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Statistical assessment of variations in soil properties within and among map units generated by GIS

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ABSTRACT

The statistical analysis conducted on the results from a second order scale (1:25,000) semi-detailed soil survey of the Al-Wafra area in Kuwait demonstrates how GIS-based survey data can be reused to provide an alternative representation of soil property distributions. The results indicate that the mapping of consociations and associations has variable accuracy depending on the type of soils and geomorphic setting of the area. The results show the average map unit purity at the subgroup classification level to be 83% and 75% at the soil series level. This shows the high precision of the soil survey data. The relative variance of diagnostic horizons was very high, reflecting the absence and presence of these features in contrasting soil material. The relative variance results for selected soil properties show that the map units have separated the landscape so that useful statements can be made in relation to soil property distribution that would assist with interpretations for land use. The statistical analysis procedures show that the information in the database can be reinterpreted and analyzed to provide additional quantifiable information. It also shows that impure map units are due to the classification as well as the placement of map boundaries and the scale of mapping used. Interpretation could be improved by using statistical data with a map.

Key words: Kuwait, land use, soil classification, soil mapping, soil survey.

INTRODUCTION

With the exception of basic statistical descriptions of map-unit composition, conventional soil surveys do not routinely provide statistical evaluation (Young *et al.* 1998). Upchurch & Edmonds (1991) reviewed methods commonly used in spatial variability research. Soil variation is effectively continuous and cannot be described perfectly by sharp boundaries (Webster 1968). Individual soil properties often vary at different rates and in different directions (Campbell 1977), and so cannot be separated by a single map-unit boundary. The degree of clustering varies with scale, so that inliers and outliers always exist (Valentine 1981), and uncertainties within the conceptual models introduce error (Hudson 1990). The USDA recommends a map-unit purity of 50% or greater for detailed survey, and advise that in addition to 50% of the eponymous soil, a map unit should contain substantial proportions of similar soils to remain a consociation. A few other national survey organizations recommend higher levels of purity (>70%), although reported levels of map purity are generally much lower, frequently in the 50-70% range (East 1994). Strict purity, the test applied here, is often low. For example Marsman & de Gruijter (as reported in East 1994) record a range of purities between 7 and 13%.

There are a few examples of comparable analyses being used for practical survey (Powell & Springer 1965, Wilding *et al.* 1965, McCormack & Wilding 1969, Edmonds *et al.* 1982, Edmonds *et al.* 1985a, b, Edmonds & Lentner 1986, Hartung *et al.* 1991, Young *et al.* 1997). In these statistical evaluations, map-unit variability in general is focused on map-unit composition as an expression of spatial variability. Recently, variance of soil properties within map units has been studied (Young *et al.* 1998). Such studies are important for the users of soil survey information. It is suggested by Moore *et al.* (1993) that soil survey data could be used as input for statistical analysis, and the demands on soil surveys for both accuracy and precision will continue to increase (Arnold & Wilding 1991). Young *et al.* (1998) stated that estimates of the variability of soil properties within map units have not been published in a standard survey. Statistical assessment of the outcomes of one area (Al-Wafra) from the semi-detailed soil survey of Kuwait was undertaken to determine map-unit variability in terms of purity, frequency distribution of soil classes and probability of occurrence of different soil classes within map units.

Analysis of variance of individual soil properties was conducted. It is important, therefore, to realize that the present statistical analysis is well beyond the standard soil survey practice. The results serve as a guide to indicate the use of statistical analysis to derive more detailed and quantitative information from the soil survey dataset. Users of the soil survey data can use these methods to enhance their interpretation and provide confidence limits for specific land uses.

STUDY AREA

The selection of the study area was made following a review of the reconnaissance scale soil mapping and prescription of criteria for a land suitability assessment for irrigated agriculture (FAO 1976, 1985). For the purpose of statistical evaluation of the soil survey data, only one sub-area (Al-Wafra in Kuwait) has been assessed. The location of the Al-Wafra study area, displayed in Figure 1, covers 13,538 ha in the southeast of Kuwait, north and east of the Al-Wafra farming area.

The study area is a gently undulating sand plain in the north and west; in the southeast it is a playa plain. Elevation is highest in the west (107 m) and lowest on the playa depressions in the southeast (41 m). Local relief is usually less than 5 m, with slope gradients of 0 to 3 percent. Slopes of 3 to 5 percent occur on the isolated low ridges that occur throughout the area. Slopes greater than 10 percent were not recorded. The land surface has many sand hummocks giving a very rough and uneven appearance. In some places, deflation has occurred exposing the hard-setting subsoil and sometimes leaving gravel lag on the soil surface. Individual playas are interspersed with low dunes of aeolian sand, which in places have blown onto and cover the surface of the playas.

