INTERPRETING SOIL DATA FROM THE PAPUA NEW GUINEA RESOURCE INFORMATION SYSTEM (PNGRIS)

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ABSTRACT

The Papua New Guinea Resource Information System (PNGRIS) is an inventory of natural resources, land use and population distribution. At a scale of 1:500,000 it is the most comprehensive assembly of information on PNG soils and their distribution. PNGRIS is an easily accessible source of soil data at a level suitable for national and provincial planning. In this paper, examples are given how the soil data can be used illustrating the value of this computerized database with its linked mapping capability.

Keywords: *soil information, digitized data, soil mapping, PNGRIS, Papua New Guinea.*

INTRODUCTION

The Papua New Guinea Resource Information System (PNGRIS) is a computer based inventory of information on natural resources, land use and population distribution which covers the whole nation (Bellamy and McAlpine 1995). It was designed to be a basic tool in resource use planning for both development and conservation. It is now installed and used in a wide range of PNG agencies involved in service provision and natural resource based activities

PNGRIS was established as a cooperative research project undertaken and funded jointly by the PNG Department of Primary Industry (DPI, now Department of Agriculture and Livestock (DAL)) and CSIRO. The project's objective was to determine both the current use and development potential of the nation's natural resources for food and cash production, taking into account present and future population growth and distribution. The aim was to integrate information relevant to development planning and to provide a system for effective use and evaluation of that information.

All of the information in PNGRIS was derived from natural resource surveys previously undertaken by DPI and CSIRO, geology mapping carried out by the Geological Survey of PNG and the Australian Bureau of Mineral Resources and population data and smallholder economic activity compiled by the National Statistics Office with data collected from the 1980 and 1990 censuses. The broad structure of PNGRIS is shown in Figure 1.

THE STRUCTURE OF PNGRIS

PNGRIS consists of: (1) a map base (in MAPINFO) showing the locations of the basic spatial units of the system known as Resource Mapping Units (RMU) and, (2) a database (in FOXPRO) comprising the inventory data describing the natural resource, land use and population distribution of each RMU. These are linked by a user-friendly interface for joint map and database analysis. The basic unit of information used to integrate and store data in PNGRIS is the *Resource Mapping Unit* (RMU). An RMU is an area of land that has the same pattern of landform, geology, climate, hydrology and soils throughout its extent. In the sense that it is made up solely of physical resource attributes it is effectively time independent (i.e. unlikely to change except over the long term). For each RMU, information is recorded on its natural (physical) resources to which is added further information on land use, population and natural (biological) resources, all of which are time dependent (i.e. likely to change over the short to medium term). The concept of an RMU is largely similar to the *land system* concept defined by Christian and Stewart (1968) and used by CSIRO as the mapping unit for its large-scale regional survey program (see definition later

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Figure 1. **PNGRIS Components.**

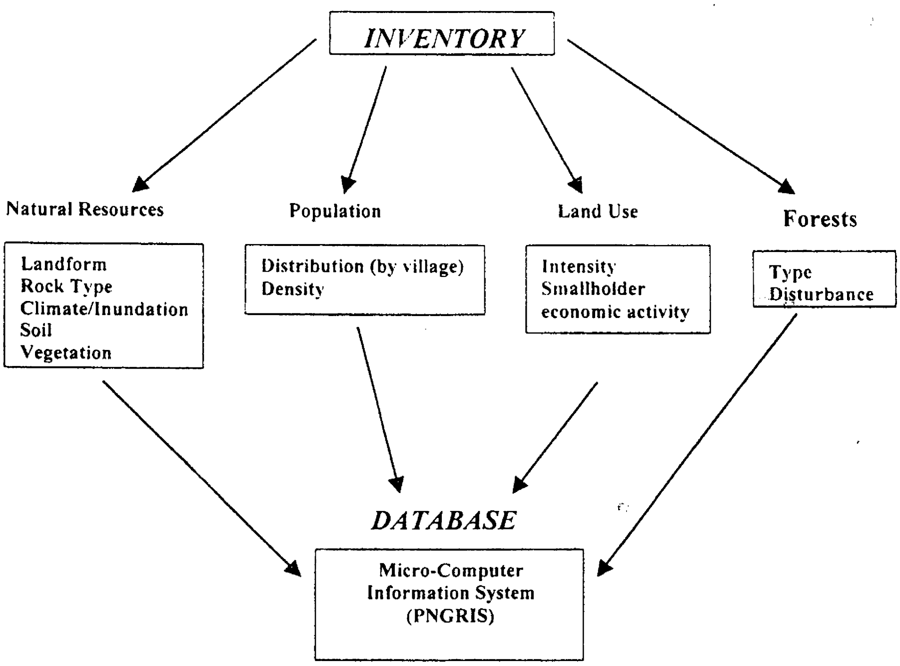
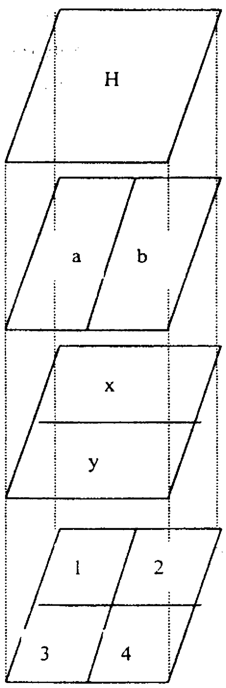


