Pro-Poor
Livestock
Policy
Initiative

Geographic Dimensions of Livestock Holdings in Vietnam

Spatial Relationships among Poverty, Infrastructure and the Environment

Michael Epprecht

A Living from Livestock

PPLPI Working Paper No. 24

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PREFACE

This is the 24th of a series of Working Papers prepared for the Pro-Poor Livestock Policy Initiative (PPLPI). The purpose of these papers is to explore issues related to livestock development in the context of poverty alleviation.

Livestock is vital to the economies of many developing countries. Animals are a source of food, more specifically protein for human diets, income, employment and possibly foreign exchange. For low income producers, livestock can serve as a store of wealth, provide draught power and organic fertiliser for crop production and a means of transport. Consumption of livestock and livestock products in developing countries, though starting from a low base, is growing rapidly.

This Working Paper presents the results of an analysis of spatial data relevant to livestock production Vietnam. The paper introduces the types of spatial data that are relevant and available for Vietnam; provides a geographic overview of livestock holding patterns in Vietnam; presents the results of a spatially explicit explorative analysis of relationships among livestock holding patterns, poverty, environment and infrastructure; and outlines possible directions for further analyses towards enhancing understanding of these linkages.

We hope this paper will provide useful information to its readers and any feedback is welcome by the author, PPLPI and the Livestock Information, Sector Analysis and Policy Branch (AGAL) of the Food and Agriculture Organization (FAO).

Disclaimer

Author

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Keywords

Vietnam, poverty, livestock, spatial analysis

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LIST OF ABBREVIATIONS

AGA	Animal Production and Health Division of FAO
FAO	Food and Agricultural Organization of the United Nations
FIPI	Forest Inventory and Planning Institute
GIS	Geographic Information System
GSO	General Statistics Office
GWR	Geographically weighted regression
IDS	Institute of Development Studies
IFPRI	International Food Policy Research Institute
MOLISA	Ministry of Labour, Invalids and Social Affairs
NASA	National Aeronautics and Space Administration
PPLPI	Pro-Poor Livestock Policy Initiative of FAO
RAFC	Rural and Agriculture and Fisheries Census
SRTM	Shuttle Radar Topography Mission
USGS	United States Geological Survey
VLSS	Vietnam Living Standards Survey
VHLSS	Vietnam Household Living Standards Survey
VTGEO	Vietnam Center for Remote Sensing and Geomatics

Abbreviations of agro-ecological regions and cities in Vietnam

RRD	Red River Delta
NE	North-East
NW	North-West
NU	Northern Uplands
NCC	North-Central Coast
SCC	South-Central Coast
CH	Central Highlands
MRD	Mekong River Delta
HCMC	Ho Chi Minh City

INTRODUCTION

For a large number of the world's poor, livestock play a crucial role in their livelihoods. Livestock-related policy decisions, however, are often based on sparse and generalized information. Better information and knowledge on livestock production patterns, and their relationships with structural and environmental realities, is therefore crucial for effective pro-poor policy making. The geographically heterogeneous nature of these factors illustrates the need for an explicit spatial dimension in information and knowledge development.

With the overall objectives of:

- contributing to characterizing and systematically targeting livestock-dependant poor,
- contributing to understanding the factors that affect poor people's livestock-related livelihoods,
- supporting the evaluation of livestock policy options, and
- facilitating decision support by stakeholders in livestock policy making,

the Pro-Poor Livestock Policy Initiative (PPLPI) seeks to develop tools to analyze the impacts of existing policies and to make pro-poor and environmentally sound and sustainable policy recommendations. To support the development of such spatially explicit decision support tools, appropriate input data sets are required and suitable analytical methods need to be developed.

The benefits of including methods based on Geographic Information Systems (GIS) for the purpose of illustrative mapping, as well as for spatially explicit analysis are increasingly being realized. The fields of application of GIS in the development of pro-poor decision support tools can be summarized in four main categories:

- Integrating data bases

  → information management
- Visualizing spatial distributions, relationships, processes etc.

  → information communication and dissemination
- Analyzing relationships in space

  → information development
- Modelling processes in space

  → information development and decision support

This Working Paper provides an introductory overview of a compilation and analysis of spatial data relevant to livestock production Vietnam. Divided into four main chapters, this paper

- introduces the types of relevant spatial data that are available for Vietnam,
- provides a geographic overview of livestock holding patterns in Vietnam, based on data available from the 2001 Rural and Agriculture and Fisheries Census (RAFC),
- describes the applied methods and presents the results of a spatially explicit explorative analyses of linkages among livestock holding patterns, poverty, the environment, and aspects of 'accessibility', based on data from the Vietnam Household Living Standards Survey (VHLSS) 2002, and
- outlines recommendations for further analysis in collaboration with ongoing efforts of the PPLPI, and of FAO in its wider context.

SPATIAL DATA FOR VIETNAM

An analysis to explore the patterns of livestock holdings in Vietnam, and their relationships to the natural and structural environment, requires certain types of data to be included, in particular, spatial data on:

- livestock,
- poverty,
- the environment, and
- transport infrastructure.

These data are generally presented either as GIS data sets, or as tabular data with explicit geo-references such as geo-coordinates of administrative codes. In the following, the main data sets on these four topics are described and illustrated.