MATERIALS AND METHODS

The general approach to analysis was to compare the soil maps with site observations of the soil resource. The maps attempt to partition a variable soil body into map units. Analysis, therefore, determined the variability within and among map units. The data used for measurement were from individual site observations, which were largely independent of the map-unit boundaries and were used mainly to identify the model from which boundaries were inferred. The sample population for the Al-Wafra survey area comprised 1,038 soil pits and auger observations. The samples were arranged within a rectangular grid, with the dimensions 300 by 400 m, each observation represents 12 ha. The data have been georeferenced and subjected to quality control by staff from the USDA (1998) before being stored in the Soil Survey of Kuwait (SSK) database. The analytical methodology used was deemed appropriate for both the functional demands of the survey and the nature of the soil database, and extends beyond the transect analysis method proposed by the USDA (Soil Survey Division Staff 1993) and draws on previous research into soil survey methodology (Bie & Beckett 1971 a, b). The survey was completed at the second order level of the USDA system (Soil Survey Division Staff 1993) and the soils classified according to the sixth edition of the *Keys to Soil Taxonomy* (Soil Survey Staff 1994). Maps from Al-Wafra area were compared against sample data collected during the soil survey. These data were not used directly to locate map-unit boundaries and were therefore independent of the maps they were being used to test. A general soil map classification at a second order of the study area is presented in Fig. 1.