Figure 2. **Example of the derivation of an RMU map (after Bellamy and McAlpine 1995).**



RMU Map

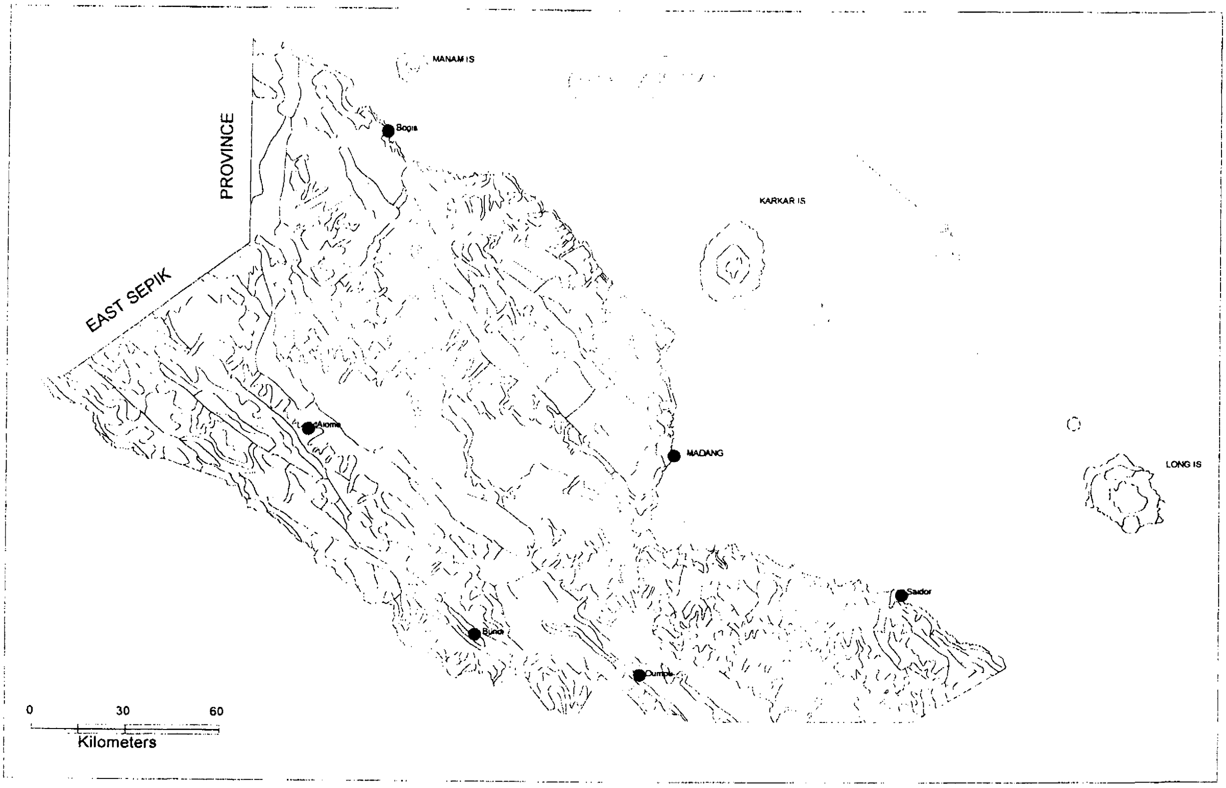
Attribute I: Landform type
H - hills

Attribute II: Rock type
a – ultrabasics
b – fine grained matamorphics

Attribute III: Altitude
x – 1200 to 1800 m
y – 1800 to 2100 m

RMU No.	Attributes			Description
	I	II	III	
1	H	a	x	Hills on ultrabasics between 1200 & 1800 m
2	H	b	y	Hills on fine grained metamorphics between 1200 & 1800 m
3	H	a	x	Hills on ultrabasics bewteen 1800 & 2100 m
4	H	b	y	Hills on fine grained metamorphics between 1800 & 212100 m

Figure 3. **Example of RMU mapping for Madang Province.**



in this paper). The total attribute set used to describe RMUs is given in Table 1. RMUs were derived by overlaying mapped attribute data to generate boundaries. Thematic maps of three attributes, namely landform type, rock type and altitude, were used to define the basic RMU as shown in Figure 2. An example of RMU mapping is given in Figure 3 and a description for one RMU is given in Table 1.

Map compilation and information integration has been carried out at a scale of 1:500,000 with 4566 RMUs having been delineated for the country as a whole. Maps have been digitised into computer compatible form, on a province by province basis, with whole country mapping also being available.

A detailed description of the computer implementation aspects of PNGRIS is provided in the *PNGRIS User's Guide* compiled by Keig and Quigley (1995). The system has been designed as an integrated database and consequently caution should be taken in desegregating the data for specific attribute analysis.

DATA SOURCES USED FOR PNGRIS

CSIRO

As mentioned before, a large amount of knowledge describing resource type and distribution, built up by CSIRO and various PNG Departments over a long period, was used as the basic source material for the PNGRIS inventory. The principal sources of natural resource information were the regional resource surveys