Mapping Land Resource Potential and Agricultural Pressure in Papua New Guinea

An Outline of New Methods to Assist Rural Planning

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Contents

Summary

This report outlines the development of new methods to assess land resource potential and agricultural pressure in Papua New Guinea (PNG). Land resource potential was derived through the classification of environmental data relevant to the growth and management of crops under village conditions. Parameters such as annual rainfall, rainfall seasonality, temperature, light, flooding, slope gradient and soil type were classified according to crop growth constraints. The environmental requirements for sweet potato, being the most important staple crop throughout PNG, were used to guide the classification. Predictions were cross-checked with known sweet potato yields in different locations. The most productive areas are those with the best combination of optimum conditions, or the fewest constraints. The least productive areas are those with many constraints such as high rainfall, steep slopes, poor soils, cold temperatures and frequent flooding.

Village agriculture in PNG involves management techniques that modify micro-environments, reduce or overcome environmental constraints, and improve productivity. These range from low input techniques such as long bush fallows and burning, to high input techniques such as planted fallows, legume rotations, composting, mounding, drainage, soil retention barriers and tillage. Where such practices are present and significant, land resource potential was adjusted to account for improved management practices.

Agricultural pressure was derived from queries of land resource potential and land-use intensity data, to highlight mismatches between the two. The areas identified range from those having strong pressure, defined as high land-use intensity in low potential environments, to no pressure, defined as low land-use intensity in high potential environments. Areas of strong pressure have severe resource degradation problems, declining crop yields and are vulnerable to food shortages, particularly during periods of drought or frost.

Information on land resource potential and agricultural pressure is being used to guide and prioritise the research activities of the PNG National Agricultural Research Institute along with the rural development activities of international development donors and all levels of government within the country. While the work is specific to PNG, the methods presented are generic and applicable to most situations depending on data availability.

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Abbreviations

ALES	Automated Land Evaluation System
CI	crop impact
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEC	Department of Environment and Conservation (of Papua New Guinea)
FAO	Food and Agriculture Organisation of the United Nations
GIS	geographic information system
LOM	Law of the Minimum (Liebig's)
MASP	Mapping Agricultural Systems Project
MRP	modified resource potential
PNG	Papua New Guinea
PNGAPA	Papua New Guinea Agricultural Pressure Assessment
PNGLES	Papua New Guinea Land Evaluation System
PNGRIS	Papua New Guinea Resource Information System
PNGRPA	Papua New Guinea Resource Potential Assessment
RDOL	relative degree of limitation
RMU	resource mapping unit
RP	resource potential
USDA	United States Department of Agriculture

List of Tables

List of Maps

Introduction

Land is a dynamic and complex continuum of resources such as bedrock, soil, vegetation, fauna and water, and processes such as precipitation, radiation, evaporation, wind, weathering, erosion, nutrient cycling and photosynthesis. Human utilisation of land requires some understanding of these resources and processes, particularly their spatial and temporal distribution and variability. Given inherent complexities, this requirement is difficult to realise when land is considered in its entirety. For this reason, complex and often chaotic systems are simplified into manageable categories and relationships through the process of land classification. This process transforms the natural continuum of the landscape into specified categories or classes with sharp boundaries.

Land classification systems are deterministic and driven by human values, goals and objectives. They are developed to provide information for particular purposes and needs at various scales and vary from simple, single-parameter classifications to complex, multiple-parameter classifications. Resource potential (RP) classifications involve the evaluation of primary environmental parameters to determine variations in the productivity of land with respect to the growth and management of plants. Such classifications can be general or crop-specific and are a necessary step in the practical application of complex environmental datasets. Agricultural pressure classifications involve the integration of environmental and land-use information to determine areas where land resources are degrading at present or may degrade in the future.

The concept of RP is well developed. Ecological literature relates the concept to terms such as net primary productivity, biological productivity, biophysical potential and biomass potential (Odum 1971; Gates 1980; Huggett 1995). Agricultural literature refers to terms such as land resource assessment, land evaluation, land capability and land suitability (FAO 1976; Charman and Murphy 1992; Davidson 1992; Roberts 1995).

The concept of agricultural pressure is less developed and is defined, in this study, as a measure of the risk of resource degradation resulting from intensive agriculture on land resources. Resource degradation is defined as change to land resources and/or ecological processes resulting in lower crop productivity. Examples of degradation include soil loss, soil structure decline, soil fertility decline, altered plant succession, altered water balances and altered micro-climates.

This report outlines the development of improved methods to assess land RP and agricultural pressure in Papua New Guinea (PNG) through the classification of complex spatial data. The work was funded by the Australian Centre for International Agricultural Research (ACIAR) and the Australian Agency for International Development (AusAID) at the request of the PNG National Agricultural Research Institute (NARI). Outcomes are being used to guide and prioritise the research activities of NARI along with the broader rural development activities of international development donors and planners at all levels of government within PNG. While the work is specific to PNG, the methods presented are generic and applicable to most situations depending on data availability.

Why Papua New Guinea?

The PNG population doubled between 1970–2000 and is presently growing at a mean annual rate of 2.3% (Keig 1999). More than three-quarters of the total population, or almost four million people, are smallholder semi-subsistence farmers who are sustained by their own food production systems, supported by some cash cropping (Allen et al. 1995).

While population growth is significant, there has been little expansion of agricultural land (McAlpine 2001), which implies a significant intensification of agriculture within existing boundaries. Thus, more food than ever before is being produced from the same area of land. Allen et al. (1995) suggest that most agricultural systems in PNG are intensifying through the combination of shortened bush fallows and longer cropping periods supported by the adoption of more efficient crops such as sweet potato, Chinese taro and triploid bananas. Various soil fertility maintenance techniques such as composting, legume rotation and improved fallows have been applied in some areas to help maintain production. However, little is known about how effective these techniques are in the long term. If current trends continue, the sustainability of some agricultural systems will be threatened.

PNG has detailed spatial data that can be used to methodically assess RP and agricultural pressure for the entire country. Over 30 years of land resource and land-use research, predominantly by the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian National University, has resulted in two detailed spatial databases. The Papua New Guinea Resource Information System (PNGRIS), completed in 1986, provides 1:500,000 scale data on environmental attributes such as altitude, terrain, bedrock, slope gradient, relief, rainfall, temperature, soils, vegetation and inundation through 'resource mapping units' (RMUs) (Bellamy 1986). The Mapping Agricultural Systems Project (MASP) database, completed in 1998, provides 1:500,000 scale data on subsistence agriculture such as staple crops, fallow length, fallow vegetation, cropping period, land-use intensity, soil management practices, cash earning activities and rural population (Allen et al. 1995). While both databases use unrelated mapping units, they can be combined through either simple cartographic overlay or more sophisticated geographic information system (GIS) methods.

An understanding of the spatial variability of RP and the identification of areas vulnerable to resource degradation will assist with the research, planning and development of more sustainable agricultural systems in PNG.

Report outline

The next section of this report discusses the evolution of RP assessment techniques and their application in PNG. Issues include mapping scales, data reliability, classification techniques and limitations. Next, an improved method for PNG is presented and supported by discussion of data availability, selection of input parameters, numerical classification and land management adjustments. Worked examples are provided to demonstrate the classification process. Results and limitations of RP and modified resource potential (MRP) for the five highland provinces are discussed. Following that, the assessment and mapping of land-use intensity in PNG is outlined, and results and limitations for the highlands region are discussed. The last major section presents the agricultural pressure assessment technique that combines MRP and land-use intensity data. Results and limitations for the highlands region are discussed.

Assessment of Land Resource Potential

Modern RP assessment techniques evolved midway through the twentieth century in response to devastating land degradation throughout Australia, Africa, India and the United States (Burrough 1978). The United States Department of Agriculture (USDA) land capability technique (Klingebiel and Montgomery 1961) pioneered land evaluation endeavours and is still the principal method used worldwide, either directly or in modified forms.

The USDA method assesses the potential productivity of primary land uses based on ecological parameters such as soil depth, soil structure, soil texture, landform, altitude, rainfall, temperature and growing season. The technique utilises the parametric approach to land classification, which gathers specific ecological parameters independently and then combines them to form land capability classes. Each of the eight capability classes within the classification are determined by limitations to land use such as erosion hazard, flood risk, slope gradient, stoniness, low fertility, rooting zone restriction and climate. Thus, as limitations increase, land-use options decrease.

Limitations to techniques based on the USDA method are well understood and documented by authors such as Moss (1978, 1985), Rowe (1980), McKenzie (1991), Davidson (1992), Bouma et al. (1993), Gessler and McKenzie (1995), Hollingsworth et al. (1995) and Thwaites (1995). Common criticisms include: biased assumptions about suitable land utilisation strategies, such as permanent annual cropping on high potential land and forestry on low potential land only; the inadequate identification of permanent and temporary land-use constraints; and the qualitative and often unverifiable nature of data processing methods.

These limitations have, to some extent, been addressed by the United Nations Food and Agriculture Organization land evaluation technique (FAO 1976, 1984a,b), which utilises ecological parameters directly relevant to crop growth through verifiable and repeatable data-processing methods. This technique is focused on providing levels of suitability for predefined land-use types based on complex land qualities such as water availability, nutrient availability, oxygen availability, rooting conditions and erosion hazard (FAO 1976). The conceptual framework of this technique has been widely adopted and in some cases improved.

The Site Productivity and Land Suitability Classification developed by Laffan (1993) utilises Food and Agriculture Organisation of the United Nations (FAO) land qualities to determine suitability for crop growth supported by additional land qualities, such as trafficability, workability, flood hazard, erosion hazard and landslide hazard, to determine suitability for practical land management. The Automated Land Evaluation System (ALES) developed by Rossiter and Van Wambeke (1991) has further improved the FAO technique through automation of the evaluation process, use of decision trees for classification, and ability to query outcomes. In addition, ALES can determine economic suitability through techniques such as gross margin analysis, predicted net present value, cost/benefit ratios and internal rates of return.