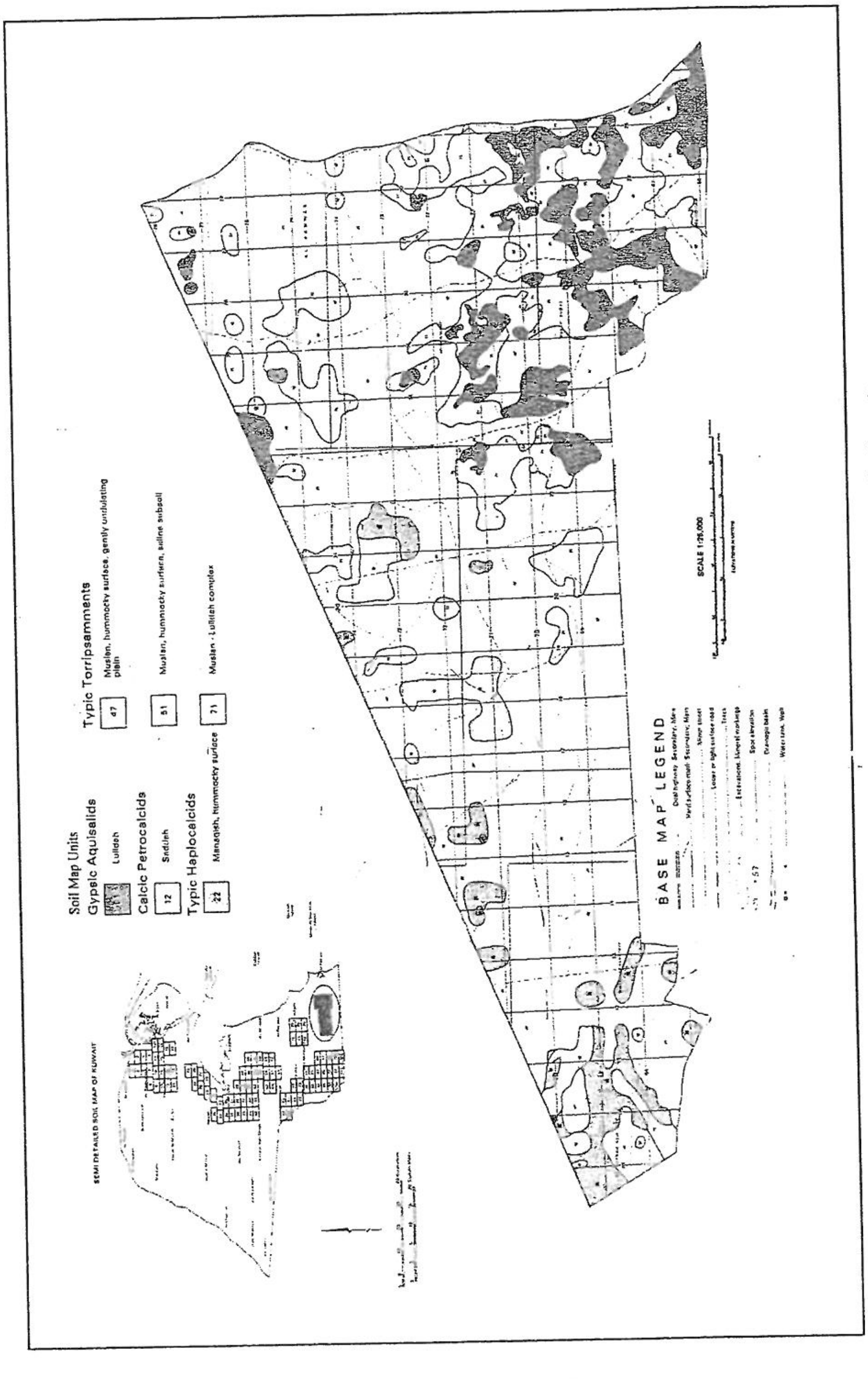

Figure 1: Site location map of Al-Wafra study area in Kuwait.

Overview of analysis

Map-unit purity

Map-unit purity is assessed simply as the proportion of sites within a map unit which contain the expected soil class. The conditional probability p (soil-class S | map-unit M) is the probability of finding soil class S, given the name of the map unit M. Purity can be computed easily from cross tabulation as:

$$Purity = \frac{number\ of\ sites\ in\ map\ unit\ M\ of\ class\ S}{total\ number\ of\ sites\ in\ M}$$

A perfect map unit will have a purity of 1. A neutral map will have a purity equal to the average occurrence (not zero) of the soil class over the map.

Partitioning of soil classes between map units

This can be expressed as the conditional probability, p (map-unit M | soil class S), which is computed easily from cross tabulation as:

$$p(map\ unit|\ soil\ class) = \frac{number\ of\ sites\ in\ map\ unit\ M\ of\ class\ S}{total\ number\ of\ sites\ with\ soil\ S}$$

An effective map unit will contain all or no members of a given soil class and take a value approaching 100% or 0. An ineffective map will take a value close to the proportional area of the map unit.

Relative variance

Relative variance (RV) assesses the proportion of variations, which is controlled by partitioning or map units. RV varies between a value of 100% (perfect classification i.e., all variation occurs between map units and none within) and 0 (ineffective classification, i.e., no variation controlled by map units). RV was performed using conventional one-way analysis of variance, using map unit or soil class as a factor. The results were interpreted further using regression tree models to explain the progressive accumulation of variance, which occurs as increasingly dissimilar map units are included. It is estimated as:

$$RV = 1 - \frac{within\ SS}{total\ SS}$$

where within and total sums of squares (SS) are taken from a conventional analysis of variance table. Variables such as depth to diagnostic calcic, gypsic, petrocalcic, petrogypsic and salic horizons were selected for analysis, as they are critical to land evaluation. For properties with approximately normal distributions (i.e., calcic, gypsic, petrogypsic and petrocalcic horizons), simple one-way analysis of variance was used. For highly skewed data, i.e., salic horizon, the non-parametric Kruskal-Wallis method of analyzing variance was used. Calculation of RVs only for sites with positive identification of a diagnostic horizon seriously underestimates the ability of classification or map units to partition variance, because it ignores the successful exclusion of soils which have a recorded absence of diagnostic horizon. Analysis was therefore repeated after assigning a diagnostic horizon at an arbitrary depth (249 cm) to sites which had none recorded.

Likelihood of occurrence of diagnostic horizons

The likelihood of a diagnostic horizon occurring at a given depth within a given map unit subgroup can be expressed by its conditional probability of occurrence, given identification of the map unit in question, which is enumerated as:

$$p(diagnostic \mid map\ unit) = \frac{number\ of\ sites\ in\ map\ unit\ M\ with\ diagnostic{-}horizon}{total\ number\ of\ sites\ in\ M}$$

These probabilities were estimated from counts of occurrence in sample data for the survey areas. The strength of association between a diagnostic feature and a map unit was summarized by the log-odds ratio. The ratio for the association between the presence of a diagnostic feature and map unit (i.e., if I am in map unit M, what is the likelihood that a diagnostic horizon is present?) is as follows:

$$LS = \frac{p\ (M \mid diagnostic\ present)}{p\ (M \mid diagnostic\ absent)}$$

The ratio for the converse association (i.e., if I am outside map unit M, is the diagnostic absent?) is:

$$LN = \frac{p\ (outside\ M \mid diagnostic\ present)}{p\ (outside\ M \mid diagnostic\ absent)}$$

The two can be combined in a log-odds ratio, to give a single measure of strength of association:

$$LOR = \ln \frac{odds(LS)}{odds\ (LN)}$$

A large positive result indicates a strong positive association between the diagnostic feature and map unit; a negative result, a negative association; and '0' represents no association.

