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Geographical constituents of human well-being in Papua New Guinea: A district-level analysis

Colin Filer and Terence Wood

Abstract

We derive two measures of human well-being from the 2000 national census and seek to establish the relative strength of their association with 12 geographical variables in a comparative study of the 85 partially rural districts of Papua New Guinea. We find that the accessibility of health and education services for rural villagers, along with the proximity of the rural village population to a coastline, are the two geographical variables that have the strongest association with lower child mortality rates and higher school attendance rates. These findings are placed within the context of a broader discussion of ways to improve the measurement of such relationships at a district level in light of the acknowledged failure of the 2011 national census and the possible failure of the national census due to be conducted in 2021. Our findings are also located within the context of a longstanding international debate about the geographical constituents or determinants of human development at a national scale. The distinctive quality of our own contribution to this debate resides in our focus on the measurement of variation between districts within a single country.

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Colin Filer and Terence Wood

Colin Filer is an Honorary Professor at the Crawford School of Public Policy, The Australian National University.

Dr Terence Wood is a Research Fellow at the Development Policy Centre, Crawford School of Public Policy, The Australian National University.

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1. Introduction

It is now more than 20 years since the United Nations endorsed the Millennium Development Goals as a global standard for measuring the progress of its member countries in the quest to eliminate human poverty. At the same time, then Secretary-General Kofi Annan called for an assessment of the extent to which 'ecosystem services' were making a contribution to the maintenance or improvement of human well-being. Shortly afterwards, a group of human geographers at the Australian National University published a Rural Development Handbook containing a sequence of maps that showed critical features of the relationship between geography and development in each of the 85 wholly or partially rural districts or electorates in Papua New Guinea (PNG). In this paper, we revisit the contents of the Handbook, with additional data and a new set of calculations, in order to assess the relative significance of a number of geographical variables in what we shall call the constitution of human well-being in PNG. In doing so, we also position our calculations within the international body of literature that has tried to grapple with the question of how to situate our understanding of human well-being in the tension or contradiction between demands for economic development and environmental conservation.

Our argument proceeds as follows. First, we provide summary reviews of the international literature and the literature that deals specifically with the relationship between geographical variables and measures of human well-being in PNG in order to establish the parameters within which a new version of the Handbook might be constructed. Then we identify two specific district-level measures of human well-being that are derived from the 2000 national census and that were not available to the authors of the Handbook when it was being drafted. This is followed by the identification of a number of geographical variables for which we also have district-level measures derived from various sources, including those used in the Handbook, as well as the 2000 national census, and which might be expected to be associated with one or both of these two measures of human well-being. There follows a provisional assessment of the statistical relationship between the variables we have identified, and a further discussion of the ways in which this assessment might be modified in light of additional research. Finally, we return to the question of how a new version of the Rural Development Handbook might be constructed.

2. Geography, environment, development

In his well-known book about 'The End of Poverty', Jeffrey Sachs described 'physical geography and human ecology' as a distinctive group of variables that affected the rate of economic growth, and hence the level of human well-being, in different countries and regions. He divided this group of variables into five subgroups — transport conditions, population density, agronomic conditions, ecosystem functions and disease ecology (Sachs 2005, pp. 86–87). Here we shall follow Sachs in treating environmental and demographic variables as two distinctive types of geographical variable that can be separated from specific measures of human well-being for analytical purposes. However, the title of this paper reflects our acceptance of the argument that environmental and other geographical variables can also be constituent elements in people's understanding of what makes for a good life (Schleicher et al. 2018).

In an earlier paper, Sachs and his colleagues tried to calculate the extent to which different geographical variables were correlated with different levels of development at a national and regional scale (Gallup et al. 1999). They found, for example, that people living in temperate countries or regions are generally better off than those living in tropical countries or regions; that people living in countries with a coastline are generally better off than those living in landlocked countries; and that people living within 100 km of a coastline are generally better off than those living further inland. On the other hand, they could find no simple relationship between population density and levels of income. Instead, they found that population density tends to be a function of other geographical variables. In tropical regions it tends to increase with altitude, possibly because people living at higher altitudes are less vulnerable to malaria and other tropical diseases, and yet the prevalence of malaria is still correlated with population density at lower altitudes.

In both tropical and temperate regions, the agricultural potential of the land was found to be the main driver of population density, and yet the number of poor people living in areas with low agricultural potential was still growing because improvements in public health have outstripped rates of economic growth.

In the 1990s, much of the debate about the relationship between human well-being and environmental conditions was framed by a single sentence in the report of the World Commission on Environment and Development, otherwise known as the Brundtland Report:

> Many parts of the world are caught in a vicious downwards spiral: poor people are forced to overuse environmental resources to survive from day to day, and their impoverishment of their environment further impoverishes them, making their survival ever more difficult and uncertain (WCED 1987, p. 27).

A similar representation of the poverty-environment trap appeared in the World Bank report on 'Development and the Environment' that was published at the time of the Rio Earth Summit in 1992:

> Land-hungry farmers resort to cultivating unsuitable areas — steeply sloped, erosion-prone hillsides; semiarid land where soil degradation is rapid; and tropical forests where crop yields on cleared fields drop sharply after just a few years (World Bank 1992, p. 30).

The idea that poor people — especially poor farmers — are the main agents of environmental degradation has been countered by a number of alternative arguments about the relationship between social, economic and environmental change. For example, the data assembled by Sachs and his colleagues would indicate that the poverty-environment trap is better conceived as a population-environment trap, in which it is rapid population growth that is liable to degrade marginal environments, regardless of the wealth or poverty of the people who do most of the damage, or the subsequent impact of the degradation on social inequality (Barbier 2010; Gallup et al. 1999; Gray & Moseley 2005; World Bank 2008).

Nevertheless, the idea of a poverty-environment trap has carried a good deal of political weight because it enabled aid agencies and national governments to agree that measures taken to alleviate rural poverty are bound to have a positive impact on the natural environment, while measures taken to conserve or improve the natural environment should have an equally positive impact on human well-being. This agreement is evident in the design of the Millennium Development Goals (MDGs) as a framework for international cooperation in the business of ending poverty. The seventh of the eight goals, which was to 'ensure environmental sustainability', was conceived as one whose achievement would automatically support or reinforce the achievement of the first six goals, all of which were directly concerned with the improvement of human well-being. The eighth and final goal was to establish a 'global partnership for development' that would unite the governments of rich and poor countries in the pursuit of this common enterprise.

While the MDGs secured the endorsement of the United Nations at the turn of the millennium, they were not bound together by a single set of ideas about the way that environmental variables, or other geographical variables, are related to different measures of human well-being (Vandermoortele 2011). Instead, the governments that subscribed to them were left to work out how their national targets should relate to the global targets associated with each of the first seven goals, and how their own indicators of progress in meeting these targets might therefore diverge from the indicators associated with these global targets. For the governments of poor countries, the problem lay not so much in the choice of targets that would make for a coherent national sustainable development strategy, but rather in the collection of reliable statistics to measure their progress in meeting so many different targets at the same time (Jerven 2013; UN 2015). This problem only got worse when the MDGs were replaced by the 17 Sustainable Development Goals (SDGs) in 2015, since this led to a corresponding expansion in the number of targets and indicators, and hence the number of variables to be measured (UN 2017).

While the MDGs and SDGs have constituted a distinctive space for negotiation between national public servants and representatives of the international donor community, the

United Nations created a separate space for the scientific community to investigate the environmental foundations of human well-being when it authorised the conduct of the Millennium Ecosystem Assessment (MA). The MA conceptual framework (MA 2003) had a number of features that set it apart from previous approaches to understanding the relationship between geography (or environment) and development (or poverty).

To begin with, environmental variables were no longer conceived as a subset of geographical variables because the four types of ecosystem service acknowledged in the framework included a category of 'cultural' ecosystem services that essentially consisted of people's subjective perceptions of environmental quality. At the same time, a number of geographical variables — such as transport conditions — were set apart from the capacity of ecosystems to sustain human well-being and were instead treated as external drivers of change in this relationship. Furthermore, measures of human well-being were extended well beyond the indicators attached to the MDGs, and later to the SDGs, to include things like 'good social relations' and the types of freedom that Amartya Sen has argued to be essential ingredients in any process of poverty reduction (Sen 1999). As a result, the poverty-environment trap was now conceived as one of several different types of feedback loop that could connect the drivers of environmental change with changes in human well-being. Finally, these feedback loops were understood to be operating at several different scales — from the global to the local — and not necessarily operating in the same way at each of these scales. Given that ecosystem boundaries do not coincide with jurisdictional boundaries at any scale of analysis or any level of political organisation, the dynamics of these relationships were not likely to be captured by the collection of national statistics, nor by the standard forms of inter-country comparison. This in turn placed a big question mark over the location of the 'strategies and interventions' that might be adopted to change these dynamics at any particular scale.

The final reports of the MA reflect the prevalence of ecologists and ecological economists in the scientific community that produced them. A lot of emphasis was placed on the measurement of change in those three types of ecosystem service that could plausibly be measured by the use of remote sensing technologies (MA 2005a). Discussion of the category of 'cultural' services was largely consigned to the sub-global working group, where it got mixed up with an attempt to take special account of indigenous ideas about the natural environment (MA 2005b; Reid et al. 2006). Remote sensing technologies provide good measures of things like the level of urbanisation or industrialisation, as well as the subset of geographical variables that Sachs and his colleagues called 'transport conditions', but the MA conceptual framework treats these as drivers of environmental change, not as components of human well-being. There is nothing much that satellites can tell us about things like child mortality rates, let alone the quality of social relationships.

Recent attempts to establish statistical relationships between geographical or environmental variables and levels of human well-being have generally taken one or more of the indicators attached to the MDGs and SDGs as the dependent variables in the analysis. This means that they either have to rely on the statistics produced by national governments and collated by international agencies, or else to establish alternative measures by means of survey data collected outside the normal routines of government business (World Bank 2008). The independent variables have then been drawn from the same bodies of national statistics or from global datasets established by remote sensing technologies. In order to encompass the dynamics of the relationship between dependent and independent variables, and to allow for analysis of the poverty-environment trap, the population-environment trap, or other kinds of feedback loop, preference is given to those variables in which change can be consistently measured over some period of time — normally a decade or two. Even so, the range of independent variables that might be chosen for this purpose is so great that it has proven difficult to establish any general conclusions from all the studies that have been undertaken (Suich et al. 2015). If anything, the most general conclusion is a paradox — at least when framed in terms of the MA conceptual framework. For it appears that measures of human well-being show fairly consistent improvement across countries and scales, while measures of environmental quality show that ecosystems around the world are losing their capacity to supply sustainable levels of service or benefit to human consumers (Raudsepp-Hearne et al. 2010). It therefore seems that human beings have found ways to grow their consumption of some ecosystem services at the expense of other services; that a majority of human beings have done well at the expense of a minority; or that human beings in general have shown a preference for short-term gains at the expense of long-term pain.

There is a relatively small set of studies that have specific relevance to the one undertaken in this paper because they have examined the statistical relationship between measures of human well-being and a number of independent variables at a subnational level, where the unit of analysis is not the ecosystem that provides different types of ecosystem service but the 'province' or the 'district' whose government is often responsible for the provision of public services such as health or education. There are not many studies of this kind because the number of variables that can be accurately and consistently measured at this level is also quite small. Two examples will suffice by way of illustration.

The first is a study of factors influencing changes in child mortality rates between 2000 and 2010 in each of 110 districts into which Ghana was divided at the start of the decade (Arku et al. 2016). The study was based on information drawn from the national census at the beginning and end of that decade. It found that child mortality rates declined in all districts, but the decline was greater in those districts that already had lower rates at the beginning of the decade, so the net result was an increase in spatial inequality. The independent variables in this study were described as 'social and environmental risk factors'. These included a mixture of geographical variables, such as the level of urbanisation, and other measures of human well-being, such as the level of parental education. The only variable that was found to have a significant relationship with the reduction in child mortality rates was the proportion of households using liquefied petroleum gas as opposed to other fuel sources for cooking the family meals. The authors wondered if their study might have failed to consider some other variables that could have had a more significant relationship to child mortality rates.

The second example is a study with a much broader scope (Heger et al. 2018). This belongs in the long line of World Bank publications dealing with the poverty-environment relationship that was initiated by the 1992 World Development Report. The study covered 62 high-, middle- and low-income countries for which it was possible to obtain measures of the two dependent variables — average incomes and levels of income poverty — at the 'provincial' level at various points in time since 1996. The independent variables in this study were two measures of 'vegetation vigour' derived from satellite imagery, together with a measure of soil fertility derived from a separate global database.

The control variables all fell into the broad geographical category defined by Sachs and his colleagues. They included 'topographic ruggedness', the density of the road network, and the proportions of the total land area occupied by urban settlements, croplands, grasslands and forests. The study found that the three measures of environmental quality were more closely associated with lower levels of income poverty than with higher average incomes. By contrast, higher levels of urbanisation were more closely associated with higher average incomes than with lower levels of income poverty. Finally, the density of the road network had more of an effect on the reduction of income poverty than did changes in the pattern of land use, while some changes in the pattern of land use — especially the conversion of forest to farmland — might even contribute to higher levels of income poverty.

3. Papua New Guinea

Papua New Guinea (PNG) is not one of the countries that was included in the study undertaken by Heger and his colleagues. That is not surprising. The PNG Government has struggled to produce any accurate measures of its progress towards meeting the MDGs and SDGs, even at a national level (GPNG 2010a; GPNG & UNDP 2014). The prime minister officially declared the 2011 national census to have been a failure. Even in the earlier period from 1980 to 2000, for which we have three sets of national census data, there are barely any accurate and consistent measures of change in key indicators of human well-being at a subnational level. There are likewise very few measures of change over time in the geographical variables that we might wish to consider as independent variables.