Hackett (1988, 1991) has also addressed limitations of the USDA technique through the PLANTGRO software, which predicts the growth performance of annual and perennial plants based on a rigorous and pragmatic selection of soil and climate parameters. Such parameters are processed in relation to plant response information using Liebig's Law of the Minimum (LOM), which states that plant yields are driven by the most limiting ecological parameter even if all other parameters are optimal (Hackett 1991). The LOM approach is relatively rigorous compared to numerical classifications based on weighted additions or multiplications. The limitation, however, is that the LOM classification used in PLANTGRO produces smoothed and simplified results that underestimate the range and spatial variation of crop potential.

Applications in Papua New Guinea

The USDA land capability, FAO land evaluation and PLANTGRO techniques have had some application in PNG. The notable constraint is lack of consistency, with each technique being applied for different purposes at different scales and with different input data.

The USDA technique was used by the CSIRO to evaluate the 1:250,000 scale Land Systems data completed between 1953–1972 for roughly one-third of the country. While the derived RP data are the most detailed available for such a large area, the evaluation was based on industrial agricultural values that were biased towards high-input land-use systems, such as arable crops, improved pastures, tree crops and flooded rice, not low-input subsistence gardening and cash cropping (CSIRO 1965, 1968, 1970, 1972).

The USDA technique was also used to generate the 1975 CSIRO 1:1,000,000 scale Land Limitation and Agricultural Land Use Potential map for the entire country (Bleeker 1975). This evaluation was structured on land-use limitations such as low soil fertility, rockiness, drought risk, poor soil drainage, seasonal flooding and erosion hazard, which were derived from the CSIRO 1:1,000,000 scale geomorphology, vegetation, soils and climate datasets. Like the previous example, the output data were constrained by a bias towards capital-intensive land uses, not village agriculture.

The FAO land evaluation technique was applied in the national 1:500,000 scale Papua New Guinea Land Evaluation System (PNGLES) through the ALES software, which determined suitability for the smallholder production of 18 crops at both low and high levels of management (Venema and Daink 1992). Input data describing land qualities such as temperature, erosion hazard, moisture conditions, nutrient availability, rooting conditions, oxygen availability and toxicities were derived from PNGRIS. It is important to note that PNGRIS data are derived from the compilation and extrapolation of various natural resource datasets previously completed at different scales for different purposes. Consequently, the accuracy and reliability of PNGRIS data vary with location and attribute, particularly locally variable data such as soils and slope. This variability is the principal limitation to PNGLES outcomes as approximately 50% of the input data are derived from the PNGRIS soils dataset (Trangmar et al. 1995).

PLANTGRO was tested as part of the PNGLES project through a trial evaluation of five crops in the Upper Ramu Valley. Trangmar et al. (1995) note that an advantage of PLANTGRO outcomes is the identification of seasonal climate limitations for each crop, while constraints include the inability to consider land management factors, significant reliance upon PNGRIS soils data, limited mapping facilities and the production of conservative outcomes through LOM data processing.

The PNG Resource Potential Assessment technique

The PNG Resource Potential Assessment (PNGRPA) technique draws upon the proven features of previous work completed by the FAO (1976, 1984a,b), Bellamy (1986), Hackett (1988, 1991) and Laffan (1993). The technique uses reliable data, which are relevant to the growth and management of crops under smallholder conditions, through a verifiable LOM-based numerical classification method that is modified to overcome previous smoothing limitations. Where poorer quality data have been used, potential errors have been highlighted and tracked. Major and minor environmental constraints are identified for each mapping unit. Operation within an automated computing environment enables flexibility to modify expert-driven data ranges depending on specific evaluation purposes.

Data availability and purpose

The PNGRPA technique draws on data from the PNG Department of Environment and Conservation (DEC), the Australian Geological Survey Organisation, PNGRIS and MASP.

PNGRIS parameters mapped accurately at 1:500,000 scale are those that are relatively homogeneous over large areas. Such parameters are easy to recognise and map. Examples include the landform and topography datasets. The reliability of other parameters declines as either the scale of the environmental process declines, or the level of interpretation and extrapolation increases. For example, the slope gradient, inundation and soil type datasets are somewhat unreliable as they are highly variable at the local scale and are thus generalised or smoothed when mapped at the PNGRIS scale. The reliability of the annual rainfall and rainfall seasonality datasets is variable as they are based on extrapolation from point sources. The rainfall datasets have additional constraints as each province was mapped individually then joined together, resulting in significant mismatches along provincial boundaries. Where alternative data sources are not available, PNGRIS data are generalised to reduce the potential for error propagation through the classification process. The parameters used in the PNGRPA technique are as follows.

- *Annual Rainfall* affects crop growth through soil moisture availability. The dataset is derived from the DEC climate surfaces completed through the World Bank-funded BioRap Project. The annual rainfall surface is based on the interpolation of meteorological station records using the ANUDEM and ANUSPLIN software packages (Margules and Redhead 1995). The dataset was summarised into a PNGRIS RMU format and rounded to the nearest millimetre. It was then added to the PNGRIS database as a revised annual rainfall field. The dataset is considerably more reliable than the PNGRIS equivalent.
- *Rainfall Seasonality* affects crop growth through seasonal soil moisture fluctuations. The dataset is derived from the DEC climate surfaces in the same way as the annual rainfall dataset. There are no units of measurement for this field as it represents relative variation on a monthly basis. The dataset is considerably more reliable than the PNGRIS equivalent.

- *Temperature* affects crop growth by influencing photosynthesis rates and soil fertility cycles through the breakdown of humus. All plants have temperature thresholds, within which growth rates vary and outside of which plants will not survive. The dataset was derived from PNGRIS and covers the range of maximum and minimum temperatures in degrees Celsius but does not cover seasonal variations, as they are slight in PNG and considerably less than the daily range (Bellamy 1986). The dataset is very reliable as it is based on well known relationships between temperature and altitude, the latter being derived from the 1:100,000 PNG Topographic Series.
- *Light* affects crop growth through various triggers on physiological mechanisms such as changes in life cycle. Because few PNG meteorological stations have recorded light intensity, cloud cover has been adopted as a relatively accurate surrogate. Cloud information was derived from the Australian Geological Survey Organisation Drought Assessment Project (Bierwirth and McVicar 1998) that compiled and analysed advanced very high radiometric resolution (AVHRR) satellite data for PNG over a two-year period. A byproduct of this project was a simple and reliable index of 'cloudiness' based on seasonal (January, April, July and October) images. The dataset was summarised into a PNGRIS RMU format, rounded to a five-level classification and added to the PNGRIS database as a 'cloud cover' field. There are no units of measurement for this field as it represents relative variation on a seasonal basis.
- *Inundation* affects crop growth and management through either short-term destructive flood regimes or long-term waterlogging. The dataset was derived from PNGRIS and is based on interpretations of landform, vegetation and annual rainfall. The data have variable reliability due to the smoothing of local-scale flood-free areas that can not be delineated at the PNGRIS 1:500,000 scale.
- *Slope gradient* affects crop growth and management through influences on soil erosion, drainage, nutrient leaching, solar radiation receipt and labour requirements. The dataset was derived from PNGRIS and is based on distances between contours on the 1:100,000 PNG Topographic Series. The data have variable reliability due to the smoothing of local-scale deviations, but PNGRIS has, to some extent, accounted for this through the classification of up to two slope gradient classes within each RMU.
- *Soil type* affects crop growth and management through influences on nutrient availability, nutrient retention, rooting conditions, soil stability and water availability. The dataset was derived from PNGRIS and is based on the soil taxonomy classification of PNG soils completed by Bleeker (1983) and the CSIRO

Land Research Series (1964–76). The data have variable reliability due to the smoothing of local scale deviations, but PNGRIS has partially accounted for this through the classification of up to three soil-type classes within each RMU.

It is important to note that reliability problems associated with PNGRIS soils data are controlled to some extent in the PNGRPA technique through the use of a generalised soil productivity index, presented in Table 1, which was developed through interpretation of the physical and chemical properties of each PNGRIS soil type. The index is more compatible with the classification of large scale data and reduces the chance of error propagation.

Table 1. A generalised soil productivity index for Papua New Guinea (modified from Bleeker 1983).

Soil productivity	RDOL[a] value	US soil taxonomy class
High	1	Tropofluvents, Hydrandepts, Eutrandepts, Dystrandepts, Vitrandepts, Durandepts, Hapludolls
Moderate	2	Ustifluvents, Tropopsamments, Ustipsamments, Humitropepts, Eutropepts, Dystropepts, Pelluderts, Pellusterts, Calciustolls, Natrustolls, Argiustolls, Rhodustalfs, Haplustalfs, Rhodudalfs
Low	3	Troporthents, Cryorthents, Ustorthents, Tropaquepts, Plinthaquepts, Cryandepts, Ustropepts, Argiaquolls, Haplaquolls, Rendolls, Albaqualfs, Plinthaqualfs, Tropaqualfs, Natrustalfs, Natrudalfs, Tropudalfs, Rhodudalts, Tropudalts
Very low	4	Cryaquents, Sulfaquents, Hydraquents, Fluvaquents, Tropaquents, Psammaquents, Cryofolists, Tropofolists, Sulfihemists, Cryohemists, Tropohemists, Cryofibrists, Tropofibrists, Troposaprists, Halaquepts, Cryaquepts, Andaquepts, Cryochrepts, Cryumbrepts, Paleaquults, Plinthaquults, Albaquults, Tropaquults, Palehumults, Plinthohumults, Tropohumults, Paleudults, Plinthudults, Haplohumox, Acrohumox, Haplorthox, Eutrothox

[a] RDOL = relative degrees of limitation

Numerical classification

Resource potential for each RMU is determined through a relatively simple parametric technique that first classifies the seven input parameters based on relative degrees of limitation (RDOL) to crop growth and management and then sums the classified values. The RDOL classification is expert-driven and can focus on specific crops or broader crop groupings. In this case, the environmental requirements for sweet potato (*Ipomoea batatas*), being the dominant staple crop for most PNG agricultural systems, are used to guide the classification of each parameter. The ranges presented in Table 2 are based on PNG field trials and observations summarised by Bourke (1985), the tabular crop descriptions of Hackett (1984), and the Ecocrop database (FAO 1996).

