42834	29636 ±19%	29409 ±25%	na
Inland Water	5510	4123	5744 ±58%	6279 ±44%	na
Urban	111775	22518	82594 ±14%	70668 ±20%	na
Wheat	210459	159938	238003 ±6%	236736 ±6%	227637
Barley	22839	93969	53900 ±27%	55502 ±24%	50585
Summer Crops	66990	105593	89888 ±13%	96494 ±15%	82587
Grass and Forage	192582	107509	130339 ±12%	124691 ±13%	114491
Rape	29946	29047	44244 ±10%	44095 ±11%	46643

[1]pixel count, area-weighted discriminant functions; [2] pixel count, un-weighted discriminant functions [3]regression estimate, area-weighted discriminant functions; [4]regression estimate, un-weighted discriminant functions; [5]MAFF agricultural census

Class confusion for landscape change

A major problem faced by land resource managers is that inexperienced users of the data often take thematic maps produced via a GIS as "truth". Inherently, thematic maps can only be a representation of reality. At the core of a thematic map is a classification scheme that provides names to the colours or symbols shown on the map. Behind each label in the legend will be a definition, either formally stated in accompanying documentation or defined mentally by the originator of the map. Here lies the heart of many debates. How explicitly should a classification category be defined? Can the definition be applied objectively? What potential confusion is there between categories in the classification? Will the user perception of a category differ from the specialists' use of a definition?

The Monitoring Landscape Change in the National Parks (MLCNP) project (Taylor 1991a and b) had to face up to these challenging questions. A census survey of landscape change between the 1970s and 1980s in the National Parks of England and Wales formed the aim of the MLCNP project. The primary data source was stereo aerial photography at scales ranging from 1:10,000 - 1:25,000. Data interpreted from the aerial photographs were input into a GIS to analyse landscape changes and generate maps and tabular statistics.

At the heart of the mapping was a hierarchical classification system designed to represent the specialist nature of the landscape types found within the National Parks with the limitation of all categories being identifiable from aerial photograph interpretation (API). As far as possible, the classification was objectively defined but it was recognised that the boundaries between classes can be both physically and conceptually fuzzy. Each landscape feature was defined in detail to ensure consistency of interpretation between photo interpreters. Experience of using this classification has shown that apparently insignificant variations in category definitions can lead to considerable differences in classification results.

From the outset of the MLCNP project it was recognised that due to the complex nature of National Park landscapes, errors and confusion would arise during the data gathering stage. The first step was to identify where the confusion was arising. This was done using methodology similar to that used in the MARS project described above. The overall agreement for area main classes was 98%, however, this hides the confusion seen at sub class level in the classification. The agreement between ground and API survey for the Wood and Forest sub classes varied from 43% to 90%. Particular confusion arose from the separation of mixed high forest from coniferous high forest. This was due to the class definition of mixed high forest : 'Areas greater than 0.25 ha which are wider than 25 m and have a tree canopy of at least 20% by area. Composed of an intimate mixture of broadleaved and coniferous species, where the minority group comprises more than 20%.' (Taylor 1991a). The potential for confusion arises from the second part of the class definition. A decision as to what constitutes 20% is difficult when the density of the minority group approaches the threshold value. Additionally, in this example the vertical perspective is likely to give a more accurate result than the horizontal perspective because of the overall context provided by the aerial view.

A second confusion analysis was used to determine the consistency of API between interpreters. This was particularly valuable during the initial stages of the MLCNP project in that the procedure identified classes where definitions were weak, were unworkable in the context of the method used and time available or where confusion was unavoidable due to the nature of the feature mapped. Each interpreter interpreted a randomly selected set of locations within a National Park independently of the other interpreters. For each location the results from each interpreter were compared and a "consensus" derived for that location by taking the majority view. Confusion matrices relating individual interpretations to the "consensus" gave percentage overall agreement and clearly showed where the disagreements occurred.

Having recognised where errors and confusion occurred, how were they controlled during the implementation of the project? Some class subdivisions were removed when they could not be reliably discriminated. In other cases further subdivision was required, for example, mosaic categories were created to ease mapping of intimate mixtures of the relevant landscape types in each mosaic class. The API methodology adopted, sought to minimise the propagation of error and confusion. All landscape features were mapped or counted for the 1980s but only change was mapped or counted for the 1970s. This avoided the potential pitfall of mapping change where in fact no change had occurred. This method required positive identification of change for it be recorded as such. Interpretations across map sheet boundaries were carefully matched. This acted as an internal check for an interpreter where they were matching one of their existing interpretations to another. It also provided an external check where the interpretation of one interpreter bordered the interpretation from another interpreter. Where differences of landscape class identification occurred, reference was made to a third interpreter so as to arrive at a consensus view. At all stages in the interpretation process communication between interpreters was essential to resolve problems and to highlight variations in landscape classes discovered by individual interpreters. To this end, interpreters worked in teams, in the same room.

Problems finding suitable soil in Jordan

Accurate geo-coding of spatial data is necessary to ensure that data from different sources will be in the correct relative positions in the GIS to permit valid modelling. An on-going study by us in Jordan is using soil survey information, collected prior to the availability of GPS, and early GIS and database software, to develop land suitability analysis. This has uncovered several limitations, arising from the original data collection and processing methodology. These must be understood and taken into account during modelling otherwise there is a danger of generating misleading information.

The project is applying FAO land suitability analysis to the soil data, which consists of some 30,000 soil observations within the study area. The suitability ratings are to be attributed to soil polygons which have been mapped at three scales 1:250,000 (full coverage – level 1), 1:50,000 (partial coverage – level 2) and 1:10,000 (very limited coverage – level 3). Mapping was by photographic interpretation of hard copy georeferenced satellite imagery (Landsat MSS for level 1, Landsat TM merged with SPOT PAN for level 2) or aerial photography (level 3). We are investigating the best ways of assigning land suitability classifications to the soil mapping units, for these different scales. All the methods use the data of the soil observations recorded at the points falling within each of the soil mapping unit polygons. If these two data sets are not co-located correctly, the land suitability assessment for the polygon may be incorrect because some points from outside the polygon may be accidentally included in the analysis and vice versa.

Overlaying the data onto a digital version of the satellite image-map (merged TM/SPOT PAN) in a GIS enabled a preliminary assessment of the accuracy of locating both soil map polygons and observation points to be made. The visual test clearly revealed a systematic shift of polygon boundaries for level 1 and level 3 compared to the same boundaries visible on the satellite image-map. The discrepancy of point locations was discovered because some points were displayed in unlikely locations. For example, one point was displayed in the middle of a large reservoir and the original field survey documentation verified that this was incorrect.

Further investigation revealed that several different mapping systems are used in Jordan and of necessity had been used in mapping soil polygons and recording soil observations. When these data were integrated with each other and displayed on satellite imagery the differences become obvious.

We believed the discrepancies were caused by errors in converting the data to a common co-ordinate system and decided to investigate ways of correcting these.

A map projection is the representation of the curved earth surface in two-dimensions. The true shape of the earth, known as the geoid, is irregular but is approximated as an ellipsoid of revolution or spheroid. For the purposes of a regional survey a spheroid is specified by selecting a shape and origin that best approximates the local shape of the geoid. The datum is defined from the combination of shape and size of the spheroid, and the position given by the fixing the origin. This local datum approximates the geoid in that region better than a global datum. Using two different datums in the same location, leads to different co-ordinates in latitude and longitude. Ignoring this fact when converting any pairs of coordinates will result in locating the point in the wrong position in the map projection.

The soil surveyors marked the positions of soil observations on topographic maps in the field by visual interpretation. The locations of point data were derived from the digitised map co-ordinates and a special program written in JOSCIS was used to calculate the latitude and longitude from different coordinate systems. A close examination of this program showed that there was no account for the different datums in the conversion process. However, the original co-ordinates and datums were recorded. The database was reprocessed to produce a consistent set of co-ordinates for each point using ARC/INFO software to convert between different datums.

The location of 30 soil observation sites was determined in the field with the original field sheets and help from a member of the original soil survey team. In some cases, pits and road sections were undisturbed from the time of the survey. For the other cases the original surveyor determined the site location using the field documentation. Differential GPS was used to determine the co-ordinates in UTM projection with the WGS84 datum at each of these sites and they were also located by photo interpretation on enlargements of geo-referenced satellite imagery.

The co-ordinates of the soil observation sites were then transformed to be consistent with the satellite image-maps but using both the datums of the original data. These were compared with the co-ordinates recorded in JOSCIS, first by calculating the differences for each site and second by displaying the sites on the satellite image-maps. There was a systematic difference of 26-29m for the Eastings and 119-121m for the Northing as a result of using different datums. This can easily be corrected. However, there were also non-systematic differences between GPS locations and JOSCIS locations even when using the same datum, from maxima of 314m and 304m in Easting and Northing, respectively, to minima of 10m and 1m in Easting and Northing, respectively. These differences were mainly attributed to errors in locating the soil observations on the topographic map sheets, which had to be done by visual interpretation at the time of the survey. This depended to a large extent on the presence or otherwise of distinct features in the vicinity of the site for guidance. The correction of these would be a very tedious job and beyond the scope of this research. However, the errors must be kept in mind whenever this point data is used for any further work, especially soil suitability analysis

The inconsistency between soil map vectors of level 3 and level 1 with the satellite imagery was also the result of using an incorrect datum. One reason was that the GIS software, which was used originally to digitise and produce soil maps did not allow the user to select the correct combination of spheroids and datum – the user chose the correct spheroid but did not appreciate that the origin was wrong.

The above errors were creating two types of error in the land suitability maps. Firstly, the incorrect location of soil observations with respect to the soil-map polygons was causing some to be incorrectly classified in respect of the suitability rating. This would result in incorrect decision-making when using the map products for land use planning and possibly result in the waste of scarce financial resources. Secondly, the systematic shift would cause incorrect location and possibly the creation of map artefacts when using the dataset with other map information.

Conclusions and recommendations

All thematic maps of land resources, from digital classification or other methods, seem to contain considerable discrepancies when compared to independent ground observations. This may limit their utility for determining the land cover at specific locations and changes through time. Poor definition of categories can also be a source of inconsistency between the classification and ground observations.

Integrating thematic map and ground survey data using confusion matrices or regression methods improves the accuracy of area estimates for inventories and provides a tool for quality control in surveys carried out by visual interpretation of aerial photography.

The area frame random sampling methodology described above works well for this purpose and is recommended using sampling fractions between 1% and 1.5%. However, poor implementation of the methodology leads to errors that are undetectable unless quality checks are made at specific stages in the work. The following are recommended: 1) Independent checks of 5% of ground survey sites selected at random. 2) Check the sampling pattern is random to ensure that confusion matrices are unbiased. 3) Check there are a sufficient number of independent ground observations per class (>50 in important classes).

Before commencing with GIS modelling carry out a critical examination of all data sets to fully assess accuracy and to appreciate any limitations which may be present so that inappropriate analyses can be avoided. Overlay of soil survey information onto satellite image-maps using the GIS, for example can be very helpful to check consistency of map co-ordinates and location of soil observations.

References

Congalton, R. G., and Mead, R. A., 1983, A quantitative method to test for consistency and correctness in photo interpretation. Photogrammetric Engineering and Remote Sensing, **49**, 69-74.

Hanuschak, G., Sigman, R., Craig, M., Ozga, M., Luebbe, R., Cook, P., Kleweno, D. and Miller, C., 1979, Obtaining Timely Crop Area Estimates Using Ground-Gathered and Landsat Data, Statistical Research Division, Economics Statistics and Co-operative Services, USDA, Technical Bulletin No. 1609.

Story, M., and Congalton, R. G., 1986, Accuracy assessment: a user's perspective. Photogrammetric Engineering and Remote Sensing, **52**, 397-399.

Taylor, C., Sannier, C. A. D., Delincé, J., and Gallego, F. J., 1997, Regional Crop Inventories in Europe Assisted by Remote Sensing: 1988 - 1993. European Commission, EUR 17319, 80pp.

Taylor, J. C., and Eva, H. D., 1992, Regional Inventories on Beds, Cambs and Northants (UK), 1992 - Final Report to CEC - JRC, Silsoe College, ISBN 1 871564 52 2, 70p.

Taylor, J. C., and Eva, H. D., 1993, Operational use of remote sensing for estimating crop areas in England, Proceedings of Rem Sens Soc Conference - Towards Operational Applications, ISBN 0 946226 18 0, pp 1-9.

Taylor, J. C., Bird, A. C., Brewer, T. R., Keech, M. A., and Stuttard, M. J., 1991b, Landscape change in the National Parks of England and Wales - Final Report Vol II Methodology, Silsoe College, ISBN 1 871564 16 6, 98p.