Nevertheless, we do have two specific datasets that can be combined with the national census data and other survey data to enable an assessment to be made of the relationship between a number of geographical variables and two specific measures of human well-being across the 85 partially rural districts of PNG within the period from 1980 to 2000. The present study should therefore be regarded as a snapshot of the spatial relationship between a number of variables in the period leading up to the last reliable national census at the turn of the millennium.

In this section of our paper, we briefly discuss the origin of the two datasets that we are using, along with national census data, as primary sources of information about a number of geographical variables in PNG. We then proceed to discuss the way that these sources of information have previously been used to construct indicators of the relative levels of development or disadvantage exhibited by each of the 85 districts under consideration.

3.1 The PNGRIS dataset

Part of the Australian Government's investment in post-war scientific research funded the work of a multi-disciplinary team of environmental scientists associated with the Division of Land Use Research in the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). This work involved a variety of field surveys carried out over a period of 20 years (1953–1972), covering 40 per cent of the total land area of PNG, supplemented by analysis of two sets of aerial photographs with national coverage (Keig et al. 2019). The ultimate purpose of this exercise was to assess the environmental constraints on 'land use' to assist the Australian colonial administration in the formulation of its agricultural development plans (Trangmar et al. 1995).

Members of the CSIRO team published the results of this work in books and articles representing the interest of different disciplines in different types of environmental constraint (Bleeker 1983; Löffler 1977; McAlpine et al. 1983; Paijmans 1976). In the 1980s, the results were integrated in the form of a spatial dataset known as the PNG Resource Information System (PNGRIS), in which 4,566 'resource mapping units' were distinguished from neighbouring polygons by one or more of six 'physical resource attributes' — landform, rock type, altitude (treated as a proxy for temperature), relief, inundation, and mean annual rainfall (Bellamy & McAlpine 1995). These physical environments were defined in such a way that their boundaries could only change very slowly in the absence of major tectonic disturbances.[1]

[1] The dataset was constructed before it became apparent that climate change would modify mean annual rainfall and temperatures in different parts of the country.

The other variables in the PNGRIS dataset were mainly established by the attribution of one or more forest types or other vegetation types to each of the physical environments distinguished in this way, along with an estimate of the extent of 'human disturbance' in each type of forest and a separate estimate of the proportion of the surface area showing signs of having recently been used by human beings. These descriptions were summarised in hard-copy maps of 'agricultural land use' and 'forest resources' (Saunders 1993a, 1993b). Soil types and soil quality were also treated as secondary variables because of the evidence that they could be modified by the practice of agriculture (Bleeker 1983; Bellamy and McAlpine 1995).

3.2 The MASP dataset

During the 1990s, a second multi-disciplinary team of researchers from the Australian National University and the National Agricultural Research Institute in PNG embarked on a nationwide field survey of all those areas — including areas of secondary forest — which the CSIRO team had designated as areas of 'agricultural land use' (Saunders 1993a), leaving aside the commercial farms or plantations designated as areas of very high land use intensity 'with tree crops'. In the dataset produced by this Mapping Agricultural Systems Project (MASP), these areas of indigenous land use were grouped into a total of 287 local agricultural systems distinguished from each other by one or more of four variables — cultivation period, crop types, fallow period, and type of fallow vegetation (Bourke et al. 1998).

The MASP dataset therefore uses one of the variables in the PNGRIS dataset — namely land use — to establish a distinctive set of polygons, and then defines agricultural systems by reference to the way that local villagers actually use the land, while recognising that these practices are partly constrained by the physical environmental variables already measured in the PNGRIS dataset (Keig et al. 2019). Taken together, these two datasets indicate that nearly all of the land that can be used for agriculture is actually being used for this purpose, even if much of it appears to be forested land, since the forests in question are a form of fallow vegetation that is more or less frequently cleared and cultivated (Allen & Bourke 2009). The rest of the land, which accounts for most of PNG's total surface area, has environmental characteristics that make it unsuitable for agriculture, even if it is covered by forests that are suitable for commercial logging operations, or may be used by local villagers for other purposes, such as hunting and gathering or alluvial mining.

3.3 The dynamics of disadvantage

The MASP dataset was not only intended to complement the contribution of the PNGRIS dataset to agricultural and rural development plans at different levels of political organisation, it was also meant to provide an empirical test of Esther Boserup's general theory of agricultural intensification (Allen 2001; Boserup 1965), and a way of assessing the sustainability of indigenous agricultural systems in the face of rapid population growth (Allen et al. 1995). Since the basic rationale behind the MASP dataset emerged from the discipline of human geography, rather than the natural sciences, there has been a greater effort to link a range of socio-economic variables to the description of local agricultural systems. Conclusions can therefore be drawn about the relationship between population pressure, land degradation and agricultural innovation.

Population (or population density) can be treated as a dependent variable in both the PNGRIS and the MASP datasets, but it is much easier to assign the population of a rural village census unit to one of the 287 local agricultural systems than to one of the 4,566 resource mapping units because rural villages are generally surrounded by land that is used for village agriculture. The authors of the Rural Development Handbook assigned a measure of 'disadvantage' to each agricultural system on the basis of four criteria — the quality of the physical environment, population pressure, the level of access to health and education services, and the estimated level of income from village agriculture (Hanson et al. 2001).

The evidence assembled in this way suggests that there are relatively few places (or agricultural systems) that show evidence of the poverty-environment trap described in the Brundtland Report or the population-environment trap described in other international sources. Insofar as villagers have been motivated to degrade their natural environment, it is not by means of their own land use practices but by their willingness to sell the use of their land to foreign logging or mining companies (Filer

1997; Jackson 1991; Novotny 2010; Sekhran 1997). In the more densely populated agricultural systems, people have generally responded to additional population pressure with some form of agricultural innovation or by moving out of the system altogether (Allen et al. 2005; Bourke 2001). In general, forms of agricultural intensification that raise the productivity of land already in use are far more widespread than forms of agricultural expansion that entail the cultivation of land that has not previously been used for this purpose (Allen et al. 2001). Most of the rural poverty in PNG is thus associated with agricultural systems that have low population densities and low levels of agricultural intensity, where people do not have the technical capacity or economic opportunity to change what are essentially poor physical environments (Allen et al. 2005; Allen & Bourke 2009).

3.4 District development indicators

Official interest in ranking PNG's districts according to their level of 'development' dates back to the early years of Independence, when the National Planning Office allocated a significant portion of the development budget (then known as the 'national public expenditure plan') to what were known as the 'less (or least) developed areas' of the country (de Albuquerque & D'Sa 1986; D'Sa 1986; Gibson et al. 2005; Wilson 1974). This was also the motivation behind the National Nutrition Survey conducted between 1982 and 1983 (Heywood et al. 1988).

In the period from 1975 to 1995, the boundaries of the districts that were being ranked in this way rarely coincided with the boundaries of the electorates represented in the national parliament. This anomaly was removed with the passage of the Organic Law on Provincial Government and Local-Level Governments in 1995. The electoral boundaries were preserved, and the district boundaries were brought into alignment with them.[2]

[2] Unfortunately, the alignment was imperfect, so there are some areas where the boundaries recognised by the National Statistical Office do not quite coincide with those recognised by the Electoral Commission. The seven districts affected by this discrepancy are: Middle Fly and North Fly in Western Province; Ambunti, Angoram and Wosera-Gawi in East Sepik Province; and Telefomin and Vanimo-Green in West Sepik Province. For the purpose of this study, we have opted for the boundaries recognised by the National Statistical Office since these are the ones that were used in the 2000 national census. These are the boundaries shown on the map of open electorates in Appendix 1.

This meant that statistical information pertaining to the old districts could only be compared with that pertaining to the new ones if it could be assigned to smaller areas — census divisions or census units. Data from the 1980 national census were not preserved in a form that would allow for comparison with the results of the 2000 national census except in respect of basic population numbers. Likewise, the National Nutrition Survey is one of the few sample surveys conducted in the earlier period from which information can be assigned to the new districts established by the Organic Law (Müeller et al. 2001, 2002).

As previously noted, the authors of the Rural Development Handbook produced their own ranking of the new districts based on a 'disadvantage index' derived from a combination of environmental, technological, demographic and economic variables that were attached to the local agricultural systems surveyed in the 1990s. This index was also weighted to take account of two measures of child malnutrition derived from the National Nutrition Survey (Hanson et al. 2001). The index divided the 85 districts that were partially rural, and therefore contained at least one agricultural system, into 15 categories. Thirteen districts were assigned to the three categories at the bottom of the ladder, while seven districts were assigned to the three at the top.

In 2004, PNG's National Economic and Fiscal Commission (NEFC) ranked these 85 districts on a number of other criteria in pursuit of its own mandate to do what the National Planning Office had been doing in the 1970s, namely to ensure that the country's least developed areas got a fair share of public spending (GPNG 2004). The first criterion was a measure of the percentage of households living in poverty that was based on a National Household Survey conducted in 1996. That was essentially a survey of consumption patterns in a sample of 1,200 households spread across 120 census units. Variables from the PNGRIS and MASP datasets, as well as the 1990 national census, were used to stratify the sample (Gibson 2000). The consumption patterns of rural households in each of the 85 districts were imputed on the basis of a regression model applied to the sample survey households, along with a set of covariates that had overlapping distributions in the survey sample and the 2000 national census (Gibson et al. 2005).

Aside from the standard of living index obtained in this way, the NEFC was able to rank districts by reference to a couple of human development indicators derived from the 2000 national census data. One was a measure of gross school enrolment rates and the other a measure of adult literacy rates. Districts were also assigned a measure of life expectancy at birth, but the National Statistical Office could only supply this information at a provincial level, so each district in a province received the same score. By combining the standard of living index with these three additional indicators, the NEFC came up with a composite District Development Index that was meant to resemble the Human Development Index that the UN Development Programme applies to cross-country comparisons. On this ranking, the four least developed districts were the four districts located in West Sepik (or Sandaun) Province.

The 89 open electorates, including the 85 partially rural ones, have proven to be the most stable features of PNG's subnational political landscape because their boundaries have not changed since 1977, despite occasional calls for those with the largest populations to be subdivided. Indeed, their significance as units of administration was enhanced by the establishment of District Development Authorities in 2014, because this gave local MPs even greater control over public spending within their electorates. However, politicians and public servants who wish to base district development plans on a firm statistical footing have struggled to find the numbers required for this purpose.

The failure of the 2011 national census does not bode well for the next national census that is due to be conducted in 2021 (Laveil 2021). No one has been able to make district-level extrapolations from the Household Income and Expenditure Survey that was completed in 2010 or from any other national sample surveys conducted since the 2000 national census. Some national government departments have continued to collect district-level statistics on a regular basis, but little investment has been made in the work of assessment, comparison, analysis and explanation. Our own discussion of older but more reliable data might help to stimulate some remedial action.

4. Identification of variables for this study

For the purpose of this study, we have selected two measures of human well-being (or 'human development') that are available at the district level and we have treated these as our dependent variables. We have then identified a range of independent geographical variables that might serve to explain the district-level variation in each of these two dependent variables. Before we proceed to discussion of statistical relationships between these different variables, it is necessary to explain how we came to select them for consideration in the first place and why they might be more significant than other variables we could have chosen for this study.

Like most of the previous studies of 'district development' in PNG, ours is confined to the 85 electorates that are at least partially rural. That is because we cannot measure some of the variables in which we are interested in purely urban areas. The three urban electorates in the national capital, Port Moresby, and the one that comprises the second city of Lae have therefore been excluded from the analysis. This does not mean that there is no point in seeking to identify the geographical constituents of human well-being in purely urban areas. It simply means that a different methodology would need to be adopted.

Maps showing the current boundaries of PNG's provinces and districts are included in Appendix 1.

4.1 Measures of human well-being

As we have seen, some measures of human well-being at the district level were already available to the authors of the Rural Development Handbook that was published in 2001, before the release of data from the 2000 national census. These included measures that were derived from the National Nutrition Survey conducted between 1982 and 1983 and from the National Household Survey conducted in 1996. In this paper, we have preferred to focus attention on two dependent variables for which measures can be extracted from the 2000 national census, because census data are generally more reliable than data extrapolated from surveys with relatively small stratified samples. One of our two dependent variables was already present in the calculation of the District Development Index in 2004, while the other one was only calculated after that ranking had been compiled.