Table 2. **Relative degree of limitation (RDOL) classification ranges for the Papua New Guinea (PNG) Resource Potential Assessment technique guided by the environmental requirements for sweet potato production.**

Input parameter	Source[a]	Data range	Description	RDOL value
Temperature[b] (°C)	PNGRIS	1–3	min. 12–23 and max. 23–32	1
		4–6	min. 9–12 and max. 19–23	3
		7–8	min. < 9 and max. < 19	4
Annual rainfall[c] (mm)	DEC		2301–2800	1
			1801–2300 or 2801–3500	2
			3501–5000	3
			1000–1800 or > 5000	4

[a] Sources: PNGRIS = PNG Resource Information System; DEC = Department of Environment and Conservation (of PNG); AGSO = Australian Geological Survey Organisation.

[b] This temperature classification correlates to altitude ranges of 1–1800 m (RDOL 1), 1800–2400 (RDOL 3) and >2400 m (RDOL 4). There is no RDOL 2 class given the broad temperature range where sweet potato performs well due to the adaptation of lowland and highland varieties.

[c] There are no entries in the 'data' column as the DEC rainfall data are in millimetres and are thus the same as the 'description' column.

[d] Rainfall seasonality has only one RDOL value of 2 representing a 3–8 month seasonal rainfall deficit. This variation was designed due to the correlation between low annual rainfall and rainfall seasonality, where a complete 1–4 RDOL classification would bias resource potential values towards rainfall limitations. Given that there are some areas where seasonality is strong and rainfall relatively high, such as the south coast of New Britain and inland Madang, a compromise RDOL value of 2 is assigned for the classification.

[e] Light has only one RDOL value of 2 representing four cloudy seasons on the AGSO index. This variation was designed due to the coarse nature of the AGSO cloud index and a reluctance to use the data beyond their inherent reliability.

[f] < 2 degrees is downgraded to a RDOL value of 2 given the prevalence of poor drainage, waterlogging and/or inundation on flat ground.

[g] Classification of soil productivity from US Soil Taxonomy classes is presented in Table 1.

Table 2. (cont'd) Relative degree of limitation (RDOL) classification ranges for the Papua New Guinea (PNG) Resource Potential Assessment technique guided by the environmental requirements for sweet potato production.

Input parameter	Source[a]	Data range	Description	RDOL value
Rainfall seasonality[d] (DEC seasonality index)	DEC	1–41	0–2 month seasonal deficit	0
		42–90	3–8 month seasonal deficit	2
Light[e] (AGSO cloud index)	AGSO	0–3	0–3 seasons cloudy	0
		4	4 seasons cloudy	2
Inundation (PNGRIS class)	PNGRIS	0	no inundation	1
		1–2	waterlogging or brief inundation	2
		3–4	seasonal inundation	3
		5–8	near permanent inundation	4
Slope gradient[f] (degrees)	PNGRIS	2–3	2–10	1
		1, 4	<2 or 10–20	2
		5	20–30	3
		6	>30	4
Soil productivity[g]	PNGRIS	1	high	1
		2	moderate	2
		3	low	3
		4	very low	4

[a] Sources: PNGRIS = PNG Resource Information System; DEC = Department of Environment and Conservation (of PNG); AGSO = Australian Geological Survey Organisation.

[b] This temperature classification correlates to altitude ranges of 1–1800 m (RDOL 1), 1800–2400 (RDOL 3) and >2400 m (RDOL 4). There is no RDOL 2 class given the broad temperature range where sweet potato performs well due to the adaptation of lowland and highland varieties.

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[e] Light has only one RDOL value of 2 representing four cloudy seasons on the AGSO index. This variation was designed due to the coarse nature of the AGSO cloud index and a reluctance to use the data beyond their inherent reliability.

[f] < 2 degrees is downgraded to a RDOL value of 2 given the prevalence of poor drainage, waterlogging and/or inundation on flat ground.

[g] Classification of soil productivity from US Soil Taxonomy classes is presented in Table 1.

Given the heterogeneous nature of PNGRIS mapping units, additional steps are required to prepare slope gradient and soils data for the final classification as the former has up to two and the latter up to three classes within each RMU. Processing of these parameters is based on one class representing 100% of the RMU, two classes representing 40 and 60% of the RMU and three classes representing 30, 30 and 40% of the RMU. Final RDOL values are derived through a weighted addition for each RMU.

Unlike previous LOM-based numerical classification methods that determine RP from the single most limiting parameter only, the PNGRPA technique sums the most limiting value for each input parameter. This modification significantly extends the range of RP values and thus better differentiates subtle variations within the data. Major and minor constraints to crop growth and management are documented alongside final RP values. A worked example of this process is presented in Table 3.

The final step is the consolidation of five RP classes, presented in Table 4, based on the spatial distribution of RP values and the frequency of major and minor constraints. Once developed, the PNGRPA technique was automated within the ArcView GIS. ArcView is an inexpensive, menu-driven, user-friendly and personal computer-based program that allows widespread dissemination of results and alternative applications of the technique.

Table 3. Worked example of the Papua New Guinea (PNG) Resource Potential Assessment numerical classification process.

Parameter	Data	Working value	RDOL value
Temperature (°C)	min. 19–23 max. 30–32	1	1
Annual rainfall (mm)	3650	3	3
Rainfall seasonality (DEC index)	45	2	2
Light (AGSO cloud index)	3	0	0
Inundation (PNGRIS class)	none	1	1
Slope gradient (degrees)	> 30 (60%) 20–30 (40%)	$4 \times 0.6 = 2.4$ $3 \times 0.4 = 1.2$	(3.6) 4[a]
Soil productivity	Cyrofolist (40%) Hydrandept (30%) Cyrorthent (30%)	$4 \times 0.4 = 1.6$ $1 \times 0.3 = 0.3$ $3 \times 0.3 = 0.9$	(2.8) 3[b]
	Resource potential value		14[c]
	Major constraints		Slope gradient (S)[d]
	Minor constraints		Annual rainfall (a)[e] Soil productivity (r)

Note:

RDOL = relative degree of limitation; DEC = Department of Environment and Conservation (of PNG); AGSO = Australian Geological Survey Organisation; PNGRIS = PNG Resource Information System.

[a] RDOL value for slope gradient is derived from the weighted addition of the two input values ($4 \times 0.6 + 3 \times 0.4 = 3.6$) and rounding up to 4.

[b] RDOL value for soil productivity is derived from the weighted addition of the three input values ($4 \times 0.4 + 1 \times 0.3 + 3 \times 0.9 = 2.8$) and rounding up to 3.

[c] Resource potential value of 14 is derived from the addition of all seven RDOL values ($1 + 3 + 2 + 0 + 1 + 4 + 3 = 14$).

[d] Slope gradient is considered a major constraint as it has the maximum limitation value of 4. Such constraints are represented by the following UPPER case letters: slope gradient (S); temperature (T); annual rainfall (A); inundation (I); and soil productivity (R). Rainfall seasonality and light can not be major or minor constraints within this classification as the maximum and only possible RDOL value is 2.

[e] Annual rainfall and soil productivity are considered minor constraints as they have the second highest limitation value of 3. Such constraints are represented by the following lower case letters: slope gradient (s); temperature (t); annual rainfall (a); inundation (i); and soil productivity (r).

Table 4. Resource potential classes and general description. Note that in some cases the combination of constraints in each class can vary.

Resource potential class	Resource potential range	Description
Very high	5–7	No constraints; RMUs dominated by RDOL values of 1
High	8	No constraints; RMUs dominated by RDOL values of 2
Moderate	9–10	One minor constraint; RMUs dominated by RDOL values of 2
Low	11–13	One major constraint and/or up to three minor constraints
Very low	14–19	Two major constraint and/or up to four minor constraints

Note:
RMU = resource mapping unit;
RDOL = relative degree of limitation

Modified resource potential (MRP)

Resource potential values reflect plant growth potential in unmodified environments — in short, the growth potential when plants are grown without management. In practice, PNG village agriculture involves numerous management techniques that modify micro-environments and improve productivity. These range from low-input techniques, such as natural bush fallows and burning, to high-input techniques, such as improved fallows, legume rotations, composting, mounding, drainage, soil retention barriers and tillage. One benefit of using the simple parametric classification process within the PNGRPA technique is the ability to modify RP values according to management practices. Given that RP values are based on the summation of limiting factors, MRP values can be derived by adjusting input values where limitations have been reduced or overcome.

Information on land management practices is derived from the MASP database. Presence and significance data are available for the following management practices.

- *Legume rotation* is a measure of whether leguminous crops such as peanuts or winged beans are grown between plantings of staple food crops. Such practices reduce soil productivity limitations by increasing available nitrogen and breaking staple crop pest and disease cycles.

- *Planted tree fallows* are a measure of whether tree species such as Casuarina oligodon are planted in final-year gardens to reduce soil productivity limitations by increasing available nutrients, notably nitrogen, during the fallow period.
- *Compost* is a measure of whether organic matter is placed in gardens to reduce soil productivity limitations by increasing soil fertility.
- *Contribution of silt from flooding* is a measure of whether silt from floods is deposited either regularly or sporadically in gardens, reducing soil productivity limitations by increasing soil fertility.
- *Animal manure* is a measure of whether animal manure is placed in gardens to reduce soil productivity limitations by increasing soil fertility.
- *Inorganic fertiliser* is a measure of whether inorganic fertiliser is placed in gardens to reduce soil productivity limitations by increasing soil fertility.
- *Soil retention barriers* are a measure of whether planted barriers such as tanget (*Cordyline fruticosa*) or structures such as pegged logs, fences or stone walls are used to reduce the down-slope movement of topsoil.
- *Soil tillage* is a measure of whether soil is tilled before crops are planted to reduce soil productivity limitations by improving soil structure, drainage and aeration.
- *Drains* are a measure of whether ditches are used around and within gardens to reduce soil productivity and annual rainfall limitations by removing excess surface and/or groundwater.
- *Mounds* (small, medium and large) are a measure of whether soil is formed into circular mounds of varying dimensions within gardens to reduce soil productivity and annual rainfall limitations by improving soil structure, drainage and aeration and removing excess surface water.
- *Garden beds* (square and long) are a measure of whether soil is raised into elevated beds within gardens to reduce soil productivity and annual rainfall limitations by improving soil structure, drainage and aeration and removing excess surface water.

Given that MASP and PNGRIS have different mapping units, the first step in the MRP classification is to overlay and join the mapping units. This ensures that RPs are modified only where land management adjustments are made. The result of this joining process is 40,000 unique polygons covering all provinces in PNG.