Taylor, J. C., Bird, A. C., Keech, M. A., and Stuttard, M. J., 1991a, Landscape change in the National Parks of England and Wales - Final Report Vol. I Main Report, Silsoe College, ISBN 1 871564 15 8, 97p.

Chapter Four

This chapter contains one paper for peer reviewing. The raw data used to derive tables and figures for this paper are found in the attached CDROM. The data exists under the directory CHAPTER 4. This includes the three satellite images of the study area, the scanned topography map, and a directory containing the raw data for DEMs derived from topography maps and aerial photography. The 3D visualisation of the satellite image is much better on a computer display device than a hardcopy print. The data for this visualisation is provided under the directory DEM which requires the Virtual GIS package of the ERDAS Imagine software for visualisation. This directory also contains the level three soil map polygons and the observation points. The views are also supplied as BMP files (SLIDES directory).

During the preparation of this Chapter, a lot of literature was reviewed. However for the purposes of publication not all of these were included. Appendix b contains further references for this Chapter, which are arranged according to their subject content.

Merging Landsat TM imagery with topographic data to aid soil mapping in the Badia region of Jordan

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Abstract: Detailed soil maps are required for land evaluation and subsequent comprehensive land use planning of the Jordanian arid to semi-arid area. The purity and the details of a suitability map are better when a detailed soil map is used to produce it. This paper investigates the use of Landsat TM images and topographic data to assist in detailed soil mapping. Landsat TM image data used with 1:50,000 or 1:25,000 scale topographic maps, contour lines or even three-dimensional viewing provide insufficient information to compete with air photo interpretation. A 3-D viewing of Landsat TM image data using an air photo-derived DEM proved the best method to assist in detailed soil mapping. Overlaying the soil observation points enhances this viewing. Further research is needed to investigate the interactive use of air photo-derived DEMs and Landsat images, with more focus applied to site specific planning and field verification of the technique.

Keywords: Remote sensing, GIS, topographic data, soil mapping, land use planning

Introduction

One of the first steps in producing a land use plan is to use available soil survey information to produce land suitability maps (FAO, 1976). Detailed information about the nature and extent of soils serves as a primary source of information about potential resources (Dwivedi 1985).

A sound land use plan requires that suitability maps are of an acceptable accuracy, when compared with the land suitability determined at specific sites. This is attainable only when the soil map used to produce the suitability maps is sufficiently detailed; i.e. the soil mapping units are homogeneous. Ziadat et al. (in press (a)) found that the accuracy of suitability maps using Jordanian soil maps increased from level one (1:250,000) and level two (1:50,000) to level three (1:10,000). Although, level three provided much more detail about land suitability, which is ideal for land use planning, the accuracy for site specific observations was still only 60 to 70%. Land use planning in the arid to semi-arid region of Jordan is one of the main objectives of the Jordan Arid Zone Productivity Project (JAZPP). Unfortunately, level three mapping is available for only a very limited area within the JAZPP zone. The preparation of soil maps at this detailed level, by traditional methods, is a costly and time-consuming process. The National Soil Map (NSM) project of Jordan prepared level three soil maps by detailed interpretation of 1:10,000 scale air photos. Slope maps derived manually from topographic maps and very intensive field observation points were used to help in the delineation and refinement of soil-mapping units. The final soil map was also checked and corrected in the field (MoA 1995). Dent and Young (1981) estimate the absolute cost of soil survey at scale 1:10,000 to be as much as £500-£1000 per km^2, using 1980 costs.

Remote sensing provides good possibilities for soil mapping. Landsat data has proved to have some advantages over aerial photography, for example, in differentiating the surface material. This is mainly due to the better spectral resolution provided by Landsat TM images (Mulders 1987, Lee et al. 1988). Another advantage is the possibility of on-screen digitising, which removes the requirement to manually draw soil boundaries, improving the accuracy and reducing soil map production time (Trotter 1991, Hinton 1996). Arid and semi-arid regions are considered ideal for the application of remote sensing to soil investigation. This is mainly due to the scarcity of vegetation cover, long periods of cloud-free skies, low soil moisture, and the close relationship between terrain units and soil associations (Leone et al. 1995, Dinc 1993).

Integration of remote sensing within a GIS database can decrease the cost, reduce the time, and increase the detail of information gathered for soil survey (Green 1992). For example, Liengsakul et al. (1993) estimate time savings of about 60% to 80% when using the digital format and experienced staff, compared with manual methods. GIS was used to incorporate the data about topography, vegetation, geology, and climate, to produce data layers to facilitate the fieldwork, by providing interpreted information. For example, a slope class map was used instead of interpreting slope manually from the topographic maps (Hinton 1996, Hammer et al. 1991, Mulders 1987).

The aim of this study is to investigate the utility of Landsat TM imagery, integrated with various representations of topographic data, as an alternative and improved method for detailed soil mapping in the JAZPP area not currently covered by level three mapping.

Study area, available data and approach

The research was undertaken in an area of 8 km^2 covered by level three soil mapping (1:10,000), near Al-Mafraq in the northern part of Jordan. The average annual rainfall is 150 mm, with a thermic temperature regime, and a relatively flat topography (slope less than 5%) with few hilly areas. The dominant land use is natural range, field crops and irrigated vegetable farms (MoA 1995). To satisfy the objectives of this research different approaches utilising various data sets were investigated. The data used were Landsat TM images, acquired on different dates, topographic maps at two scales, and aerial photographs (table 1). In each case, the approaches were compared qualitatively with the existing level three soil map, and wherever possible, quantitative comparison was undertaken. The tools and approaches investigated were arranged from the simplest and fastest to the most complicated and time consuming. The findings and results from one approach were used to develop the next one.

Table 1 Satellite images, topographic maps, aerial photograph and soil map used in this research.

Data layer	Date	Row / Path	Scale
Landsat TM-5	07.08.1989	173 / 38	------
Landsat TM-5	15.03.1992	173 / 38	------
Landsat TM-5	01.05.1998	173 / 38	------
Aerial Photographs	15.09.1992	------	1 : 30,000
Topographic Maps	1969	------	1 : 50,000
Topographic Maps	1982	------	1 : 25,000
Soil Map (Level Three)	1994	------	1 : 10,000

The investigation included:

- The identification of the best acquisition date and band combination for the satellite data.

- The analysis of topographic data from maps with the imagery by visual comparison and perspective viewing in an image processing system, to improve the interpretation of soil boundaries.

- The creation of a more detailed DEM from stereo pairs of aerial photographs and the investigation of the benefits of this DEM for 3-D perspective viewing for soil mapping purposes.

Use of Landsat TM for soil mapping

The spatial resolution of 30m and the spectral resolution of Landsat Thematic Mapper (TM) are important characteristics for soil mapping. TM images provide a spectral resolution of six bands in the visible and short wave infrared plus a seventh thermal band (Mulders 1987). The two bands in the middle infrared region (TM Bands 5 and 7) and the band in the thermal region (TM Band 6) provide the best information for soil and vegetation investigations according to Thompson et al. (1984). An important starting point is to find a good relationship between ground features and their responses on the satellite imagery. Ideally, the spectral response should be homogeneous within the soil mapping unit boundary, and different from adjacent units (Mulders 1987). Research shows that TM bands have good potential for responding to differences in soil properties and hence the separation of soil types (Dinc 1993, Thompson et al. 1984).

The use of Landsat data for soil survey is either by digital analysis of images or by the visual interpretation of false colour composites (Reddy and Hilwig 1993). The digital approach of image interpretation is quantitatively orientated, using automated classification methods, pixel by pixel (Buiten 1993). Many researchers have used this approach for the purposes of soil mapping, mostly at a reconnaissance level (Thompson et al. 1984, Leone et al. 1995). However, soil grouping using Landsat TM is less useful at the level of detail used in conventional soil surveys. Soil mapping units extend across several spectral classes. Hence, the spectral classification of the Landsat TM data alone is not enough to discriminate the soil mapping units (Lee et al. 1988).

Careful visual image interpretation can be better than digital image classification. Without ground truth information, it can achieve a higher level of accuracy in soil unit delineation. It is also more expedient and less expensive, and the interpreters can use their own knowledge and experience to improve the delineation of mapping units (Trotter 1991). Different band combinations have been found to provide images of optimum contrast for the identification of physiographic units, landforms, catchment characteristics and land resources. For example: Bands 5 or 7 with bands 3 or 4, or the display of one band divided by total intensity (Mulders 1987); bands 4, 5, 6 and 7 (Thompson et al. 1984); soil brightness image (Lee et al. 1988); and, bands 4, 5 and 7 (Liengsakul et al. 1993). The image characteristics that are frequently used in these investigations are the colour-tone, texture, pattern recognition, shape and size (Reddy and Hilwig 1993), which is similar to air photo interpretation principles (Carroll et al. 1977).

Application of Landsat TM images for soil mapping in Jordan

The Landsat TM images available were acquired on different dates in three different years (table 1). This might affect pixel values due to differences in the vegetative status, soil moisture content and the soil surface condition, and hence might affect the potential of the Landsat TM image for distinguishing soil types. An assessment of this was made by digitally 'draping' the soil mapping unit boundary over each image and making a visual comparison with the image features underneath, using the EASI/PACE® image processing package. Different image band combinations were investigated to identify which one gave optimum visual differentiation. In addition, the grey level ranges (maximum minus minimum value) within closed soil polygons inside the project area was calculated. The range within each soil-mapping unit was standardised by dividing by the range for the whole study area, to enable comparison between bands. These calculations identify the bands with the lowest grey level variation within soil mapping units, which might indicate their relative potential for soil mapping.

The grey value ranges within different soil mapping units for the Landsat 1989 image are presented in figure (1). Band 6 was excluded due to its low spatial resolution (120m). The grey level variations in Landsat TM bands 5 and 7 were lower than the other bands, in most cases (figure 1). Other researchers, Thompson et al. (1984) and Liengsakul et al. (1993), have also reported the usefulness of these particular bands for visual interpretation of soil and land identification activities. In addition to bands 5 and 7, a third band was selected to display a false colour composite for the purposes of visual interpretation. Figure 1 shows that band 3 also exhibits low variation in grey levels. However, the false colour composite of bands 1, 5 and 7 visually revealed a better correspondence with the soil mapping unit polygons than that of bands 3, 5 and 7. In recent research in Jordan, Al-Bakri and Taylor (in press) also reported a good correlation between bands 1, 5 and 7 and certain soil characteristics, namely, sand, clay, and carbonate content.

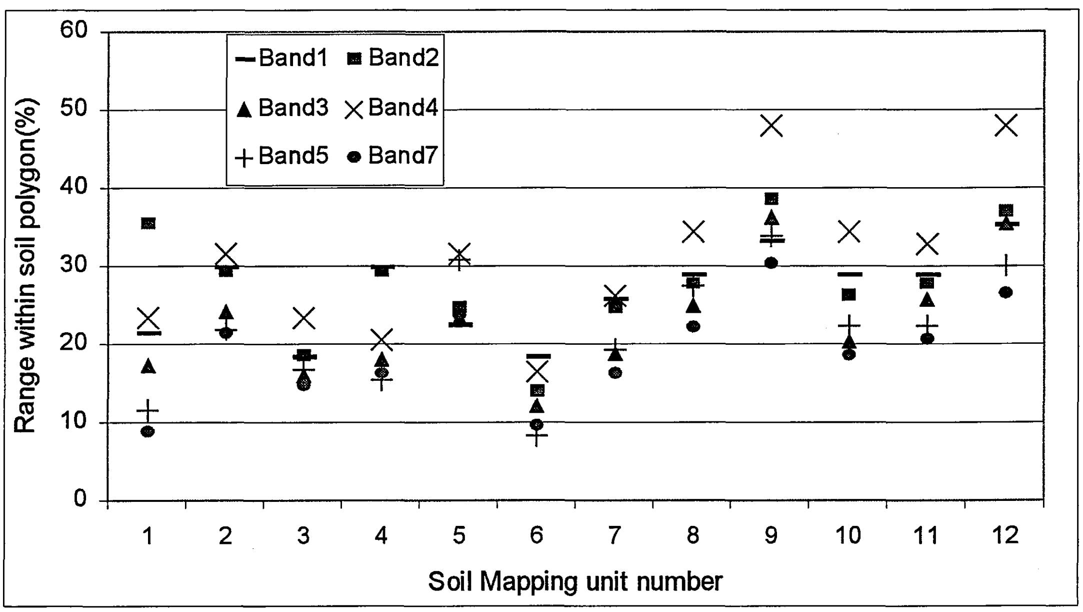


Figure 1 Normalised range of grey levels of Landsat TM (1989 image) bands within some soil mapping units.