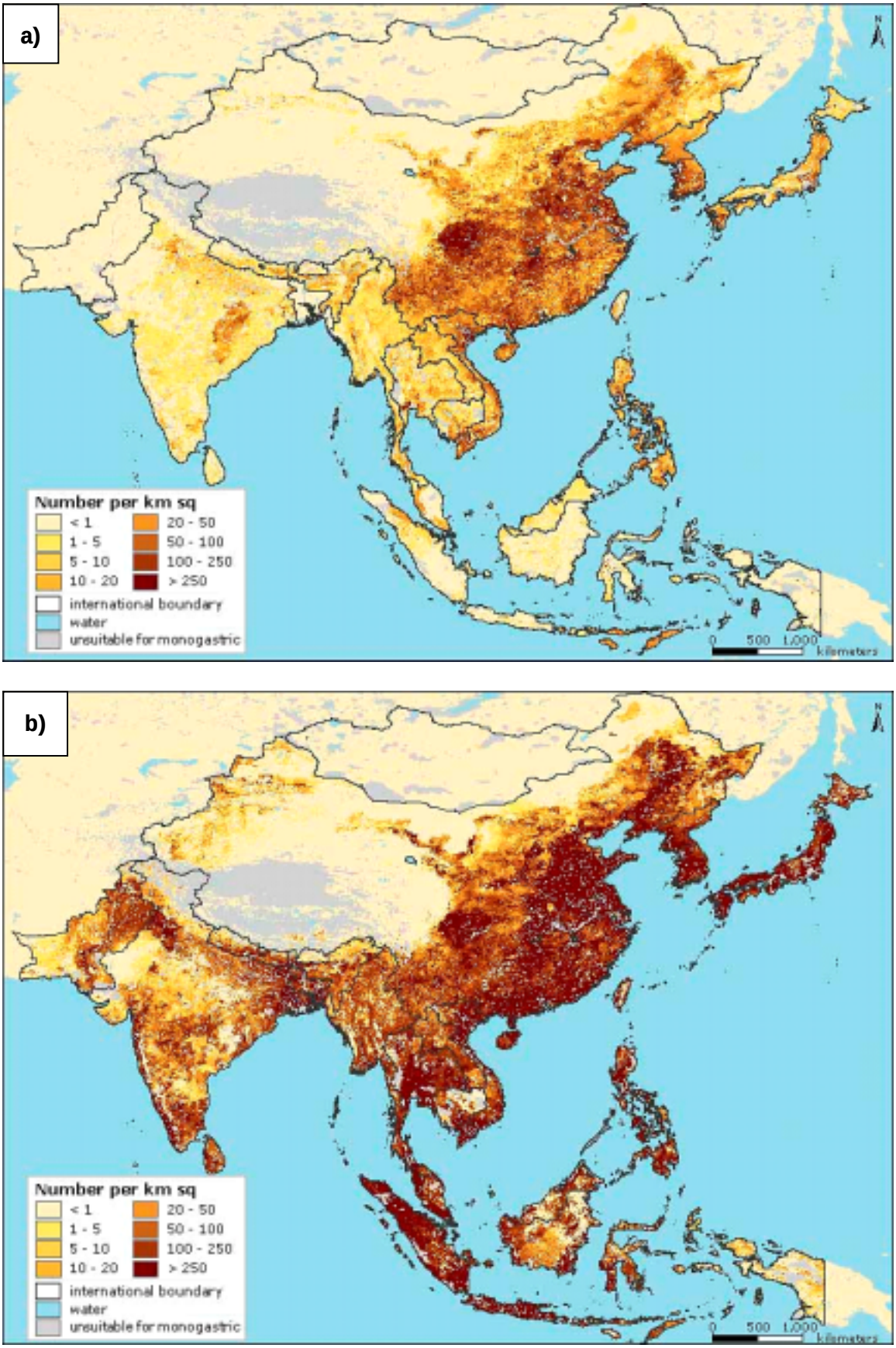
Livestock

Spatial data

There are very few livestock specific GIS data available in Vietnam. At present, the most detailed and up-to-date national (and regional) coverage of livestock data in GIS format are those developed under FAO-AGA's global livestock mapping project[1]. Available data sets include 3-minute (~5km) gridded estimates of densities of cattle, buffalo, small ruminants, pigs and poultry (heads/km^2). Figure 1 provides examples of the distributions of pigs and poultry for Southeast Asia. The data sets were developed through spatial disaggregation of available sub-national statistics, based on multivariate modelling with remotely sensed and other environmental data.

[1] These, and gridded livestock data for other regions of the world can be downloaded through FAO's GeoNetwork portal: http://www.fao.org/geonetwork/srv/en/main.search

Figure 1: *Gridded estimates of a) pig densities and b) poultry densities in Southeast Asia.*



Source: FAO-AGA 2004

These data sets provide very detailed pictures of spatial distributions of livestock in Southeast Asia, but their use for spatial analysis of livestock-environment and livestock-accessibility linkages might be problematic, since the spatial disaggregation of the original sub-national livestock numbers was based on many of the same environmental datasets with which we hope to identify linkages in the present analysis.

Geo-referenced tabular data

Geo-referencable statistical data on livestock that are presently available are largely limited to annual provincial livestock production numbers, and are spatially too coarse to be useful in the present analysis.

Living Standards Survey data provide a wealth of information on household-level livestock production patterns, though the data can be referenced to their respective survey location only, and cannot directly be used to estimate complete geographical coverage.

The 2001 Rural Agriculture and Fisheries Census includes data on the agricultural production of each rural household, and of each urban household involved in agriculture. These data could be geo-referenced to commune-level, allowing the highly detailed livestock population and production system maps to be produced. At the time of writing this paper, however, the data were only available in a highly aggregated form (see also chapters Conclusions and Outlook).

Poverty

Spatial data

Spatially disaggregated poverty estimates have been produced by the International Food Policy Research Institute (IFPRI) and the Institute of Development Studies (IDS) (Minot *et al*. 2003). The data have been developed by combining 1997/98 Vietnam Living Standards Survey (VLSS) data with 1999 Population and Housing Census data[2]. Figure 2 shows the interesting contrast between poverty rate (incidence) and the number of poor people (density), reflecting that in the more densely populated areas, although the average poverty rate is often lower, the absolute number of poor can be very high, and that the highest poverty rates occur in the more remote, less densely populated areas.

Geo-referenced tabular data

Living Standards Survey data provide information on income and expenditure of households. The data can be referenced at survey location level only, and do not provide and spatially continuous coverage. Furthermore, the survey data are representative at regional level only.

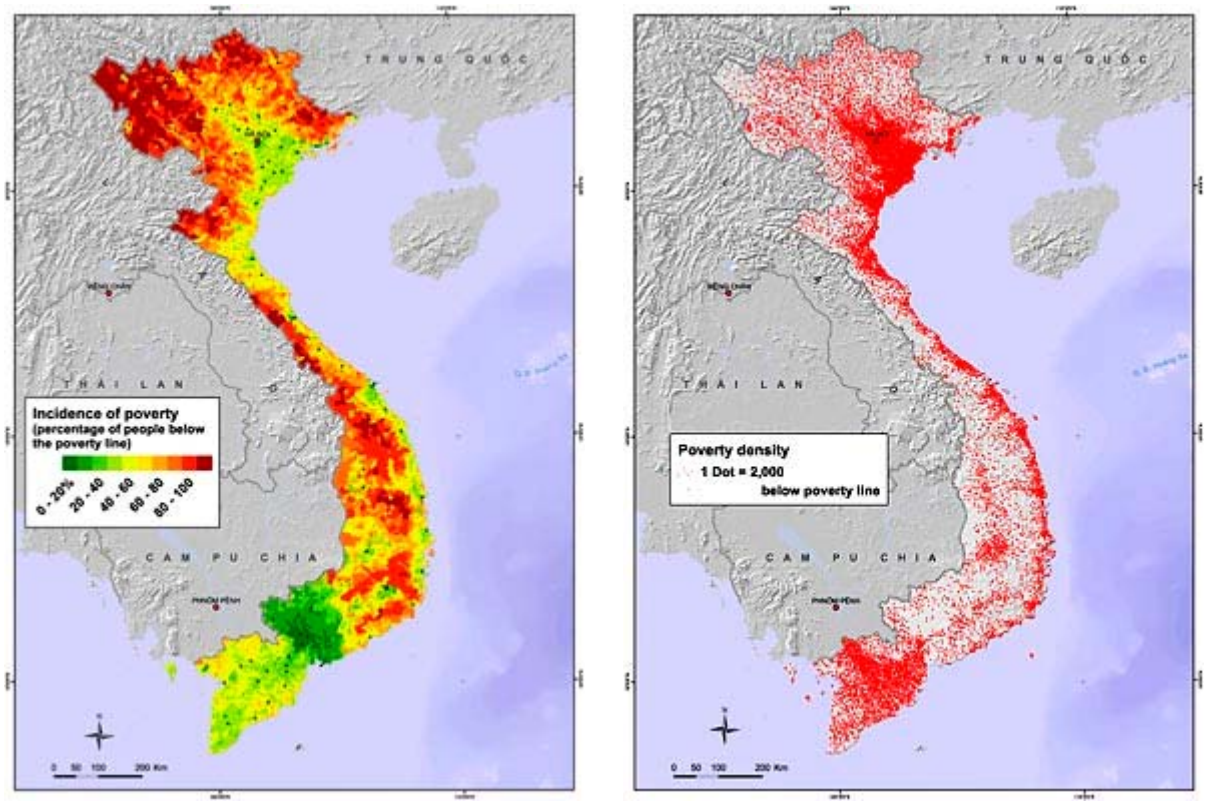
The Ministry of Labour, Invalids and Social Affairs (MOLISA) collects information on poverty at commune level. However, the data are generally available only at provincial level.