An additional assessment of the difference between whole-frequency distributions of depths to diagnostic horizon was trailed using the Kolmogorov-Smirnov measure. This detects significant differences between the entire distributions, as opposed to the likelihood of occurrence of individual depths.

Comparison of means

The variables such as depth to diagnostic calcic, gypsic, petrocalcic, petrogypsic and salic horizons were analyzed. Means were compared at the level of $p = 0.05$. 95% confidence limits and significant differences were assessed from analysis of variance using T-tests between pairs of map units. Properties with few occurrences were not analyzed. Properties with highly skewed distributions (normally caused by a few large values) were analyzed using the Kruskal-Wallace non-parametric rank sum test. All site data was obtained from the SSK database (KISR 1999). The data was exported as an Excel^{TM} spreadsheet for processing and preliminary statistical analysis. Classical statistical analysis was completed in Statistix^{TM} (Analytical Software 1996) and SPLUS^{TM} v4.0 (MathSoft 1997).

RESULTS AND DISCUSSION

The general approach taken in the statistical assessment was to compare the soil maps with site observations of the soil resource. The maps attempt to partition a variable soil body into map units. Analysis, therefore, determined the variability within and between map units. The data used for measurement were from individual site observations, which were largely independent of the map-unit boundaries and were used mainly to identify the model from which the boundaries were inferred. Comparisons between the map units can be useful and can assist in more detailed interpretation of the maps. The main value of this statistical analysis was to assist with final map compilation and interpretations of the maps in conjunction with other information provided by the survey, including the soil legend and accompanying report.

Map unit purity

The survey area is comprised of six map units (Table 1). These can be subdivided into 32 soil series, of which only 16 occupy $\geq$ 0.5 percent. It is not the objective of the study to give detailed descriptions of soil types; therefore, the details of the soil series can be accessed in KISR (1999).

Table 1: List of map units for the Al-Wafra study area.

Map Symbol	Map unit name	Summary
W01	TTP1 consociation,	The dominant unit occurs throughout the survey area. It occurs on all landscape positions of the well drained, level to gently undulating sand plain (0 to 5% slopes).
W02	THC10, TCH13 association	Occurs as slightly deflated areas within the gently undulating sand plain (1 to 2% slopes). It is often surrounded by the W01 unit. This unit's soils have a dominantly calcic horizon within 100 cm. A petrocalcic horizon may occur below 100 cm.
W04	TPC1, CPC1 association	Deflated areas within the gently undulating sand plain. Slopes are usually less than 2%, and where erosion has been most severe, the surface may be smooth rather than hummocky.
W05	TTP8, GAS	A complex of deep sands with a saline water table at depth, which occur on sandy flats adjacent to playas and small areas of playas. The unit occurs on a playa plain in the southeast of the survey area. The dominant soil on the flats is a sand with a saline water table below 150 cm (TTP8), while on the playas, Aquic Salids (GAS and TAS) and Saline Haplogypsids (THG4) occur.
W06	TTP8, TTP1 consociation	Occurs on sandy flats adjacent to the playas and contains deep sands with a saline water table at depth. The surface is hummocky.
W07	GAS1 consociation	Map-unit W07 is comprised of playas, which occur on a playa plain at the base of the gently undulating sand plain. This unit is common in the southeast of the survey area. The soils are saline and waterlogged, and usually gypsic (GAS, TAS and THG4).

Purity of subgroups within map units

Map-unit purity was assessed from 1038 site records. The Typic Torripsamments (TTP) subgroup is dominant in this area, occupying 76.4% of the area. Other subgroups (Table 2) with over 1% representation include Gypsic Aquisalids (GAS) subgroup (5.6%), Typic Haplocalcids (THC) subgroup (4.6%), Typic Haplogypsids (THG) subgroup (3.5%), Typic Petrocalcids (TPC) subgroup (2.6%), Calcic Petrocalcids (CPC) subgroup (2.3%) and Typic Aquisalids (TAS) subgroup (1.4%). Subgroups with less than 1% representation include (0.6%), Petrocalcic Petrogypsic (0.5%), and Typic Petrogypsic (0.5%).