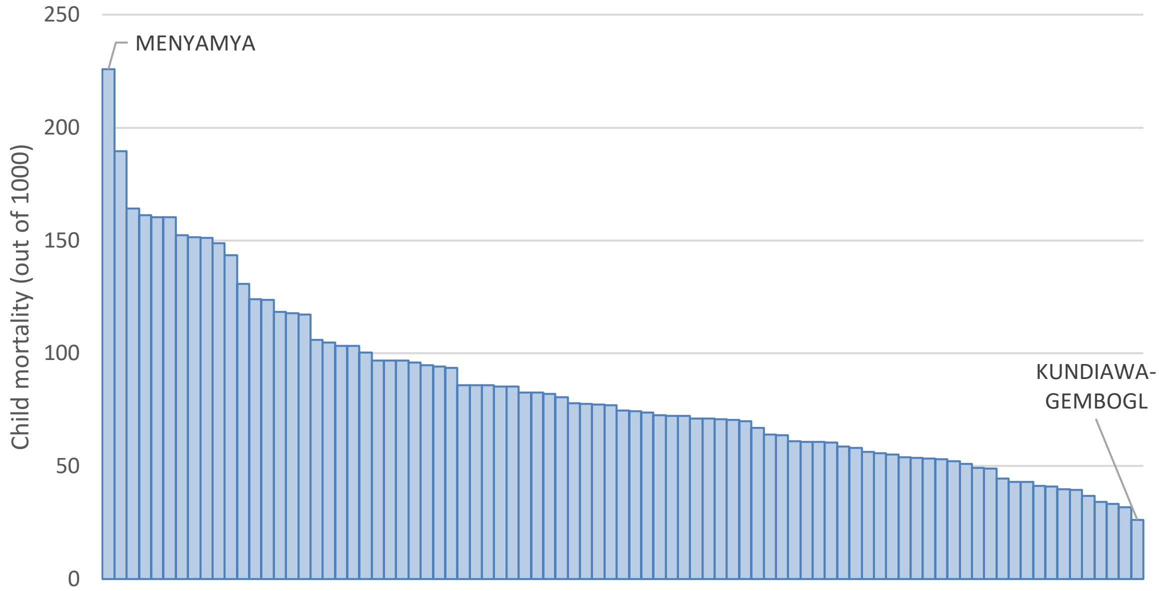
4.1.1 Child mortality rate

In 2009, the Australian aid program and the Gates Foundation funded a study of historical changes in the under-five (child) mortality rate in PNG. This was an example of a partnership established under MDG #8 being deployed to obtain a more accurate measure of one of the key indicators of progress towards MDG #4 (now SDG #3). The child mortality rate, along with infant and maternal mortality rates, is widely acknowledged as a critical measure of human well-being in all the countries of the world, and already held this status before the MDGs were established (World Bank 2008).

The scientists who undertook this study were unable to extract any useful information from the 2006 Demographic and Health Survey (GPNG 2009), so they made estimates of the changes that had taken place between 1976 and 1999 — at national, provincial and district levels — based on evidence from the 2000 national census data (Bauze et al. 2012; Tran et al. 2011). In the published version of the dataset, the district-level estimates cover each year between 1985 and 1999. This could therefore be the dependent variable in a longitudinal study of the relationship between human well-being and any geographical variables for which change could be measured over a similar period. However, in the absence of time series data for most of these geographical variables, we have calculated our dependent variable as the average of the child mortality rates estimated for each district over the five-year period from 1995 to 1999.

There were 14 districts in which the average rate was less than 50 per 1,000 live births over this period, but 22 districts in which it was over 100, and one district — Menyamya in Eastern Highlands Province — in which it was over 200 (see Appendix 2). The full range of variation between districts is shown in Figure 1.

Figure 1: Child mortality rates across 85 districts, 1995–99



4.1.2 School enrolment or attendance rate

In 2010, PNG's National Research Institute (NRI) published a set of district profiles that included measures of both gross and net school enrolment rates (PNGNRI 2010). The difference between these two measures is that gross enrolment rates are calculated as the number of pupils enrolled in school as a proportion of the school-age population, while net enrolment rates are calculated as the proportion of school-age children enrolled in school. Gross enrolment rates can therefore be higher than net enrolment rates if some of the pupils are above school age. They can even exceed 100 per cent if many of the pupils do not belong to the school-age population.

There is a quite remarkable discrepancy between the gross enrolment rates quoted in these district profiles and those that were incorporated into the District Development Index produced by the National Economic and Fiscal Commission in 2004. The former exceed the latter by an average of 30 percentage points across all 85 districts. In one district, which happens to be the electorate of former prime minister Peter O'Neill, the difference is more than 80 per cent.

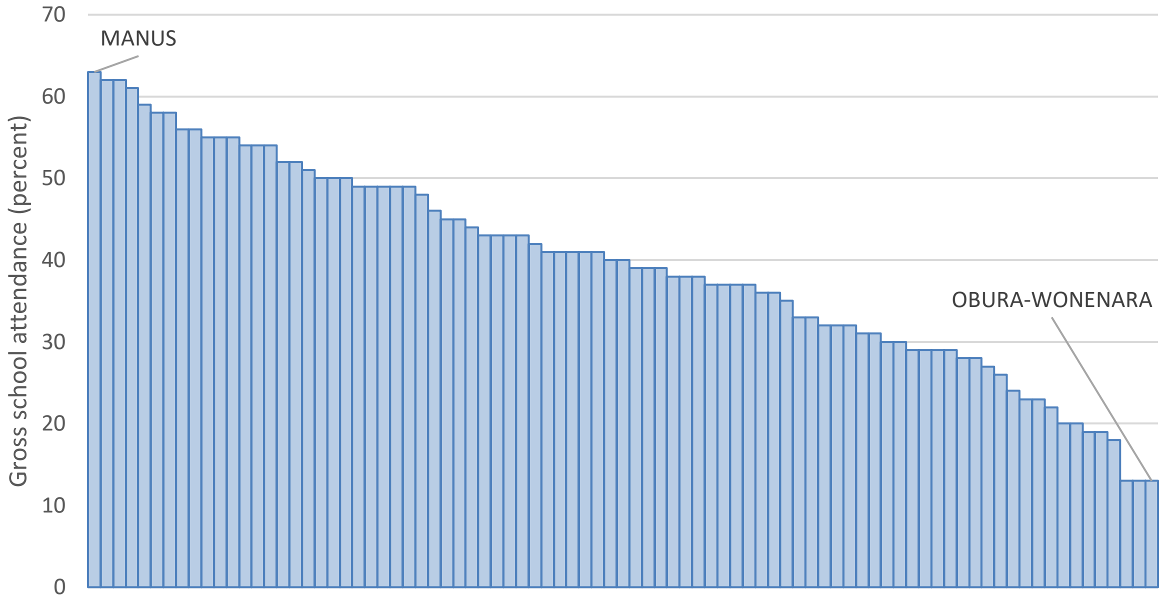
These discrepancies are not due to a sudden and dramatic improvement in school enrolment rates over the space of a few years but to differences in the way the data were collected. The numbers quoted in the NRI district profiles were apparently derived from statistics collected by PNG's Department of Education in 2007. The Department's enrolment statistics are based on reports submitted by school heads at the beginning of each school year. The statistics derived from the national census are based on a question about whether persons over five years old are 'attending' school at the time of the census, which is conducted in the middle of the school year.

The Department's numbers are liable to overestimate the actual number of students in school because those enrolled at the beginning of the school year may not be attending school in the middle of the year, if they ever turned up in the first place, and because school heads may be inclined to overestimate their enrolment rates in order to get more resources for their schools. In addition, school heads would not know the size of the school-age population in their catchment areas unless they were to conduct their own census, and it is not clear how the Department has injected these numbers into its own calculation of enrolment rates.

For these reasons, we have selected the NEFC measure as our second dependent variable, and have chosen to call it the gross school *attendance* rate in order to avoid confusion about the meaning of the word 'enrolment'. This choice has the advantage of aligning the measures of our two dependent variables, since both are based on the 2000 national census.

There are 21 districts with gross school attendance rates above 50 per cent, and 12 with rates below 25 per cent (see Appendix 2). The full range of variation between districts is shown in Figure 2.

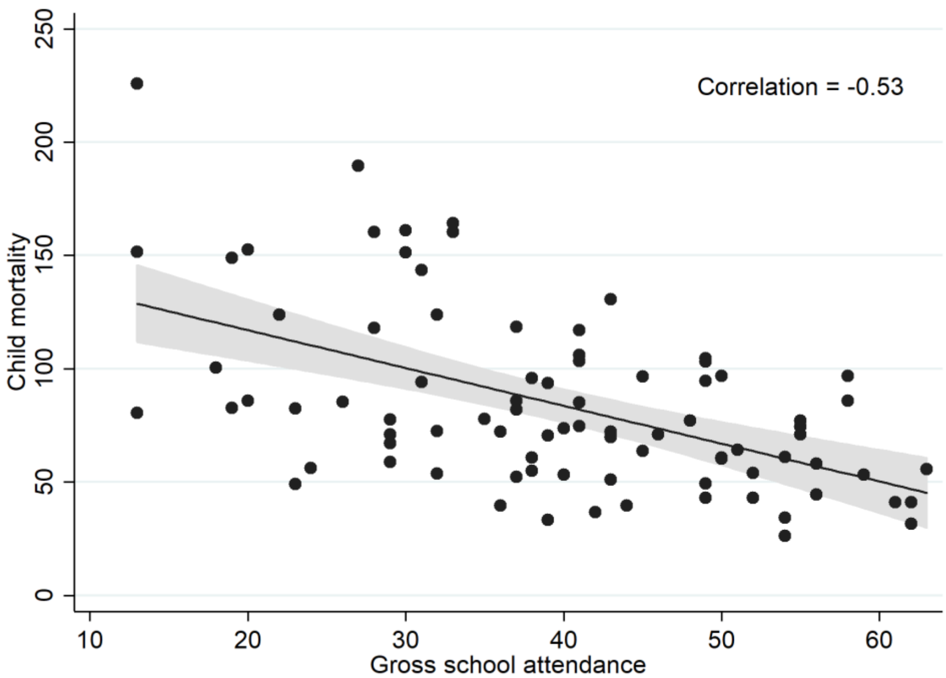
Figure 2: Gross school attendance rates across 85 districts in 2000



4.1.3 Some correlations

Figure 3 shows that our two measures of human well-being are clearly, though not perfectly, correlated with each other — in other words, that higher levels of school attendance tend to be associated with lower levels of child mortality.

Figure 3: Relationship between child mortality and school attendance rates



We would expect to find some measure of correlation between the child mortality rate (1995–99) and one or other of the child malnutrition rates documented in the National Nutrition Survey (1982–83), namely the percentage of children under five who were below the standard height-for-age (i.e. 'stunted') and the percentage who were below the standard weight-for-age (i.e. 'wasted'). There is a fairly clear correlation (r = 0.45) between the child mortality rate and the previous measure of stunting, but a weaker correlation (r = 0.3) with the previous measure of wasting. This difference is partly explained by the weakness of the correlation between the two different measures of malnutrition, and that in turn appears to have been a function of altitude. The National Nutrition Survey found that children living at altitudes above 1,200m were significantly shorter but heavier than those living at altitudes below 600m, so highland children were more likely to be stunted and less likely to be wasted than lowland children, while children living in the intermediate altitudinal zone, between 600m and 1,200m, had higher rates of both stunting and wasting than either highland or lowland children (Heywood et al. 1988).

We would likewise expect to find some degree of correlation between the gross school attendance rate in 2000 and the rough estimates of incomes from village agriculture contained in the Rural Development Handbook.[3] That is because all parents were obliged to pay school fees in the 1990s, so villagers with low levels of cash income would struggle to meet this obligation and might therefore be less inclined to send their children to school. But once again the correlation is fairly weak (r = 0.37). So the two dependent variables in our dataset are more closely associated with each other than with other variables with which they have a stronger conceptual relationship.

4.2 Geographical variables

We have extracted 12 geographical variables from four main sources: the PNGRIS dataset, the MASP dataset, the 1:100,000 topographic map series, and the 2000 national census. This does not represent the full range of geographical variables that could be extracted

[3] Allen et al. (2001) provide a detailed explanation of the methodology used to arrive at these estimates.

from these sources and for which there are reasonably accurate measures at the district level. Our selection has been based on the expectation that they might have some effect on human well-being, given their correspondence with some of the key variables discussed in the international literature on this subject. We have not made any attempt to derive additional variables from satellite imagery or from other global datasets at this juncture.

4.2.1 Environmental quality

We have obtained two measures of basic environmental quality from the PNGRIS dataset. The first, which we are calling a measure of 'flat geography', has been calculated as the percentage of a district's total surface area that is neither inundated nor hilly and mountainous. This measure is derived from two of the six 'physical resource attributes' that constitute independent variables in the PNGRIS dataset, namely landform and inundation. This is a somewhat arbitrary choice, since other measures of environmental quality could be derived from the same dataset.

Although this particular measure might seem to discriminate against the 34 districts of the Highlands Region — one of the four main regions into which PNG is conventionally divided — this region contains 9 of the 22 districts with more than one-third of their surface area falling into the 'flat' category. That is because some of the central highland valleys are relatively flat and some districts in the Highlands Region include areas at relatively low altitudes that have the same attribute.

Our second measure of environmental quality is the percentage of a district's total surface area that was counted as 'land in use' in 1975, and thus contained the agricultural systems described in the MASP dataset. This includes the land occupied by plantations and human settlements, as well as the land used for village agriculture. The authors of the MASP dataset found that the proportion had barely changed between 1975 and 1995, and the figure is reproduced in the district profiles produced by PNG's National Research Institute in 2010 (PNGNRI 2010). This can be taken as a measure of environmental quality on the basis of the finding made by the authors of both datasets, that 'unused' land has environmental characteristics that make it unsuitable for agriculture.[4]

The proportion of the surface area that counts as 'land in use' varies enormously, from only 8 per cent in two of the districts of Western Province to 100 per cent in two of the districts in Western Highlands Province. There are 36 districts in which it accounts for more than half of the surface area, and half of these districts are located in the Highlands Region.

4.2.2 Altitude

The altitude classes used to distinguish resource mapping units in the PNGRIS dataset covered intervals of 600m. The resulting altitudinal zones were incorporated into the sampling frame used in the National Nutrition Survey. As we have seen, one of the main findings of that survey was that children living in the intermediate zone between 600m and 1,200m were more likely to display symptoms of malnutrition than children living in the highlands (above 1,200m) or the lowlands (below 600m). We might therefore expect to find higher rates of child mortality, if not lower rates of school attendance, in districts with a significant proportion of the population living in this zone.