[2] Many of the census variables mapped at commune level are published in: Socioeconomic Atlas of Vietnam: A Depiction of the 1999 Population and Housing Census http://www.agroviet.gov.vn/html/BandoKT-XHVietnam/Contents.asp

Figure 2: *Poverty incidence and poverty density.*

Incidence of poverty
(percentage of popultion below the poverty line)

Poverty density
1 dot = 2,000 people below the poverty line



Data source: Minot, N. *et al* 2003

Environmental aspects

Spatial data

An increasing number of GIS data sets on different agro-ecological variables such as soil, land cover, elevation, etc., are being produced at global and regional levels, and most are publicly available. Examples include global Digital Terrain Models (DTM) produced by the American National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS), the FAO natural resources databases, etc.

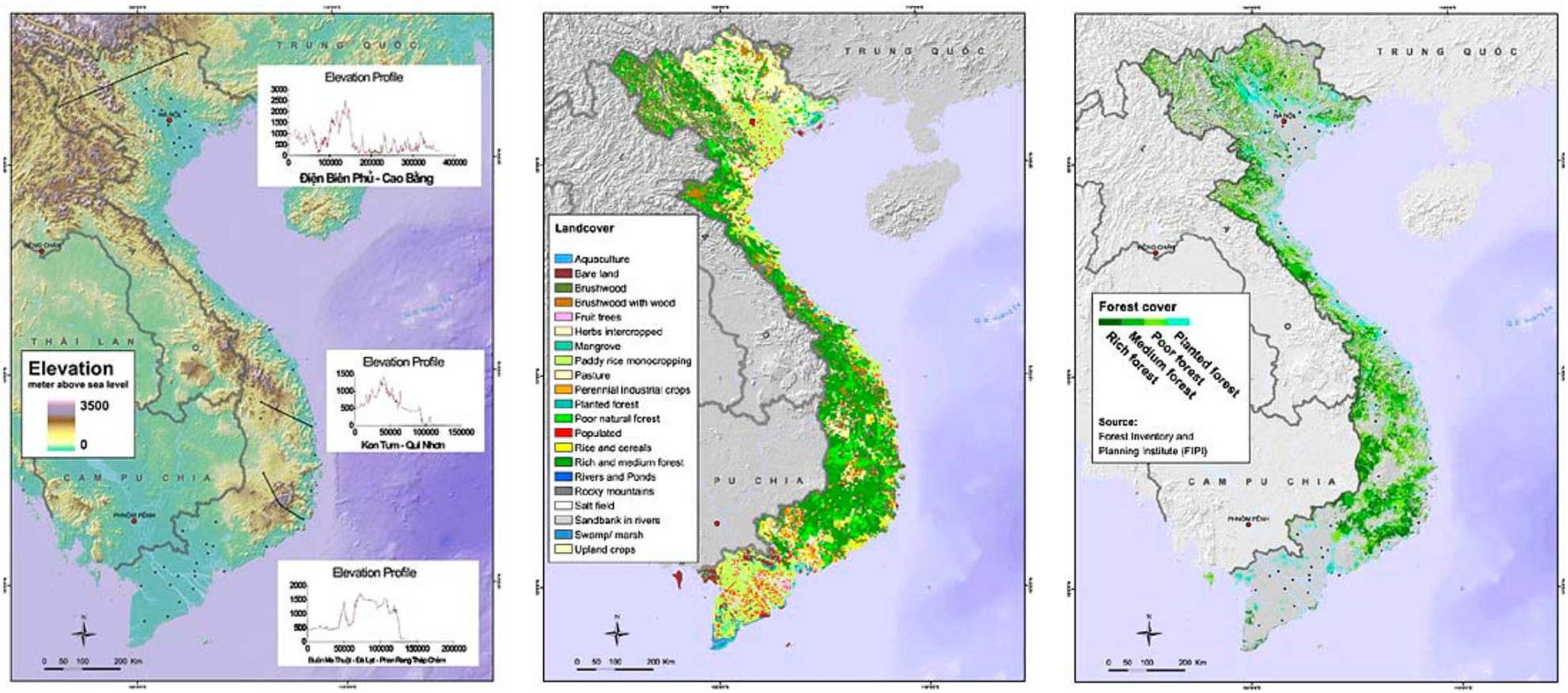
National GIS data sets on environmental variables have been produced in Vietnam for several years, and are of varying quality, scales and recentness. A lack of a quality control, and of documentation, for most of these data sets limit their usefulness.

Geo-referenced tabular data

Tabular data on environmental aspects that can be geo-referenced are generally only available provincial levels (e.g. arable areas, forested areas, etc.) and can not therefore be considered sufficiently detailed to contribute to the present analysis.

Figure 3: *Examples of regional and national GIS data sets on environmental aspects.*

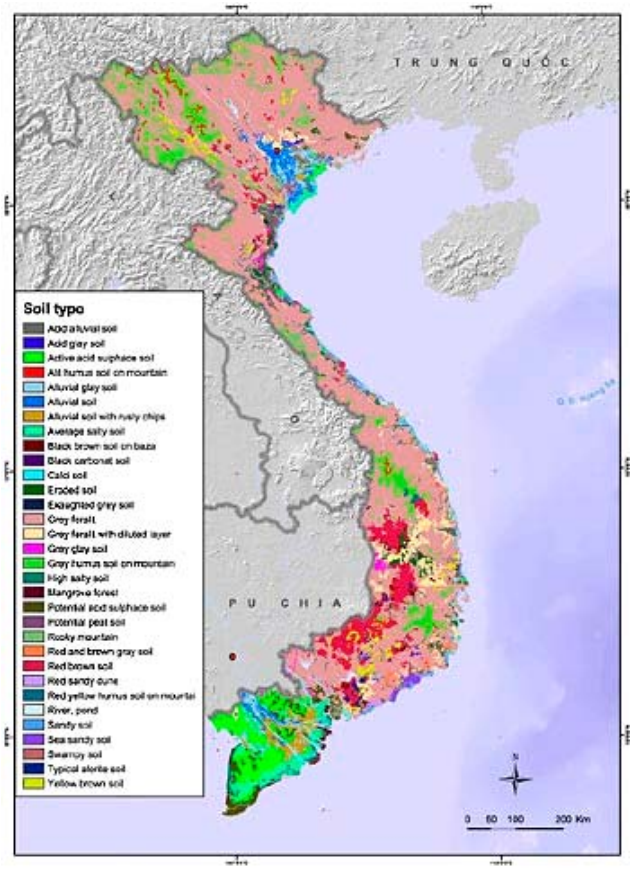
Elevation | **Landcover** | **Forest cover**