Table 2: Distribution of SUbgroups within map units.

	Map Unit (%)						
Subgroup	W01	W02	W04	W05	W06	W07	Subgroup area %
TTP	97	8	21	58	100	16	76.4
GAS	0			15		46	5.6
THC	1	67	6				4.6
THG	0	6	3	13		18	3.5
TPC		4	29			1	2.6
CPC	0	2	27				2.3
TAS				6		9	1.4
OUP				4		2	0.6
PPG			6				0.5
TPG	0		3	1		1	0.5
Map-unit area %	68.5	5	7.6	9.2	1.1	8.7	

At the subgroup level, the large map units are exceptionally pure. Average purity is 83%. Map unit W01 which occupies 68.5% of the survey area is almost pure with a purity of 97% TTP. The only other subgroup with a significant (>1%) presence in this map unit is THC, and even then these soils are characterized by an unusually deep calcic horizon. In the map-unit W01, impurities share important similarities with the main subgroup. Map-unit W05 which occupies 9.2% of the survey area is less pure, but even here the main subgroup (TTP) occupies 58% of the map unit. The next most widespread subgroup is GAS at 15%, and then THG at 13%. Map unit W07 occupies 8.7% of the survey area and contains 46% GAS, 18% THG, 16% TTP and 9% TAS. Map-unit W04 occupies 6.9% of the survey area and is an impure map unit containing TPC (30%), CPC (27%), TTP (20%), and THC (6%). Despite its impurity, this map unit is useful in that it segregates 84% of the TPCs from the surrounding area. Map-unit W02 occupies 5.0% of the area and is predominantly THC (67%) with some TTP (8%). Map-unit W06 is of minor spatial significance occupying only 1% of the survey area. W06 appears to be identical to W01 and is occupied exclusively by TTPs.

Purity of series within map units

The proportion of series within each map unit is shown in Table 3. Thirty-two soil series were identified within the Al-Wafra area, of which 17 occupy less than 0.5% of the total area and were excluded from further analysis. Series TTP1 dominates the survey area and occupies 67.5%. The five next most widespread

(CPC1, GAS1, THG4, TPC1, and TTP8) cover a further 18%, and the next five a further 9.3%, leaving 21 series within the remaining 5%.

Table 3: Distribution of series within map units.

	Map unit (%)						
Series	W01	W02	W04	W05	W06	W07	Series %
CAG1		2	1				0.2
CPC1	0	2	28				2.3
CPG1			1				0.1
EHG1				1		1	0.2
GAS1	0			15		45	5.5
GHS1				1		1	0.2
OUP1				4		2	0.6
PHS1						2	0.2
PPA1		2	1				0.2
PPG1			7				0.5
TAG1						1	0.1
TAS1					6	9	1.4
TCA1				1			0.1
TCG1		6					0.3
TGA1		2					0.1
THA1		2					0.1
THC1		2					0.1
THC10	1	29					2.0
THC13	0	29	5				1.9
THC14		2					0.1
THC15		8	1				0.5
THG3				2		1	0.3
THG4	0			10		18	2.5
THS1						1	0.1
TPC1		4	30			1	2.6
TPG1	0		3	1		1	0.5
TTP1	92	2	1	22	82	6	67.5
TTP2	3						2.0
TTP3	0			3			0.6
TTP6	1	6	17				2.0
TTP7			1				0.1
TTP8	1		1	34	18	10	5.1
Map-unit area (%)	68.5	5	7.6	9.2	1.1	8.7	

The largest map unit, W01, is extremely pure, being occupied by 92% TTP1, 3% TTP2, and 1% each of TTP6 and TTP8. Map-unit W05 contains 34% TTP8, 22% TTP1 and 15% GAS1. Map-unit W07 contains 45% GAS1, 18% THG4 and 10% TTP8. Map-unit W04 is 58% petrocalcids (TPC1 and CPC1), 17% TTP6. Map unit W02 contains 70% Typic Haplocalcids, mainly THC10 (29%) and THC13 (29%). The small map-unit W06 is dominated by TTP1 (82%) with the remainder occupied by TTP8. Average purity is 74.7%. These levels of purity are higher than reported in other studies (Soil Survey Division Staff 1993, East 1994) and shows the high precision of the survey data. In fact, in the Al-Wafra area, soils were easy to separate due to the simple distribution of soil forming-material i.e., aeolian sand.