undertaken by the CSIRO Division of Land Research, Canberra between 1953 and 1972 and subsequent disciplinary studies of the whole country. These regional resource or 'land system' surveys were designed to provide rapid information on the natural resources of large areas of PNG, both in inventory and map form, for the initial assessment of agricultural potential and limitations. The surveys involved close integration of specialist studies (namely, landform, soil, climate and vegetation), extensive use of aerial photographs, reconnaissance ground sampling and multi-attribute land classification.

Table 1. Example of PNGRIS information in an RMU.

PROVINCE 13 Madang	RMU No. 1	LAT.	5 deg 7 min S
DISTRICT 2 Madang		LONG.	145 deg 47 min
		AREA	99 sq km

NATURAL RESOURCES

LANDFORM Raised coral reefs and associated back reef plains

ROCK TYPE Alluvial deposits
Limestone

SLOPE <2 degrees

ALTITUDE 0-600 m
MAX TEMP 32-30 degC
MIN TEMP 23-19 degC

RELIEF Negligible <10 m

RAINFALL

Annual	3500-4000 mm
Seasonality	100-200 mm to >200 mm
Deficit	Infrequent, slight deficit

INUNDATION Waterlogged area
Extent <20%

VEGETATION See Land Use file

FOREST TYPE

		sq km
Hm - Low alt on uplands - medium crowned forest	50% undisturbed	9

LAND USE

'USED' AREA 91 sq km = 92 % of total area

POPULATION DENSITY

Total Population	34103	
Density on Total Area	344	persons/sq km
Density on 'Used' Area	375	persons/sq km

		sq km
LAND USE INTENSITY	Significant	90
	Low	1
REGROWTH		
No fallow (i.e. totally used)		46
Mixture of tall and short woody		44
Tall woody		1

NON-SUBSISTENCE USE

Coconuts w/wo under-cropping
Urban

SMALLHOLDER ECONOMIC ACTIVITY

Total Households 5353

Activity	Households No.	Households % Total	Activity	Households No	Households % Total
cocoa	172	3	spices	26	1
coffee	18	0	fish	245	8
rubber	0	0	grow others	8	0
oil palm	0	0	pigs	208	8
c'nut/copra	375	10	poultry	90	8
betelnut	481	14	goats	0	0
fruit	352	12	cattle	1	0
banana	410	16	sheep	0	0
veg crop	419	15	raise others	1	1