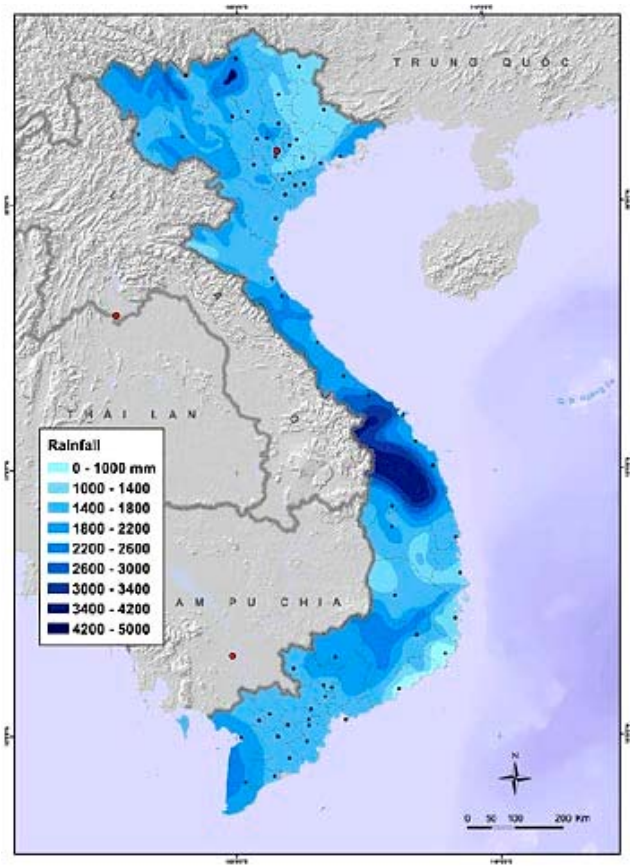
Data sources: USGS, various Vietnamese Governmental institutions

Figure 3 *(continued)*

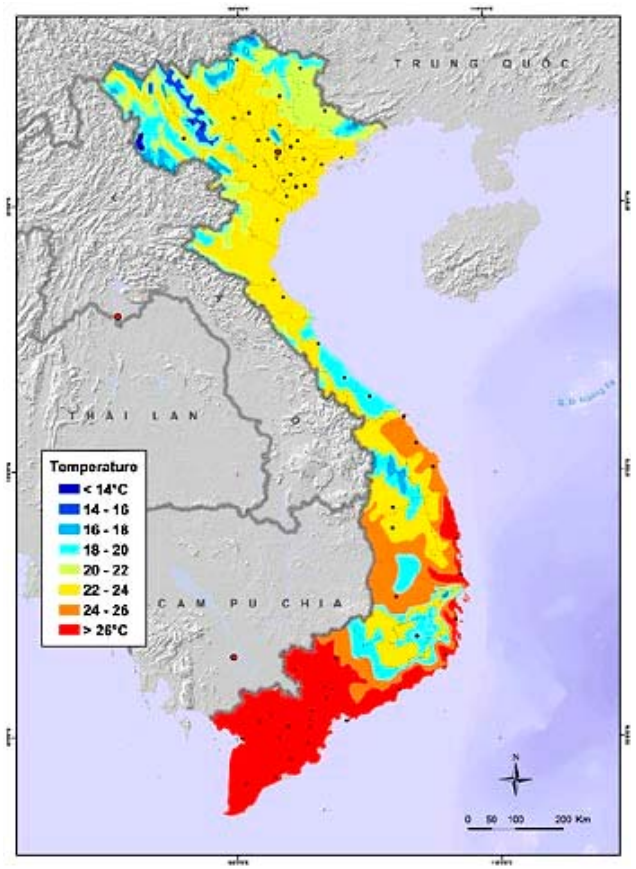
Soil type



Rainfall



Temperature



Data sources: USGS, various Vietnamese Governmental institutions

Infrastructure and accessibility

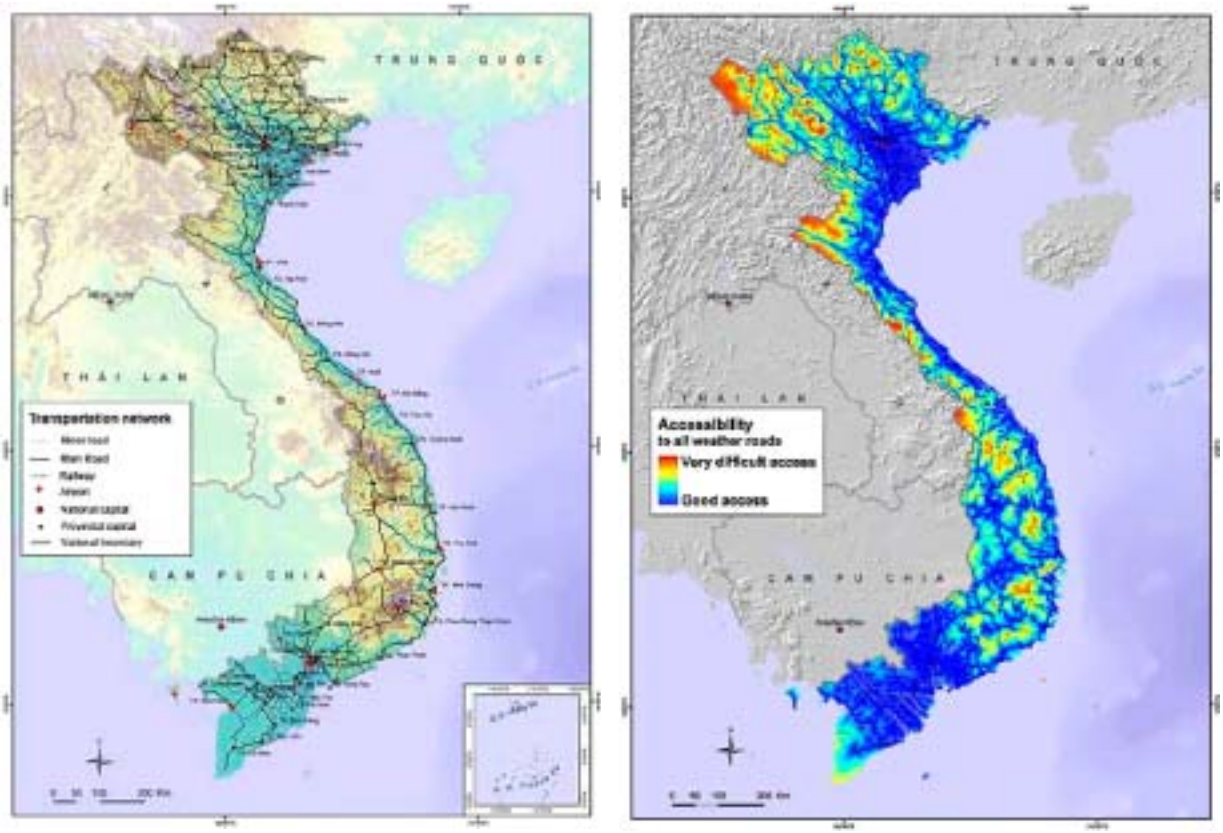
Spatial data

National spatial data on road, railway and river networks in Vietnam are available to varying degrees of recentness, quality, accuracy, level of detail, and scale. A considerable amount of work would be required to build a detailed, current national transportation data set in GIS format.