The image acquired in August 1989 has less grey level variability within soil mapping unit boundaries, for bands 5 and 7 compared to the other image dates (figure 2). For band 1, however, the image acquired in May 1998 has the lowest variations in grey level. In addition, the image acquired in March 1992 has the highest variations in grey level of all dates and bands studied. This was attributed to the above average rainfall in 1992, which affected the response from the soil surface through the increase in the moisture content and vegetation cover.

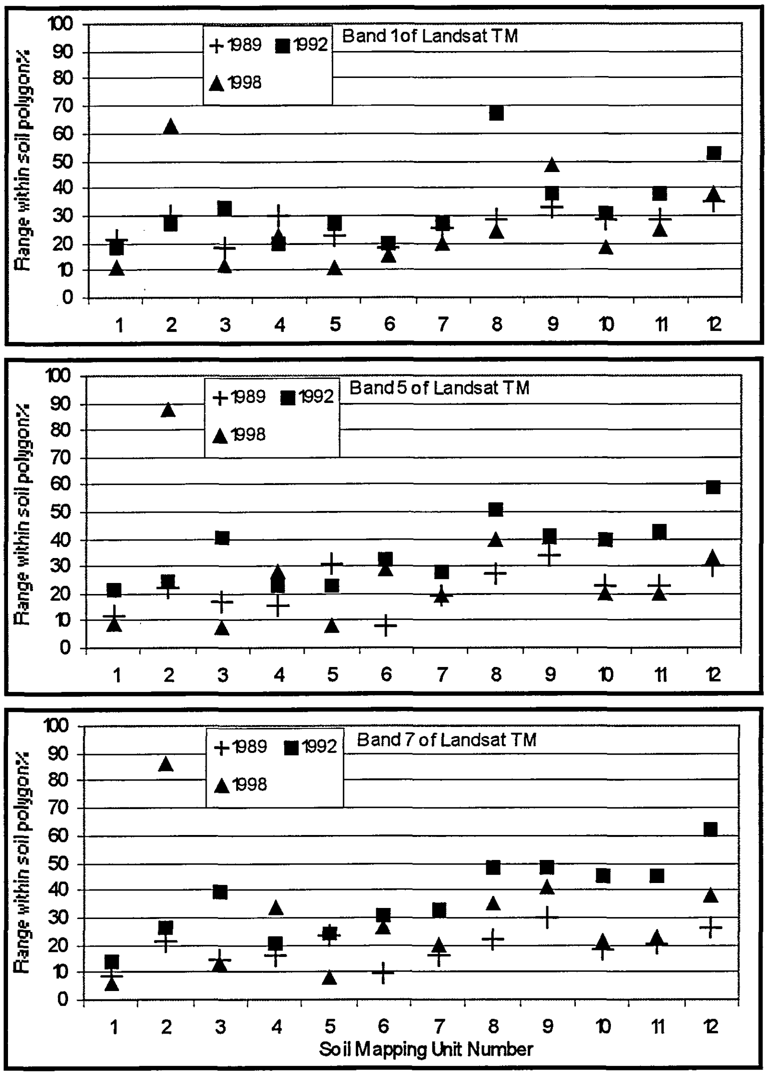
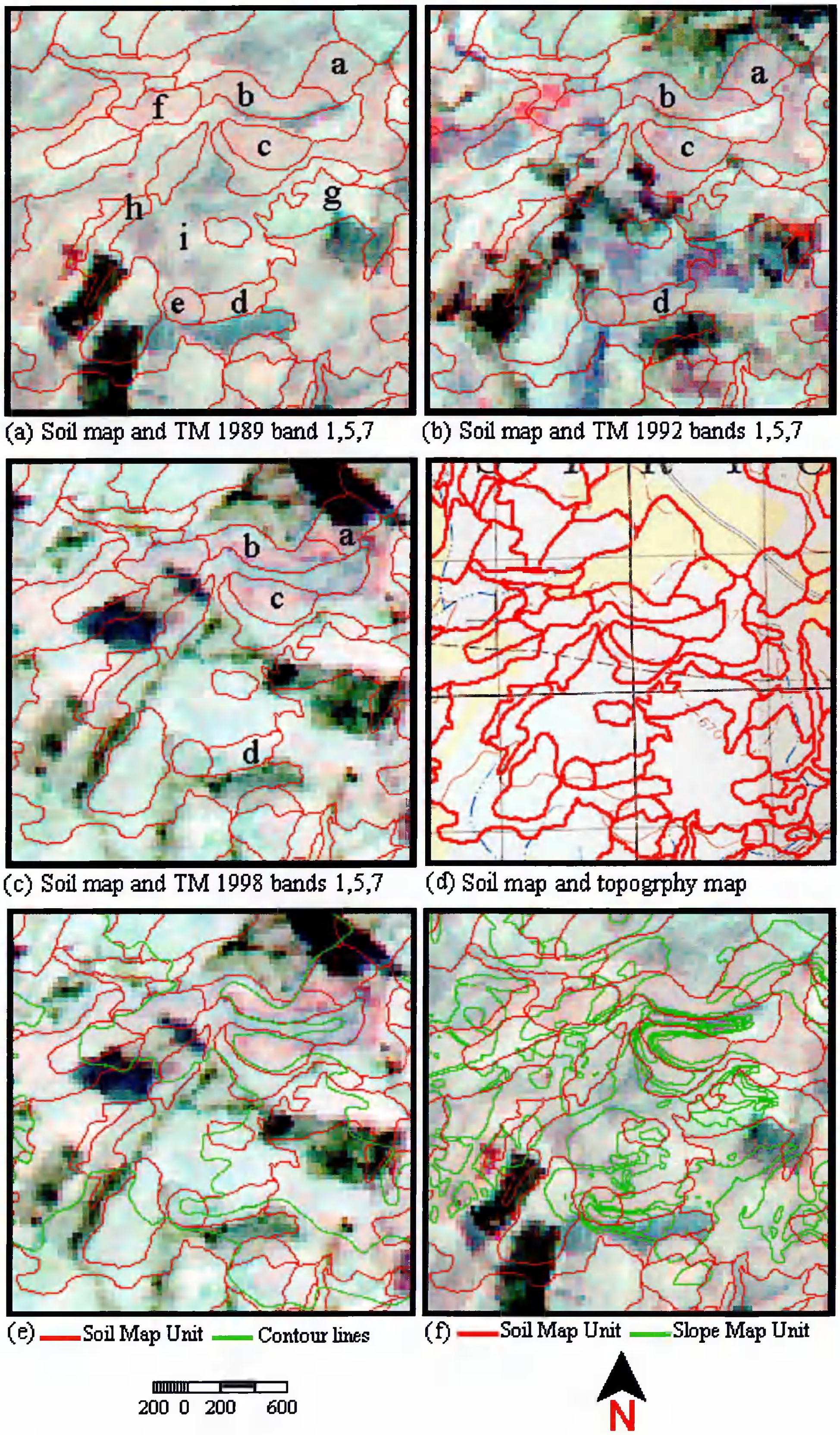


Figure 2 Normalised range of grey levels within soil mapping units for Landsat images acquired on different dates.

A visual comparison of the three dates of satellite imagery is presented in figures 3a, 3b and 3c and shows that some soil polygons match reflectance values in the imagery. Polygons that are dominated by a pink colour mostly refer to shallow soils with an average slope of 3%, whereas polygons dominated by a green colour mostly refer to deeper soils with an average slope of 2%. However, the images also record some features which do not relate to soil boundaries, for example, irrigated farms, which appear as dark areas, due to high absorption by soil moisture in the Landsat bands.

Overall, the 1989 image showed the best correspondence between soil mapping unit boundaries and the underlying image appearance, i.e. the pixels within a polygon appear homogeneous and apparently different from outside. This is clear, for example, by comparing polygons 'a', 'b', 'c' and 'd' of the 1989 imagery (figure 3a) with the same polygons in the other images (figure 3b and 3c). This can be related to the acquisition dates of these three images (table 1). In March and May the study area has some vegetation cover on the soil surface, which interferes with the soil response. In August the vegetation has disappeared, due to grazing and the harvesting of field crops in June. Dinc (1993) states that the best time for acquiring Landsat imagery for soil mapping in the arid region of Turkey is in September and October. This is also attributed to the minimal crop cover, minimal effect of surface roughness, and the very low soil moisture content.

The agreement between the selected image of 1989 and the soil mapping units boundaries was not complete. The image justified the existence of some soil mapping boundaries but not others. For example, the boundaries between polygons 'a', 'b' and 'f', and between polygons 'd' and 'e' (figure 3a) cannot be determined from the imagery alone. Furthermore, some polygons included areas that seem very heterogeneous, for example, polygons 'g', 'h' and 'i' (figure 3a). Therefore, the best available image was not enough to map the soil at level three. This approach does not explicitly use any information about topography, which is considered to be one of the most important factors affecting the formation of soils in this area (Taimeh 1989). The procedure of producing the soil map at this level by the NSM project emphasises the need for the incorporation of topographic data with satellite imagery.



Figure(3) Examples of on-screen viewing of Landsat TM with topographic data (subset from the study area).

Incorporating 2-Dimensional representations of topographic data with satellite imagery for soil mapping

Ancillary data has been used with Landsat images to improve their visual interpretability (Trotter 1991). Examples are topographic maps as paper prints or scanned images, digitised contour maps, watershed boundaries, and geological maps (Hammer et al. 1991). A GIS can be used to integrate this data and to produce information that might identify surface features that are unnoticeable in stereo aerial photographs, for example, a "premap" produced from maps of slope, aspect and landform (Klingebiel et al. 1987).

The level three soil mapping unit boundaries were overlaid on the scanned and registered topographic map (1:50,000 scale) and on the satellite image. The boundaries of the soil mapping units on both the Landsat TM image and topographic map were compared to investigate the information supplied by the topographic map for improving the interpretability of the satellite imagery by displaying the images adjacent to one another. The topographic map features utilised in this investigation were mainly, the contour lines, vegetation symbols and parent material (for example Basalt areas and Limestone areas).

To improve the clarity of the topographic data, contour line separations were scanned and used instead of the whole topographic map. This provided transparent topographic information, which was draped over the imagery together with the soil mapping unit boundaries. The scale of the contour separations was 1:25,000, mapped with a contour interval of 5m. The raster representation of the contours was converted into vector data format, using the ArcScan programme provided in the ARC/INFO® software. This process is superior to traditional manual digitising for this type of data; the user only needs to point to the beginning of each line and press a button to trace the whole line, assuming the line of pixels is clean. The whole process was relatively easy, fast and could be applied to larger areas. The accuracy of registration between topographic data and satellite imagery was within 30 m.

Benefits of 2-Dimensional topographic data displayed simultaneously with Landsat imagery

Viewing the 1:50,000 topographic map and satellite data together provided an opportunity to look at the same soil mapping polygon in both formats at the same time (figure 3a and

3d). In practice, the topographic map did not add significantly to the soil information extracted from the image. The contour spacing (10m) was too coarse for level three soil mapping. Other relevant features, such as vegetation and parent material also were not helpful, due to lack of sufficient detail.

The representation of the contour lines (figure 3e), with a spacing of 5m also was too coarse for level three mapping. The chosen area was relatively flat, with the dominant slope being less than 5%. The topographic information added by this contour layer was therefore, not able to clarify most of the soil boundaries. However, in a few locations with steeper slopes, for example, polygons 'a', 'b', 'c' and 'd' (figure 3e) the position of the soil boundary was identifiable. The contour lines alone did not serve to enable the easy interpretation of topography in relation to soil variations.

Digital Elevation Models (DEMs) for 3-Dimensional viewing of satellite images

A 3-Dimensional representation of the landscape is required to visualise the soil and landform relationships. Attributes related to soil-landscape features are considered important for separating soils using remote sensing data (Florinsky 1998, Su et al. 1989). Due to the capability of air photos to provide a stereoscopic view, their use in soil mapping is still common and more familiar than the use of satellite images (Mulders 1987).

Recent developments in computer software enable the production of DEMs from different sources in a reasonable time. The source of a DEM can be stereopairs of aerial photography, satellite imagery, or a digitised contour map (Hammer et al. 1991). This opens the way for 3-D viewing of the landscape, which enhances feature representation and the human perception of spatial entities and helps the visual interpretation of images and the understanding of relationships between landscape elements (Green 1992, Florinsky 1998). Information derived from DEMs, such as elevation, slope and aspect maps can also be used with the images to improve their capabilities for soil mapping (Lee et al. 1988). However, the use of these capabilities has not been widely investigated for soil mapping and other forms of land resource management (Trotter 1991, Hinton 1996).