SOILS

SOIL 1 Tropofluvents
Mainly well drained undifferentiated soils with high (>=0.2%) or fluctuating org C to >=125cm

EXTENT	30-50% of RMU	ERODIBILITY	Moderate
DEPTH	Deep (>1m)	REACTION	Weakly acid to
DRAINAGE	Well-drained	AVAIL WATER CAPACITY	
STONINESS	Not stony/rocky (<1%)	0-25 cm	Low
SALINITY	None	0-50 cm	Moderate
CATION EXCH	High (>25 meq%)	0-100 cm	High
BASE SAT'N	High (>60%)	MIN RESERVE	High
% NITROGEN	Moderate (0.2-0.5%)	TEXTURE TOP	Medium
AVAIL P	High (>20ppm)	TEXTURE SUB	Medium
EXCHK	Moderate (0.2-0.6 meq%)	ANION FIX'N	No problem

SOIL 2 Fluvaquents
Poorly drained, undifferentiated soils with high (>=0.2%) or variable org C contents to >=125 cm

EXTENT	20-40% of RMU	ERODIBILITY	Moderate
DEPTH	Deep (>1m)	REACTION	Weakly acid to
DRAINAGE	Poorly to very poorly	AVAIL WATER CAPACITY	
STONINESS	Not stony/rocky (<1%)	0-25 cm	Low
SALINITY	None	0-50 cm	Moderate
CATION EXCH	High (>25 meq%)	0-100 cm	High
BASE SAT'N	High (>60%)	MIN RESERVE	High
% NITROGEN	Moderate (0.2-0.5%)	TEXTURE TOP	Very fine
AVAIL P	High (>20ppm)	TEXTURE SUB	Very fine
EXCHK	High (>0.6 meq%)	ANION FIX'N	No problem

SOIL 3 Rendolls
Shallow, dark, weakly acid to neutral soils formed on calcareous parent materials

EXTENT	20-40% of RMU	ERODIBILITY	Low
DEPTH	Very shallow (<25cm)	REACTION	Weakly acid to
DRAINAGE	Well-drained	AVAIL WATER CAPACITY	
STONINESS	Moderately stony/rocky	0-25 cm	Very low
SALINITY	None	0-50 cm	Very low
CATION EXCH	High (>25 meq%)	0-100 cm	Very low
BASE SAT'N	High (>60%)	MIN RESERVE	High
% NITROGEN	High (>0.5%)	TEXTURE TOP	Medium
AVAIL P	High (>20ppm)	TEXTURE SUB	Medium
EXCHK	Moderate (0.2-0.6 meq%)	ANION FIX'N	No problem

SUSTAINABILITY

	SOIL 1 (30-50%)	SOIL 2 (20-40%)	SOIL 3 (20-40%)
CHEMICAL FERTILITY	High	Very High	Very High
INHERENT FERTILITY	Very High	Very High	Moderate
SOIL ERODIBILITY	Moderate	Moderate	Low

SOIL FORMATION	Moderate (1.2mm - 1.6mm / year)
RAINFALL EROSIVITY	High (30,001 - 40,000 Joules sq. m.)
INUNDATION / SLOPE	Little inundation
TECTONICITY	Areas subject to common earthquakes of low magnitude
MASS MOVEMENT	Nil

RURAL POPULATION AND VILLAGES (1990)

	Total Population
1980	27218
1990	34103

District	Division / Village	Population
Dist 2 Madang	Divsn 9 North Ambenob	
	Village 7 BUDAD	168
	Village 22 MALAMAL	323
	Village 25 MIS	517
	Village 29 RIWO	516
	Village 31 SEK	810
	Village 32 SIAR	904
	Village 33 SILIBOB	275
	Village 501 ALEXISHAFEN CTH	80
	Village 502 AMRON LUTH MISS	169
	Village 503 BAITABAG LUTH	200
	Village 508 MILILAT PLTN	311
	Village 509 NAGADA	394
	Village 510 ST FIDELIS COLL	377
	Village 511 SIAR PLTN	152
	Village 512 VUDAR PLTN	43
Dist 2 Madang	Divsn 13 Sek - Rempi	
	Village 4 BAGILDIK	240
	Village 7 BOMASA	472
	Village 8 DEDA	257
	Village 9 KAWE	222
	Village 11 SEMPI	236
	Village 501 MURUNASS PLTN	127
	Village 502 WEWAK TIMBERS	203
Dist 2 Madang	Divsn 14 Saker - Garus	
	Village 12 KUDAS	114
	Village 15 MATUKAR	228
	Village 501 MATUKAR PLTN	128