In order to model 'accessibility' to major urban areas, main transportation lines, etc. 'accessibility surfaces' have been developed representing travel-cost-distance to the closest urban area, major road, etc. Figure 4 illustrates accessibility to all-weather roads. The travel-cost-distance is calculated taking into account best available local means of transport, road quality, land cover for off-road travel, river navigability, and slope.

Figure 4: *Land surface transportation network and modelled accessibility to major roads.*

Transportation network **Accessibility to all weather roads**



Data source: VTGEO 2001 Source: modelled by the author

Geo-referenced tabular data

While the Vietnam Living Standards Surveys provide information on access to roads, markets and other types of service for each survey location, the 2001 Agricultural Census provides information on road accessibility, as well as on access to other types of infrastructure and services, such as, for example, markets, postal and other communication services and educational infrastructure for each rural commune in the country. This makes this latter data set a potentially very interesting source of information that could be geo-referenced at commune level. However, at the time of writing this paper these data were not available (see chapters Conclusions and Outlook).

SPATIAL ASPECTS OF LIVESTOCK HOLDING

In this chapter, geographic aspects of different livestock holdings, and their relationships with environmental indicators and with aspects of accessibility will be explored.

In the first part, the general geographic distributions of income contributions from different livestock to total household income are explored through visualization of these patterns on maps. Income estimates used numbers available at district level from the Agricultural Census 2001. The income variables used include total income, including home consumption, barter, etc., and include total production (i.e. not net income). A comparison of these maps with maps on the spatial distributions of poverty, accessibility, population density and relief allow a visual exploration of spatial relationships among livestock holding patterns, poverty, accessibility, etc. The maps presented on livestock income are all based on district aggregate data released from the 2001 Rural and Agriculture and Fisheries Census (RAFC).

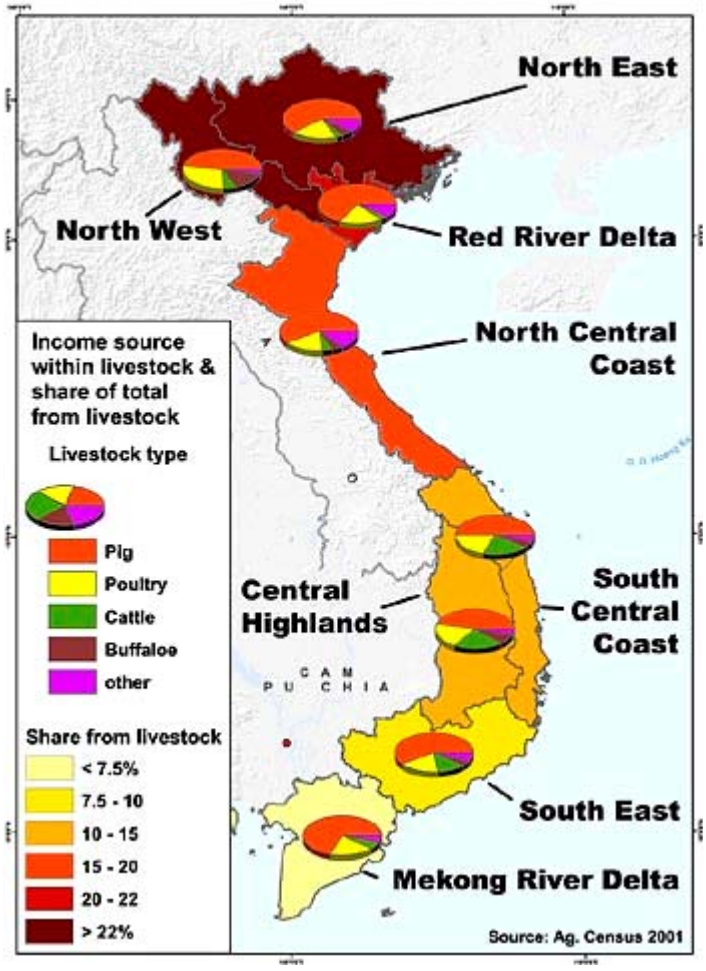
In the second part, spatial aspects of livestock holding by different livestock types and by income group are examined. These maps are based on data derived from the 2002 Vietnam Household Living Standards Survey (VHLSS) 2002.

General geographic patterns of livestock holdings

Spatial variation in livestock holding

Figure 5 illustrates the stark regional variation in the importance of livestock as a source of income. Furthermore, the map shows the variations in types of livestock as a source of household income. Probably most striking is the north-south decline of the share of the total income that is derived from livestock. While the two regions in the northern uplands (NU), the North East (NE) and the North West (NW), both exhibit an overall share of livestock-derive income in total income that is above 22%, this share gradually declines moving southward, to a share of below 7.5% in the Mekong River Delta (MRD), which is less than a third of that in the northern uplands. Furthermore, the graphs on the map clearly show the general high importance of pig production within the livestock sector, but it also illustrates the comparatively lower importance of pig production in poorer areas (see below, and compare, for example, with Figure 8). Overall, poultry takes the second place in terms of importance as an income source within the livestock sector. Cattle appear to be a significant source of household income mainly in the Central Highlands (CH) and along the South Central Coast (SCC).

Figure 5: *Regional variation in livestock holding.*

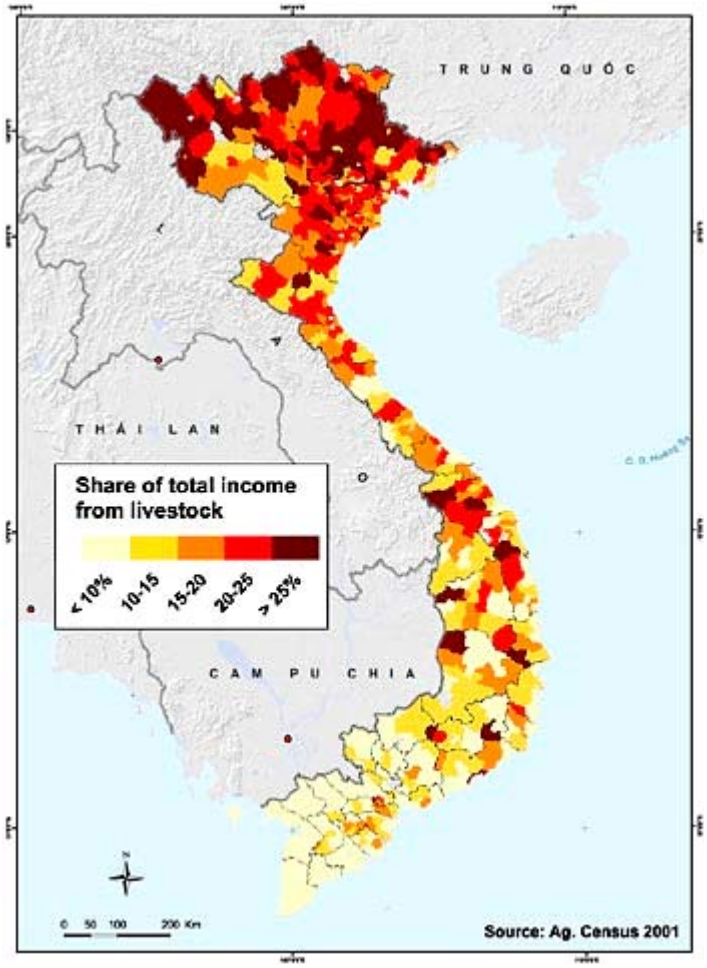


Data source: Ag. Census 2001

Mapping out the spatial distribution of the share of livestock-derived income with respect to total household income at district-level provides a much more fragmented picture, illustrating some strong intra-region variability (Fig. 6). While the NU still exhibits the largest shares of total income derived from livestock, large parts of the NW, particularly Son LA Province, show comparatively lower rates, whereas in some districts of the Red River Delta (RRD) this share is among the highest in the country (above 25% of total income earned from livestock holding).