Creation of a map-derived DEM

Height values were added to the contour lines used previously as the first step in creating the DEM. This was the most time consuming stage of the process, as each line had to be edited separately. The DEM was required in a raster format to use with satellite imagery. Based on a study by Gao (1997), the accuracy (RMSE, m) of a raster DEM is related to the contour density (D, km km^{-2}) and the DEM resolution (S, m) through the following:

$$\text{DEM accuracy (RMSE)} = \frac{(7.274 + 1.666\,S)\,D}{1000} \qquad R^2 = 0.9659$$

The RMSE for the study area, for six resolutions, reveals that although the error increases as resolution decreases, all were low enough to be acceptable, considering the source data (table 2). This is because of the very low contour density in the area (2.92 km km^{-2}), i.e. the area was relatively flat, so a DEM at low resolution will accurately represent the topography. A resolution of 40m was used to be consistent with the DEM produced later from aerial photography. The accuracy of the DEM was also investigated by comparing the elevation figures of eight locations with the original topographic map. These were within +/- 3m.

Table 2 Accuracies of DEMs generated at different resolutions.

DEM Resolution (m)	10	20	30	40	50	60
RMSE (m)	0.07	0.12	0.17	0.22	0.26	0.31

Utility of map-derived DEM and slope map for soil mapping

The soil mapping unit boundaries were draped over the elevation surface to produce the 3-D perspective view in figure 4a. The same view, including the satellite image, is shown in figure 5a. The ability of the 3D view to explain soil mapping unit boundaries depended on the topography. In the flatter areas, insufficient information was added to justify polygon boundaries, for example, polygons 'a', 'b', 'c', 'd', 'e', 'f', and 'g' in figure 5a. This is due to the limited detail of the contour lines. Klingebiel et al. (1987) also indicate some limitations of using a 30m DEM to aid soil mapping with slopes less than 5%. Slope and slope-shape maps were also produced from the DEM. The slope layer and the soil mapping unit boundaries were also draped over the 2-D view of the satellite imagery in figure 3f.

This clearly shows the insufficiency of topographic detail in the flatter area due to the low resolution of the contour interval. Large areas of the study site have only one slope class, whereas the soil map shows many soil mapping polygons.

In steep areas, however, both 3-D visualisation (figures 4a and 5a) and slope map (figure 3f) show some correspondence between topography, Landsat image detail and the soil mapping unit boundaries, for example, the boundaries between polygons 'a' and 'h', and 'g' and 'i' (figure 5a).

Creation of an aerial photography-derived DEM

The aim was to investigate whether an improved DEM derived from 1:30,000 scale aerial photography would further assist in soil mapping The aerial photographs were digitised by scanning at high resolution (1200 dpi) and ortho rectified using the ERDAS Orthomax software package. The easting and northing coordinates of five ground control points per stereo pair were taken from a geometrically corrected SPOT PAN image of 10m resolution. The elevation values were taken from the map-derived DEM because survey observations were not available. Therefore, the accuracy of the aerial photo-derived DEM, in terms of absolute elevation values, was limited by these estimates. However, the relative differences in elevation were more important for this research and these are less affected.

The DEM produced automatically using aerial photography is not perfect and generally contains anomalies, which have to be removed by manual editing. The software facilitates editing with a program to visualise the DEM as a grid of spot heights together with the stereo photographic model. The number of anomalies generally increases as the spatial resolution of the DEM is increased resulting in more time required for editing. The DEM with 40 m resolution required approximately 2 hours to edit 8 sq. km point-by-point. Editing time was approximately proportional to the number of points in the DEM thus halving the resolution causes 4 times the editing time. The 40 m resolution DEM was taken as a reasonable compromise between editing time and the accuracy of representation of the topography, which according to table 2 does not increase markedly in the study region when spatial resolution is increased.

The effect of editing the automatically generated DEM can be seen in the area covered by polygon 'a' in figures 4c and 4b. In this case, the edited DEM shows better coincidence between landscape features and soil mapping boundaries. Soil boundaries around this polygon are not justifiable in the unedited DEM, whereas the edited DEM shows that they follow a reasonable slope break with a homogeneous upwardly convex surface.

Comparing the air photo and the map-derived DEM

Figures 4a and 4c enable visual comparison between the airphoto and map-derived DEMs and show that the airphoto-derived DEM contains greater topographic detail. The topographic justification of soil boundaries for polygon 'a' is particularly good. However, the added topographic detail near polygons 'b' and 'c' suggests possible revisions may be needed.

The slope and slope shape values derived from modal values within 3 by 3 pixel windows from both DEMs were compared with values recorded in the field at 104 observation points (table 3). Correct points for slope are those where the slope percent from the DEM, rounded to integer, is equal to the slope percent recorded in the field. Similar comparison is reported for slope shape. Three classes; convex, linear and concave, reported in the field are compared to equivalent indicators derived from the DEMs. These results indicate a better agreement for slope derived from the aerial photo DEM. However, the number of points correctly estimated was only 24 points out of 104. The agreements for slope shape were higher with the map-derived DEM being slightly the better.

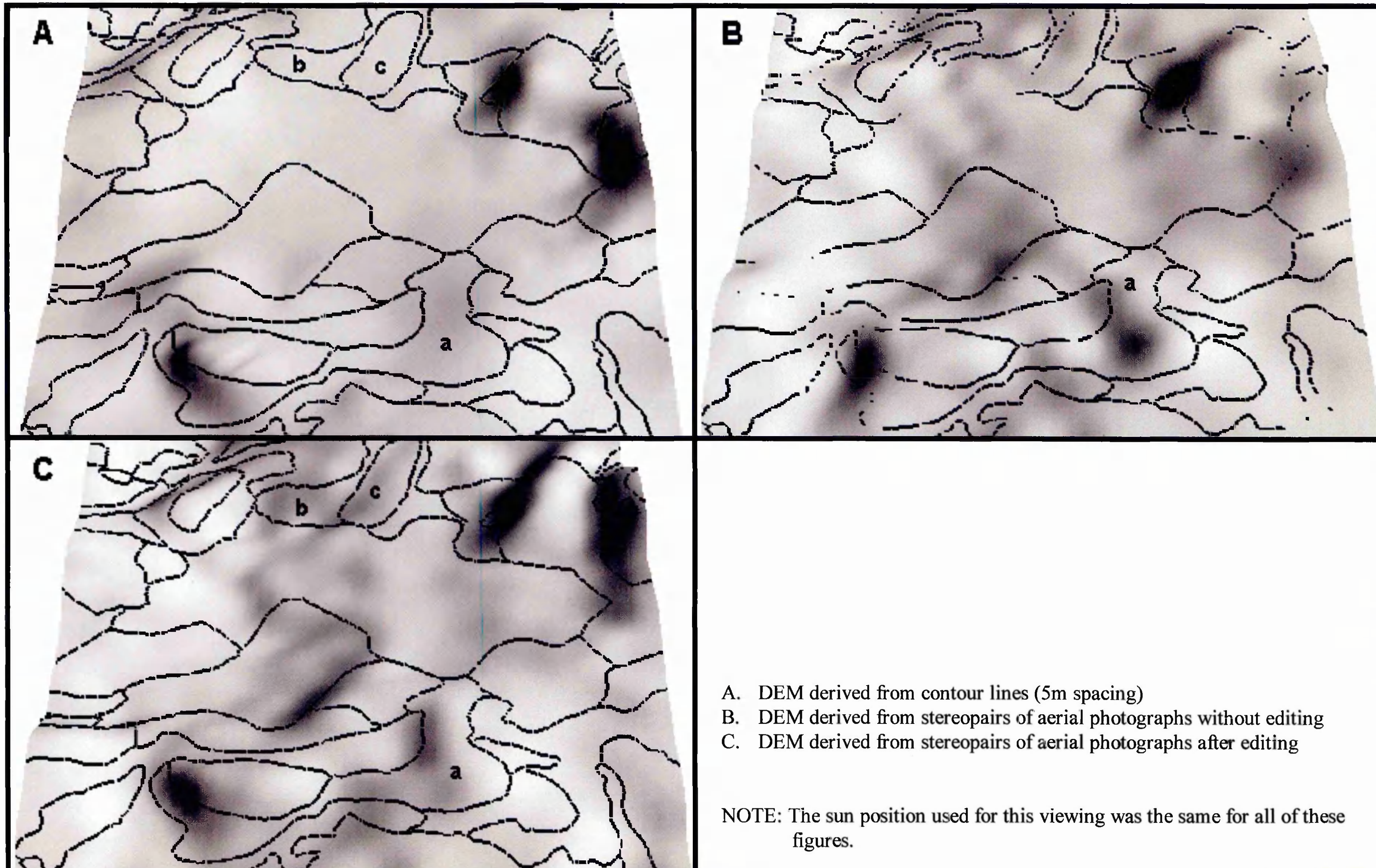
Table 3 Number of points where field recorded slope and shape agreed with those derived from two DEMs.

Variable		Airphoto-derived DEM	Map-derived DEM
Slope (percent)	Underestimated	74	93
	Correct	24	8
	Overestimated	6	3
Slope Shape (curvature)	Underestimated	11	18
	Correct	71	78
	Overestimated	22	8

Hammer et al. (1995), found that soil survey techniques classified a lower percentage of points into the correct slope class compared to a 10 m DEM derived slope map (30% versus 50%), and that the former did not capture landscape heterogeneity. Klingebiel et al. (1987)

also report that some topographic features which could be overlooked on aerial photographs were identified with a GIS-generated DEM. However, they also indicated that for slopes less than 5%, there was insufficient detail for soil survey in the standard USGS 30 m DEM-derived slope maps. No publications are available regarding the use of aerial photo-derived DEM for soil mapping purposes but from this research it can be argued that a DEM carefully generated from stereopairs of aerial photography is superior to the traditional methods, even in areas with a slope less than 5%. This is particularly important in the study area, since it is dominated by slope classes less than 5%, and slight differences in slope can result in significant differences in soil characteristics.

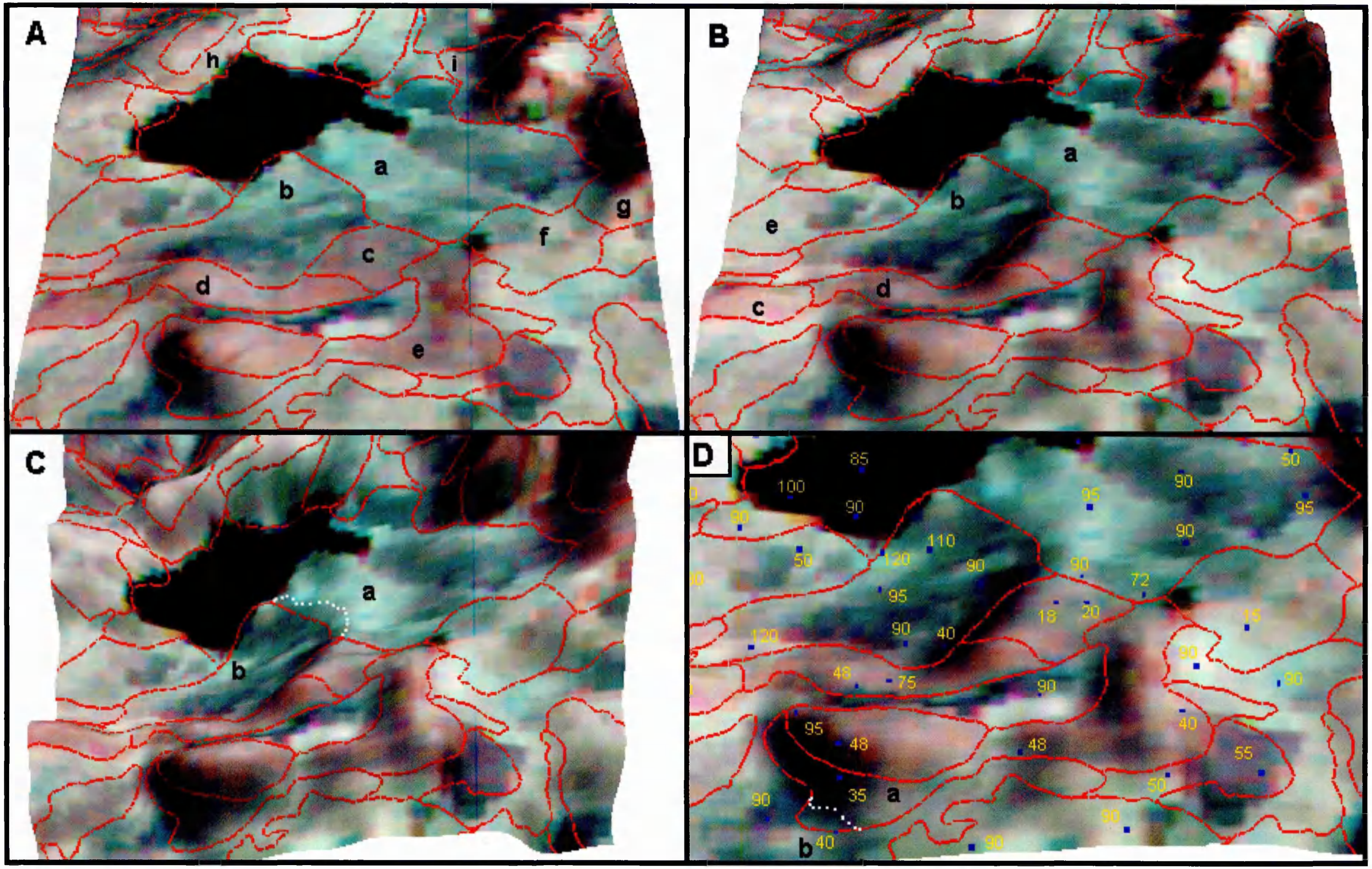
Figure 4 3-D viewing of DEMs derived from different sources and overlaid by soil mapping units boundaries.