A basic assumption of the land system surveys was that the landscape is organized in an hierarchical structure, such that small relatively uniform land components (land units) are arranged in larger spatially contiguous but recurrent patterns to form complexes (land systems) (Christian and Stewart 1968; Mabbutt 1968). Information is provided at two levels of spatial resolution: descriptive information at *land unit* level, and mapped information at *land system* level. A land unit is defined as a group of similar sites that can be described in terms of major inherent characteristics of consequence to land use. A land system is defined as an assembly of land units which are geographically and/or geomorphologically related, and throughout which there is a recurring pattern of landform, soils, and vegetation (Christian and Stewart 1968).

Landform, and particularly geomorphology, was the basic factor used in defining and delineating both the land system and its subsidiary components (land units). The methodology depends on the assumption that visible differences in landform and geomorphology (as recognized on aerial photographs) will reflect, in general, differences in the associated resources (such as soils, vegetation and climate).The regional resource survey program collected and presented information in an 'integrated' form. It did not provide resource information for presentation on an individual disciplinary basis.

After the conclusion of the regional resource survey program a series of publications were prepared which drew together existing information either as compendia (Analytical Soils Data for PNG, Bleeker and Healy 1980; Climatic Tables for PNG, McAlpine *et al.* 1975), or as maps at a scale of 1:1,000,000, indicating the type and distribution of a resource (Geomorphology Map of PNG, Loffler 1974; Vegetation Map of PNG, Paijmans 1975). The latter two maps were based on extrapolation of the previous regional survey data using air photography, with small gaps filled in with SLAR. Finally, four definitive reference books were produced covering the vegetation (Paijmans 1976), geomorphology (Loffler 1977), soils (Bleeker 1983) and climate (McAlpine *et al.* 1983) of PNG.

Other Data

The information described above was combined with information from four other sources:

* Reconnaissance, semi-detailed and detailed soil and land resource surveys carried out by the Department of Primary Industry over a period of forty years. These surveys covered complete provinces (Simbu, New Ireland and Manus), large regional areas (Talasea-Bialla Area of West New Britain, Markham Valley of Morobe Province, Abau District of Central Province and many others) plus hundreds of localized project areas.

* PNG 1:250 000 Geological Series maps covering the whole of the country and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development Australia and the Geological Survey of Papua New Guinea, Department of Minerals and Energy, Papua New Guinea.

* 1:100 000 Topographic Survey maps covering the whole of the country and available from the National Mapping Bureau, Department of Lands and Survey, Papua New Guinea.

* National censuses of population and agricultural activity in 1980 and 1990

PNGRIS SOILS DATA

Provision of information about soil attributes, for the country as a whole, based on limited soil data acquired through reconnaissance surveys, presented a major problem of spatial extrapolation. It was necessary to derive soils data on the basis of observed correlations between soil characteristics and landforms and vegetation as seen on aerial photographs. Certain levels of generalization in soil classification and in attribute description are, therefore, essential to allow spatial extrapolation with a reasonable degree of confidence in its reliability.

It is important to understand that soil types were determined within the boundary of each RMU (see Figure 2), either from existing data on the RMU or by extrapolation, and that the only additional soil boundaries that can be defined using PNGRIS will be derived from amalgamation of adjoining RMUs. The soil classification adopted for the inventory is the USDA scheme of Soil Taxonomy (U.S. Dept of Agriculture 1975). This system is internationally accepted and has been used in PNG since the DPI

Table 2. **Great soil groups within the order Entisols, their distribution and correlation to previously named soil groups.**