Whereas in much of the central and southern part of the country livestock earnings make up for a comparatively small share of the total income, there are still a sizable number of districts where livestock appears to play an important role. This is particularly the case in the CH and the SCC.

Figure 6: *District-level variation in livestock holding.*



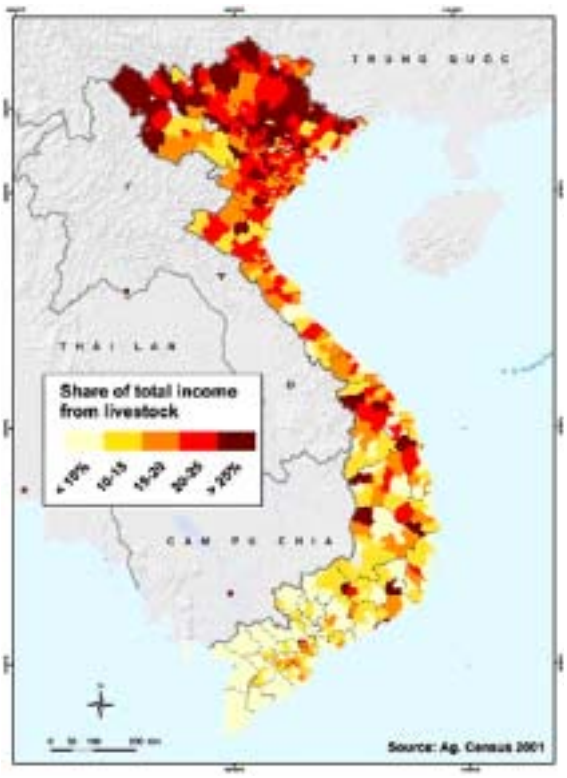
Data source: Ag. Census 2001

Comparatively high shares of household income derived from livestock appear to coincide in many parts of the country with areas of lowest accessibility to urban areas (Fig. 7). Many of the districts lying in dark red areas of the accessibility map exhibit average income shares from livestock of 25% and higher. Many districts in the RRD, however, a region with generally good accessibility to urban areas, also exhibit relatively large shares of livestock derived income.

Mapping the spatial distribution of the share of livestock derived income alongside the spatial distribution of poverty (Fig. 8) reveals the coincidence between areas with higher shares of livestock derived income and poor areas (i.e. areas with a high percentage of the total population living below the national poverty line). This impressively illustrates the importance of livestock as a source of income particularly in the poorest areas of the country, where more than 80% of the population lives in economic poverty.

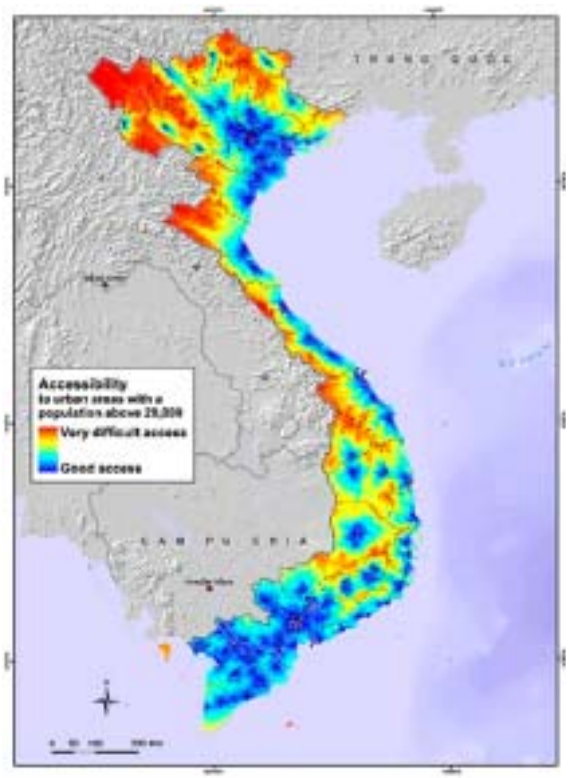
Figure 7: *District-level variation in livestock holding and accessibility to main urban areas.*

Share of total income from livestock



Data source: Ag. Census 2001

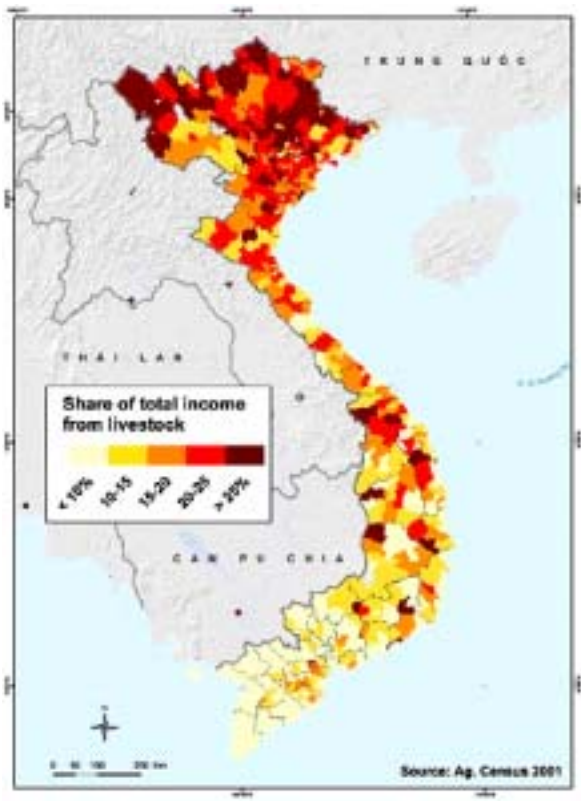
Accessibility to urban areas with a population above 20,000



Source: modelled by the author

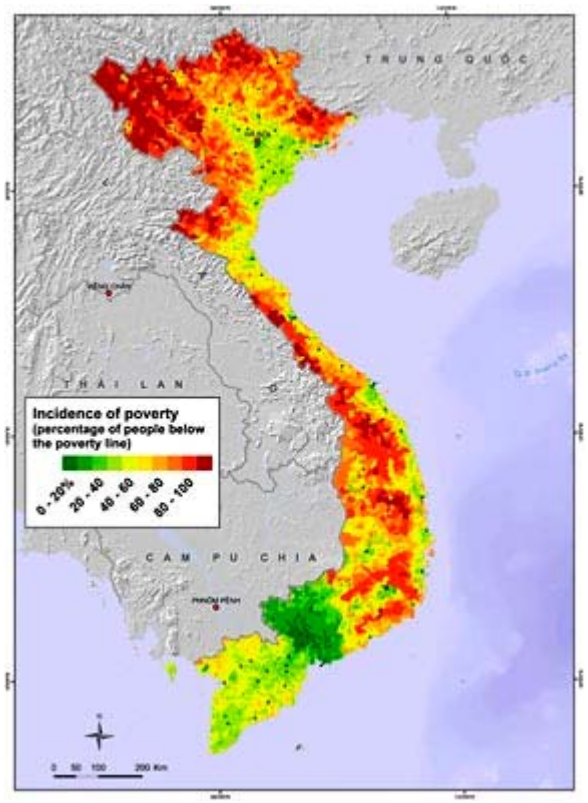
Figure 8: *District-level variation in livestock holding and the spatial distribution of poverty.*