Our first altitudinal variable is therefore calculated as the percentage of the rural citizen population living within this altitudinal zone at the time of the 2000 national census. We refer to these people as 'highland fringe dwellers' because most of them are to be found around the fringes of PNG's central highland range, although some are living on the upper slopes of other mountain ranges in other parts of the country. Less than 15 per cent of the people in this zone were actually living in one of the 34 districts that make up the Highlands Region. The largest proportions of highland fringe dwellers are found in some of the mountainous districts of Morobe Province.

[4] The authors of the MASP dataset made some adjustments to the boundaries of agricultural systems to take account of specific forms of land use that were not visible in the aerial photographs used to construct the PNGRIS dataset, most notably in areas where wild sago swamps were the primary source of carbohydrates for local villagers (Bourke et al. 1998).

The 1:100,000 topographic map series produced by Australian army cartographers around the time of PNG's Independence in 1975 establishes contour lines for the whole country at intervals of 50m above sea level for the first 200m and then at intervals of 200m for higher altitudes. Geolocation of census units in the 2000 national census enables each one to be assigned to one of these intervals. We can thus obtain a second measure of altitudinal constraints on human well-being by counting the range of altitudes at which the rural citizen population was found to be living at that time. If this is taken as a measure of the variety of environmental conditions facing the rural population in each district, we might expect it to be correlated with lower levels of well-being because a higher range of altitudes makes it harder for people to move between different parts of the district.

For this purpose we have only counted the range of altitudes that encompassed more than 90 per cent of the population, since there are some districts where small numbers of people were found at higher or lower altitudes — sometimes quite a lot higher or lower than those where the vast majority were living. Even so, there is one district — Telefomin in West Sepik Province — where the majority is distributed across a range of 2,000m, and another 17 districts where they are distributed across a range of more than 1,000m, while there are 15 districts where they are confined to a range of only 200m.

Our third altitudinal variable is not conceived as a likely constraint on measures of human well-being, but one that might be expected to contribute to lower levels of child mortality, if not higher levels of school attendance. The sources that enable us to assign the rural citizen population to a range of altitudes also enable us to determine the proportion of these people who were living at altitudes above 1,800m at the time of the 2000 national census. These 'mountain dwellers' accounted for 29 per cent of the total rural citizen population at that time, while the proportion found in the 34 districts of the Highlands Region varied from 24 per cent to 100 per cent. As recognised by Jeffrey Sachs and his colleagues (Gallup et al. 1999), people living at these altitudes are largely safe from the ravages of malaria, which might be expected to have a positive impact on their child mortality rate, but they pay a price for this privilege in their vulnerability to periodic droughts and frosts that ravage the harvest of sweet potato on which nearly all of them depend for their subsistence (Allen et al. 1989).

4.2.3 The coastal zone

Sachs and his colleagues suggest that people living in the 'coastal zone' should also have higher levels of well-being than those living further inland. Whereas they define this zone in rather broad terms at a global scale, we have defined it more narrowly to be the area within 10km of a coastline as the crow flies. Generally speaking, we would expect people living within this zone to be able to walk to the coast and walk back to their homes within a single day, and would expect their access to the coastline to be good for their well-being insofar as it enables them to supplement their diet with fish, even if they do not go fishing themselves, and to participate in maritime transport and trading systems. There is some evidence to suggest that those who live on small offshore islands may also be less susceptible to malaria because most of these islands lack the water bodies in which mosquitoes breed.

In order to make the proportion of 'coastal people' in districts with a coastline comparable to the proportion of 'mountain dwellers' in districts with high mountains, we have only counted the proportion of the rural village population that was living within 10km of a coastline at the time of the 2000 census, excluding those who were living in urban areas or 'rural non-villages'.[5] There are five districts in which the whole of the rural village population was living within the coastal zone in 2000, and another 23 districts in which more than half of the rural villagers counted as coastal people. On the other hand, there are 48 districts, including all of the 34 districts in the Highlands Region, in which there were no coastal people at all.

[5] The results of this exercise are not entirely accurate because the geolocation places some census units in the sea. This is not the result of sea-level rise due to global warming, but rather the way that the coastline, as previously shown on maps of PNG, has been incorporated into the geographical information system.

4.2.4 Population density

A measure of gross population density, which includes both urban and rural populations, can readily be derived from the 2000 national census. This measure is likely to be associated with various measures of human well-being insofar as it has been a major factor in determining the allocation of public goods and services. When public spending is allocated equally between districts, regardless of their population, or is allocated between them on a per capita basis, it is liable to benefit a larger proportion of the district population in districts with a higher population density.

Here again there is enormous variation between districts. The two districts in Western Province that have the lowest proportion of 'land in use' also have the lowest population densities — barely more than one person per square kilometre. On the other hand, there are eight districts with more than 100 people per square kilometre, six of which are located in the Highlands Region.

A second measure of population density can be derived from the MASP dataset. This could be described as 'village-level' or net population density because it is calculated as the number of rural villagers per square kilometre of land used for village agriculture in 2000. This is the way that the authors of the Rural Development Handbook arrived at their calculation of the level of population pressure in each of the agricultural systems within each district. Since they count population pressure as one of the three measures of 'disadvantage', one might expect an inverse correlation with various measures of human well-being. However, if population pressure constitutes a motive for people to migrate out of the area where it is experienced, it might be associated with higher rates of school attendance because of the value of educational qualifications to would-be migrants.

The lowest village-level population density — less than 10 people per square kilometre — is found in the North Fly District of Western Province, although this is not one of the two districts (Middle Fly and South Fly) that have the lowest gross population densities and proportions of land in use. Rabaul, in East New Britain Province, is the district with the highest population density on both counts. There are 15 districts with village-level population densities in excess of 100 people per square kilometre, 13 of which are located in the Highlands Region.

4.2.5 Agricultural potential

We have two different measures of agricultural potential because of the previously noted capacity of local farmers to change the quality of the soil through activities such as drainage, composting, or the management of fallow vegetation in the swidden cycle. The 'natural' potential has been derived from the measures of soil quality already contained in the PNGRIS dataset (Bleeker 1983), while the 'modified' potential is based on the observations made by the authors of the MASP dataset in their assessment of local agricultural systems during the 1990s. In each case, the variable has not been measured as the proportion of the district's land area that has a high level of natural or modified fertility, but as the proportion of the village population (as estimated in 2000) that was using land with high or very high fertility. It seems reasonable to expect that soil quality would be connected with levels of human well-being because of its effect on the productivity of subsistence agriculture (Kuchikura 1999; Wood 1984).

By these measures, there are 14 districts in which the proportion of the village population using land with high or very high natural potential was greater than 50 per cent, and these were amongst the 26 districts in which more than half the village population was using land with high or very high modified potential. On the other hand, there were nine districts in which none of the villagers were using land with high or very high potential on either of the two criteria. Of the 19 districts that show a divergence of more than 20 per cent between these two measures — where villagers have clearly made the most radical improvements to soil fertility through their own agricultural practices — 13 are located in the Highlands Region. The most extreme case of such divergence is Wapenamanda District in Enga Province, where none of the villagers were cultivating land with high or very high natural potential, but 75 per cent were cultivating land with high or very high modified potential.

4.2.6 Accessibility

As we have seen, the authors of the Rural Development Handbook estimated the level of access to health and education services as one of their measures of the relative advantage or disadvantage of the people resident in each of the agricultural systems that they identified. From this dataset it is possible to calculate the proportion of each district's rural village population that has different levels of access to such services. The authors of the Rural Development Handbook reckoned that those with 'very good' access were those who could reach a 'major regional centre' (normally a provincial capital) in less than one hour, while those with 'good' access were those who could reach a 'major service centre' (normally a provincial capital or district headquarters) in less than four hours (Hanson et al. 2001).

One potential problem with this measure is that the time it takes to reach any specific location is liable to fluctuate from one decade to the next, or even one year to the next, depending on the state of the roads that connect one place to another, the availability of vehicles (including motor boats), and the cost of using any specific mode of transport (Allen & Lowe 2006). Seasonal variations in weather conditions make a further contribution to this level of uncertainty, and so do longer-term changes in the quality of the services available at the end of the journey. In a temporal sense, this is the most variable of the independent variables under consideration here — and certainly more variable than the distribution of the human population between different places.

With these qualifications in mind, the combination of the Handbook's estimates with the national census data from 2000 can be used to calculate the proportion of the rural village population that had good or very good access to health and education services at that time, whether or not they still have such access today. When aggregated at a district level, it seems that there were 20 districts in which hardly any rural villager had this level of access, 46 districts in which more than half of them had it, and 10 districts in which all of them had it. Eight of these last 10 districts had gross population densities in excess of 100 people per square kilometre.

4.2.7 Urbanisation

To compensate for the rural village bias inherent in the PNGRIS and MASP datasets, it is necessary to take some account of the way that the population of each district is distributed between rural villages and the two other kinds of census unit recognised in the national census, namely those that belong to urban areas or are classified as 'rural non-villages'.

There are 19 provincial capitals in our sample of 85 districts. Most of the major towns in the sample are provincial capitals, though some of the areas classified as urban areas in the census are associated with mining projects or oil palm schemes. About half of these urban areas, including 11 of the 19 provincial capitals, are located on the coast. Thirty-six of the 85 district headquarters were too small to be classified as urban areas in the 2000 census; they were simply counted as rural non-villages.

In 2000, the 'non-village' population accounted for 13 per cent of the total population living outside of the two major cities, and was equally distributed between urban areas and rural non-villages.[6] The vast majority of these people would have had 'very good' access to health and education services according to the measure adopted in the Rural Development Handbook. One would therefore expect the level of urbanisation in each district, including the proportion of people living in rural non-villages, to have some bearing on measures of human well-being, even if some of the 'non-villagers' were living in relative poverty.

Forty out of the 85 districts had less than 5 per cent of their citizens living in urban or rural non-village census units in 2000. Thirty had more than 10 per cent, and 16 had more than 20 per cent. The only district that had more than 50 per cent was Talasea District in West New Britain Province, which is not only home to the provincial capital but also hosts the two biggest oil palm schemes in PNG.

[6] The proportion is thought to have expanded substantially over the last 20 years, especially in peri-urban areas, but the failure of the 2011 census means that we do not have an accurate measure of this change.

5. Three regression models

Summary statistics for the 14 variables discussed in the previous section of this paper are shown in Table 1. The full set of numbers is shown in Appendix 2.

Table 1: Summary statistics for core variables of interest

Variable	Obs.	Min.	Max.	Mean	Std. dev.
Child mortality	85	26	226	84	40
Gross school attendance	85	13	63	40	13
Flat geography	85	0	98	24	20
Land in use	85	8	100	44	22
Highland fringe dwellers	85	0	43	6	9
Range of altitudes	85	1	20	7	5
Rural mountain dwellers	85	0	100	28	34
Coastal village population	85	0	100	26	36
Gross population density	85	1	283	35	49
Village population density	85	9	463	70	76
Natural agricultural potential	85	0	100	21	26
Modified agricultural potential	85	0	100	32	30
Accessibility for rural villagers	85	0	100	45	40
Level of urbanisation	85	1	55	11	12

We proceed to analyse the relationships between these variables by means of three sets of regressions applied to each of the two dependent variables. We have taken this approach because, with a sample of 85, the number of independent variables of interest is too large to produce meaningful results if they are simultaneously combined in a single set of models. For the first two sets of regressions, we divide the 12 independent variables into two groups of six, as shown in Table 2. From our previous discussion, it should be evident that five of the six pairs of variables divided in this way can be understood as alternative versions of a single variable, so that one could be taken as a proxy for the other. The exception is the pair that consists of rural mountain dwellers and coastal village people, since these are diametrical opposites. There are only five districts that contain some mountain dwellers and some coastal villagers, and none in which both groups account for more than 10 per cent of the rural population.

Table 2: Division of independent variables between two sets of regressions

FOR THE FIRST SET	FOR THE SECOND SET
Flat geography	Land in use
Highland fringe dwellers	Range of altitudes
Rural mountain dwellers	Coastal village population
Gross population density	Village population density
Natural agricultural potential	Modified agricultural potential
Accessibility for rural villagers	Level of urbanisation

We then construct a third set of regressions combining those independent variables from each pair of variables in Table 2 that perform best in the first two sets. The best performing variables are those that most consistently produce statistically significant results across the first two sets of regressions and across both dependent variables. In other words, we have chosen not to explore the differences between the results initially obtained for each of the two dependent variables, but to construct the third set of regressions with the same group of independent variables in order to establish a single measure of their relative importance.

In all three sets of regressions, the results are presented in tables that show the bivariate relationship between the independent variables of interest and the relevant dependent variable (columns 1–6), followed by the multiple regression model in which all six independent variables are tested together (column 7). Multiple regressions reduce the risk that observed relationships between the dependent and independent variables are spurious because they are the product of a third variable that has not been included in the analysis. However, even the use of multiple regressions does not completely eliminate this risk. To further reduce the risk that omitted variables may be driving the results, we also add provincial fixed effects to the regression model (column 8). This effectively eliminates all differences between the 19 rural provinces that existed at the turn of the millennium and gains analytical leverage solely from differences within provinces.[7]

[7] For the purpose of this analysis, the Autonomous Region of Bougainville is treated as one of the 19 provinces.

Adding provincial fixed effects accounts for a suite of potential influences on development outcomes that is associated with the quality of provincial administration. This is potentially important because of the role that provincial governments play in the delivery of health and education services — especially the former (Howes et al. 2014). However, with a small sample of 85 districts, and with 19 provinces, using provincial fixed effects runs the risk of obscuring real findings. For this reason, we use fixed effects primarily as a sort of robustness test in order to enhance confidence in those findings that emerge from the models.