A. DEM derived from contour lines (5m spacing)
B. DEM derived from stereopairs of aerial photographs without editing
C. DEM derived from stereopairs of aerial photographs after editing

NOTE: The sun position used for this viewing was the same for all of these figures.

Figure 5 Draping satellite image, soil mapping units and observations over DEMs derived from different sources, and with different vertical exaggeration.



A. Map-derived DEM, exaggeration 30 times; B. Aerial photo-derived DEM, exaggeration 30 times;
C. Aerial photo-derived DEM, exaggeration 60 times; D. Aerial photo-derived DEM and field observation of soil depth.

Improvement of soil mapping using 3-D visualisation of Landsat TM

The satellite imagery and soil mapping unit boundaries were draped over the airphoto-derived DEM to create a 3-D perspective view of the area. This produced a better visualisation than when the map-derived DEM was used (compare figures 5b and 5a).

The 3-D view was capable of clarifying cases when soil mapping unit boundaries were not the same as those suggested by colour differences on the satellite image. A good example is polygon 'a' in figure 5b. Several internal boundaries are present on the image but are not justified by relief effects. In other cases, the 3-D view justifies boundaries in areas that appear uniform on the image alone. An example is the boundary between polygon 'c' and 'd' in figure 5b, compared with the same boundaries between polygons 'f' and 'b' in figure 3a. Using the satellite image alone figure 3a indicates a homogeneous tonal pattern over the two polygons. However, the 3-D view reveals an obvious slope break between the two polygons.

The stereo viewing of air photos creates vertical exaggeration that enables the interpreter to see very slight relief differences (Carroll 1977). This study revealed the benefit of vertical exaggeration of the DEM to clarify terrain features for soil mapping. An example is shown in figure 5c (exaggerated 60 times), compared with figure 5b (exaggerated 30 times). The interpreter can switch easily between different exaggeration factors to clarify specific terrain features. For example, the increased exaggeration in figure 5c makes the differences in topography between polygons 'a' and 'b' more apparent compared to figure 5b. Furthermore, the alignment of the slope break between the two polygons is shown more clearly and hence, the boundary could be amended to follow the dashed line.

However, if the vertical exaggeration is increased too much in flat areas, small height variations that are actually random heighting errors can appear as terrain features and this should be avoided. The optimum vertical exaggeration is found by trial and error.

Integration of soil observations with 3-D visualisation

The integration of soil observations within 3-D visualisation of terrain features, is demonstrated in figure 5d, and can be used to check the consistency of their locations and attributes with soil polygons and image features. In figure 5d, values of soil depth within most of the mapping units fall within a narrow range, which is different from the surrounding polygons. Also, the 3-D view shows that the soil depths are consistent with their topographic position, the deeper soils occupying the lower flatter areas. This is consistent with the soil genesis in the study area. Therefore, establishing a relationship between terrain features as viewed in this study and such non-surface characteristics of land will also benefit the delineation of soil boundaries and the preparation of the map legend.

An example is polygon 'a' in figure 5d where the boundary might follow the dashed line, which follows the slope break more closely. However, the soil depth value on the original boundary (40 cm) is closer to the values of all points within polygon 'a' (40, 48 and 35 cm), and very different from those in polygon 'b' (90 cm), which might explain the existing boundary. However, the locations of soil observations contain unsystematic errors caused by map reading errors during georeferencing of observation points in the field (Ziadat et al., in press (b)). These are difficult to correct and an alternative explanation is that the proposed boundary change is correct and the point observation is in the wrong place. Thus the 3-D viewing and GIS approach can be used to identify specific areas requiring field checks.

Conclusions

False colour composites of bands 1, 5 and 7 of the Landsat TM images provided the best match between image and the soil map polygons in the semi arid and arid areas of Jordan. The image acquired in August was better than those acquired in March or May. However, Landsat TM imagery alone was not enough to map the soil at level three (1:10,000 scale).

Perspective viewing of the Landsat TM imagery draped over a DEM derived from 1:30,000 scale aerial photography was the best of all the methods for assisting soil mapping at level three. This DEM provides a high level of topographic detail, even in areas with a slope less than 5%, which is enhanced by exaggerating the elevation factor.

The overlay of soil observation points with the 3-D view of Landsat TM indicates a promising tool to assist in soil mapping. This overlay revealed the areas to target for field checking of points and boundary location.

More research is required to focus on the use of Landsat TM data integrated with aerial photo-derived DEMs for soil mapping and land use planning. In particular the use of the 3-D view to start delineating soil boundaries in the absence of a soil map with subsequent verification in the field. Additionally, the use of the 3-D view with soil observations classified according to their suitability rating could be investigated to estimate land suitability directly for site-specific planning.

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References

Al-Bakri, J. T., and Taylor, J. C., 2000, Monitoring soil surface variables in the Badia transition zone of Jordan using satellite imagery spectral data, In Press.

Buiten, H. J., 1993, Image interpretation: visual or digital. In Land Observation by Remote Sensing, Theory and Application, Edited by H. J. Buiten and J. G. P. W. Clevers. Current Topics In Remote Sensing, Vol. 3, (New York: Gordon & Breach Science Publishers), pp. 507-513.

Carroll, D. M., Evans, R., and Bendelow, V. C., 1977, Air photo-interpretation for soil mapping. Soil Survey, Technical Monograph No. 8. (Dorking: Bartholomew Press).

Dent, D., and A., Young, 1981, Soil Survey and Land Evaluation (London: Allen & Unwin).

Dinc, A. O., 1993, Detailed soil mapping in rangelands using Landsat-TM and SPOT-XS data in Southern Anatolia region of Turkey. M.Phil. Thesis. Cranfield University.

Dwivedi, R. S., 1985, The utility of data from various airborne sensors for soil mapping. International Journal of Remote Sensing, **6**, 89-100.

FAO, 1976, Framework for Land Evaluation. Food and Agriculture Organisation, Rome, Italy.

Florinsky, I. V., 1998, Combined analysis of digital terrain models and remotely sensed data in landscape investigations. Progress in Physical Geography, **22**, 33-60.

Gao, J., 1997, Resolution and accuracy of terrain representation by grid DEMs at a micro-scale. International Journal of Geographic Information Systems, **11**, 199-212.

Green, K., 1992, Spatial imagery and GIS, integrated data for natural resource management. Journal of Forestry, **90**, 32-36.

Hammer, R. D., Astroth, J. H. J. R., Henderson, G. S., and Young, F. J., 1991, Geographic information systems for soil survey and land-use planning. In Spatial Variabilities of Soils and Landforms. Proceedings, International Symposium, Las Vegas, Nevada, 17 Oct., edited by M. J., Mausbach, and L. P., Wilding, SSSA Special Publication No. 28. Madison, Wisconsin, USA, pp. 243-270.

Hammer, R. D., Young F. J., Wollenhaupt, N. C., Barney T. L., and Haithcoate T. W., 1995, Slope class maps from soil survey and digital elevation models. Soil Science Society of American Journal, **59**, 509-519.

Hinton, J. C., 1996, GIS and remote sensing integration for environmental applications. International Journal of Geographic Information Systems, **10**, 877-890.

Klingebiel, A. A., Horvath, E. H., Moore, D. G., and Reybold, W. U., 1987, Use of slope, aspect, and elevation maps derived from digital elevation model data in making soil surveys. Soil Survey Techniques, Soil Science Society of America, 677 South Segoe Road, Madison, WI 53711 USA. SSSA Special Publication No. 20, pp. 77-90.

Lee, K., Lee, G. B., and Tyler, E. J., 1988, Thematic Mapper and digital elevation modelling of soil characteristics in hilly terrain. Soil Science Society of American Journal, **52**, 1104-1107.

Leone, A. P., Wright, G. G., and Corves C., 1995, The application of satellite remote sensing for soil studies in upland areas of Southern Italy. International Journal of Remote Sensing, **16**, 1087-1105.

Liengsakul, M., Mekpaiboonwatana, S., Pramojanee, P., Bronsveld, K., and Huizing, H., 1993, Use of GIS and remote sensing for soil mapping and for locating new sites for permanent cropland: a case study in the highlands of Northern Thailand. Geoderma, **60**, 293-307.

MoA (Ministry of Agriculture, Jordan), 1995, The Soils of Jordan. Report of the National Soil Map and Land Use Project, Undertaken by Ministry of Agriculture, Huntings Technical Services Ltd., and European Commission. Level One, Level Two, Level Three and JOSCIS Manual.

Mulders, M. A. (ed.), 1987, Remote Sensing in Soil Science (Amsterdam Oxford: Elsevier).

Reddy, R. S., and Hilwig, F. W., 1993, Color additive viewing techniques for small-scale soil mapping in an area of Karimnagar district, Andhra-Pradesh, India. International Journal of Remote Sensing, **14**, 1705-1714.

Su, H., Ransom, M. D., and Kanemasu, E. T., 1989, Detecting soil information on a native prairie using Landsat TM and SPOT satellite data. Soil Science Society of American Journal, **53**, 1479-1483.

Taimeh, A., 1989, Soils of Muwaqqar. Faculty of Agriculture, University of Jordan (Amman: University of Jordan Press).

Thompson, D. R., Henderson, K. E., Houston, A. G., and Pitts, D. E., 1984, Variation in alluvial-derived soils as measured by Landsat Thematic Mapper. Soil Science Society of American Journal, **48**, 137-142.

Trotter, C. M., 1991, Remotely sensed data as an information source for geographical information systems in natural resource management: a review. International Journal of Geographical Information Systems, **5**, 225-239.

Ziadat, F.M., Taylor, J.C., and Brewer, T.R., (a), Application of GIS for optimising the use of soil survey data for land suitability analysis in Jordan. Submitted to the International Journal of Geographic Information Science.

Ziadat, F.M., Taylor, J.C., and Brewer, T.R., (b), Detection and correction of errors in soil information using satellite images and GIS: a case study in Jordan. Submitted to the International Journal of Geographic Information Science.

Chapter Five

Conclusions

This research investigated three various aspects of land use planning in the arid to semi-arid area of Jordan: 1) examining different approaches of using the GIS to process soil maps and observations to derive suitability maps, implementing the FAO approach, 2) the role of remote sensing, GIS and GPS in detecting and correcting errors in soil maps and observations, and 3) the use of remote sensing and GIS for detailed soil mapping to assist in site-specific planning. The work was presented in the preceding chapters in the form of papers, supported by data in appendices and on a CD ROM. The main findings are listed for each of these investigations, followed by more broad conclusions and implications.

Optimising the use of soil data for land suitability calculations

At all levels, suitability maps derived by calculating the average or the mode of observation points within soil mapping units, only partially reflected the situation on the ground. However, these methods are using the soil mapping unit boundaries and produce a suitability mapping units with one class. The calculation of averages of all land characteristics, after re-scaling those ordinal characteristics, is recommended for ease of calculation. The suitability maps which contain an association of suitability classes (association method), have a higher apparent purity. This was because the use of associations created a more flexible classification scheme.

The methods that used interpolation techniques between observation points (layer overlay and interpolation methods) produce extremely high levels of apparent map purity but the true purity of these maps, measured with independent observations to assess the agreement, was much lower. In addition, the boundaries produced are dependent on the spatial distribution of the point observations, as the soil boundary information is not used.

The results indicate that the level two mapping polygons are no better than those of level one in accounting for the underlying soil variation. Level three soil mapping considerably improves the agreement of suitability maps, however, the purity is only between 60 and 70% and hence, they should be used with caution when site-specific estimates of land suitability are to be made. This points to the need to improve soil mapping and increase the homogeneity of the soil polygons.

Detection and correction of errors in soil data using remote sensing and GIS

Systematic error (30m in easting and 130m in northing) as a result of using different datums in collecting and georeferencing soil maps and observation points was reported. Unsystematic errors were found and were the result of using the topographic map reading to locate and georeference the observation points, in the absence of the GPS. The correction of these errors is not feasible, since each observation would have to be relocated and compared with coordinates measured by a GPS. Attribute errors were also revealed when the suitability of observation points was compared with the surrounding features on the satellite image. Overlaying the soil observations and polygons on to geocoded satellite imagery was indispensable for detecting and correcting location and attribute errors.