Share of total income from livestock



Data source: Ag. Census 2001

Incidence of poverty
(percentage of people below the poverty line)

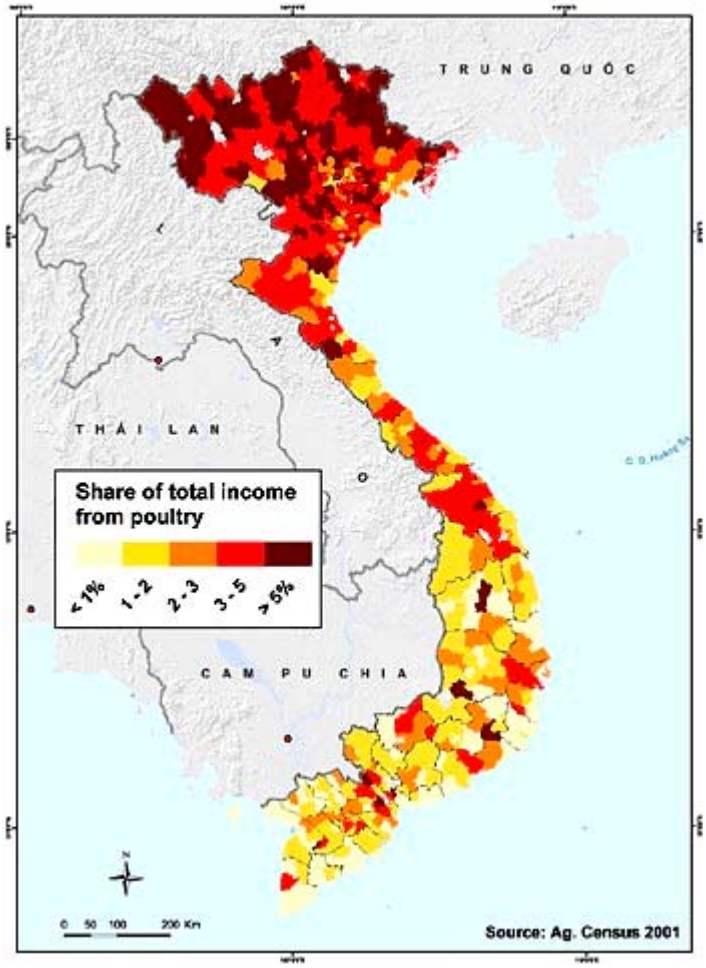


Data source: Minot, N. *et al* 2003

Spatial variation in poultry holding

While the previous maps illustrated the spatial distribution of the importance of livestock as a source of income in general, the following maps describe such spatial patterns by type of livestock. Figure 9, the spatial distribution of the share of poultry derived income in total household income, reveals a similar pattern as for livestock as a whole (Fig. 6): a clear north-south decline is palpable, and the high importance of poultry, particularly in large parts of the NU and of the RRD, is evident.

Figure 9: *District-level variation in poultry holding.*



Data source: Ag. Census 2001

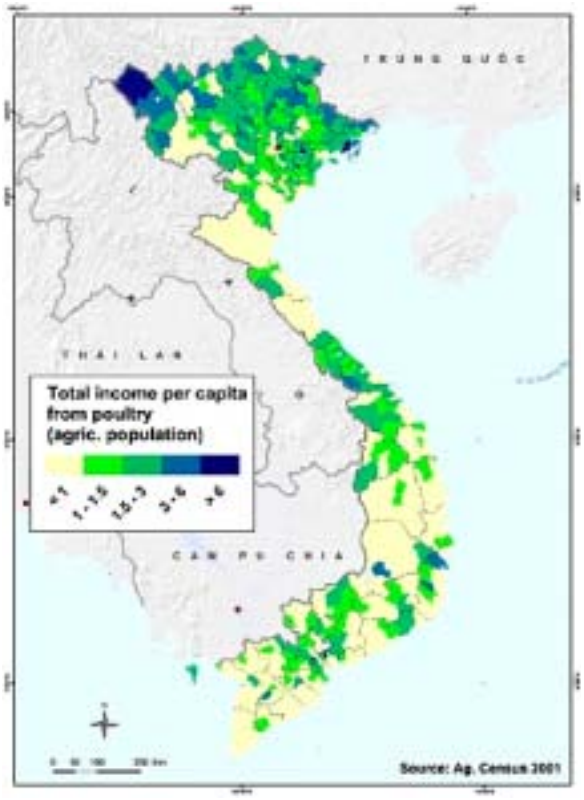
Comparing this map to that showing the geographic distribution of poverty incidence (Fig 8) reveals the high importance of poultry as a source of household income in many of the poorest areas of the country. Moreover, comparing per capita income from poultry with poverty incidence (Fig. 10), Vietnam's poorest areas in the north-western corner, bordering Laos and China, appear to be among those with the highest per capita income from poultry. A similar pattern of comparatively high per capita income from poultry can be found in much of the NE, as well as in the central part of the country. Since these calculations are based on district-level aggregates of income from poultry and total agricultural population, this does not necessarily imply that in the areas coloured dark blue in Figure 10 the poultry producing household derive more income from poultry compared to those, coloured for example in light green. It may also be that in those areas a larger share of all agricultural households is involved in poultry production. Information on the number of poultry producing households was not, however, available from the district-level aggregated data base released from the 2001 Agricultural Census results.

Looking at income density from poultry per km^2, illustrated in Figure 11 by total income from poultry per km^2, the RRD emerges as the clearest cluster of high income density from poultry per km^2. Other high-population areas with comparatively high poultry

production densities can also be identified: for example areas around and south of Ho Chi Minh City (HCMC), around Nha Trang and just south of Danang.