Distribution of subgroups between map units

The distribution of subgroups between map units is summarized in Table 4. The TTP subgroup covers 76.4% of the Al-Wafra survey area. Other subgroups include GAS (5.6%), THC (4.6%), TPC (2.6%) and THG (3.5%). Subgroups are contained well by the map units, 87% of the TTPs occur in map-unit W01, 72% of the GASs are contained within map-unit W07, 72% of the THC's occur in map-unit W02, and over 80% of the TPCs and CPCs are contained within map-unit W04. In addition, 78% of the THGs are within map-units W05 and W07.

Table 4: Distribution of subgroups within map units.

	Map Unit (%)						
Subgroup	**W01**	**W02**	**W04**	**W05**	**W06**	**W07**	**Subgroup area %**
TTP	87	1	2	7	1	2	76.4
GAS	4			25		72	5.6
THC	17	72	11				4.6
THG	8	8	6	33		44	3.5
TPC		7	85			4	2.6
CPC	8	4	88				2.3
TAS				43		57	1.4
OUP				67		33	0.6
PPG			100				0.5
TPG	20		40	20		20	0.5

Distribution of series between map units

Distribution of the major soil series between map units is summarized in Table 5. The major soil series TTP1 is found almost exclusively (95%) in map-unit W01 and occupies 66.6% of the studied area. Seventy one percent of GAS1 occurs in map-unit W07, while 62% of the TTP8 occurs in map-unit W05. On the other hand, 62% of the THG4 is found in the map-unit W07, 85% of the TPC1 is found in map-unit W04 and 100% of the PPG1 occurs exclusively in map-unit W04.

Table 5: Distribution of series within map units.

	Map unit (%)						
Series	W01	W02	W04	W05	W06	W07	Series %
TTP1	95	0	0	3	1	1	66.6
GAS1	4			25		71	5.5
TTP8	15		2	62	4	17	5.1
TPC1		7	85			4	2.6
THG4	4			35		62	2.5
CPC1	8	4	88				2.3
THC10	33	67					2.0
TTP2	100						2.0
TTP6	24	14	62				2.0
THC13	5	74	21				1.9
TAS1				43		57	1.4
OUP1				67		33	0.6
TTP3	50			50			0.6
PPG1			100				0.5
THC15		80	20				0.5
TPG1	20		40	20		20	0.5
Map unit area %	68.5	5	7.6	9.2	1.1	8.7	100

Relative variance

Table 6 summarizes the RV for the five properties analyzed according to map unit, subgroup and series. The results for salic horizon should be viewed with caution because of the skewed distribution of salic horizon depth. The RV of partitioning according to map unit is extremely large for the calcic and gypsic horizons, with 92% and 86% of the variation, respectively. This indicates that the map units control a very large proportion of property variance. The RV of the petrocalcic horizon at 54% is also high. However, the RV of the petrogypsic horizon is low (7%).

Table 6: Relative variances for diagnostic horizons within map units.

			Map Unit		
	Calcic	**Gypsic**	**Salic**	**Petrocalcic**	**Petrogypsic**
Within	72185	149578	1.08E+07	229087	118958
TOTAL	854682	1067575	1.95E+07	494692	128432
n	1001	1001	1001	1001	1001
RV	92%	86%	45%	54%	7%
			Subgroup		
	Calcic	**Gypsic**	**Salic**	**Petrocalcic**	**Petrogypsic**
Within	90230	156004	9.08E+05	75629	52386
TOTAL	854682	1067575	1.99E+07	496162	129921
n	1037	1037	1036	1037	1037
RV	89%	85%	95%	85%	60%
			Series		
	Calcic	**Gypsic**	**Salic**	**Petrocalcic**	**Petrogypsic**
Within	72185	149578	1107449	65282	49998
TOTAL	854682	1067575	1.99E+07	496162	129921
n	1038	1038		1038	1038
RV	92%	86%	94%	87%	62%

RV by subgroup and series classification is very high for the calcic, gypsic, salic and petrocalcic diagnostic features with classification controlling over 80% of the variation of these properties. This was expected, since these features are used to classify soils at the subgroup level, and when taken with the RV for map units, indicate that the classification closely follows the map units. Series identification fails to partition variation further because diagnostic horizons are not used for subdivision into series level. The RV of depth to the petrogypsic horizon is lower at 60%. This can be explained by the distribution of petrogypsic horizons, which occur below the depth at which they influence classification (the mean depth of the petrogypsic horizon is 105.6 cm). The probabilities of occurrence at any depth can be estimated statistically from the known distribution of these properties and are summarized in Table 7. The calcic and gypsic horizons peak within the arbitrary cut-off depth of 100 cm. They, therefore, have relatively small probabilities of occurrence beyond 100 cm (22% and 23%, respectively). The mean depth of the petrocalcic horizons is 84 cm, and the probability of occurrence below 100 cm is larger at 43%. The mean depth of the petrogypsic horizon is 95 cm, and the probability of occurrence at depths greater than 100 cm is 35% (Table 7). Substantial variation will therefore be omitted by the classification and hence, excluded from the map units.