5.1 First set of regressions

Tables 3 and 4 show the results of our first set of regressions applied to each of the two dependent variables. Most of the independent variables are correlated with the dependent variables in the bivariate models, but only some are correlated in the multiple regressions, and the number is reduced again when fixed effects are added. The accessibility variable performs particularly well, being associated with both dependent variables even when fixed effects are included. Gross population density also performs well across both models. Of the other variables, most are associated with school attendance in the full model, but not in the model with fixed effects. None of the other variables except flat geography is associated with the child mortality rate. Of interest is the fact that the sign on the coefficient for natural agricultural potential changes between the bivariate and full models.

Table 3: First regression results with child mortality rate as the dependent variable

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Flat geography	-0.44**						-0.34*	-0.09
	(0.17)						(0.19)	(0.26)
Highland fringe dwellers		1.51***					0.50	0.68
		(0.43)					(0.42)	(0.55)
Rural mountain dwellers			-0.17				0.17	0.53*
			(0.11)				(0.14)	(0.30)
Gross population density				-0.37***			-0.14**	-0.18
				(0.07)			(0.06)	(0.11)
Natural agricultural potential					-0.35**		0.26	0.09
					(0.17)		(0.16)	(0.23)
Accessibility for rural villagers						-0.59***	-0.56***	-0.48***
						(0.09)	(0.12)	(0.14)
Constant	94.97***	76.02***	89.03***	97.59***	91.81***	111.18***	109.93***	74.55***
	(7.27)	(4.48)	(5.34)	(5.15)	(5.64)	(6.52)	(11.19)	(23.94)
Provincial fixed effects	No	No	No	No	No	No	No	Yes
Observations	85	85	85	85	85	85	85	85
R^2	0.05	0.11	0.02	0.21	0.05	0.35	0.43	0.57

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4: First regression results with school attendance rate as the dependent variable

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Flat geography	0.22***						0.11**	0.05
	(0.06)						(0.05)	(0.07)
Highland fringe dwellers		-0.07					-0.07	-0.05
		(0.12)					(0.12)	(0.15)
Rural mountain dwellers			-0.17***				-0.26***	-0.09
			(0.04)				(0.03)	(0.08)
Gross population density				0.07***			0.08***	0.08***
				(0.02)			(0.03)	(0.03)
Natural agricultural potential					0.14***		-0.10**	-0.08
					(0.05)		(0.05)	(0.06)
Accessibility for rural villagers						0.07**	0.11***	0.12***
						(0.03)	(0.03)	(0.04)
Constant	34.36***	39.94***	44.24***	36.98***	36.60***	36.35***	38.91***	51.84***
	(1.97)	(1.64)	(1.50)	(1.69)	(1.86)	(2.14)	(2.89)	(6.30)
Provincial fixed effects	No	No	No	No	No	No	No	Yes
Observations	85	85	85	85	85	85	85	85
R^2	0.12	0.00	0.20	0.08	0.08	0.05	0.48	0.71

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5.2 Second set of regressions

Tables 5 and 6 show the results from the second set of regression models. These are models that use the second set of variables shown in Table 2. Three variables — land in use, range of altitudes, and coastal village population — perform reasonably well with both dependent variables. Village population density is clearly associated with a lower child mortality rate, but the only sign of a relationship between village population density and the school attendance rate is in model 8, and the relationship is fairly weak. Urbanisation is clearly correlated with the school attendance rate, as might be expected, but is not associated with the child mortality rate in the multiple regressions.

Table 5: Second regression results with child mortality rate as the dependent variable

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Land in use	-0.53***						-0.30*	-0.16
	(0.16)						(0.15)	(0.23)
Range of altitudes		3.02***					1.77**	0.82
		(0.75)					(0.87)	(1.06)
Coastal village population			-0.18**				-0.14	-0.37*
			(0.09)				(0.10)	(0.19)
Village population density				-0.31***			-0.27***	-0.17*
				(0.05)			(0.07)	(0.10)
Modified agricultural potential					-0.42***		0.01	-0.24
					(0.14)		(0.15)	(0.18)
Level of urbanisation						-0.68**	-0.25	-0.42
						(0.30)	(0.24)	(0.38)
Constant	107.93***	63.96***	89.69***	103.28***	98.03***	91.97***	108.61***	104.87***
	(8.53)	(6.27)	(6.02)	(5.83)	(6.60)	(5.99)	(15.15)	(26.23)
Provincial fixed effects	No	No	No	No	No	No	No	Yes
Observations	85	85	85	85	85	85	85	85
R^2	0.09	0.13	0.03	0.21	0.10	0.04	0.35	0.55

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Second regression results with school attendance rate as the dependent variable

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Land in use	0.11*						0.08**	0.10**
	(0.06)						(0.04)	(0.05)
Range of altitudes		-1.22***					-0.40*	-0.04
		(0.24)					(0.22)	(0.24)
Coastal village population			0.20***				0.15***	0.13***
			(0.03)				(0.02)	(0.04)
Village population density				0.03			0.03	0.04**
				(0.02)			(0.02)	(0.02)
Modified agricultural potential					0.08*		0.01	0.04
					(0.05)		(0.04)	(0.04)
Level of urbanisation						0.55***	0.33***	0.30***
						(0.10)	(0.09)	(0.08)
Constant	34.59***	47.84***	33.73***	37.63***	36.84***	33.47***	28.60***	38.63***
	(3.08)	(1.98)	(1.50)	(2.08)	(2.18)	(1.67)	(3.35)	(5.82)
Provincial fixed effects	No	No	No	No	No	No	No	Yes
Observations	85	85	85	85	85	85	85	85
R^2	0.04	0.21	0.37	0.02	0.04	0.27	0.56	0.78

Standard errors in parentheses

* p < 0.1, ** p < 0.05, *** p < 0.01

5.3 Regressions with best performing variables

Table 7 highlights the best performing variables from the first two sets of regressions. Tables 8 and 9 show how these six variables perform in a third set of regressions. Accessibility for rural villagers and coastal village population both perform well, being clearly associated with both dependent variables in the multiple regressions and the multiple regressions with fixed effects. Gross population density also performs well. It only ceases to be statistically significant in the fixed effects model with child mortality as the dependent variable.

Table 7: Best performing variables from first two sets of regressions

FROM THE FIRST SET	FROM THE SECOND SET
Flat geography	Land in use
Highland fringe dwellers	Range of altitudes
Rural mountain dwellers	Coastal village population
Gross population density	Village population density
Natural agricultural potential	Modified agricultural potential
Accessibility for rural villagers	Level of urbanisation

As noted above, natural agricultural potential also performs quite well in terms of the frequency of its significance, but the signs on its coefficients are puzzling. In both tables it has the expected bivariate relationships with the dependent variables. Greater natural agricultural potential is associated with higher school attendance rates and lower child mortality rates. However, in the full regression models and the models with fixed effects, when the relationship is statistically significant, it is in the opposite direction: higher agricultural potential is associated with lower school attendance rates and higher child mortality rates. This finding warrants further investigation.

Table 8: Third regression results with child mortality rate as the dependent variable

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Land in use	-0.53***						-0.04	0.05
	(0.16)						(0.14)	(0.23)
Range of altitudes		3.02***					0.96	0.92
		(0.75)					(0.86)	(0.99)
Coastal village population			-0.18**				-0.31***	-0.47***
			(0.09)				(0.11)	(0.18)
Gross population density				-0.37***			-0.16***	-0.16
				(0.07)			(0.06)	(0.10)
Natural agricultural potential					-0.35**		0.29**	0.12
					(0.17)		(0.12)	(0.22)
Accessibility for rural villagers						-0.59***	-0.58***	-0.50***
						(0.09)	(0.13)	(0.14)
Constant	107.93***	63.96***	89.69***	97.59***	91.81***	111.18***	113.91***	97.63***
	(8.53)	(6.27)	(6.02)	(5.15)	(5.64)	(6.52)	(13.55)	(25.07)
Provincial fixed effects	No	No	No	No	No	No	No	Yes
Observations	85	85	85	85	85	85	85	85
R^2	0.09	0.13	0.03	0.21	0.05	0.35	0.49	0.61

Standard errors in parentheses

* p < 0.1, ** p < 0.05, *** p < 0.01

Table 9: Third regression results with school attendance rate as the dependent variable

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Land in use	0.11*						0.01	0.06
	(0.06)						(0.05)	(0.05)
Range of altitudes		-1.22***					-0.36	-0.19
		(0.24)					(0.24)	(0.23)
Coastal village population			0.20***				0.21***	0.18***
			(0.03)				(0.03)	(0.04)
Gross population density				0.07***			0.04*	0.07***
				(0.02)			(0.02)	(0.02)
Natural agricultural potential					0.14***		-0.02	-0.11**
					(0.05)		(0.03)	(0.05)
Accessibility for rural villagers						0.07**	0.07**	0.13***
						(0.03)	(0.04)	(0.03)
Constant	34.59***	47.84***	33.73***	36.98***	36.60***	36.35***	31.04***	42.61***
	(3.08)	(1.98)	(1.50)	(1.69)	(1.86)	(2.14)	(4.04)	(5.88)
Provincial Fixed Effects	No	No	No	No	No	No	No	Yes
Observations	85	85	85	85	85	85	85	85
R^2	0.04	0.21	0.37	0.08	0.08	0.05	0.53	0.79

Standard errors in parentheses

* p < 0.1, ** p < 0.05, *** p < 0.01

5.4 Regressions with a focus on population density

In light of suggestions in the literature that high or growing population densities may have a positive or negative effect on different measures of human well-being, we have run a final set of regressions with a focus on population density as the independent variable and with the three best performing geographical variables from Tables 8 and 9 added as controls. The results are shown in Tables 10 and 11. The full models are run both with and without provincial fixed effects.

We have already seen that there is a clear bivariate relationship between both measures of population density and child mortality rates (see Tables 3 and 5). Child mortality is lower where population density is higher. This relationship continues to be present when controls are added into the full models in Table 10. The relationship is also present when provincial fixed effects are included (in columns 2 and 4).

There is also a positive bivariate relationship between gross population density and school attendance rates (see Tables 4 and 6), but in the case of village population density the relationship is not statistically significant. These findings are also present when controls are added into the full models in Table 11. Furthermore, the relationship becomes statistically significant for village population density as well as gross population density when provincial fixed effects are added (in columns 2 and 4).

In neither case do our findings tell us the direction of the causal relationship between the independent and dependent variables.

Table 10: Fourth regression results with child mortality rate as the dependent variable

	(1)	(2)	(3)	(4)
Gross population density	-0.16**	-0.16**		
	(0.06)	(0.08)		
Village population density			-0.14**	-0.14*
			(0.05)	(0.07)
Coastal village population	-0.36***	-0.52***	-0.38***	-0.52***
	(0.08)	(0.15)	(0.08)	(0.15)
Accessibility for rural villagers	-0.61***	-0.51***	-0.60***	-0.50***
	(0.11)	(0.16)	(0.11)	(0.16)
Natural agricultural potential	0.27**	0.08	0.25**	0.06
	(0.12)	(0.17)	(0.11)	(0.17)
Constant	122.69***	109.78***	125.69***	112.01***
	(8.16)	(31.23)	(8.02)	(31.13)
Provincial fixed effects	No	Yes	No	Yes
Observations	85	85	85	85
R^2	0.48	0.60	0.48	0.60

Standard errors in parentheses

* p < 0.1, ** p < 0.05, *** p < 0.01

Table 11: Fourth regression results with school attendance rate as the dependent variable

	(1)	(2)	(3)	(4)
Gross population density	0.05*	0.08***		
	(0.02)	(0.03)		
Village population density			0.01	0.05**
			(0.02)	(0.02)
Coastal village population	0.23***	0.19***	0.23***	0.19***
	(0.02)	(0.04)	(0.02)	(0.05)
Accessibility for rural villagers	0.08***	0.13***	0.11***	0.13***
	(0.03)	(0.03)	(0.03)	(0.03)
Natural agricultural potential	-0.01	-0.10**	0.01	-0.08*
	(0.03)	(0.04)	(0.03)	(0.04)
Constant	27.80***	42.78***	27.56***	41.35***
	(2.26)	(7.46)	(2.24)	(7.83)
Provincial Fixed Effects	No	Yes	No	Yes
Observations	85	85	85	85
R^2	0.51	0.78	0.50	0.77

Standard errors in parentheses
* p < 0.1, ** p < 0.05, *** p < 0.01

6. Discussion

In any statistical assessment of this kind, it is necessary to consider the possibility that the measurement of a different set of variables would have produced a different set of results, whether or not such measures can be derived from the data sources that are currently available. Given that our dataset is now more than 20 years old, our discussion of the findings reported in the previous section of the paper is not so much concerned with an assessment of the findings themselves as with the question of how the limitations of this dataset might be overcome in the future construction of a second dataset to address the questions posed in our review of the existing literature and data sources.

6.1 Predictable and unexpected findings

In this paper, we have not attempted to test a hypothesis about the relative significance of different geographical constituents of human well-being. We have selected 12 out of a larger number of geographical variables for which we have reasonably accurate measures at a district level around the time of the 2000 national census, and we have made this selection based on predictions made in the international literature, as well as on previous assessments of the determinants of human well-being in PNG. We have then provided our reasons for believing that each of these variables should be associated with at least one of our chosen measures of human well-being.