The land management adjustments take two steps. Where the above land management practices are present and significant (codes two and three) in the

MASP database, adjustments are made to RP values for each RMU. For example, where fallow vegetation, legume rotation, animal manure, silt from flooding, artificial fertiliser and/or soil retention barriers are present and significant, one RDOL value per management practice is subtracted from the final RP value, reflecting improvements to soil fertility. Where small mounds, large mounds, square beds and long beds are present and significant, one RDOL value is subtracted from the final RP value, reflecting improvements to soil drainage and in some cases soil structure. Where composting is present and significant, two RDOL values are subtracted from the final RP value, reflecting significant improvements to soil fertility and soil structure. Note that where drains or tillage are present and significant, one RDOL value is subtracted from the final RP value only when mounds or beds are not present, as such management practices tend to overcome the same environmental constraints.

The second step involves more complicated rules to correct possible anomalies between management practices and environmental conditions. For example, Wood (1984) demonstrated that composting and mounding on slopes greater than 10 degrees in the Tari Basin of Southern Highlands Province often led to erosion during intense rainfall events. Thus while the practices on one hand improve soil fertility and soil structure, they also have negative effects that must be accounted for. Where such practices occur on slopes over 10 degrees, one RDOL value per practice is added back to the final RP value, negating the allocated improvement from the first step. Where mounds, large mounds, drains or beds are present and inundation is severe (defined as greater than 'long term inundation' in PNGRIS), two RDOL values are subtracted from the final RP value, reflecting significant improvements to soil drainage. Such adjustments account for situations where swamps and/or floodplains have been drained, resulting in the cropping of fertile organic soils. A worked example of the MRP classification process is presented in Table 5.

Table 5. **Worked example of the modified resource potential classification. Note the extra adjustments made in Example 3 because of large mounds and composting on slopes greater than 10 degrees.**

EXAMPLE 1			
Parameter	**RDOL[a] value**	**Land management**	**Adjusted RDOL value**
Temperature	1		1
Annual rainfall	3	Drains (–1)	2
Rainfall seasonality	2		2
Light	0		0
Inundation	1		1
Slope gradient	4	Soil retention barriers (–1)	3
Soil productivity	3		3
Resource potential	14	Modified resource potential	12
Constraints[b]	S a r		s r
EXAMPLE 2			
Parameter	**RDOL value**	**Land management**	**Adjusted RDOL value**
Temperature	3		3
Annual rainfall	2	Large mounds (–1)	1
Rainfall seasonality	0		0
Light	2		2
Inundation	1		1
Slope gradient	1		1
Soil productivity	3	Compost (–2)	1
Resource potential	12	Modified resource potential	9
Constraints	t r		t
EXAMPLE 3			
Parameter	**RDOL value**	**Land management**	**Adjusted RDOL value**
Temperature	4		4
Annual rainfall	2	Large mounds (–1) (+1)	2

[a] RDOL = relative degree of limitation
[b] For explanation of constraints, see Table 3

Table 5. (cont'd) Worked example of the modified resource potential classification. Note the extra adjustments made in Example 3 because of large mounds and composting on slopes greater than 10 degrees.

EXAMPLE 3 (cont'd)			
Parameter	**RDOL value**	**Land management**	**Adjusted RDOL value**
Rainfall seasonality	0		0
Light	2		2
Inundation	1		1
Slope gradient	3	Slope > 10 degrees	3
Soil productivity	3	Compost (–2) (+1)	2
Resource potential	15	Modified resource potential	14
Constraints	T s r		T s

[a] RDOL = relative degree of limitation
[b] For explanation of constraints, see Table 3

Ideally, the constraints that the management practices reduce or overcome should be directly related to the structure of the RP classification. That is, if a site is constrained by permanent inundation (RDOL value of four) according to PNGRIS but is completely drained according to MASP, then the RDOL value should be adjusted from four to one. This does in fact happen in the MRP classification. The situation becomes more problematic in the case of composting, legume rotation or improved fallows because it is difficult to quantify the impact of such practices in terms of improvements to crop productivity and then relate that directly to the MRP classification structure based on relative degrees of limitation. As a result of this difficulty, the conceptual approach is cautious and more likely to underestimate than overestimate MRP values.

Results for the highlands region

Results from the classification of unmodified RP for six example RMUs in the highlands region are presented in Table 6.

Table 6. Resource potential (RP) results for selected highlands sites.

Site details	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Province[a]	WHP	SHP	WHP	SHP	CHIM	ENG
Location	Mt Hagen	Tari	Banz	Nipa	Gembogl	Kandep
PNGRIS RMU[b]	90050	70079	90059	70166	100002	80009
Temperature	1	1	1	3	3	4
Annual rainfall	1	2	1	1	2	1
Rainfall seasonality	0	0	0	0	0	0
Light	0	2	0	2	2	2
Inundation	1	1	2	1	1	1
Slope gradient	2	1	2	3	4	3
Soil productivity	2	1	3	3	2	3
RP value	7	8	9	13	14	14
Resource potential	Very high	High	Moderate	Low	Very low	Very low
Constraints[c]	–	–	r	t r s	S t	T r s

[a] WHP = Western Highlands Province; SHP = Southern Highlands Province; CHIM = Chimbu Province; ENG = Enga Province

[b] Papua New Guinea Resource Information System Resource Mapping Unit

The first example RMU is located north of Mt Hagen, Western Highlands Province, in undulating volcanic fans and has very high unmodified RP with no constraints. Temperature, annual rainfall, rainfall seasonality, light and inundation conditions are optimum for subsistence sweet potato production while slope gradient and soil productivity have RDOL values of two.

The second example RMU is located east of Tari, Southern Highlands Province, on undulating volcanic plains and has high unmodified RP with no constraints. In this case, annual rainfall and light are slightly limiting to crop production while the remaining parameters are optimum with RDOL values of one and zero.

The third example RMU is located north of Banz, Western Highlands Province, on relatively flat depositional fans and has moderate RP limited by a minor constraint of soil productivity. The remaining parameters have RDOL values ranging from zero to two.

The fourth example RMU is located south of Nipa, Southern Highlands Province, on rugged limestone hills and has low RP with a major constraint of temperature and minor constraints of soil productivity and slope gradient.

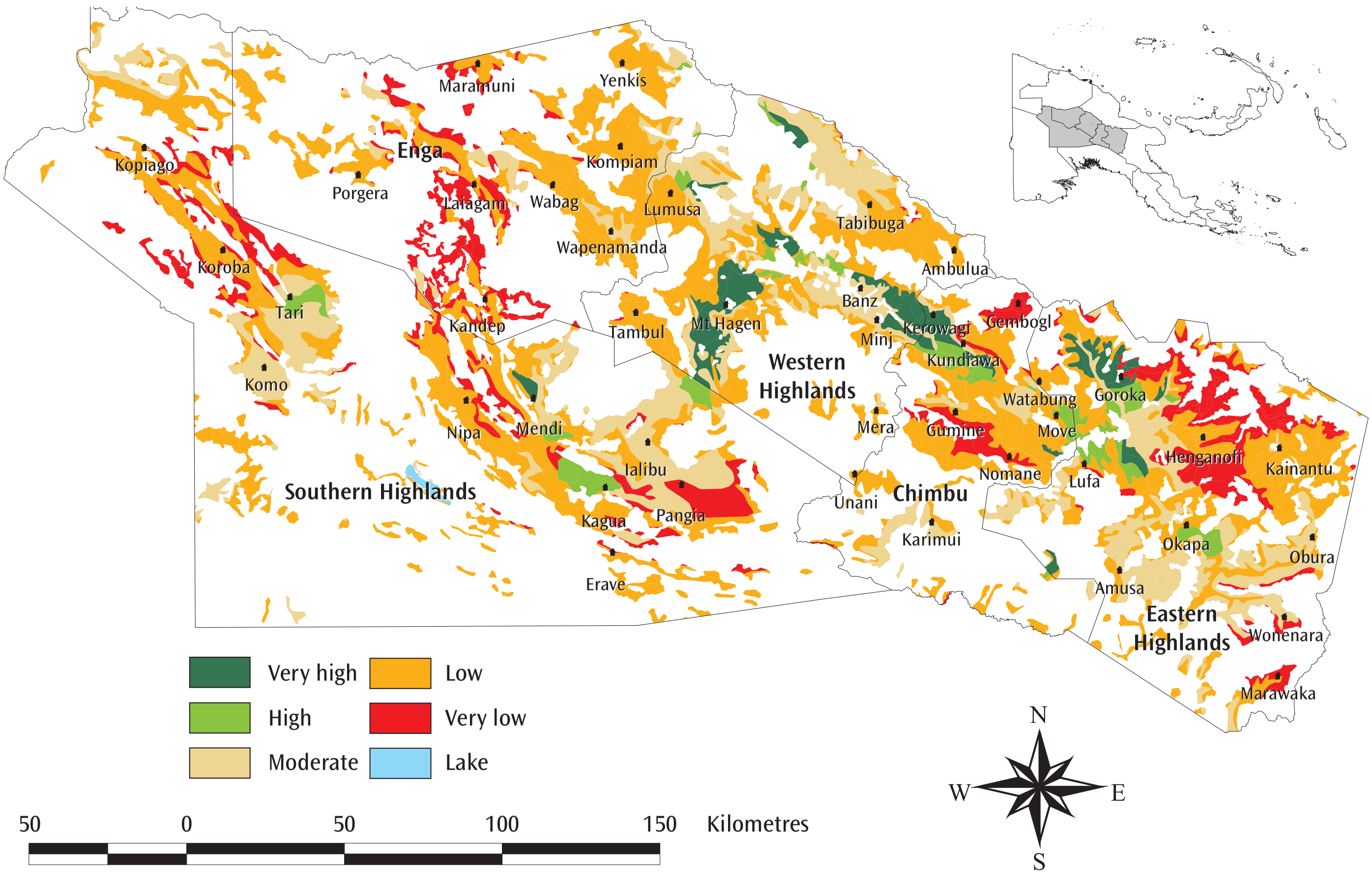
The fifth example RMU is located south of Gembogl, Chimbu Province, in mountainous terrain and has very low RP with a major constraint of slope gradient and minor constraint of temperature.