Table 7: Estimated probabilities of diagnostic horizons occurring within a given depth

Horizon →	**Calcic**	**Gypsic**	**Petrocalcic**	**Petrogypsic**
Mean upper depth	69	62	84	95
S.D.	40.71	42.30	42.89	35.08
Depth	Estimated probability that diagnostic occurs beyond a given depth			
100 cm	0.22	0.23	0.43	0.56
150 cm	0.02	0.03	0.09	0.10

Comparison of mean depths to diagnostic horizons between map units

Table 8 summarizes the mean, standard error and 95 percent confidence interval for the depths to diagnostic calcic, gypsic, petrocalcic, petrogypsic, and salic horizons in each map unit. Map-unit W06 was pure TTP and lacks diagnostic horizons. Three clear situations were distinguished in map units W04, W02 and W01. Calcic horizons were recorded in 41% of soils in map-unit W04, where they tended to be shallow with a mean depth of 37 cm. Calcic horizons occurred widely (>80%) through map-unit W02 with a mean depth of about 60 cm. Calcic horizons occurred at only 5% of the sites in map-unit W01, where they tended to be deep with a mean depth of 106 cm. Too few sites with calcic horizons occurred in map-units W05 and W07 to estimate means and variances. The mean depth of gypsic horizons varied between map units from 51.4 cm (map-unit W07) to 97 cm (map-unit W01). Gypsic horizons were abundant (>70%) in map-unit W07 and moderately shallow with a mean depth of about 50 cm. They occurred at the same depth, but less frequently (13%) in map-unit W04. Deeper (83-cm) gypsic horizons were more common (45%) in map-unit W05. Deep gypsic horizons occurred in about a quarter of map-unit W02. Gypsics were virtually absent from map-unit W01, and where present, were deep. Mean depths to petrocalcic horizon varied between 82 and 160 cm. Petrocalcics were widespread (>80%) in map unit W07 and occurred over a very wide range of depths with a mean of about 82 cm. They were rare in map unit W04, but at about the same depths. Petrocalcic horizons were common in map-unit W02 (20%), but deeper, occurring at greater than 100 cm depths. In map-units W01 and W05, petrocalcics were rare and deep when present.

Mean depths of petrogypsic horizons varied from 87.3 to 121 cm, but due to a lack of observations, confidence intervals remain wide at the 95% level. Petrogypsic horizons were fairly common (about 10%) in map-units W07, W04 and W05, and covered a broad range of depths between about 65 and 150 cm. Petrogypsic horizons were more frequent in map-unit W02 (20%) and deeper. With the exception of map-units W07, W01 and W02, it was not possible to clearly discriminate between map-units.

Table 8: Comparison of mean depths of diagnostic horizons among map units.

					95% Confidence limits		Significantly different from.			
Map Unit	Mean	n	SD	SE	Upper	Lower	W07	W05	W01	W02
Calcic										
W04	37.2	32	26.3	4.6	45.1	29.3				
W02	59.5	44	27.7	4.2	66.5	52.5	x			
W01	106.1	34	33.1	5.7	115.7	96.5	x	x		
W05	140.0	1	1.0	1.0	ND	ND	✓	✓	✓	
W07	150.0	1	1.0	1.0	ND	ND	✓	✓	✓	✓
							W07	W04	W05	W02
Gypsic										
W07	51.4	64	38.6	4.8	59.5	43.3				
W04	52.2	10	26.9	8.5	67.8	36.6	x			
W05	83.0	43	45.2	6.9	94.6	71.4	✓	✓		
W02	91.6	14	25.0	6.7	103.4	79.8	✓	✓	x	
W01	97.0	10	36.0	11.4	117.9	76.1	✓	✓	x	x
							W04	W07	W02	W01
Petrocalcic										
W04	82.1	3	62.1	35.9	186.8	-22.6				
W07	84.7	68	39.9	4.8	92.8	76.6	x			
W02	107.9	18	40.6	9.6	124.5	91.3	✓	x		
W01	129.5	10	30.0	9.5	146.9	112.1	✓	x	x	
W05	160.0	2	0.0	0.0	160.0	160.0	✓	✓	x	x
							W07	W01	W04	W05
Petrogypsic										
W07	87.3	11	42.4	12.8	110.5	64.1				
W01	95.0	1	0.0	ND	ND	ND	x			
W04	104.3	14	39.0	10.4	122.8	85.8	x	x		
W05	118.7	4	28.4	14.2	152.1	85.3	x	x	x	
W02	121.0	11	17.5	5.3	130.6	111.4	✓	✓	x	x
							W01		W07	
Salic										
W01	0.0	4	0.0	0.0	0.0	0.0				
W07	2.8	24	48.17	9.8	19.6	-14.1	x			
W05	30.2	56	17.63	2.4	34.1	26.3	x		✓	