We were somewhat surprised to find that the level of urbanisation did not perform as well in our regression models as the accessibility of health and education services for rural villagers. That is partly because most of the country's health centres and secondary schools are already located in places that make them more accessible to people living in towns or 'rural non-villages', but it is mainly due to the lack of precision in our measure of accessibility for the rest of the population. That in turn is due to the fact that the Rural Development Handbook assigns a single measure to all the people who occupy a single agricultural system. Since there are, on average, less than four of these agricultural systems in each of our 85 districts, the rural village population in each district is distributed between a very small number of categories. This is equally true of some of the other variables derived from the MASP dataset, like our two measures of agricultural potential, but the agricultural potential of the soil or the environment can readily be understood as an attribute of the agricultural system itself. The time it takes for rural villagers to access some central location is not an 'agronomic condition' but a 'transport condition', and there is no reason to assume that all the occupants of a single agricultural system will take the same amount of time to reach this goal.

We were also somewhat surprised by the seeming absence of a significant relationship between child mortality rates and the proportion of highland fringe dwellers in the rural population. That is because the National Nutrition Survey found that child malnutrition rates were especially pronounced amongst the people who occupied this altitudinal zone in the early 1980s. On the other hand, the relationship might not be detectable in our own statistical analysis because there are only six districts in which the proportion of highland fringe dwellers was greater than 20 per cent at the time of the 2000 national census, so the distinctive features of this minority might be obscured by the average scores for each district.

We were not so surprised to find that our two measures of population density were positively but not especially strongly associated with one or other of our two measures of human well-being. That is because we had grounds for thinking that higher population densities might either be associated with higher levels of access to health and education services — as proved to be the case — or else with the higher levels of what is described as 'agricultural pressure' in the Rural Development Handbook, and hence with the possible presence of a population-environment trap.

6.2 Missing geographical constituents

The 12 geographical variables that we have selected as independent variables for the purpose of this study are primarily related to three or four of the five subgroups of variables that Jeffrey Sachs assigned to the general category of 'physical geography and human ecology'. We have two measures of population density and a number of other variables that have something to do with transport conditions or agronomic conditions. The two variables that we have derived from the PNGRIS dataset (flat geography and land in use) might perhaps be assigned to the subgroup that Sachs calls 'ecosystem functions', but only insofar as the PNGRIS dataset yields a number of criteria for the classification of (terrestrial) ecosystems and a measure of the extent to which these ecosystems were being used for agricultural production around the time of Independence in 1975. Our range of altitude variable, which is not derived from the PNGRIS dataset, could perhaps be taken as a proxy for the range of ecosystems that are being occupied or used for one purpose or another. But what we do not have is anything like a measure of the overall volume or value of the 'ecosystem services' that people in each district have been consuming at any particular moment in time.

Nor does our dataset contain any variables that could clearly be assigned to the category of 'disease ecology'. The mountain-dwelling variable can be taken as a proxy for the proportion of the rural population that is not vulnerable to malaria, since there is no local transmission of either strain of the disease at altitudes above 1,700m (Mueller et al. 2003). However, this variable does not seem to be associated with any significant reduction in child mortality rates, even though small children are known to be especially vulnerable to this disease at lower altitudes. At these lower altitudes, the prevalence of malaria seems to have been associated with population density, and the resulting increase in mortality rates would have placed a limit on further population growth in areas already densely populated (Riley 1983). However, despite the efforts made by the Department of Health and the Institute of Medical Research, we still have no reliable measures of its prevalence, let alone the extent of its contribution to child mortality rates, in all the districts where it is present. Since this one disease has been the primary focus for research on 'disease ecology' in PNG, there is even less information on district-level variations in the prevalence of other diseases that might be associated with variations in child mortality rates.

6.3 A better measure of accessibility

If the accessibility of health and education services for rural villagers has such a significant association with our two dependent variables, despite its lack of precision, we need to ask whether the measure could be refined by detaching it from agricultural systems and reattaching it to individual census units. Given that the geographical location of each census unit is already specified in the 2000 national census data, this refinement can largely be achieved by measuring the distance of each census unit from a 'national road', and then counting the proportion of the rural village population living within a certain distance — say 10km — of such a road. This would certainly be an improvement, though it would not deal with the variable quality of the roads themselves or the availability of vehicles to take advantage of their existence (Allen & Lowe 2006). Nor would it tell us anything about the accessibility of high schools or health centres for people living on small islands that do not contain any national roads, where people have to rely on motor boats to reach these facilities. However, there are only half a dozen districts where the small island population exceeds 5 per cent of the total rural population, and it would not be too difficult to construct a maritime equivalent of the measure of proximity to a national road.

It would be interesting to see whether a more precise measure of accessibility would be more closely correlated with our measure of proximity to a coastline, which is already based on the geographical information system attached to the 2000 national census, and which has turned out to be the second most significant of the geographical variables in our regression models. We might reasonably expect to find a closer correlation because coastal communities on the main island of New Guinea and the larger offshore islands tend to be connected to each other by means of a national road that runs roughly parallel to the coastline. A closer correlation would reinforce the impression already gained from our regressions, which is that 'transport conditions' are more significantly associated with both of our dependent variables than are any of the other types of geographical variable included in our dataset.

6.4 Imperfect measures of human well-being

Each of our two measures of human well-being may be regarded as a proxy for a cluster of variables that should be closely related to each other. The child mortality rate can be treated as a proxy for the cluster that relates to life expectancy, while the school attendance rate can be treated as a proxy for the cluster that relates to levels of education. But the child mortality rate, as measured in the national census, is almost certainly a better proxy for the cluster to which it relates, and the life expectancy cluster as a whole is probably a better indicator of human well-being than the educational cluster, given the way that the variables have been measured.

The most recent Demographic and Health Survey (GPNG 2019a), which was conducted between 2016 and 2018, contains some information on maternal, neonatal and child mortality rates because it attempts to measure the country's progress towards meeting some of the Sustainable Development Goals (including SDG #3). However, it gives no information on variations in these measures between provinces, let alone between districts, nor can we tell whether the information it does contain is sufficiently robust to meet some of the objections made to the way in which these rates have previously been measured (e.g. Mola & Kirby 2013). Only the conduct of a successful national census will suffice for the construction of robust district-level life tables, and even if the forthcoming national census is deemed a success, a good deal of analytical work will still be required to construct such tables.

Our choice of the school attendance rate as the second measure of human well-being might be questioned on the grounds that it does not tell us much more about the acquisition of knowledge than the school enrolment rate. There are two other national census questions that might yield better information on this score. One of them asks for the 'highest formal educational grade completed' by people aged five and over, while the other one asks whether people aged 10 or over can read and write one of the three national languages 'with understanding'. It would not be too difficult to extract a district-level measure of the percentage of citizens with a certain level of formal education from the 2000 national census data, though it seems that no one has so far published this set of numbers, nor have we had the time to make the calculations ourselves. As previously noted, district-level literacy rates obtained from the same source were incorporated into the District Development Index produced by the National Economic and Fiscal Commission in 2004. Although we could have used the literacy rate as our second measure of human well-being, in preference to the school attendance rate, we decided not to do so because of the findings reported from an Education Experience Survey and Literacy Assessment that was conducted in five provinces (including the National Capital District) between 2009 and 2010 (ASPBAE & PEAN 2011).

This survey found that actual or functional literacy rates were well below the self-declared rates contained in the national census data — on average 12.5 per cent when compared to the internationally reported (and self-declared) national average of 52 per cent. Inclusion of the self-declared rate in our own dataset would therefore give a misleading impression. The authors of the survey report did suggest a rough correlation between the functional literacy rate and each of the three educational variables measured in the national census, but this could not be demonstrated with a sample of only five provinces. There is a strong correlation (r = 0.86) between the school attendance rates and the self-declared literacy rates derived from the 2000 national census, so the former might still be taken as a proxy for the educational cluster as a whole.[8] In the absence of any reliable census data since that time, the best substitute would be the school examination results collected by the Department of Education, although these are not

[8] The correlations between the self-declared literacy rates in 2000 and the gross or net school enrolment rates reported by the Department of Education in 2007 are much weaker — 0.55 and 0.48, respectively.

currently published in a form that would allow for the construction of such a measure at either a provincial or district level.

6.5 Well-being and development

In this paper we have avoided the temptation to produce a district-level version of the UN Human Development Index that would be comparable to the one produced by PNG's National Economic and Fiscal Commission in 2004. That is because we do not have an accurate district-level measure of average personal incomes, let alone a district-level measure of economic inequality. The closest approximation would be the imputations made from the 1996 National Household Survey, which were included in the 2004 District Development Index. However, we decided that the resultant 'standard of living index' could not be treated as a dependent variable in our regression models because geographical variables derived from the PNGRIS and MASP datasets had been used to stratify the original survey sample and then to make the district-level projections from that sample. The estimates of 'incomes from village agriculture' made by the authors of the Rural Development Handbook on the basis of observations made in the 1990s are likewise problematic because, like the measure of accessibility, they are only estimates attached to different agricultural systems, and do not take account of other sources of income at either the village level or the district level (Hanson et al. 2001). Although these estimates have since been revised and updated at a national level (Allen et al. 2009), the results do not enable a comparable revision to be made at a district level. Nor can any district-level projections be made from the latest Household Income and Expenditure Survey (GPNG 2010b).

Given the way that we have framed our problem around the distinction between geographical variables and measures of human well-being, it is not even clear whether a measure of 'economic development' should be assigned to the first or second of these categories. That is because most of the economic activity that takes place in the 85 partially rural districts belongs to the primary sector of the economy, and therefore involves the modification or transformation of the natural landscape.

Nor is it obvious what Papua New Guineans actually mean when they deplore the lack of 'development' in many parts of the country. On one hand, they often seem to be complaining about the failure of their government to deliver more in the way of public goods and services; on the other hand, they often seem to be complaining about the absence of public or private investment in major 'development projects' that would radically transform the local landscape (GPNG & UNDP 2014). They rarely seem to be thinking about village agriculture or any other kind of small-scale economic activity, since these things are already taken for granted as the basis of most people's livelihoods, even if most villagers would prefer the security of a wage-earning job, either for themselves or their children.

From the variables within our own dataset, the one that most closely approximates a conventional measure of economic development would be the level of urbanisation, since people living in urban areas and rural non-villages are far more reliant on the market economy to sustain their livelihoods. As we have seen, the level of urbanisation appears to be a geographical constituent of higher school attendance rates in our regression models, but does not seem to have a parallel association with lower child mortality rates. The absence of an association with child mortality rates is primarily a reflection of the fact that 69 out of 85 districts had more than 80 per cent of their populations living in rural villages in 2000, and what seems to matter for the rural village population is the accessibility of the health services available in urban areas.

6.6 Geography and history

Since we have only been able to produce a statistical snapshot of the relationship between a range of geographical variables and two measures of human well-being at a single moment in time, there is not much that we can add to debate about the presence of a poverty-environment trap or a population-environment trap in different parts of the country in the absence of measures of change on both sides of these two equations. We can produce measures of change in a number of demographic variables at the district level — including the child mortality rate — over the period from 1980 to 2000.

What we currently lack are parallel measures of the rate of environmental degradation at this same level.

Since the authors of the MASP dataset took the trouble to reassign the 1980 census units to the new district boundaries established in 1995, we have reasonably accurate measures of the overall rate of population growth in each district during the period from 1980 to 2000. We have not included the rate of population growth as one of the geographical variables in the present study because it is partly influenced by the child mortality rate, which is one of our dependent variables. Nor do we know how much of the rate of population growth was determined by the rate of natural increase, the level of migration between districts, or failures of enumeration in the 2000 census.[9] If we wanted to investigate the presence of a poverty-environment trap or a population-environment trap, we would need to have a measure of environmental degradation that might or might not be associated with changes in the child mortality rate or the overall population growth rate.

The authors of the Rural Development Handbook tried to assess the risk of environmental degradation by pinpointing those agricultural systems in which high village population densities were associated with low levels of agricultural potential. In our own regression models, neither of these variables appears to have a strong relationship with low measures of human well-being, so we have very little evidence of a poverty-environment trap as opposed to a population-environment trap. Satellite imagery might yield a more direct measure of decline in 'vegetation vigour' at a district level over the period in which we are interested (Barbier & Hochard 2018; Heger et al. 2018), but we have not been able to access the relevant datasets for the purpose of this paper.

We do know that donor-funded consultants to the PNG Forest Authority (PNGFA) have used satellite imagery to assess the rate of deforestation over the period from 2000 to 2015, both at national and provincial levels (GPNG 2019b), and this assessment could be

[9] It is generally agreed that the population figures in the 1990 census were less reliable than those in the 2000 census, which were in turn somewhat less reliable than those in the 1980 census (World Bank 2004), while the figures produced by the 2011 census were almost entirely meaningless (Allen 2014).

extended down to the district level, but the dataset has not been placed in the public domain. It is also possible to obtain a proxy measure of the extent to which forests have been converted to croplands over this same period by calculating the volume of round log exports from areas over which the PNGFA has granted forest conversion concessions for large-scale agricultural projects (Filer 2019; Gabriel et al. 2017).[10] However, although most of these concessions can be assigned to specific districts, there is no good reason to suppose that the rate of deforestation would be associated with changes in the child mortality rate or the overall rate of population growth over previous decades. Most of PNG's large-scale logging concessions cover plains and fans that make for what we have called 'flat geography', are generally within 100km of a coastline, and at altitudes below 200m. Insofar as forest conversion concessions remove large areas of land from the subsistence economy, they would exert additional pressure on village agricultural systems. However, the number of districts significantly affected by this change in land use is still quite small.