The final example RMU is located north of Kandep, Enga Province, in mountainous terrain and has very low RP with a major constraint of temperature and minor constraints of soil productivity and slope gradient.

Note that while some of these example RMUs have similar RP values, the conditions within each RMU are different. It is thus important to consider both RP values and constraints when reviewing and applying results of the PNGRPA technique.

Map 1 presents the distribution of unmodified RP throughout the highlands region. Areas of very high potential account for 2% of land in use for subsistence agriculture and 10% of the rural population. Areas of high potential account for 2% of land in use and 5% of the rural population. Areas of moderate and low potential dominate the region with 16% and 53% of land in use and 22% and 51% of the rural population, respectively. Areas of very low potential account for 27% of land in use and 12% of the rural population.

Table 7 presents the area, estimated 2000 population and respective mean population densities for each RP class. Estimated 2000 populations are based on the growth rates for each province determined by Keig (1999) from changes between the 1980 and 1990 PNG National Population Censuses. Mean population densities have a near linear relationship with RP, decreasing consistently from 140 persons/km^2 in the very high potential areas to 11 persons/km^2 in very low potential areas. This relationship is an important finding as it suggests that environmental quality is a major factor in influencing where people live. The relationship is also reassuring from a methodological point of view as it suggests the technique used to classify RP matches the reality on the ground with respect to crop productivity, land-use intensity and population density.



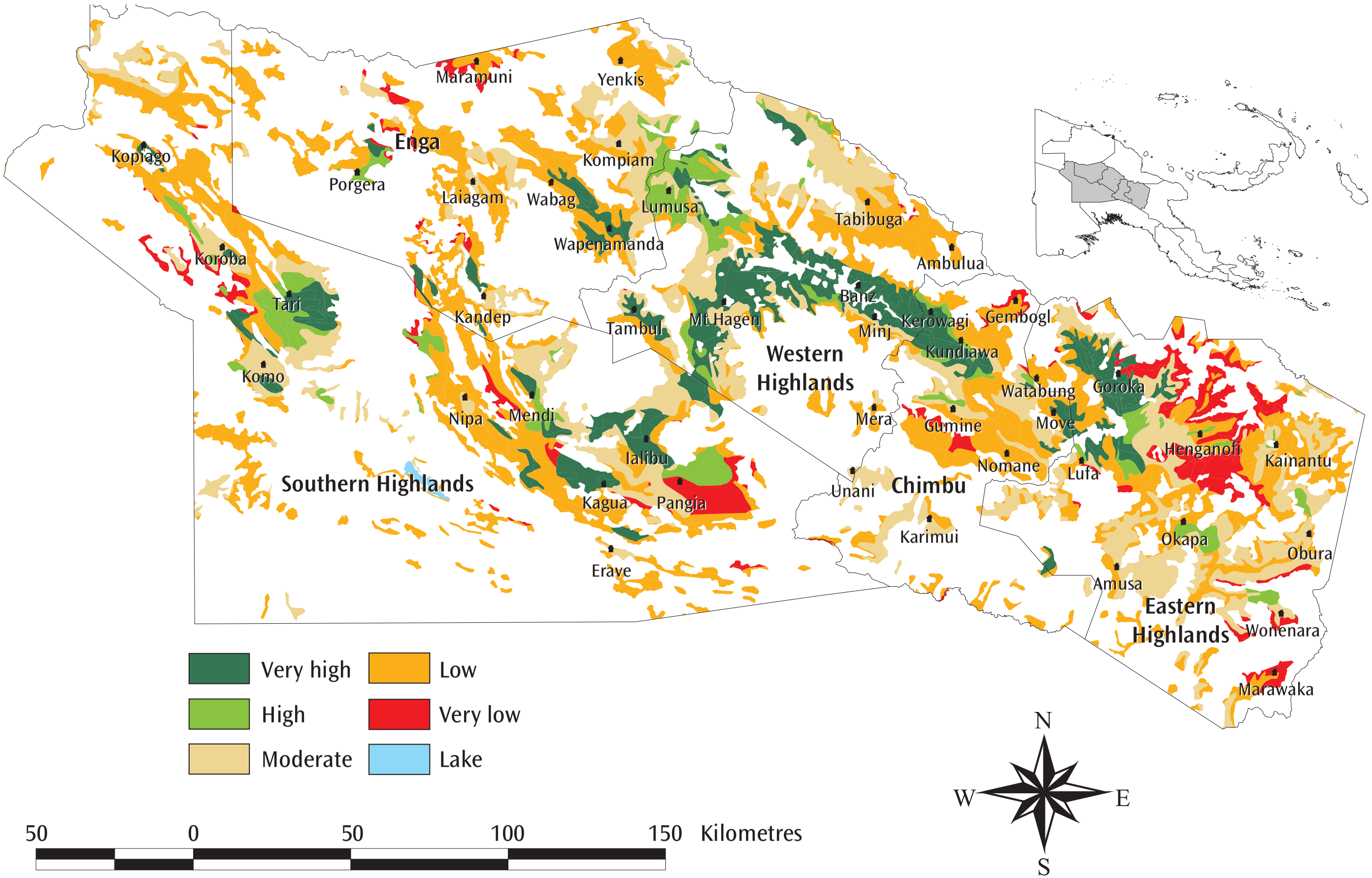
Map 1. Distribution of resource potential in the highlands region, for agricultural land only.

Table 7. Summary of resource potential classes in the highlands region.

Resource potential	Resource potential range	Total area (km^2)	Estimated 2000 population	Mean 2000 population density (persons/km^2)
Very high	5–7	1210	168 500	140
High	8	1530	94 500	62
Moderate	9–10	10 300	367 000	36
Low	11–13	34 000	876 000	26
Very low	14–20	17 000	195 000	11

Map 2 presents the distribution of MRP throughout the highlands region. Note that the spatial extent of very high and high potential land has doubled in conjunction with a decrease in very low potential land. The increase in very high potential areas is clearly related to flat land where innovative land management practices such as composting, legume rotation and drainage are most effective. While such practices are present on sloping land, their impact is minimised due to side effects such as increased soil erosion. Table 8 presents MRP results for the six example RMUs. Table 9 presents the area, estimated 2000 population and respective mean population densities for each MRP class in the highlands region.

Note that for the following outline, (–1) denotes the subtraction of one RDOL value from the RP value while (+1) denotes the addition of one RDOL value to the RP value. The Mt Hagen RMU has a net improvement of one resulting from the presence of legume rotation (–1) and square beds (–1, +1), however the effect of the latter is negated due to the dominant slope gradient being over 10 degrees. The Tari RMU has a net improvement of three resulting from the presence of composting (–2) and mounds (–1). The Banz RMU has a net improvement of four resulting from the presence of legume rotation (–1), square beds (–1) and drains (–2), the latter completely overcoming long-term inundation defined in PNGRIS. The Nipa RMU has a net improvement of one resulting from the presence of compost (–2, +1) and square beds (–1, +1) on slopes greater than 10 degrees. The Gembogl RMU has a net improvement of one resulting from the presence of soil retention barriers (–1) and mounds (–1, +1) on slopes significantly greater than 10 degrees. Finally, the Kandep RMU has a net improvement of one resulting from the presence of composting (–2, +1) and mounds (–1, +1) on slopes greater than 10 degrees.



Map 2. **Distribution of modified resource potential in the highlands region, for agricultural land only.**

Table 8. Modified resource potential (MRP) results for selected highlands sites. Note in sites 1, 4, 5 and 6 where 'slope' gradient is greater than 10 degrees, extra adjustments have been made where 'beds' and 'mounds' are present. Also note in site 3 where 'inundation' is greater than long term, extra adjustments have been made to 'drains'.

Site details	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Province[a]	WHP	SHP	WHP	SHP	CHIM	ENG
Location	Mt Hagen	Tari	Banz	Nipa	Gembogl	Kandep
PNGRIS RMU[b]	90050	70079	90059	70166	100002	80009
Resource P otential value	7	8	9	13	14	14
MASP[c] agricultural system	905	704	902	714	1002	807
Legume rotation	(–1)		(–1)			
Compost		(–2)		(–2) (+1)		(–2) (+1)
Soil retention barriers					(–1)	
Mounds		(–1)			(–1) (+1)	(–1) (+1)
Drains	Present	Present	Present (–2)	Present		Present
Beds	(–1) (+1)		(–1)	(–1) (+1)		
Slope >10 degrees	Yes			Yes	Yes	Yes
Inundation >long term			Yes			
MRP value	6	5	5	12	13	13
MRP	Very high	Very high	Very high	Low	Low	Low
Constraints	–	–	–	t s	S t	T s

[a] WHP = Western Highlands Province; SHP = Southern Highlands Province; CHIM = Chimbu Province; ENG = Enga Province
[b] Papua New Guinea Resource Information System Resource Mapping Unit
[c] Mapping Agricultural Systems Project

Table 9. Summary of modified resource potential (MRP) classes in the highlands region.

MRP	MRP range	Total area (km^2)	Estimated 2000 population	Mean 2000 population density (persons/km^2)
Very high	5–7	3450	480 000	138
High	8	2275	133 000	58
Moderate	9–10	10 800	368 000	34
Low	11–13	31 800	642 000	20
Very low	14–20	15 200	76 000	5

Results for the lowland and island provinces

The 14 lowland and island provinces of PNG are dominated by moderate to very low land RP. Common constraints include combinations of long-term inundation, high rainfall, long dry seasons, steep slopes, poor soils and frequent cloud cover. Much of this land is uninhabited. There is little change between RP and MRP as intensive land management practices are uncommon. Table 10 presents the area for each MRP class in the lowland and island provinces. Examples of very high and high potential land include: the southern slopes of the Torricelli Range in Sandaun Province and East Sepik Province; Karkar Island in Madang Province; Umboi Island in Morobe Province; the Popondetta plains in Oro Province; Fergusson Island in Milne Bay Province; Cape Gloucester in West New Britain Province; the Gazelle Peninsula and Duke of York Islands in East New Britain Province; and the north-eastern coast of Bougainville Island in Bougainville Province. Detailed results from the PNGRPA technique for these provinces are available from the Land Management Group, Australian National University. Hanson et al. (1998) provide maps of agro-ecological zones, RP and MRP (hypothetical, not real) for areas in lowland and island provinces below 600 metres in altitude. The focus crop in this study was cocoa (*Theobroma cacao*) but the results are applicable to most other smallholder cash and staple crops.