The investigation revealed that the area and location of suitability classes were affected by the location and attributes errors, and could have resulted in a poor land use decision. This indicates the necessity of checking data before proceeding with any spatial analysis.

Merging satellite image with topographic data for detailed soil mapping

The investigation revealed that Landsat imagery alone was not sufficient to extend or improve the soil mapping at detailed level (1:10,000). A perspective viewing of satellite imagery draped over an air photo-derived DEM was promising for these purposes. Exaggerating the effect of topography with the computer enhances the ability to detect more landscape features in areas with slopes less than 5%. The capability of integrating the soil observation points with this viewing provides further enhancement for this technique.

Further research is recommended to develop perspective viewing for the production of detailed soil maps especially in the absence of a priori soil mapping information. A thorough field checking is also required to validate the technique.

Broad conclusions and implications for land use planning in the JAZPP area

This research indicates that the quality of a suitability map is affected by the method of deriving the map and the quality of the soil survey data used. The latter varied depending on the presence of errors of location and in attributes.

The quality of the suitability maps determines the accuracy of estimating the area and location of suitable land for certain uses. These are two important inputs for the land use planning within JAZPP. The investigations revealed that the errors in co-locating soil maps and observations resulted in classifying the land into the wrong class. This emphasises the need for high quality land suitability maps. However, the unsystematic errors in the location of observation points remained uncorrected, due to the difficulties of relocating all observations, for example, it took 30 man-days to relocate 26 sites. The location error for the investigated sites was as much as 300m, and could be in any direction. Users should be aware of this if they intend to use the soil observations in an analysis that requires accurate spatial location. The use of differential GPS is recommended to locate observation points in the future to minimise the magnitude of location errors, producing more consistent datasets.

The errors in the attributes attached to a sub-set of soil observations systematically resulted in soil at those locations being classified as 'not suitable' because soil depth was erroneously set to zero. This resulted in systematic underestimation of land suitability that could have excluded large areas from important uses thus undermining the aim of land use planning which was to make the best use of the limited resources.

This work has shown that critical examination of the database for all errors is necessary to avoid poor quality suitability maps, which could lead to incorrect decision making. Another important consideration is to ensure the compatibility of the suitability maps with other data required for land use planning, for example, hydrological and socio-economic data.

The overlay of soil observation points on to the 3-D view of Landsat TM imagery using the air photo-derived DEM identified some cases where the locations of points may have been wrong because of the map reading errors. Thus, this technique can be used to target observations that need field checking. Alternatively, these points can be identified and eliminated from the analysis.

In the study area, the results indicated that level two soil mapping units do not improve the purity of suitability maps when compared with level one units. Therefore, further mapping to extend the areas covered at level two would not appear to improve the suitability analysis results. This may be because visual interpretation of hard copy satellite images was used for both levels of mapping and although the satellite imagery for level two had improved spatial resolution it was not possible to take advantage of this. With the higher density of soil observations collected for level two, maps produced by spatial interpolation were as good as using the mapping polygons. Augmenting the number of observations, in areas not covered by level two, and using spatial interpolation is therefore an alternative.

The planning at level three (1:10,000) requires site-specific land suitability information. The use of the existing soil map at this scale indicates relatively low purity suitability maps (60% to 70%). The technique of using Landsat images with a DEM produced from aerial photography is promising for extending the coverage with more detailed maps and improving the purity of the suitability maps. However, further research and field checking is needed to develop the use of this technique for detailed soil mapping.

Another possibility is to overlay the suitability calculated at soil observation points onto the 3D view of Landsat imagery to assist in site-specific planning. The approach is to link the suitability of an observation with the appearance of the surrounding area, including the topographic setting. The errors in locating the observations should be kept in mind. For example, points located in the fringe of two different areas should be checked in the field.

General conclusions

Although this work was necessarily focussed on the issues and problems particular to one data set used in a Jordanian context, a number of general lessons have been learned.

1. Careful examination of all input data is necessary to eliminate georeferencing and attribute errors.

2. Overlay of input data onto a geocoded satellite image is extremely useful for detecting potential sources of input data errors and is recommended.

3. The GIS can be used to calculate indicators of map quality, such as map purity and these should be attached to output products.

4. The GIS was extremely useful for rapid investigation of alternative processing procedures for combining soil observations with soil maps.

5. In new projects, differential GPS is recommended for location of soil observations as this will provide adequate precision for future analyses.

6. In old data sets where GPS technology was not applied, revisiting a sample of soil observation sites and locating them with GPS should be used to assess the location accuracy of the original methodology. This will provide some guidance to GIS users when carrying out analyses where accurate locations of soil observations are important.

7. Integration of soil observations with imagery and a DEM, produced using digital photogrammetry, shows promise method to assist detailed soil mapping and land use planning.

References

Aandahl, A. R., 1958, Soil survey interpretation: theory and purpose. Soil Science Society of American Proceeding, **22**, 152-154.

Al-Bakri, J. T., and Taylor, J. C., 2000, Monitoring soil surface variables in the Badia transition zone of Jordan using satellite imagery spectral data, In Press.

Al-Shoubaki, A., 1999, Water Harvesting Potential of Different Land Types in Arid to Semi-Arid Region in Jordan. MSc. Thesis, University of Jordan, Amman, Jordan.

Arbia, G., Griffith, D., and Haining, R., 1998, Error Propagation modelling in raster GIS: overlay operations. International Journal of Geographical Information Science, **12**, 145-167.

Asrar, G., (ed.), 1989, Theory and Applications of Optical Remote Sensing (New York: John Wiley & Sons).

Barrett, E. C., and Curtis, L. F., 1992, Introduction to Environmental Remote Sensing, 3rd edn (New York: Chapman & Hall).

Beckett, P. H. T., and Webster, R., 1971, Soil variability: a review. Soils and Fertilizers, **34**, 1-15.

Bernhardsen, T., 1992, Geographic Information Systems (Norway: VIAK IT Longman Park).

Biswas, R. R., and Singh, C. P., 1991, Capability of TM data for evaluation of soil and land resources in the Malwa plateau (Chambal and Mahi catchment) in Madhya Pradesh, India. International Journal of Remote Sensing, **12**, 1905-1913.

Bolstad, P. V., and Smith, J. L., 1992, Errors in GIS: assessing spatial data accuracy. Journal of Forestry, **90**, 21-29.

Bolstad, P. V., Gessler, P., and Lillesand, T. M., 1990, Positional uncertainty in manually digitised map data. International Journal of Geographical Information Science, **4**, 399-412.

Bregt, A. K., Stoorvogel, J. J., Bouma, J., and Stein, A., 1992, Mapping ordinal data in soil survey: a Costa Rican example. Soil Science Society of American Journal, **56**: 525-531.

Bronsveld, K., Huizing, H., and Omakupt, M., 1994, Improving land evaluation and land use planning. ITC Journal, **4,** 359-365.

Brunsdon, C., and Openshow, S., 1993, Simulating the effects of error in GIS. In Geographical Information Handling - Research and Applications. Mather, P. M. (ed.). (New York: John Wiley & Sons), pp. 47-61.

Buiten, H. J., 1993, Image interpretation: visual or digital. In Land Observation by Remote Sensing, Theory and Application, Edited by H. J. Buiten and J. G. P. W. Clevers. Current Topics In Remote Sensing, Vol. 3, (New York: Gordon & Breach Science Publishers), pp. 507-513.

Burrough, P. A., 1992, Integration of Environmental and Utility Data in GIS: Problems and Opportunities. Geographic Information Systems and the European Challenge: A Solution for Common Problems Across Europe. Proceedings European Conference VIII, Montreux, Switzerland, 7-9 October. AM/FM International, European Division, Basel, Switzerland.

Burrough, P. A., 1993, Soil variability: a late 20th century view. Soils and Fertilizers, **56,** 529-562.

Burrough, P. A., 1995, Accuracy and error in GIS. In The AGI Source Book for Geographical Information Systems. Green, D. R. (ed.), pp. 87-92.

Burrough, P. A., and McDonnell, R. A., 1998, Principles of Geographical Information Systems, 2nd Ed, (Oxford: Oxford University Press).

Carroll, D. M., Evans, R., and Bendelow, V. C., 1977, Air photo-interpretation for soil mapping. Soil Survey, technical Monograph No. 8. (Dorking: Bartholomew Press).

Chagarlamundi, P., and Plunkett, G. W., 1993, Mapping applications for low-cost remote sensing and geographic information systems. International Journal of Remote Sensing, **14**, 3181-3190.

Chinene, V. R. N., 1992, Land evaluation using the FAO framework: an example from Zambia. Soil Use and Management, **8**, 130-139.

Chrisman, N. R., 1991, The error component in spatial data. In Geographical Information Systems Principles and Applications, Volume 1: Principles. Edited By D. J., Maguire, M. F., Goodchild, and D. W., Rhind (Harlow: Longman), pp. 165-174.

Congalton, R. G., and Green, K., 1992, The ABCs of GIS, an introduction to geographic information systems. Journal of Forestry, **90**, 13-20.

Congalton, R. G., and Mead, R. A., 1983, A quantitative method to test for consistency and correctness in photo interpretation. Photogrammetric Engineering and Remote Sensing, **49**, 69-74.

Dalal-Clayton, D. B., and Robinson, D. A., 1992, An assessment of the success of a geomorphologically based reconnaissance soil survey in Eastern Zambia. Geoderma, **45**, 213-230.

Davidson, D. A., 1992, The Evaluation of Land Resources. (Harlow: Longman).

Dent, D. L., 1988, Guidelines for land use planning in developing countries. Soil Survey and Land Evaluation, **8**, 67-76.

Dent, D., and A., Young, 1981, Soil Survey and Land Evaluation (London: Allen & Unwin).

Derenyi, E., and Pollock, R., 1990, Extending a GIS to support image-based map revision. Photogrammetric Engineering & Remote Sensing, **56**, 1493-1496.

Dinc, A. O., 1993, Detailed soil mapping in rangelands using Landsat-TM and SPOT-XS data in Southern Anatolia region of Turkey. M.Phil. Thesis. Crandfield University.

Dodson, A. H., and Haines-Young, R. H., 1993, Datum transformation and data integration in a GIS environment. In Geographical Information Handling - Research and Applications. Mather, P. M. (ed.). (New York: John Wiley & Sons), pp. 79-90.

Dwivedi, R. S., 1985, The utility of Data from various airborne sensors for soil mapping. International Journal of Remote Sensing, **6**, 89-100.

FAO, 1975, Land Evaluation in Europe. Soils Bulletin No. 29, Rome, Itally.

FAO, 1976, Framework for Land Evaluation. Food and Agriculture Organisation, Rome, Italy.

FAO, 1983, Guidelines: Land Evaluation for Rainfed Agriculture. FAO Soils Bulletin No. 52, Rome, Itally.

FAO, 1985, Production Year Book. Food and Agriculture Organisation, Rome, Italy.

FAO, 1989, Guidelines for Land Use Planning. Food and Agriculture Organisation, Rome, Italy.

FAO, 1993, Guidelines for Land Use Planning. FAO Development Series No. 1, Rome, Itally.

Fernandez, R. N., and Lozano-Garcia, D. F., 1991, Accuracy assessment of map coordinate retrieval. Photogrammetric Engineering & Remote Sensing, **57**, 1447-1452.

Flaherty, M., and Smit, B., 1982, An assessment of land classification techniques in planning agricultural land-use. Journal of Environmental Management, **15**, 323-332.

Florinsky, I. V., 1998, Combined analysis of digital terrain models and remotely sensed data in landscape investigations. Progress in Physical Geography, **22**, 33-60.

Flowerdew, R., 1991, Spatial data integration. In Geographical Information Systems Principles and Applications. Volume 1: Principles. Maguire, D. J., Goodchild, M. F., and Rhind, D. W. (eds.). (Harlow: Longman), pp. 375-387.

Gao, J., 1997, Resolution and accuracy of terrain representation by grid DEMs at a micro-scale. International Journal of Geographic Information Systems, **11**, 199-212.

Goldschmidt, A. P., and Jones, J. A., 1988, A land evaluation of three Ujamaa villages in Dodoma Region, Tanzania. Soil Survey and Land Evaluation, **8,** 183-201.

Goodchild, M. F., 1993, Data models and data quality: problems and prospects. In Environmental Modelling with GIS. Goodchild, M. F., Parks, B. O., and Steyaert, L. T. (eds.). (Oxford: Oxford University Press), pp. 94-103.

Green, K., 1992, Spatial imagery and GIS, integrated data for natural resource management. Journal of Forestry, **90**, 32-36.