It has previously been argued that the rate of deforestation and forest degradation across the whole of PNG was already increasing at a quite alarming rate in the period from 1972 to 2002, and that village agriculture was responsible for roughly half of the loss (Shearman et al. 2008). If the rate of deforestation can be taken as a measure of environmental degradation, this would seem to indicate the presence of a population-environment trap, if not a poverty-environment trap, in many parts of the country. However, the study in question overestimated the extent of forest cover at the beginning of that period and made the false assumption that secondary forest fallows cleared by swidden farmers fail to regenerate after the land has been cultivated for one or two years (Filer et al. 2009). If and when the more recent satellite imagery is made available by the PNGFA, it might provide some evidence that forest fallow periods are getting shorter, or that swidden farmers are clearing areas of primary forest that were not previously used for agriculture. Nevertheless, it is unlikely that this kind of population-environment trap

[10] Large-scale forest conversion concessions were not being granted in the period between 1975 and 2005.

will be found to extend beyond agricultural systems that have already been identified as high-pressure systems by the authors of the Rural Development Handbook.

6.7 Evidence of trade-offs

If it is difficult to determine the presence of a poverty-environment trap in particular parts of the country, it is equally difficult to see how measures taken to alleviate rural poverty would necessarily be consistent with measures taken to protect the natural environment or halt any process of environmental degradation that might be taking place. Like many other tropical countries, PNG has hosted a number of 'integrated conservation and development projects' based on the assumption that these goals are mutually consistent, but the experience of their implementation suggests that this assumption may be false (McCallum & Sekhran 1997; van Helden 1998).

Insofar as rural villagers exhibit some level of enthusiasm for large-scale development projects that are likely to damage the natural environment, it might be argued that they are suffering from some kind of false consciousness because of the way that they understand the concept of 'development' (Anderson 2005). But if it is true that access to public goods and services is one of the primary determinants of human well-being for rural villagers, as seems to be the case, then their desire for more and better roads is a perfectly reasonable reflection of their desire for an improvement in their overall standard of living (Gibson & Rozelle 2003). The only trouble is that the fulfilment of this desire may not be so good for the maintenance of biodiversity values or some of the ecosystem services that underpin their subsistence economy if roads facilitate deforestation (Alamgir et al. 2019). So what we have here is not so much a vicious circle or downward spiral as a simple trade-off between the benefits of a better transport network and the costs of environmental degradation, which may be a trade-off between short-term gains and long-term pain.

A similar dynamic may well be at work in the coastal zone, where communities are often linked by a road that runs along the coastline, or can otherwise access urban centres with motor boats. Here again, improvements in the level of access to urban markets may be associated with an increase in the rate at which marine resources are harvested for sale, and this may also prove to be unsustainable (Cinner & McClanahan 2006). So, if villagers living within 10km of a coastline have higher levels of well-being, rapid population growth may still be eroding their subsistence base.

These trade-offs would be a matter of more concern if the PNG Government had been able to implement its plans to improve local transport networks over the course of the last two or three decades. However, the targets specified in long-term and medium-term development plans have generally not been met, so the threat posed to the health of forest and marine ecosystems has been correspondingly reduced. If the targets had been met, then the measures applied to the two independent variables that appear to have the most significant effect on human well-being in our regression models would be seriously out of date by now. On the other hand, it can be argued that geographical constraints to any major improvement in transport conditions simply constitute an incentive for rural villagers to migrate in the direction of major service centres, and thus alleviate the pressures of population growth on the natural environments they currently inhabit (Allen et al. 2005).

There is one final trade-off that may be obscured by the results of our regressions. Politicians and public servants might take these results as evidence that more public money should be devoted to the construction of new roads, or to the maintenance of those that already exist, on the assumption that this is the best way to improve the well-being of the rural population. However, an improvement in the level of access to health and education services does not entail an automatic improvement in the quality of those services. So, if there is a choice to be made between spending on one or other of these two things, it is not at all obvious that an improvement in transport conditions should take priority (Allen et al. 2005; Gibson & Rozelle 2003; Howes et al. 2014). And since the quality of health and education services is an institutional variable, not a geographical one, the existence of this choice and this trade-off should alert us to a question not so far posed in this paper, which is whether geographical constituents of human well-being are more or less significant than institutional constituents.

7. Conclusion

By way of conclusion, we return to the question posed at the beginning of this paper, which is how we might now set about the task of producing a new version of the Rural Development Handbook that would not only take account of the statistical evidence we already possess but make a substantial addition to this body of evidence. After all, it hardly makes sense to base political decisions about the allocation of resources between districts on evidence that is now more than 20 years out of date.

Much clearly depends on the outcome of the national census scheduled for the middle of 2021. There is no great cause for optimism on this score, given the failure of the 2011 census and the additional complications arising from the coronavirus epidemic. Even if the upcoming census is deemed a success, relevant district-level datasets might not appear for another three or four years, if at all. If there is a substantial undercount, district-level figures may not be sufficiently reliable to warrant publication or analysis. And even if the figures are sufficiently reliable, officers of the National Statistical Office might not be able to produce a new set of indicators, especially for the variables in our life expectancy cluster, without the support of international agencies and experts, and that support might not be requested or supplied (Bourke & Allen 2021).

What about other sources of data?

Satellite imagery can tell us quite a lot about changes in the physical landscape over the course of the past two decades, including changes in some of the geographical variables that have not been included in our own dataset. However, as we have noted in the case of deforestation rates, the imagery may not tell a simple story, even when matched to current district boundaries, partly because of technical questions of interpretation, but mostly because of arguments about the factors or drivers responsible for the changes that are documented in this way.

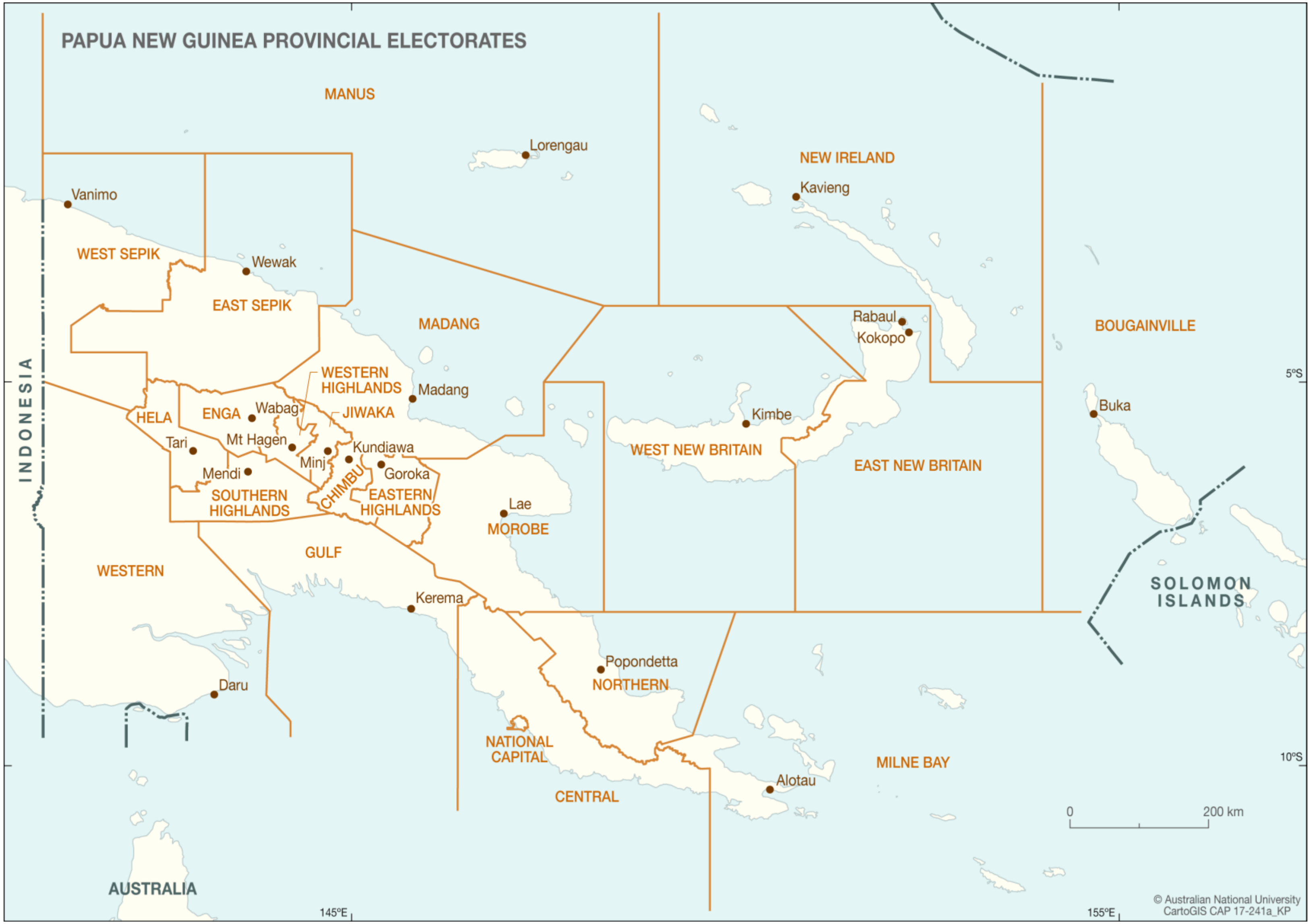
Satellite images of night lights, or measures of 'luminosity', have been used as a proxy for levels of economic activity, at both a national and subnational level, in countries where conventional statistical measures of economic output or incomes are absent or defective

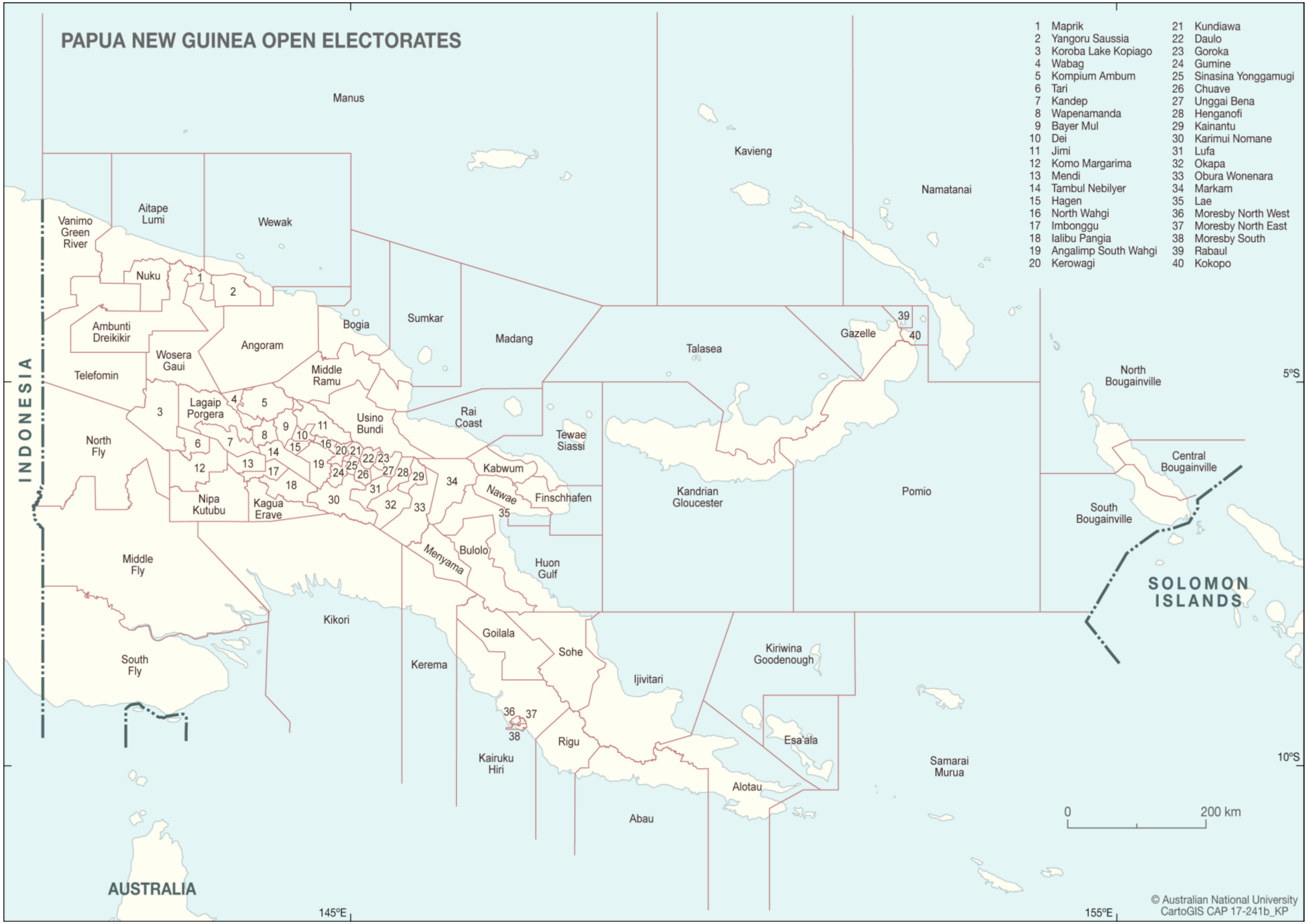
(Henderson et al. 2012). However, in countries like PNG, such imagery only serves as a proxy for the level of urbanisation or industrialisation, since the only lights that are sufficiently bright to be recorded by the satellites are those emanating from townships or large-scale resource projects (Gibson et al. 2020). This means that the rural village population, which still accounts for as much as 80 per cent of the total population of PNG, is consigned to a state of total economic darkness or backwardness.