Table 10. **Summary of modified resource potential (MRP) class areas in the lowland and island provinces.**

Province	Very high	High	Moderate	Low	Very low
	(km^2)				
Western	0	30	7300	60 100	30 000
Gulf	530	360	6900	24 200	2400
Central	700	1450	6250	13 200	8300
Milne Bay	1000	2900	5780	4180	450
Oro	1650	1300	7600	9750	2450
Morobe	450	850	9400	18 300	4700
Madang	300	650	10 500	11 500	5750
East Sepik	950	3020	9500	27 800	1900
Sandaun	4150	6050	10 200	13 500	1900
Manus	50	25	990	950	65
East New Britain	1100	550	2400	9400	1800
West New Britain	520	800	7000	9400	2650
New Ireland	220	480	2130	6590	120
Bougainville	1110	1420	3700	2900	220

Limitations

The results from the PNGRPA technique must be interpreted with respect to limitations in the data and methods. The principal limitation to the application of these results is the scale at which the data are collected and presented. Any presentation of complex environmental data at regional scales will have generalised or smoothed micro- and meso-scale variation, and while such variation is not present in the data, it is present on the ground. For example, flood-free terraces with well-drained, fertile soils are often narrow land units too small to be mapped at regional scales. Instead, such terrace land units would be smoothed over and classified as poorly-drained flood plains. If RP was mapped in more detail, such terraces would be delineated as there would be more spatial variation in smaller mapping units. No comprehensive field validation was undertaken as part of this particular project, however the MASP and PNGRIS datasets are based on extensive field observations and were ground-truthed according to 1:500,000 scale standards. Example areas around Gembogl in Chimbu

Province and Bulolo and Salamaua in Morobe Province were used as field case studies to examine the above limitations for training purposes.

The second limitation to these results is related to the inherent problems of hard-edged classification on continuous datasets. When a classification range is enforced there are always similar data that fall on either side of the break and into different classes. This problem can then compound when classes are reclassified and manipulated. The only way to overcome this problem, outside of more sophisticated fuzzy classification techniques, is to view class boundaries as zones of uncertainty and refer to the base data for clarification where necessary.

Assessment of Land-use Intensity

Assessment of land-use intensity requires some measure of land resource use, depletion or change. Traditional methods have been simple and focused more towards agricultural outputs than management processes. More recent methods have focused on the level of management intervention into a predefined 'natural' condition where the most intensive land-use systems are those which most modify the 'natural' condition and vice versa.

An example is the method described by Baxter and Russell (1994) where land-use intensity increases along a landscape intervention gradient such as gathering/hunting, native forestry, rough grazing, plantation forestry, dryland grazing, dryland perennial cropping, dryland annual cropping, irrigated grazing, irrigated perennial cropping and irrigated annual cropping. The problem with this type of approach is that different management practices within each land-use type can significantly alter the extent to which land resources are depleted or changed.

Mapping land-use intensity adds another level of complexity, given the difficulties with mapping temporal processes such as management practices. Efforts to map land-use intensity rely on delineation of representative spatial units through the interpretation of air and/or satellite photographs supported by ground validation of management practices.

Mapping land-use intensity in PNG

The first attempt to map land-use intensity consistently for all of PNG was completed at 1:500,000 scale by Saunders (1993) based on 1973 aerial photographs. Areas of cultivated land, defined through the presence of anthropogenous vegetation such as current gardens or various stages of fallow, were first mapped and then classified on the basis of the total area of anthropogenous vegetation and the percentage of current gardens within the total area. Thus, land-use intensity in this context is based on change to non-anthropogenous vegetation and measured according to the spatial extent of present and previously cultivated land.

The Saunders classification has seven classes of cultivated land and seven classes of uncultivated land. The latter are of little interest to this study and include grassland, sago stands, sub-alpine grassland, alpine grassland, savanna woodland, urban areas, and other dryland and wetland areas. The cultivated land classification ranges from the most intensive class, defined as greater than 75%

anthropogenous vegetation with greater than 20% current use, through to the least intensive class, defined as less than 10% anthropogenous vegetation with less than 1% current use.

While the delineated areas of cultivated and uncultivated land have remained largely consistent since 1973 (McAlpine 2001), the levels of land-use intensity within the cultivated areas have changed significantly given high rural population growth over the last 25 years. This intensification of agriculture renders much of the classification detail out-of-date, although there are good reasons to assume that, where population growth has been consistent, areas would have moved up the classification scale on a consistent and relative basis.

The second attempt to map land-use intensity consistently for all of PNG was completed by Allen et al. (1995) through MASP. Land-use intensity was defined for each agricultural system through the Ruthenburg R-value, which is derived from the ratio of the cropping period in years (C) to the length of cultivation cycle in years (F), the latter being the sum of the cropping and fallow periods (Ruthenberg 1980). The formula is $R = C \times 100/(C + F)$. The R-value is a powerful temporal measure of land-use intensity and indicator of the intensification process when monitored over time.

The R-value measure of land-use intensity was chosen over the Saunders classification for this study because it is process-based, more recent and consistent with other MASP data used in the PNGRPA technique.

Results for the highlands region

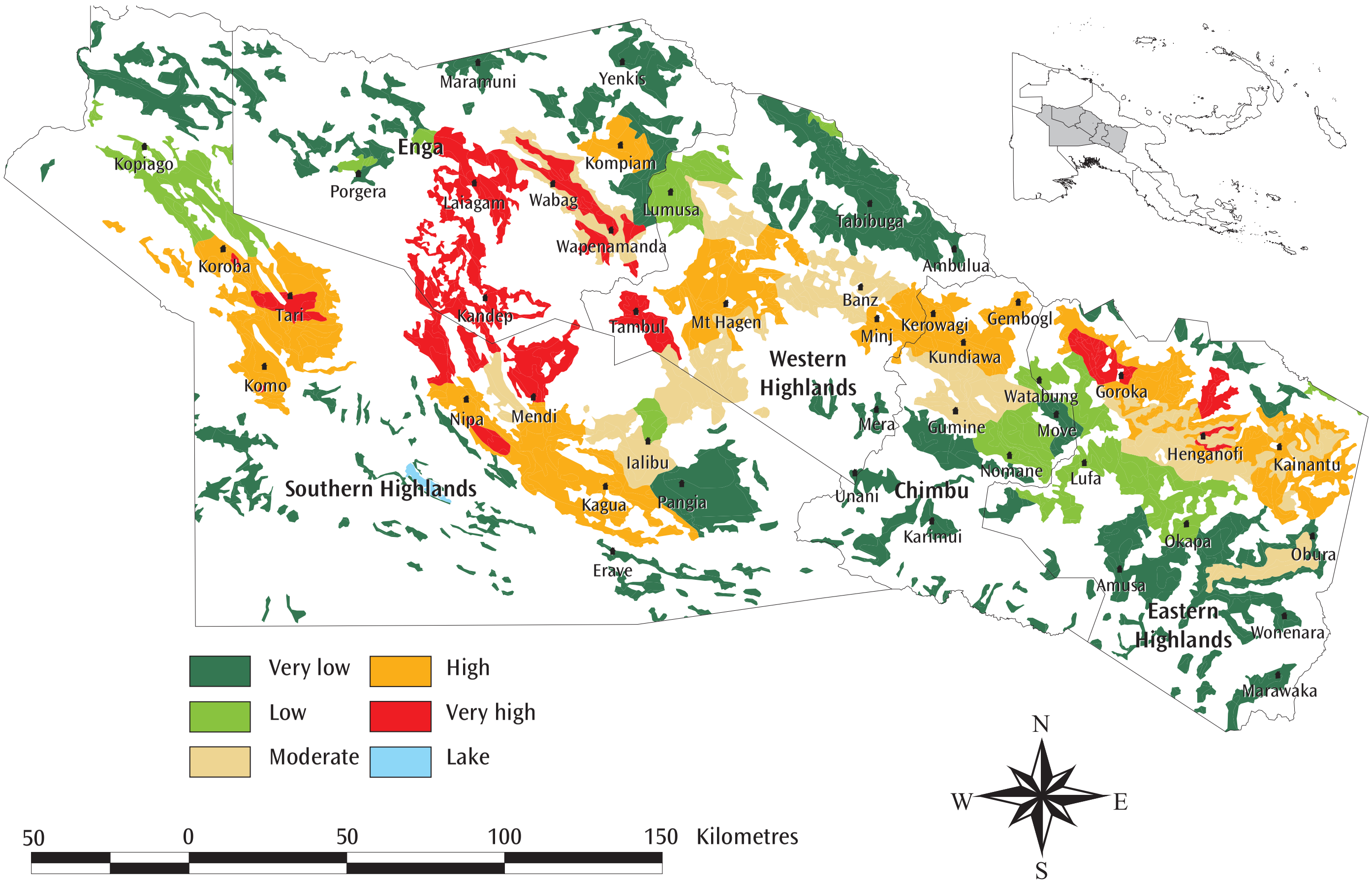
Map 3 presents R-values for the highlands region. There is a strong relationship between high land-use intensity and gentle sloping land. Examples include the Tari Basin in Southern Highlands Province, the Kandep Basin and Lai and Tsak valleys in Enga Province, the Kaugel and Waghi valleys in Western Highlands Province and the Asaro Valley in Eastern Highlands Province. There is also a strong relationship between low land-use intensity and remoteness, with the majority of low-intensity agricultural systems occurring in the remote highland-fringe areas. There are important exceptions to these relationships that are discussed later in this report.

Of the six example RMUs discussed previously, the Tari and Kandep RMUs have the highest land-use intensity with R-values of 100 derived from cropping periods of 40 years and no significant fallow period ($100 = 40 \times 100/(40 + 0)$). The Mt Hagen and Gembogl RMUs have R-values of 50 derived from cropping periods of 10 years and fallow periods of 10 years ($50 = 10 \times 100/(10 + 10)$). The Banz RMU has a R-value of 29 derived from a cropping period of 4 years and a fallow period of 10 years ($29 = 4 \times 100/(4 + 10)$). The Nipa RMU has a R-value of 17 derived from a cropping period of 4 years and a fallow period of 20 years ($17 = 4 \times 100/(4 + 20)$).