SD = standard deviation; SE = standard error; ND = not determined; ✓ = significantly different; X = non significantly different at p = 0.05.

Mean depths of salic horizons varied between 87.3 cm and 121.4 cm, but because of the highly skewed nature of these data, precise comparison was not possible. Nevertheless, analysis of variance using the Kruskal-Wallis procedure was able to identify a significant difference between soils in map-unit W07 with a relatively shallow salic horizon (a mean of 2.8 cm) and other map units.

CONCLUSIONS

The results showed a strong contrast in the ability of the conventional soil map to partition variation. The discussion shows how the results can be used for interpreting the map units, rather than interpretation for specific purposes. The 1:25,000 soil map of Al-Wafra was very successful at identifying soil variation, due principally to a simple geomorphologic pattern which could be recognized and mapped reliably. Map-unit purity was very high, with the strict purity of the major map unit exceeding 90%. The RV of diagnostic horizons was also very high, reflecting the absence and presence of these features in contrasting soil material. Diagnostic horizons were generally absent in the aeolian sand. Their occurrence and form could be predicted well from analysis of the map units. For example, no calcic, gypsic, petrocalcic or petrogypsic horizon is expected in the main map-unit W01. Where they occurred, they tended to be deep. A similar, though less extreme pattern occurred in map-unit W05. A calcic horizon, but no gypsic horizon, was likely in map-unit W02, while calcic and petrocalcic horizons were likely in map-unit W04. A gypsic or petrogypsic horizon, but no calcic horizon, was likely in map-unit W07. The interpretation was improved by using statistical data with map.

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التقييم الإحصائي للتباين في صفات التربة بين الخرائط التي يولدها نظام المعلومات الجغرافي

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خلاصة

إن التحليل الإحصائي في نتائج مسح التربة نصف التفصيلي على مقياس (1: 25،000) لمنطقة الوفرة الزراعية في دولة الكويت والذي استخدمت فيه نظم المعلومات الجغرافية، يوفر بدائل في تقديم معلومات عن توزيع أنواع التربة.

وبينت النتائج أن تحديد أنواع التربة - عشائرها وتحت عشائرها - يعتمد على نوع التربة والتشكيلات الجيومورفولوجية للمنطقة، كما أن متوسط نقاوة وحدة خريطة التربة على مستوى المجموعات الفرعية كان (83٪) وعلى مستوى السلسلة كان (75٪)، الأمر الذي يعكس درجة عالية من الدقة في معلومات تصنيف التربة. وكان التباين النسبي ف تشخيص قطاعات التربة كبيراً، مما يعكس غياب أو تواجد السمات المختلفة في مواد التربة المتباينة.

كذلك ساعدت نتائج الاختلافات النسبية المتغايرة لأنواع مختارة من التربة وخصائصها في إمكانية استخدام وحدات الخرائط في توزيع التضاريس بحيث يمكن استخلاص معلومات مفيدة في مجال استخدامات الأراضي.

إن إجراءات التحليل الإحصائي لأنواع التربة تبين أن بيانات قواعد المعلومات يمكن إعادة تفسيرها وتحليلها لتوليد معلومات إضافية، كما أنها توضح أن نقاوة أو عدم نقاوة وحدات الخرائط تعتمد على تصنيف التربة، إلى جانب تعيين المكان المناسب لوضع حدود المنطقة، والمقياس المستخدم في إعداد الخرائط.

وهذا يمكن تحسين طريقة تحليل البيانات باستخدام التحليل الإحصائي لمعلومات في الخرائط.