If satellite imagery tells us little or nothing about spatial or temporal variations in levels of household income, it tells us even less about variations in the indicators of human well-being that we have assigned to the life expectancy cluster or the educational cluster. Nor does it seem possible to derive district-level measures of human well-being from the national sample surveys conducted by the National Statistical Office in the intervals between each national census. Without such measures, it is hard to see how any assessment can be made of the risk that people in some parts of the country are falling into a population-environment trap or a poverty-environment trap.

So, if the forthcoming national census is unable to fill the gap, the only other way to assess this risk would seem to be a different kind of survey that targets those parts of the country that are known to be more vulnerable because of the extent of the geographical and environmental transformations already documented from other sources. One such survey could be directed towards the people who occupy the relatively small number of agricultural systems that are shown in the Rural Development Handbook as systems with 'very strong agricultural pressure' or 'strong pressure and very low incomes'. Another could be directed towards the people who live in areas where environmental degradation has resulted from large-scale logging or mining operations rather than the 'pressure' exerted by local farmers, especially areas where mines have closed or logging operations have come to an end. But neither exercise would be cheap or easy to undertake.

Appendix 1: Provinces and districts of Papua New Guinea




PAPUA NEW GUINEA OPEN ELECTORATES
1 Maprik
2 Yangoru Saussia
3 Koroba Lake Kopiago
4 Wabag
5 Kompium Ambum
6 Tari
7 Kandep
8 Wapenamanda
9 Bayer Mul
10 Dei
11 Jimi
12 Komo Margarima
13 Mendi
14 Tambul Nebilyer
15 Hagen
16 North Wahgi
17 Imbonggu
18 Ialibu Pangia
19 Angalimp South Wahgi
20 Kerowagi
21 Kundiawa
22 Daulo
23 Goroka
24 Gumine
25 Sinasina Yonggamugi
26 Chuave
27 Unggai Bena
28 Henganofi
29 Kainantu
30 Karimui Nomane
31 Lufa
32 Okapa
33 Obura Wonenara
34 Markam
35 Lae
36 Moresby North West
37 Moresby North East
38 Moresby South
39 Rabaul
40 Kokopo
Manus
Kavieng
Namatanai
Vanimo Green River
Aitape Lumi
Wewak
Nuku
Ambunti Dreikikir
Wosera Gaui
Angoram
Bogia
Sumkar
Madang
Talasea
Gazelle
Telefomin
Middle Ramu
Lagaip Porgera
Usino Bundi
Rai Coast
Tewae Siassi
North Fly
Kabwum
Nawae
Finschhafen
Nipa Kutubu
Kagua Erave
Kandrian Gloucester
Pomio
North Bougainville
Central Bougainville
South Bougainville
Menyama
Bulolo
Huon Gulf
Middle Fly
Kikori
Kerema
Goilala
Sohe
Ijivitari
Kiriwina Goodenough
South Fly
Esa'ala
Rigu
Kairuku Hiri
Samarai Murua
Alotau
Abau
INDONESIA
SOLOMON ISLANDS
AUSTRALIA
5°S
10°S
145°E
155°E
0
200 km
© Australian National University
CartoGIS CAP 17-241b_KP

Appendix 2: Variables used in this study

Measures of human well-being

Code	Description	Sources
CHM	The **under-five (child) mortality rate** (deaths per 1,000 live births), averaged over the period from 1995 to 1999	2000 national census data (Tran et al. 2011)
GSA	The **gross school attendance rate**, calculated as the number of pupils enrolled in school as a percentage of school-age children in 2000	2000 national census data (GPNG 2004)

Geographical variables

Code	Description	Sources
GGY	**Flat geography,** calculated as the percentage of a district's total land/surface area that is neither inundated nor hilly and mountainous	PNGRIS dataset
LIU	**Land in use**, calculated as the percentage of a district's total land/surface area used for agriculture or occupied by human settlements between 1975 and 2000	PNGRIS and MASP datasets
HLF	Proportion of **highland fringe dwellers**, calculated as the percentage of the rural citizen population living at altitudes between 600 and 1200 metres in 2000	Topographic map series and 2000 national census data
ROA	**Range of altitudes** (at intervals of 100m) occupied by more than 90 per cent of the rural citizen population in 2000	Topographic map series and 2000 national census data
MTN	Proportion of **mountain dwellers**, calculated as the percentage of the rural citizen population living at altitudes above 1800 metres in 2000	Topographic map series and 2000 national census data
CST	Proportion of **coastal people**, calculated as the percentage of the rural village (citizen) population living within 10km of a coastline in 2000	Geolocation of 2000 national census units
GPD	**Gross population density**, calculated as the average number of resident citizens per square kilometre of a district's total surface area in 2000	2000 national census data
VPD	**Village population density**, calculated as the average number of rural villagers per square kilometre of land used for village agriculture in 2000	MASP dataset with 2000 population estimates
NAP	**Natural agricultural potential**, calculated as percentage of rural villagers using land with high or very high natural fertility in 2000	PNGRIS dataset with population estimates
MAP	**Modified agricultural potential**, calculated as percentage of rural villagers using land with high or very high modified fertility in 2000	PNGRIS and MASP datasets with population estimates
ACS	**Accessibility**, calculated as the percentage of the rural village population with good (or very good) access to (health and education) services in 2000	MASP dataset
URB	Degree of **urbanisation**, calculated as the percentage of the citizen population resident in 'urban' or 'rural non-village' census units in 2000	2000 national census data

Table A1: Values of variables by district (Southern and Highlands Regions)

District name	CHM	GSA	FGY	LIU	HLF	ROA	MTN	CST	GPD	VPD	NAP	MAP	ACS	URB
MIDDLE FLY	97	50	76	8	0	3	0	26	1	13	0	4	0	15
NORTH FLY	86	58	51	25	13	7	0	0	2	5	0	0	0	40
SOUTH FLY	71	55	78	8	0	1	0	56	1	13	0	0	22	31
KEREMA	164	33	10	42	15	15	2	47	9	18	15	15	6	13
KIKORI	94	39	37	10	4	1	0	84	2	14	0	0	0	15
ABAU	53	59	19	17	1	1	0	94	5	26	0	18	52	17
GOILALA	124	22	4	22	10	11	39	0	4	16	0	0	9	3
KAIRUKU-HIRI	45	56	13	20	6	2	0	62	8	31	5	5	93	22
RIGO	43	52	5	39	6	5	0	53	8	19	7	7	73	5
ALOTAU	77	55	17	44	13	8	0	78	10	17	19	39	33	23
SAMARAI-MURUA	77	48	30	39	0	1	0	100	14	34	29	34	31	5
KIRIWINA-GOODENOUGH	85	41	50	58	1	2	0	100	45	75	15	21	0	3
ESA'ALA	105	49	19	56	1	1	0	99	18	32	29	63	0	2
IJIVITARI	72	43	36	24	19	9	0	62	5	17	18	23	26	23
SOHE	72	36	25	15	11	7	0	6	6	36	57	62	79	17
IALIBU-PANGIA	59	29	16	46	0	7	50	0	21	45	0	25	41	3
IMBONGGU	94	31	60	61	0	7	88	0	58	95	17	57	94	1
KAGUA-ERAVE	100	18	9	27	3	8	44	0	16	55	36	41	76	3
KOMO-MAGARIMA	80	13	35	25	0	12	67	0	16	63	0	33	8	2
KOROBA-LAKE KOPIAGO	86	20	2	29	3	12	71	0	13	44	0	27	0	4
MENDI	71	29	34	41	0	5	100	0	71	159	16	19	69	9
NIPA-KUTUBU	83	19	24	12	14	15	66	0	14	119	0	7	56	2
TARI-PORI	49	23	51	54	0	4	84	0	40	73	27	68	0	3
KANDEP	149	19	15	27	0	4	100	0	24	85	0	15	0	1
KOMPIAM-AMBUM	56	24	4	39	6	13	61	0	15	38	0	7	41	2
LAGAIP-PORGERA	85	26	2	23	0	9	98	0	20	81	0	6	55	4
WABAG	70	43	5	36	0	9	99	0	54	136	0	36	77	8
WAPENAMANDA	71	39	23	45	0	7	87	0	51	110	0	75	86	3
ANGALIMP-SOUTH WAHGI	52	37	19	27	0	3	30	0	49	141	24	71	97	23
DEI	67	29	40	58	1	5	28	0	86	135	53	87	98	10
HAGEN	49	49	74	100	0	4	69	0	166	106	45	72	100	36
JIMI	83	23	5	55	6	8	24	0	16	28	2	4	0	2
MUL-BAIYER	61	38	48	55	1	10	47	0	41	73	1	60	60	3
NORTH WAHGI	33	39	37	66	0	3	30	0	114	150	49	70	100	13
TAMBUL-NEBILYER	78	29	32	100	0	12	52	0	33	32	38	57	100	3
CHUAVE	51	43	0	83	0	5	84	0	66	76	19	23	100	3
GUMINE	40	36	7	53	0	7	60	0	51	95	18	22	90	1
KARIMUI-NOMANE	189	27	24	25	18	12	48	0	10	41	0	0	7	2
KEROWAGI	37	42	10	64	0	5	48	0	100	145	69	89	100	8
KUNDIAWA-GEMBOGL	26	54	1	49	0	9	94	0	123	211	15	31	100	17
SINASINA-YONGGOMUGL	43	49	1	85	0	6	80	0	106	123	20	20	100	1
DAULO	40	44	19	52	0	6	70	0	50	90	38	49	99	5
GOROKA	34	54	48	66	0	5	36	0	242	252	57	72	100	31
HENGANOFI	54	32	6	68	0	5	70	0	59	86	0	13	99	2
KAINANTU	74	40	11	65	0	7	51	0	92	126	0	1	97	12
LUFA	73	32	5	47	0	6	54	0	34	71	28	30	95	1
OBURA-WONENARA	151	13	2	39	2	8	62	0	8	19	0	5	49	2
OKAPA	86	37	0	53	0	5	78	0	29	54	6	6	42	2
UNGGAI-BENA	53	40	10	69	0	7	35	0	49	69	33	46	97	1

Table A2: Values of variables by district (Momase and Islands Regions)

District name	CHM	GSA	FGY	LIU	HLF	ROA	MTN	CST	GPD	VPD	NAP	MAP	ACS	URB
BULOLO	119	37	4	28	43	14	9	0	11	24	11	15	54	39
FINSCHHAFEN	97	45	5	49	28	15	1	36	17	32	0	0	0	8
HUON GULF	64	45	13	26	4	2	0	47	8	23	2	4	1	27
KABWUM	117	41	1	35	5	11	31	0	15	42	0	0	0	2
MARKHAM	78	35	23	31	26	13	0	0	11	35	0	30	55	3
MENYAMYA	226	13	0	58	3	9	24	0	18	31	1	6	0	3
NAWAE	103	49	13	31	26	15	5	26	11	33	3	5	0	8
TEWAE-SIASSI	75	41	41	42	23	17	8	81	17	39	23	35	0	5
BOGIA	96	38	15	53	0	3	0	52	14	25	0	2	4	6
MADANG	54	52	8	97	2	3	0	55	34	20	16	16	80	42
MIDDLE RAMU	152	20	11	52	9	18	16	0	8	15	0	0	0	2
RAI COAST	124	32	16	42	17	18	8	57	10	24	1	1	1	3
SUMKAR	71	46	22	86	3	4	0	92	33	35	67	67	22	9
USINO-BUNDI	118	28	21	50	15	14	6	0	5	8	1	1	4	20
AMBUNTI-DREIKIKIR	160	33	13	22	4	4	0	0	5	22	39	54	32	4
ANGORAM	160	28	11	11	1	1	0	10	4	32	11	11	7	7
MAPRIK	103	41	30	66	0	3	0	0	53	77	70	90	97	4
WEWAK	97	58	10	78	0	3	0	78	28	20	12	12	20	44
WOSERA-GAWI	55	38	11	15	0	1	0	0	5	36	44	58	59	3
YANGORU-SAUSSIA	95	49	42	53	2	4	0	0	18	33	28	66	68	1
AITAPE-LUMI	106	41	25	22	18	7	0	53	9	37	56	61	0	11
NUKU	151	30	20	65	17	6	0	0	13	20	86	86	0	2
TELEFOMIN	144	31	20	15	9	20	32	0	2	14	0	0	0	3
VANIMO-GREEN RIVER	161	30	32	24	7	5	0	17	5	16	53	53	8	22
MANUS	56	63	33	87	0	3	0	99	22	20	13	16	16	19
KAVIENG	60	50	51	57	0	1	0	100	18	25	3	16	86	19
NAMATANAI	64	51	18	38	2	1	0	100	10	24	8	34	20	7
GAZELLE	58	56	20	32	4	3	0	73	24	61	82	84	92	20
KOKOPO	41	62	98	51	0	3	0	100	142	226	89	100	100	19
POMIO	131	43	10	18	18	8	0	58	4	20	5	7	0	15
RABAUL	32	62	29	61	0	2	0	95	283	316	100	100	100	32
KANDRIAN-GLOUCESTER	82	37	33	34	1	3	0	78	4	12	9	14	0	8
TALASEA	61	50	26	20	0	2	0	94	16	36	21	21	51	55
NORTH BOUGAINVILLE	74	55	52	55	1	2	0	99	24	42	53	64	57	5
CENTRAL BOUGAINVILLE	61	54	39	57	28	9	0	56	16	26	78	78	58	6
SOUTH BOUGAINVILLE	41	61	60	51	4	5	0	27	16	31	3	3	4	3

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