Caution is needed when interpreting R-value maps given the extrapolation of site-specific temporal data such as cropping periods, fallow lengths and ultimately R-values to the Saunders land-in-use boundaries that define the outer edge of MASP agricultural systems. Problems arise because extrapolation overestimates the spatial extent of R-values given the shifting nature of agricultural systems within the Saunders land-in-use boundaries. As R-values increase, however, the problem is less significant as the spatial extent of gardens within the land-in-use boundaries also increases.

Results for the lowland and island provinces

Most of the lowland and island provinces have low to very low land-use intensity. Exceptions include the Gazelle Peninsula in East New Britain Province and much of Bougainville Island where intensities are high to moderate, respectively. The most important exceptions to note are the peri-urban settlement areas around the cities of Port Moresby and Lae and the numerous small islands in Milne Bay, Bougainville, Manus, Morobe and West New Britain provinces. Many of these islands have permanent cropping (R-values of 100) and very high population densities that are often greater than 200 persons/km^2.



Map 3. Distribution of land-use intensity (R-values) in the highlands region, for agricultural land only.

Assessment of Agricultural Pressure

Previous efforts to map agricultural pressure, as defined in this study, have focused on single issues such as soil erosion, soil salinisation, rising watertables or soil acidification. These are commonly seen as outcomes of agricultural pressure. An example of such efforts is the use of process models like the Universal Soil Loss Equation (USLE) to predict potential erosion rates based on sets of predefined conditions such as rainfall erosivity, soil erodability, slope steepness, vegetation cover and land management practices. Results from such models are extrapolated to similar sites or mapping units based on the occurrence of similar conditions. Other methods have relied on image processing and GIS technology to map conditions such as salinisation, erosion or waterlogging through the classification of spectral signals identified on satellite photographs. The results of such efforts provide a simple, single parameter view of the condition of particular land resources.

The principal constraint to the mapping of agricultural pressure is the need for large amounts of land resource and land-use data, which is expensive to collect and maintain. Alternative approaches have avoided the issue of mapping and focused on detailed site studies supported by assessments of environmental indicators to determine land 'health' or 'quality'. Hamblin (1998) suggests that such indicators facilitate a site-level understanding of pressure on land resources, present condition of resources and management responses. Examples of indicators for soil erosion include the percentage of cultivated land with exposed soils (pressure), surface soil loss index (condition) and percentage of cropped land with reduced tillage and stubble retention (response). While such indicators can be used to monitor sites over time, the problems of spatial representation and extrapolation remain. The key concern of the environmental indicator approach to assessing agricultural pressure is ensuring the monitoring sites are representative of broader land resource and land-use patterns. This can only be achieved by guidance from detailed spatial datasets.

The PNG Agricultural Pressure Assessment technique

The PNG Agricultural Pressure Assessment (PNGAPA) technique queries combinations of land-use intensity and MRP data to highlight mismatches between the two. The areas identified range between those that are strongly overutilised, defined as high land-use intensity in low potential environments, to no over-utilisation, defined as low land-use intensity in high potential environments.

A crop impact (CI) index was developed from R-value and altitude data, reflecting the impact of cropping on soil resources at different altitudes. In PNG lowland environments, sweet potato crops reach maturity roughly 50% faster than the same crops in highland environments (Bourke 1985), resulting in a greater impact in lowland environments per crop over time. Higher rainfall and warmer temperatures in the lowlands also lead to faster breakdown of organic matter and more rapid rates of nutrient leaching. Thus the assumption behind the CI index is that where land-use intensity (R-values) is the same in lowland and highland environments, the impact on soil resources over time is greater in the lowlands. The CI index is presented in Table 11 and is based on the classification of R-values according to three altitude classes. One example interpretation of Table 11 is that R-values of 15–27 in the lowlands (0–600 m) have a similar impact on the environment over time as R-values of 28–49 in mid-altitude areas (600–1200 m) and R-values of 50–65 in the highland areas (1200–2500 m). Table 12 presents the queries used to define four levels of over-utilisation that form the agricultural pressure scale.

Table 11. Crop impact (CI) index based on the classification of R-values according to altitude. A value of one has the lowest crop impact, while a value of five has the highest crop impact.

R–value	Lowlands (1–600 m)	Mid-altitude (601–1200 m)	Highlands (1201–2800 m)
1–14	1 (very low)	1 (very low)	1 (very low)
15–27	2 (low)	1 (very low)	1 (very low)
28–49	3 (moderate)	2 (low)	2 (low)
50–65	4 (high)	3 (moderate)	2 (low)
66–100	5 (very high)	4 (high)	3 (moderate)

Areas of *very strong agricultural pressure* are those that have severe resource degradation problems resulting from very high land-use intensity (in some cases permanent agriculture) in low potential environments. These areas are limited to the small islands in Milne Bay, Manus, Morobe and Bougainville provinces where few innovative techniques are used to improve production. The islands are vulnerable to reduced crop yields and food shortages.

Areas of *strong agricultural pressure* are those that have severe resource degradation problems resulting from very high land-use intensity (in some cases permanent agriculture) in low potential environments. Land resource constraints are overcome to some extent by innovative techniques such as drainage, composting and mounding, but often these techniques are applied beyond their beneficial range and thus have the potential to compound existing problems. For example, composting and mounding on steep slopes resulting in accelerated soil loss. These areas are vulnerable to reduced crop yields and food shortages, particularly in high altitude areas during periods of drought and frost.

Table 12. Queries used to identify agricultural pressure in the Papua New Guinea Agricultural Pressure Assessment technique.

Mismatch type	Crop impact index	Modified resource potential	Agricultural pressure
very strong over-utilisation	high, very high (4,5)	very low (14–19)	very strong
very strong over-utilisation	high, very high (4,5)	low (11–13)	very strong
very strong over-utilisation	high, very high (4,5)	moderate (9–10)	very strong
very strong over-utilisation	moderate (3)	very low (14–19)	very strong
strong over-utilisation	moderate (3)	low (11–13)	strong
strong over-utilisation	low (2)	very low (14–19)	strong
moderate over-utilisation	moderate (3)	moderate (9–10)	moderate
moderate over-utilisation	low (2)	low (11–13)	moderate
marginal over-utilisation	low (2)	moderate (9–10)	marginal

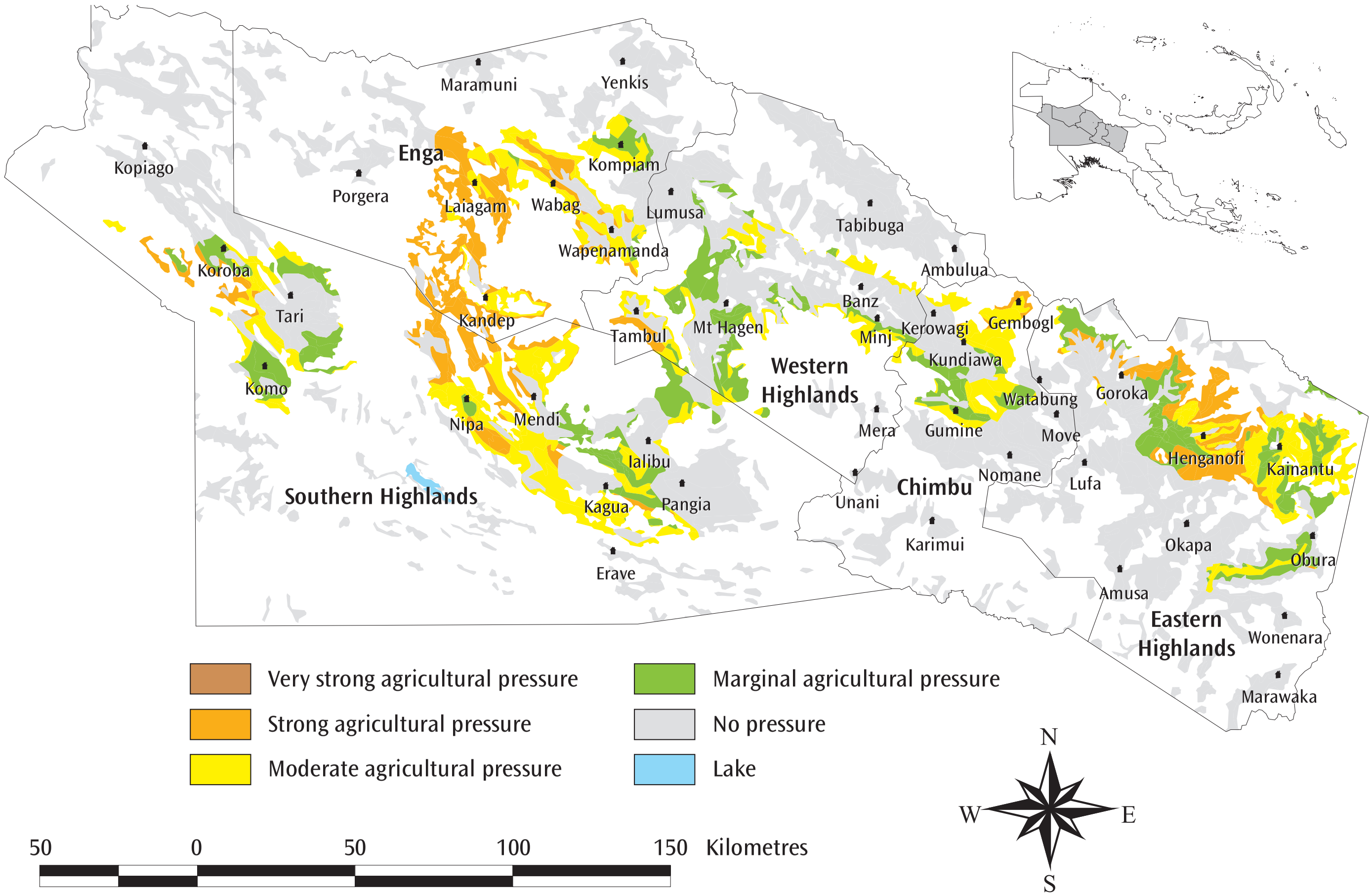
Areas of *moderate agricultural pressure* are those with minor resource degradation problems resulting from very high land-use intensity in moderate potential environments through to moderate land-use intensity in very low potential environments. The former may have some innovative management practices, while the constraints are so severe in the latter that innovative techniques may have little impact.