Guptill, S. C., 1992, Inclusion of accuracy data in a feature based, object-oriented data model. In the Accuracy of Spatial Databases. Goodchild, M., and Gopal, S. (eds.). (London: Taylor & Francis), pp. 91-97.

Hammer, R. D., Astroth, J. H., Henderson, G. S., and Young, F. J., 1991, Geographic Information Systems for soil survey and land-use planning. In Spatial Variabilities of Soils and Landforms. Proceedings, International Symposium, Las Vegas, Nevada, 17 Oct. Edited by Mausbach, M. J., and Wilding, L. P., SSSA Special Publication No. 28. Madison, Wisconsin, USA, Soil Science Society of America Inc. pp. 243-270.

Hammer, R. D., Young F. J., Wollenhaupt, N. C., Barney T. L., and Haithcoate T. W., 1995, Slope class maps from soil survey and digital elevation models. Soil Science Society of American Journal, **59**, 509-519.

Hanuschak, G., Sigman, R., Craig, M., Ozga, M., Luebbe, R., Cook, P., Kleweno, D. and Miller, C., 1979, Obtaining Timely Crop Area Estimates Using Ground-Gathered and Landsat Data, Statistical Research Division, Economics Statistics and Co-operative Services, USDA, Technical Bulletin No. 1609.

Hardy, E. E., 1987, Data Preparation for a GIS in a Developing Country Situation. Annual International Conference, Exhibits and Workshops on Geographic Information Systems. Falls Church, Virginia, USA, American Society for Photogrammetry and Remote Sensing, pp. 498-508.

Hatten, C. J., 1998, Improvement of agricultural productivity in arid and semi-arid zones of Jordan, unpublished visit report of land resources specialist of Hunting Technical Services Limited, UK. Training and Consultancy Services, School of Agriculture Food and Environment, Cranfield University. 5th-19th July 1995.

Hennebert, P. A., Tessens, E., Tourenne, D., and Delvaux, B., 1996, Validation of a FAO land evaluation method by comparision of observed and predicted yields of five food crops in Burundi. Soil Use and Management, **12**, 134-142.

Hinton, J. C., 1996, GIS and remote sensing integration for environmental applications. International Journal of Geographic Information Systems, **10**, 877-890.

Iliffe, J. C., 1995, Datums and Map Projections for Remote Sensing and GIS. Workshop held at University College London on 18 December 1995.

Jaradat, A. A., 1988, An Assessment of research Needs and Priorities for Rainfed Agriculture in Jordan. Published by the United States Agency for International Development (Irbid, Jordan: Al-Hurria P. Press).

JAZPP, 1997, Improvement Of Agricultural Productivity In Arid And Semi-Arid Zones Of Jordan, Annual Report (Unpublished), Jordan Arid Zone Productivity Project, SEM/O3/628/021. University of Jordan, Amman, Jordan.

JRV (Jordan Rift Valley Project), 1998, Personal communication.

Kassam, A. H., Velthuizen, H. T., Van Fischer, G. W., Shah, M. M., and Van Velthuizen, H. T., 1991, Agro-ecological land resources assessment for agricultural development planning: a case study for Kenya. Resources Data Base and Land Productivity. World Soil Resources Reports No. 71-7, Food And Agriculture Organization (FAO), Rome, Italy.

Khalil, K. I., Assal, M. H., and Fahim, M.M., 1995, The application of GIS to soil survey data. Egyptian Journal of Soil Science, **35,** 129-145.

Kiiveri, H. T., 1997, Assessing, representing and transmitting positional uncertainty in maps. International Journal of Geographical Information Science, **11**, 33-52.

Klingebiel, A. A., and Montgomery, P. H., 1961, Land capability Classification. USDA Handbook 210, Washington.

Klingebiel, A. A., Horvath, E. H., Moore, D. G., and Reybold, W. U., 1987, Use of slope, aspect, and elevation maps derived from digital elevation model data in making soil surveys. Soil Survey Techniques, Soil Science Society of America, 677 South Segoe Road, Madison, WI 53711 USA. SSSA Special Publication No. 20, pp. 77-90.

Lee, J. E., and Walsh, J. M., 1984, Map Projections for Use with the Geographic Information System. Fish and Wildlife Service, U.S. Department of the Interior. Reproduced by National Technical Information Service, U.S. Department of Commerce, Springfield, VA. 22181. Microfiche.

Lee, K., Lee, G. B., and Tyler, E. J., 1988, Thematic Mapper and digital elevation modelling of soil characteristics in hilly terrain. Soil Science Society of American Journal, **52**, 1104-1107.

Leone, A. P., Wright, G. G., and Corves C., 1995, The application of satellite remote-sensing for soil studies in upland areas of Southern Italy. International Journal of Remote Sensing, **16**, 1087-1105.

Lewis, A., and Hutchinson, M. F., 1996, Data accuracy to data quality: using spatial statistics to predict the implications of spatial error in point data. In Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, Second International Symposium. Edited By H., Todd Mowrer, R. L., Czaplewski, and R. H., Hamre. Fort Collins, Colorado, pp 577-584.

Liengsakul, M., Mekpaiboonwatana, S., Pramojanee, P., Bronsveld, K., and Huizing, H., 1993, Use of GIS and remote sensing for soil mapping and for locating new sites for permanent cropland: a case study in the highlands of Northern Thailand. Geoderma, **60**, 293-307.

Lillesand, T. M., and Kiefer, R. W., 1994, Remote Sensing and Image Interpretation, 3rd edn (New York: John Wiley & Sons).

Lodwick, W. A., Monson, W., and Svoboda, L., 1990, Attribute error and sensitivity analysis of map operations in geographical information systems: suitability analysis. International Journal of Geographical Information Systems, **4**, 413-428.

Lopez-Blanco, J., and Villers-Ruiz, L., 1995, Delineating boundaries of environmental units for land management using a geomorphological approach and GIS: a study in Baja California, Mexico. Remote Sensing of Environment, **53**, 109-117.

Makhamreh, Z. M., 1996, Optimal Land Use Alternatives for Arid to Semi-Arid Areas in Jordan. MSc. Thesis, University of Jordan, Amman, Jordan.

Mazahreh, S., 1998, Alternatives for Land Utilization in Arid to Semi-Arid Region in Jordan. MSc. Thesis, University of Jordan, Amman, Jordan.

MoA (Ministry of Agriculture, Jordan), 1995, The Soils of Jordan. Report of the National Soil Map and Land Use Project, Undertaken by Ministry of Agriculture, Huntings Technical Services Ltd., and European Commission. Level One, Level Two, Level Three and JOSCIS Manual.

Mulders, M. A. (ed.), 1987, Remote Sensing in Soil Science (Amsterdam Oxford: Elsevier).

Oberthur, T., Dobermann, A., and Neue, H.U., 1996, How good is a reconnaissance soil map for agronomic purposes. Soil Use and Management, **12,** 33-43.

Qudah, B. H., 1983, Land Use in Jordan. Published by the Manistry of Agriculture, Amman, Jordan.

Rashdan, W., 1999, Potential Utilization of Barley and Rangelands in Arid to Semi-Arid Region in Jordan. MSc. Thesis, University of Jordan, Amman, Jordan.

Reddy, R. S., and Hilwig, F. W., 1993, Color additive viewing techniques for small-scale soil mapping in an area of Karimnagar district, Andhra-Pradesh, India. International Journal of Remote Sensing, **14**, 1705-1714.

Riezebos, H. T., 1989, Application of nested analysis of variance in mapping procedure for land evaluation. Soil Use and Management, **5,** 25-30.

Rogowski, A. S., 1995, Quantification soil variability in GIS applications, I. estimates of position. International Journal of Geographical Information Science, **9**, 81-94.

Rondal, J. D., 1985, Determining appropriate land utilisation types for areas with a long dry season. ITC Journal, **1**, 35-41.

Rossiter, D. G., 1990, ALES - A Framework For Land Evaluation Using A Microcomputer. Soil Use And Manegement, **6**, 7-20.

Rossiter, D. G., 1994, Lecture Notes: Land Evaluation. SCAS Teaching Series T94-1, Department of Soil, Crop & Atmospheric Sciences, Cornell University, Ithaca NY USA.

Rossiter, D. G., 1995, Economic land evaluation: why and how. Soil Use and Management, **11**, 132-140.

Rossiter, D. G., 1996, A theoretical framework for land evaluation (with discussion). Geoderma, **72**, 165-202.

Shankarnarayan, K. A., Kolarkar, A. S., and Singh, N., 1983, Application of the FAO framework for land evaluation to an arid area of Western Rajasthan, India. Soil Survey and Land Evaluation, **3**, 59-68.

Smit, B., Brklacich, M., Dumanski, J., Macdonald, K. B., and Miller, M. H., 1986, Integral land evaluation and its application to policy. Soil Survey and Land Evaluation, **6**, 99-113.

Smyth, A. J., Dumanski, J., Spendjian, G., Swift, M. J., and Thornton, P. K., 1993, FESLM: an international framework for evaluating sustainable land management. World Soil Resources Report No. 73, Food and Agriculture Organization of the United Nations.

Storie, R. E., (1976), Storie index soil rating (revised), 1978. Special Publication Division of Agricultural Science, University of California, Berkely, Calif.

Story, M., and Congalton, R. G., 1986, Accuracy assessment: a user's perspective. Photogrammetric Engineering and Remote Sensing, **52**, 397-399.

Su, H., Ransom, M. D., and Kanemasu, E. T., 1989, Detecting soil information on a native prairie using Landsat TM and SPOT satellite data. Soil Science Society of American Journal, **53**, 1479-1483.

Sys, C., 1985, Land Evaluation. Part I, II, and III. (Ghent: State University of Ghent).

Tadrus, K. I., 1984, Effect of grazing intensity by sheep on the production of Atriplex nummularia in Jordan. Research Proposal.

Taimeh, A., 1989, Soils of Muwaqqar. Faculty of Agriculture, University of Jordan (Amman: University of Jordan Press).

Taylor, C., Sannier, C. A. D., Delincé, J., and Gallego, F. J., 1997, Regional Crop Inventories in Europe Assisted by Remote Sensing: 1988 - 1993. European Commission, EUR 17319, 80pp.

Taylor, J. C., and Eva, H. D., 1992, Regional Inventories on Beds, Cambs and Northants (UK), 1992 - Final Report to CEC - JRC, Silsoe College, ISBN 1 871564 52 2, 70p.

Taylor, J. C., and Eva, H. D., 1993, Operational use of remote sensing for estimating crop areas in England, Proceedings of Rem Sens Soc Conference - Towards Operational Applications, ISBN 0 946226 18 0, pp 1-9.

Taylor, J. C., Bird, A. C., Brewer, T. R., Keech, M. A., and Stuttard, M. J., 1991b, Landscape change in the National Parks of England and Wales - Final Report Vol II Methodology, Silsoe College, ISBN 1 871564 16 6, 98p.

Taylor, J. C., Bird, A. C., Keech, M. A., and Stuttard, M. J., 1991a, Landscape change in the National Parks of England and Wales - Final Report Vol. I Main Report, Silsoe College, ISBN 1 871564 15 8, 97p.

Theocharopoulos, S. P., Davidson, D. A., Mcarthur, J. N., and Tsouloucha, F., 1995, GIS as an aid to soil surveys and land evaluation in Greece. Journal of Soil and Water Conservation, **50**, 118-124.

Thompson, D. R., Henderson, K. E., Houston, A. G., and Pitts, D. E., 1984, Variation in alluvial-derived soils as measured by Landsat Thematic Mapper. Soil Science Society of American Journal, **48**, 137-142.

Trotter, C. M., 1991, Remotely-sensed data as an information source for geographical information systems in natural resource management: a review. International Journal of Geographical Information Systems, **5**, 225-239.

TYDAC Research Inc., 1997, SPANS Manual by TYDAC Research Inc., 2 Gudwara Road, Suite 210, Nepean, Ontario, Canada K2E1A2. Edited by Diane Burke.

Van De Putte, R., 1989, Land evaluation and project planning. ITC Journal, **2,** 139-142.

Van Diepen, C. A., Van Keulen, H., Wolf, J., and Berkhout, J. A. A., 1991, Land evaluation: from intuition to quantification. In Advances in Soil Science, Stewart, B. A. (ed.), (New York: Springer), pp. 139-204.

Van Kuilenburg, J., De Gruijter, J. J., Marsman, B. A., and Bouma, J., 1982. Accuracy of spatial interpolation between point data on soil moisture supply capacity, compared with estimates from mapping units. Geoderma, **27,** 311-325.

Van Lanen, H. A. J., Hack-Ten Broeke, M. J. D., Bouma, J., and De Groot, W. J. M., 1992, A mixed qualitative/quantitative physical land evaluation methodology. Geoderma, **55**, 37-53.