Order	Sub-Order	Great Group	Distribution	Major previously named soil group
Entisols	Aquents	Cryaquents	Very local	Skeletal soils, Peat soils.
		Sulfaquents	Common	Saline Peats and Muds, Mangrove soils
		Hydraquents	Very common	Young Alluvial soils. Very poorly drained Alluvial soils
		Fluvaquents	Very common	Alluvial soils, Young Alluvial soils, Recent Alluvial soils
		Tropaquents	Very common	As for Fluvaquents
		Psammaquents	Common	Recent Alluvial soils
	Psamments	Tropopsamments	Common	Coarse textured Beach soils
		Ustipsamments	Very local	Coarse textured Beach soils
	Fluvents	Tropofluvents	Common	Young Alluvial soils, Recent Alluvial soils, Coarse textured Beach soils
		Ustifluvents	Local	As for Tropofluvents
	Orthents	Troporthents	Very common	Lithosols, Skeletal soils, Slope soils
		Cryorthents	Very local	As for Troporthents
		Ustorthents	Very local	Colluvial soils

study undertaken in the Markham Valley (Holloway *et al.* 1973). Also Bleeker (1983) used Soil Taxonomy to classify PNG soils for his book on the subject.

Data Sources

The principal sources of information for the classification of soil class in each Resource Mapping Unit were:

* Analytical Data on PNG soils (Bleeker and Healy 1980)
* Soils of PNG (Bleeker 1983)
* CSIRO Land Research Series publications (1964-76)
* DPI and DAL Publications and unpublished soil survey

At the outset the Great Soil Groups tentatively identified in PNG were correlated with previously named soils groups (as identified in the CSIRO Land Research Series (1964-1976) and DPI) and an estimate made of the distribution of each. These are listed in the PNGRIS Handbook (Bellamy and McAlpine 1995) and an example for one Soil Order shown in Table 2.

In view of the broad scale of mapping (1:500,000), the limited amount of available soil information and the need to keep the resource attribute descriptions to a manageable size, a maximum of three different soils were listed for each RMU. As a general rule 'minor' soils assessed to cover less than 20% of the RMU are not listed. When only one soil is described in the RMU it covers by definition more than 80% of the total area. RMUs with two soils were considered to cover an approximate area of 40 to 60% for the first, and 20 to 40% for the second great soil group. If three soils are listed in RMU description, the areal distribution will be 30-50% for the first and 20-40% for the second and third great soil groups.

Soil Attributes

Soil attributes used as criteria to distinguish 'great soil group' classes (Soil Taxonomy, USDA 1975) are often inadequate by themselves for meaningful land evaluation for agricultural uses. Consequently, for each great soil group described in an RMU, an additional data set of 15 soil attributes is provided. These soil attributes are listed in Table 2 and are grouped into physical and chemical properties. This additional soil information is required for matching crop requirements to land characteristics for land evaluation. It also provides soil information at a level more readily understood by users not familiar with the terminology used Soil Taxonomy.

These soil attributes were derived primarily from the compendium of Analytical Data of PNG Soils (Bleeker and Healy 1980) and soil analytical data contained in the files of the Land Utilization Section of the Department of Agriculture and Livestock, Port Moresby. Where available, soil attribute descriptors for each RMU are derived directly from the sources referred to above. For those RMUs without field observation or analytical data, the soil attribute descriptors were derived, using the database, through extrapolation of soil data from other RMUs with similar environment characteristics (such as climate, rock type, landform, vegetation) and modified by field experience. To facilitate spatial extrapolation, as well as data storage, the values for each attributes were classified, and class codes are used in the database as attribute descriptors. It was recognized that this extrapolation may be subject or errors, therefore the system was established to enable corrections to the database to be made whenever site specific information becomes available.

USING THE SOILS INFORMATION IN PNGRIS

In the introduction to the 2nd Edition of the PNGRIS Handbook, Bellamy and McAlpine remind users that the system was designed as an integrated database and caution against desegregating the data for specific attribute analysis. Nevertheless, soil workers with in-depth experience of Papua New Guinea environments have demonstrated that the soils files in PNGRIS provide a most valuable and convenient source of data to evaluate land use potential and soil management strategies at provincial and national level. The following four applications of PNGRIS demonstrate how the system may be used for a variety of applications.