Areas of *marginal pressure* are those with few resource degradation problems at present but may encounter future problems if agriculture is intensified without suitable land improvement practices. Conditions for marginal pressure include high land-use intensity in moderate potential environments through to low land-use intensity in very low potential environments. The former may have some innovative management practices, while such practices in the latter have little impact due to the severity of the constraints.

It is important to note that these agricultural pressure classes are static and represent conditions at a particular point in time. Both the land-use intensity and MRP datasets were finalised in the mid-1990s so the results reflect conditions at that time. As classification input parameters change, such as fallow lengths or cropping periods (which determine land-use intensity values), the pressure classes will also change. The driving force behind such change is related to altered demographic patterns such as migration and population growth and improved land management practices such as the adoption of soil fertility maintenance techniques. For this reason, the agricultural pressure scale is designed to be relative and dynamic. If populations increase resulting in the intensification of agriculture with few improved land management practices, then the areas in question will move up the pressure scale, perhaps from none to marginal or moderate to strong. The extent to which R-values change will determine the change on the pressure scale. If, however, innovative management practices are adopted, resulting in improved RP without land-use intensification, then those areas will move down the scale. Many combinations of conditions can occur and they can be tracked through the PNGAPA classification process and corrected over time if necessary.

Results for the highlands region

Map 4 presents the distribution of agricultural pressure throughout the highlands region. There are no areas with very strong pressure. Enga Province has significant areas of strong pressure in the Lagaip, Kera, Lai, Ambum and Wage valleys along with the Kandep Basin and Sirunki Plateau, while Southern Highlands Province has areas of strong pressure in the Wage Valley, Lai Valley and Nembi Plateau. Other areas of strong pressure are located in the Dunantina Valley in Eastern Highlands Province, the upper Chimbu Valley in Chimbu Province and the Kaugel Valley in Western Highlands Province. In most of these areas, high-intensity village agriculture has extended beyond more suitable valley bottoms onto land constrained by steep slopes, poor soils, cold temperatures and frost. Areas with moderate and marginal pressure are located on the fringe of the Tari Basin, Mendi Valley and Nembi Valley in Southern Highlands Province, the Lai Valley in Enga Province, the upper Chimbu and Waghi valleys in Chimbu Province and the upper Ramu Valley in Eastern Highlands Province. Areas not classified as vulnerable are those where land-use intensity is compatible with the MRP.



Map 4. Distribution of agricultural pressure in the highlands region, for agricultural land only.

The six example RMUs have diverse results. The Mt Hagen RMU has very high MRP and high land-use intensity (R-value of 50, CI index of 2), resulting in no pressure. The Tari RMU has very high MRP and very high land-use intensity (R-value of 100, CI index of 3), resulting in no pressure. The Banz RMU has very high MRP and moderate land-use intensity (R-value of 29, CI index of 2), resulting in no pressure. The Nipa RMU has low MRP and low land-use intensity (R-value of 17, CI index of 1), resulting in no pressure. The Gembogl RMU has low MRP and high land-use intensity (R-value of 50, CI index of 2), resulting in moderate pressure. Finally, the Kandep RMU has low MRP and very high land-use intensity (R-value of 100, CI index of 3), resulting in strong pressure.

While land-use intensity in the first four examples is compatible with MRP, they are quite different from one another, with the Tari RMU being the most intensive and the Nipa RMU the least. A more detailed classification for different purposes could separate these four.

Tables 13–16 present the area and estimated 2000 populations for each agricultural pressure class. Estimated 2000 populations are based on the growth rates for each province determined by Keig (1999) from changes between the 1980 and 1990 PNG National Population Censuses. In summary, areas with strong pressure cover 2230 km^2 and an estimated 2000 population of 214,800. Areas with moderate and marginal pressure cover 3770 km^2 and 2720 km^2 and estimated 2000 populations of 312,150 and 180,700, respectively.

Table 13. Summary of strong agricultural pressure areas in the highlands region. Note that the population for Chimbu is low because people live in lower parts of the Chimbu Valley.

Province	Area (km^2)	Estimated 2000 population
Southern Highlands	570	35 100
Enga	920	133 900
Western Highlands	60	8450
Chimbu	36	50
Eastern Highlands	650	37 300

Table 14. Summary of moderate agricultural pressure areas in the highlands region.

Province	Area (km^2)	Estimated 2000 population
Southern Highlands	1440	116 000
Enga	680	75 550
Western Highlands	420	33 200
Chimbu	500	50 100
Eastern Highlands	730	37 300

Table 15. Summary of marginal agricultural pressure areas in the highlands region.

Province	Area (km^2)	Estimated 2000 population
Southern Highlands	900	51 000
Enga	120	135 000
Western Highlands	595	53 600
Chimbu	260	26 300
Eastern Highlands	845	36 300

Table 16. Summary of agricultural pressure classes in the highlands region.

Agricultural pressure	Area (km^2)	Estimated 2000 population
Strong	2236	214 800
Moderate	3770	312 150
Marginal	2720	180 700

Results for the lowland and island provinces

Given the low land-use intensities in the lowland and island provinces, there are limited areas of agricultural pressure. There is very strong pressure on the Tulun, Nuguria, Takuu and Nukumanu islands in Bougainville Province and strong pressure around Teptep in Madang Province, Cape Vogel in Milne Bay Province, Malai and Tuam islands in Morobe Province, and the Bali Witu and Arawe islands in West New Britain Province. Larger areas of moderate and marginal pressure are located on the coastal plains of Madang Province, the coast of Collingwood Bay in Oro Province, the Namatanai area of New Ireland Province, and most of Buka and Bougainville Islands in Bougainville Province. Table 17 presents areas and estimated 2000 populations for all pressure classes in the lowland and island provinces.

Limitations

The results of the PNGAPA technique share the same limitations as the PNGRPA technique discussed previously. Extra care is needed when interpreting pressure classes due to the potential propagation of data and classification error through the classification stages. An example is the allocation of site-specific R-value data to Saunders land-in-use boundaries discussed previously. When such errors are combined with errors related to the smoothing of micro-environments in the PNGRPA technique, such as the flood-free terrace example discussed previously, then the pressure result could be inaccurate.

In the Kandep example RMU for instance, a particular intensive garden (R-value of 100) with composting and mounds may be located in a flat drainage line area with good soils and a slope gradient below 10 degrees. However, this garden is too small to be mapped by the PNGRPA technique. When such a garden is broadly classified as occurring in a poor soil and steep sloping RMU, as seen in Table 6, the garden is defined as having strong pressure. If the soil productivity and slope gradient RDOL values reflected the true conditions on the ground and thus were reduced from three to one, then the RP value would be 10. The land improvement adjustments would then have full effect, as the slope gradient is below 10 degrees, resulting in a MRP value of seven. Even with an R-value of 100 this particular garden, when classified at the site scale, would have no pressure. Furthermore, if a similar drainage line site within the same land-in-use boundary had not been gardened for over 30 years, then it may well be defined as under-utilised if classified at the site scale.

This example demonstrates the need to interpret the results within the context of the regional scale conditions defined by the MASP and PNGRIS data. Any extrapolation to local or site scales must be supported by further data collection and validation to ensure the site conditions match those defined by MASP and PNGRIS. If not, site adjustments can be made similar to the above example.

Table 17. Summary of agricultural pressure classes for lowland and island provinces.

Province	Very strong pressure		Strong pressure		Moderate pressure		Marginal pressure	
	2000 population	Area (km^2)	2000 population	Area (km^2)	2000 population	Area (km^2)	2000 population	Area (km^2)
Western	0	0	3520	175	0	0	0	0
Gulf	0	0	650	4	0	0	0	0
Central	0	0	20 560	450	42 000	850	7700	490
Milne Bay	0	0	4400	140	8700	360	39 900	800
Oro	0	0	1390	26	11 900	420	7300	280
Morobe	0	0	6150	90	18 400	920	29 700	1430
Madang	0	0	2240	45	21 000	530	23 600	1160
East Sepik	0	0	0	0	0	0	3680	100
Sandaun	0	0	0	0	0	0	0	0
Manus	1030	3	0	0	220	1	0	0
East New Britain	0	0	0	0	660	10	680	60
West New Britain	0	0	7200	60	16 300	280	9200	190
New Ireland	0	0	0	0	7900	360	9030	310
Bougainville	1330	30	4000	230	47 000	1800	25 300	760

Data Applications and Further Information

Spatial data on land RP and agricultural pressure are a consistent, transparent and informative basis to guide rural development activities such as agricultural extension, infrastructure development and the provision of basic social services. Such guidance is critical where human and financial resources are limited.

At a national level, such information may help define priority regions for international development projects such as the upper Chimbu Valley in Chimbu Province or high altitude areas in Enga and Southern Highlands provinces. At a provincial level, the information may determine priority areas and issues for agricultural extension projects. Examples may include suitable soil fertility maintenance techniques for intensive gardens on steep land or better adapted crop varieties for particular environmental constraints. In cases where suitable extension strategies are not known, the information can guide research activities and enable more critical reviews of how representative existing research programs are of high priority areas and issues. Furthermore, the structure of the agricultural pressure classification allows the identification of longer-term research needs where, for example, land use may be intensifying in marginal pressure areas.

Another application of agricultural pressure data can be to assist with the design of a national network of long-term monitoring sites that are representative of pressure classes, environment types, rural populations and land management practices. Such a network combined with a suitable set of environmental, social and economic indicators can monitor spatial and temporal trends, which in turn can redirect policy, planning and research activities where necessary.

More detailed results of land RP and agricultural pressure, along with information on agriculture, population, access to services and rural cash incomes are available for every district in PNG. For detailed information and analysis refer to the *Papua New Guinea District Planning Handbook* and for broad level analysis refer to the large format poster *Priority Areas and Issues for Rural Development in Papua New Guinea*. Both of these publications as well as digital information are available from the Land Management Group, Australian National University. Please contact: Land Management Group, Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra ACT 0200, Australia. Telephone: + 61 2 6125 4345. Fax: + 61 2 6125 4896.
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