Vitek, J. D., Walsh, S. J., and Gregory, M. S., 1984, Accuracy in Geographic Information Systems: An Assessment of Inherent and Operational Errors. Proceedings, PECORA IX Symposium, pp. 296-302.

Walsh, S. J., Lightfoot, D. R., and Butler, D. R., 1987, Assessment of Inherent and Operational Errors in Geographic Information Systems. Proceedings, American Society of Photogrammetry and Remote Sensing, American Congress on Surveying and Mapping, Baltimore, Maryland, pp. 24-35.

Webster, R., and Oliver, M. A., 1990, Statistical Methods in Soil and Land Resource Survey. (Oxford: Oxford University Press).

Western, S., 1978, Soil Survey Contracts and Quality Control. (Oxford: Clarendon Press).

Zhou, H. Z., Macdonald, H. B., and Moore, A., 1991, Some cautions on the use of geographic information system (GIS) technology to integrate soil site and area data. Canadian Journal of Soil Science, **71**, 389-394.

Appendix a: Requirements of land utilisation types for JAZPP.

LUT	1	2	3
Water Collection	Upslope Water Harvesting	Partial in-field Water Harvesting	In-field Water Harvesting
Water Infiltration	Colluvial Footslopes (100-200m)	Minor pits	Small run-off basins (50-200m3)
Crop Type (Specific Crops)	Field Crops (Barley, forage legumes)	Improved Rangeland (all species)	Fruit & Nut Tree Crops (olives, almonds, pistacio)
Capital Works	Commonly none: sometimes diversion & water spreading from minor gullies	Minor pitting for some re-seeding activities; fencing?	Basin bund layout and construction
Maintenance (largely off-season work)	None, or v.minor	Some minor re-pitting	Basin bund maintenance (annual)
Field Operations (Agricultural: large-ly in-season work) Cultivations	Cultivation & sowing following 1st major rains	Shallow pits to receive local run-off & retard soil erosion. Alignment of pits on contour at 2.5-4m intervals.	Large planting holes with water-retaining composts. Mulch within 2m of trees: keep weed -free.
Fertiliser	Unlikely to be justified. Perhaps late application of 20kg N / ha justified in wetter years.	None (except via natural & introduced legumes)	Chicken/goat manure applied every 3 years; compound(high-K) fertilizer applied if growing conditions favourable.
Pesticides	None	None	Insecticide as required.
Planting	Sowing following first or second major rains	Establishment in Late Autumn following good rains	Late Autumn after good rain or supplementary irrign.; irrign may be required for first 2-3yrs until root system devel.
Harvesting	Grazing by animals in most years. Harvesting by mechanical or manual cutting in wet years.	Controlled grazing & browsing by animals.	Manual harvesting by family or paid labour
Other Treatments		Reseeding & replanting to replace vacancies	Annual pruning; wind-protection & support.
Improved Practises	Selective application of fertilizer in favoured locations receiving max run-on, particularly in the better years. Cultivation oriented to intercept run-off.	Controlled grazing required to maintain range at maximum sustainable yield	Encourage rooting in limited area (<25% of total by encouraging infiltration (mulch, gypsum); in water harvest-ing area discourage infiltration.
Target Yield: (at maturity) (@ 150mm annual rainfall)	280 kg barley grain/ ha +600kg straw/ha (150mm rainfall and 50mm run-on but v. uneven application.)	350 feed units / ha	Olives: 400kg/ha

LUT	4	5	6
Water Collection	In-field Water Harvesting	Wadi Weirs/ Water Diversions	Collection Elsewhere (Large Dams)
Water Infiltration	Contour run-off Ridges/Furrows	Water Spreading: Large Basins	Use Elsewhere eg Jordan Valley
Crop Type (Specific Crops)	Forage shrubs (Atriplex for sheep & goats)	Field Crops (barley, forage legumes)	Vegetables/ Horticulture
Capital Works	Ridge/furrow layout and construction	Water diversion weir siting & construction	None
Maintenance (largely off-season work)	Ridge/furrow maintenance (annual)	Weir maintenance (every storm event); Basin bund Maintenance (every large storm event)	None
Field Operations (Agricultural: large-ly in-season work) Cultivations	Sowing/planting at edge of ridge adjacent to pits in furrow.Ridges/furrows at 2.5-4m intervals.	In large basins following first heavy rains and infiltration of ponded water (at least 50cm of soil wetted).	
Fertiliser	None	Unlikely to be justified. Perhaps late application of 20kg N/ha justified in wetter years.	
Pesticides	None	None	
Planting	Late Autumn after good rain	Late Autumn after good rain and soil wetting to >40cm.	
Harvesting	Controlled browsing by animals. Reseeding re-planting to replace vacancies.	By binder or small combine (hired); grazing by animals in poor years	
Other Treatments			
Improved Practises	Careful maintenance of ridges/furrows necessary to ensure even infiltration in rooting zones; controlled grazing/pruning required to maintain shrubs at max. yields	Careful maintenance of ridges/furrows necessary to ensure even infiltration in rooting zones; Some gypsum application may increase infiltration.	
Target Yield: (at maturity) (@ 150mm annual rainfall)	400 feed units / ha	950kg barley grain/ha +1650kg straw/ha (150mm rainfall & 150 mm supplementary irrigation; but problems with eveness of application.	170m3 water / ha @ run-off coeff.of 0.35 & water retention eff--iciency of 0.5x0.64.

LUT	7	8	9
Water Collection	Small Earth Dams (<30 000m3):pressure pipes/Gravity	Small Earth Dams (<30 000m3): pressure pipes	Small Earth Dams (<30 000m3): pressure pipes
Water Infiltration	Small basins/ Level Furrows	Small basins	-
Crop Type (Specific Crops)	Field Crops (barley, forage legumes)	Fruit & nut treecrops (olives, pistacio, alm-onds: apples/pears at high elevations)	Water sales by Tanker (irrign.use for hortic-ulture/ livestock/ dom-estic)
Capital Works	Small Earth Dams requiring careful design & siting with respect to foundation conditions & size of catchment areas and water receiving areas to be served. RC Spillway is major capital item: also wide-diam. flexible pipes and possibly also pumps required in some cases.		
Maintenance (largely off-season work)	De-silting of reservoir (every 3-5 years); Low-cost repairs to embankment (every 3-5 years);Repairs to spillway (every 5-10 years) Replacement of flexible piping (every 10 years); Maintenance on pump (annually).		
Field Operations (Agricultural: large-ly in-season work) Cultivations	In small basins for level areas & level furrows for steeper areas;cultiv/sow-ing on first significant rains.	In small basins (level/ gently sloping areas essential); med-large planting holes; water-retaining composts & surface mulches.	NA
Fertiliser	For better sites manure or fertilisers (up to 40kg N and 40kg P2O5 / ha) may be justified.	Manure applied every 2 years; compound (high K) fertilizer applied acc-ording to foliar & soil anal.Trace elements req	NA
Pesticides	For better sites in some years, herbicide applcn	Insecticide as required.	NA
Planting	Late Autumn after good rain & pre-irrign.(Some times delay til February)	Late Autumn after irrign. Suppl.irrign.may be req-ired for first 2-3 years until root system devel-opes. Close planting.	NA
Harvesting	By binder or small com-bine(hired); grazing by animals in poor years	Manual harvesting by family or paid labour	NA
Other Treatments		Annual pruning; Wind protection and support	NA
Improved Practises	For rains before end February, empty reservoir as soon as possible after each rain onto cultivated land to store water in soil and encourage deep rooting. Improve infiltration by mulches, especially dried sewage sludge, & possibly also gypsum		After any rain, empty reservoir as quickly as possible.
Target Yield: (at maturity) (@ 150mm annual rainfall)	2300kg barley grain/ha +3000kg straw/ha (150mm rainfall & 350 mm supplementary irrigation)	Olives: 2000kg/ha (150mm rainfall & 350 supplementary irrigation)	20 000m3 x 5 events = 100 000m3 transported water. (Collected over 600ha- ie 170m3 / ha @ run-off coeff of 0.5 (x0.5x0.64 efficiency)

Appendix b: Further references for Chapter 4

The following references were reviewed to build a clear idea about the integration of remote sensing with other data for soil mapping purposes. However, to save space in the paper in Chapter 4, not all of these references were used. It is useful for this thesis to contain these references, arranged according to their relevance to different subjects.

Remote sensing and soil mapping

1. Asrar, G., (ed), 1989, Theory and Applications of Optical Remote Sensing (New York: John Wiley & Sons).
2. Barrett, E. C., and Curtis, L. F., 1992, Introduction to Environmental Remote Sensing, 3rd edn (New York: Chapman & Hall).
3. Biswas, R. R., and Singh, C. P., 1991, Capability of TM data for evaluation of soil and land resources in the Malwa plateau (Chambal and Mahi catchment) in Madhya Pradesh, India. International Journal of Remote Sensing, **12**, 1905-1913.
4. Buttner, G., Csillag, F., 1989, Comparative study of crop and soil mapping using multitemporal and multispectral SPOT and Landsat Thematic Mapper data. Remote Sensing of Environment, **29**, 241-249.
5. Hawela, F. M., and El-Khattib, H. M., 1990, Geomorphology and classification of soils of wadi El-Rayan using aerial photography and remote sensing techniques. Egyptian Journal of Soil Science, **30**, 29-42.
6. Kucera, K. P., 1984, Accuracy of Landsat imagery and air photograph interpretation in predicting soils and land suitability for irrigation: an analysis of practical surveys for development in three contrasting environments. Soil Survey and Land Evaluation, **4**, 8-17.
7. Lillesand, T. M., and Kiefer, R. W., 1994, Remote Sensing and Image Interpretation, 3rd edn (New York: John Wiley & Sons).

8. Mulders, M. A., and Epema, G. F., 1986, The thematic mapper: a new tool for soil mapping in arid areas. ITC Journal, **1**, 24-29.

9. Ozturk, N., Senol, S., and Dinc, U., 1991, Classification of Urfa-Ceylanpinar soils using Landsat-TM images. 11th Turkish Soil Sience Symposium proceedings, Pub. No. 6, Ankara, Turkey.

10. Roudabush, R. D., Herriman, R., Barmore, R., and Schellentrager, G., 1985, Use of Landsat multi-spectral scanning data for soil surveys on Arizona rangeland. Journal of Soil and Water Conservation, **40**, 242-245.

11. Thompson, D. R., and Henderson, K. E., 1984, Detecting soils under cultural vegetation using digital Landsat Thematic Mapper data. Soil Science Society of American Journal, **48**, 1316-1319.

12. Welch, R., 1989, Desktop mapping with personal computers. Photogrammetric Engineering & Remote Sensing, **55**, 1651-1662.

13. Westin, F. C., and Frazee, C. J., 1976, Landsat data, its use in a soil survey program. Soil Science Society of American Journal, **40**, 81-89.

Remote sensing and GIS for soil mapping

14. Chagarlamundi, P., and Plunkett, G. W., 1993, Mapping applications for low-cost remote sensing and geographic information systems. International Journal of Remote Sensing, **14**, 3181-3190.

15. Derenyi, E., and Pollock, R., 1990, Extending a GIS to support image-based map revision. Photogrammetric Engineering & Remote Sensing, **56**, 1493-1496.

16. Faig, W., Deng, G., and Shih, T. Y., 1988, The reliability and accuracy of the englarger-digitizer approach. Proceedings of 1988 ACSM-ASPRS Fall Convention, Virginia Beach, virginia, 11-16 Sept., pp. 281-288.

17. Faust, N. L., Anderson, W. H., and Star, J. L., 1991, Geographic information systems and remote sensing future computing environment. Photogrmmetric Engineering and Remote Sensing, **57**, 655-668.

18. Lopez-Blanco, J., and Villers-Ruiz, L., 1995, Delineating boundaries of environmental units for land management using a geomorphological approach and GIS: a study in Baja California, Mexico. Remote Sensing of Environment, **53**, 109-117.

19. Sari, M., Dinc, U., Senol, S., Yegingil, I., and Pestemate, V., 1988, Computer assessted soil mapping of the Seyhan river plain using Landsat-TM data. 5th Symposium of the Working Group of Remote Sensing of ISSS: Budapest.

Use of ancillary data with remote sensing

20. Imhoff, M. L., Petersen, G. W., Sykes, S. G., and Irons, J. R., 1982, Digital overlay of cartographic information on Landsat MSS data for soil survey. Photogrammetric Engineering & Remote Sensing, **48**, 1337-1342.

21. Weismiller, R. A., Persinger, I. D., and Montgomery, O. L., 1977, Soil inventory from digital analysis of satellite scanner and topographic data. Soil Science Society of American Journal, **41**, 1166-1170.