Extent of acid soils

Humphreys and Freyne (1987) used the RMU mapping aspect of PNGRIS to estimate the extent of acid soils in Papua New Guinea. At the time of compiling the soil database for PNGRIS, there was a widespread interest in acid soils in tropical regions, which prompted the building-in of the capacity to identify their occurrence and distribution. Soils with pH < 5.5 were assumed to have aluminium toxicity problems. For their assessment Humphreys and Freyne defined "potential acid soils" as those with:

(i) pH (1:1 water) < 5.5
(ii) effective CEC < 5 cmol/kg (≈CEC <cmol/kg)
(iii) belong to the orders Oxisols or Ultisols or Inceptisols (but excluding Andepts)
(iv) are the dominant or co-dominant soil of an RMU

Based on this definition it was possible to use PNGRIS to map the distribution of potential acid soils in PNG. According to PNGRIS these soils occur in eleven (11) out of the nineteen (19) provinces, cover some 52,049 km^2 or 11.3% of the country and in 1980 supported 2.5% of the population. They are confined to coastal provinces and are found at altitudes <1,000 m a.s.l. with rainfall between 1,500 and 3,000 mm per annum.

Using PNGRIS it was possible to assess the intensity of the utilization of acid soils for both subsistence agriculture and cash crop production. It is notable that in 1980, while less than 15% of acid soils were being used and at a very low level of intensity, they are being used to produce coconuts, coffee and spices. Humphreys and Freyne demonstrated that PNGRIS provides a reliable source of data for mapping the occurrence and intensity of use of broadly defined soil types at a national level.

Land evaluation for arabica coffee

Harding, Bleeker and Freyne (1987) used PNGRIS mapping functions and soils data to compile a series of maps and accompanying report on the potential for arabica coffee production in Western Highlands Province. The following brief description of the mapping procedure followed by Harding and Freyne (1987).

At the outset, altitude Land Mapping Units (LMUs) were defined by modifying the contours provided on the 1:250,000 topographic maps. These were then subdivided with slope-steepness categories derived from the relevant 1:100,000 and 1:250,000 scale topographic maps and further divided by the appropriate rainfall isohets. The resultant LMUs were overlain with PNGRIS soil data to provide information on drainage/effective soil depth, erosion hazard and chemical fertility to generate a 1:250,000 scale map showing Suitability Mapping Units (SMUs). The reader is referred to the detailed description of the systematic procedures followed provided in the report.

Provincial Atlases

A series of three Provincial Resource Atlases were produced by a CSIRO team to undertake the upgrading of PNGRIS, and addition of a mapping capacity, from its original KMAN format to FOXPRO and MAPINFO. These atlases, one each for Madang, Morobe and Eastern Highlands Provinces, provide data on population distribution in 1990 in respect to generalized maps of the natural resources, including soil distribution. The maps are presented at 1:1,000,000 scale and are suitable for providing an indication of development potential only. Site specific investigations should be undertaken to confirm any potential indicated by the maps.

Mapped at 1:1,000,000 scale the soils information has been aggregated to the Order level thus making PNGRIS an ideal source of information. It would be possible to compile provincial soil maps at 1:500,000 scale using the PNGRIS soils files as the source information describing the soil classes at great group level.

These atlases provide and ideal source of information for educational purposes and should be available for all schools within each province. In addition, while the level of detail provided is not sufficiently detailed for planning, they serve to make planners and developers aware of the types of information and spatial relationships which should be considered in the decision making process.

Soil map of PNG

Bleeker (1988) used PNGRIS as the primary source of data in compiling the Soil Map of Papua New Guinea. As a first step data provided for each of the 4562 RMUs in PNGRIS "were grouped into approximately 600 classes, each having a similar suite of soils. The second stage involved the amalgamation of these 600 classes in more generalized assemblages of soils called soil associations." This resulted in a total of seventy-two soil associations. These associations were then combined into twenty-two more generalized major groupings, which have similar characteristics and are colour coded on the map.

In addition to providing the basic source of data for the soil map Bleeker used PNGRIS files to relate the soil associations to several other land attributes important for land evaluation, namely slope, texture and phase of the dominant soil. Four (4) slope categories, five (5) texture classes and five (5) soil phases were used in compiling the final map, all interpreted from the PNGRIS database. Finally, having mapped the soil associations using PNGRIS it was then possible to utilize the database to calculate the area within each class on a provincial basis or for the country as a whole.

CONCLUSION

PNGRIS soils data provides an ideal source of information for a wide variety of applications. It requires careful interpretation, is well suited to national and provincial level planning but should not be used at project level.

REFERENCES

BELLAMY, J.A. and **McALPINE, J.R.** (1995). *Papua New Guinea Inventory of Natural Resources, Population Distribution and Land Use Handbook*, 2nd Ed. PNGRIS Publication No. 6 (AusAID: Canberra)

BLEEKER, P. and **HEALY, P.A.** (1980). *Analytical data of Papua New Guinea Soils.* CSIRO , Division of Land Use Research, Technical Paper No. 40, Vols. 1 & 2.

BLEEKER, P., (1983). *Soils of Papua New Guinea.* CSIRO and ANU Press, Canberra.

BLEEKER, P., (1988). *Explanatory notes to the soil map of Papua New Guinea.* CSIRO, Division of Water Resources, Natural Resources Series No. 10.

CHRISTIAN, C.S., and **STEWART, G.A.** (1968). *Methodology of integrated surveys.* In 'Aerial Surveys and Integrated Studies. Proceedings of Toulouse Conference 1964', pp 233-80. (UNESCO : Paris).

HARDING, P.E., BLEEKER, P. and **FREYNE, D.F.** (1987). *Land Suitability Evaluation for Rainfed Arabica Coffee Production: Western Highlands Province, Papua New Guinea.* Coffee Research Report No. 4. C.R.I., Kainantu.

HOLLOWAY, R.C., ZIJSVELT, M.F.W., KNIGHT, M.J., BRIGATTI, J.M., LEGGER, D., STRONG, B.W., ALAND, F.P., BLACKBURN, K.J. and **HOLTZKNECHT, H.A.** (1973). *Land Resources and Agricultural Potential of the Markham Valley.* Res. Bull. No. 14, Dept. of Agric., Stock and Fish., Port Moresby.

HUMPHREYS, G.S. and **FREYNE, D.F.** (1987). *Acid soils in Papua New Guinea.* 3rd International Management Workshop entitled "Management and Utilisation of Acid Soils of Oceania", Palau, 2-6 February 1987.

KEIG, G. and **QUIGLEY, J.B.** (1995). *PNGRIS User's Guide.* Prepared by CSIRO for AusAID

LÖFFLER, E. (1974) *Explanatory notes to the Geomorphology Map of Papua New Guinea.* CSIRO Aust., Div. Land Use Res., LRS No. 33

LÖFFLER, E. (1977) *Geomorphology of Papua New Guinea.* CSIRO and ANU Press, Canberra.

MABBUTT, J.A. (1968), *Review of concepts of land evaluation In 'Land Evaluation'.* ed. G.A. Stewart, pp 11-29. Macmillan, Australia.

McALPINE, J.R. GAEL KEIG and **KAREN SHORT**, (1975) *Climatic Tables for Papua New Guinea.* Tech Paper NO. 37. Div. of Land Use Research, CSIRO, Australia.

McALPINE, J.R., KEIG, G. with **FALLS, R.** (1983). *Climate of Papua New Guinea.* CSIRO and ANU Press, Canberra.

PAIJMANS, K. (1975) *Explanatory notes to the vegetation map of Papua New Guinea.* CSIRO Aust. Land Res. Series No. 36

PAIJMANS, K. ed., (1976). *New Guinea Vegetation.* CSIRO and ANU press, Canberra.

SAVAGE, T.J., QUIGLEY, J.B. TRANGMAR, B.B. and **McALPINE, J.R.**, (1995). *Resource Atlas of Eastern Highlands Province, Papua New Guinea.* Prepared by Landcare Research New Zealand Ltd and CSIRO for AusAID, Canberra

SAVAGE, T.J., QUIGLEY, J.B., TRANGMAR, B.B. and **McALPINE, J.R.** (1995). *Resource Atlas of Madang Province, Papua New Guinea.* Prepared by Landcare Research New Zealand Ltd and CSIRO for AusAID, Canberra

SAVAGE, T.J., QUIGLEY, J.B., TRANGMAR, B.B. and **McALPINE, J.R.** (1995). *Resource Atlas of Morobe Province, Papua New Guinea.* Prepared by Landcare Research New Zealand Ltd and CSIRO for AusAID, Canberra.

UNITED STATES DEPARTMENT OF AGRICULTURE (1975). *Soil Taxonomy: a Basic System of Soil Classification for making and interpreting soil surveys.* US Govt. Printer, Washington, D.C.