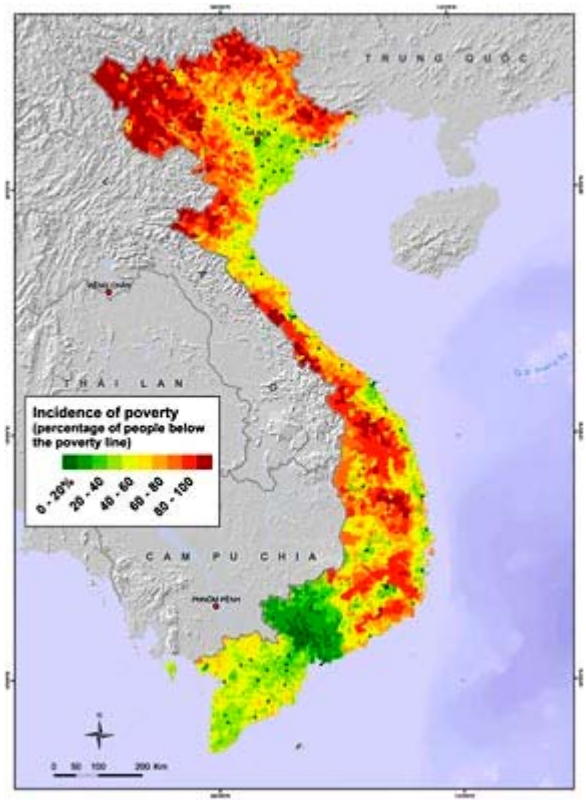
Figure 10: *District-level variation in per capita poultry income and the spatial distribution of poverty.*

Total income per capita from poultry
(agric. population)



Data source: Ag. Census 2001

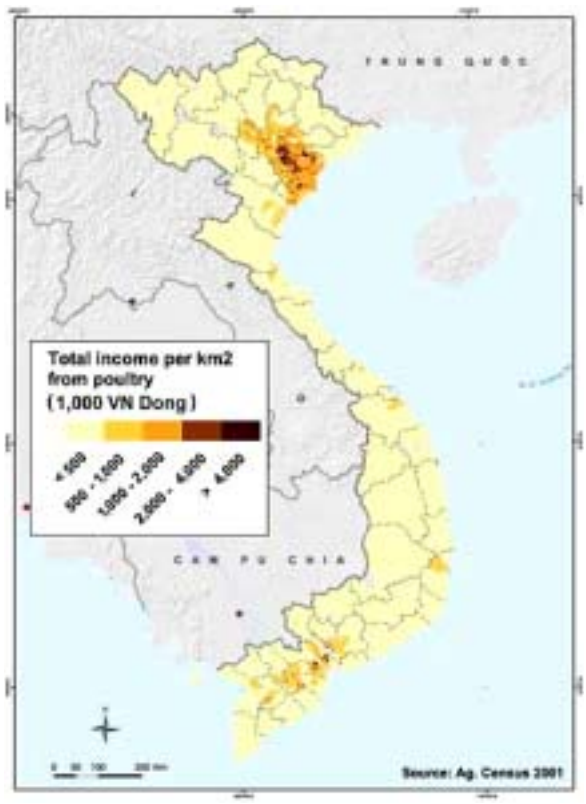
Incidence of poverty
(percentage of people below the poverty line)



Data source: Minot, N. *et al* 2003

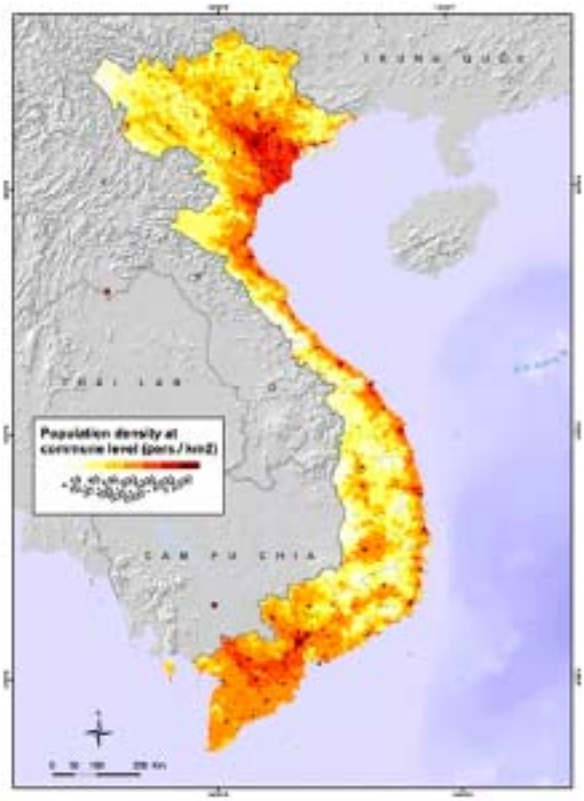
Figure 11: *District-level variation in poultry income density and population density .*

Total income per km^2 from poultry
(agric. population)



Data source: Ag. Census 2001

Population density



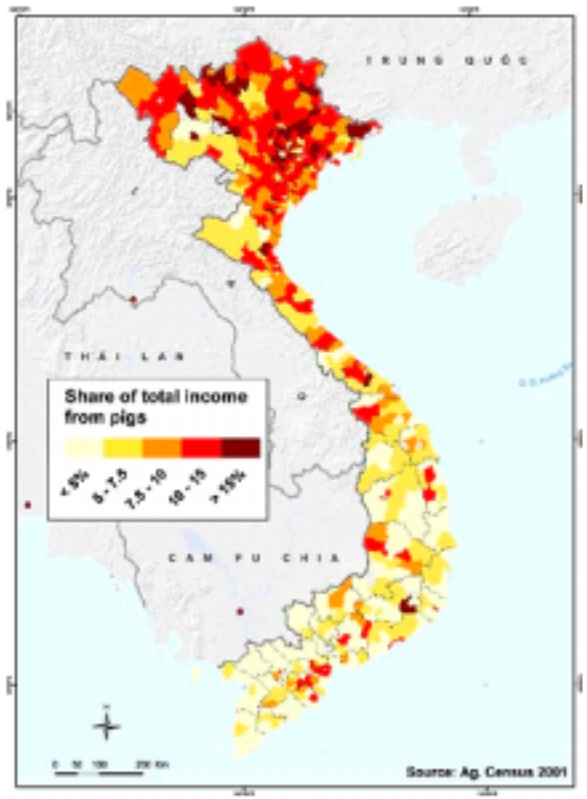
Data source: Population & Housing Census 1999

Spatial variation in pig holding

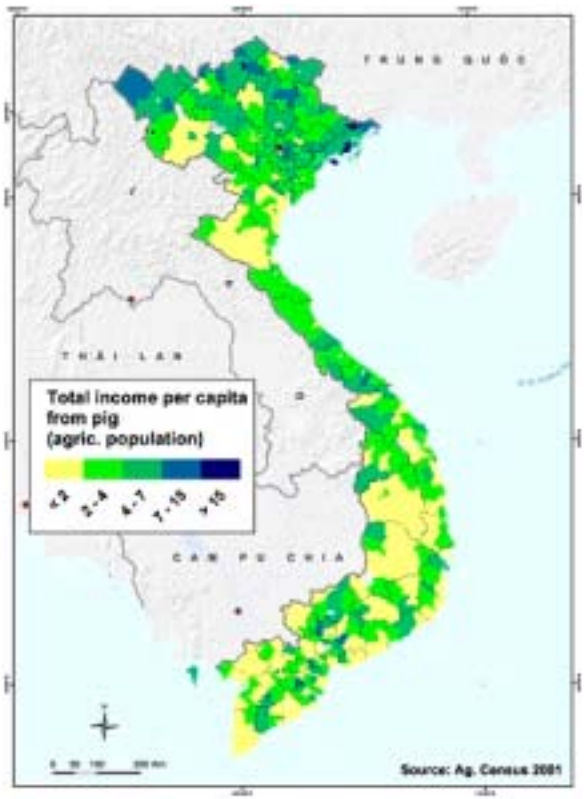
Figure 12 illustrates the spatial patterns in pig holding, and the patterns are very similar to those of poultry production (Fig. 9 – 11). Many of the districts with a large share of the total household income derived from poultry also appear to gain much from pig production. However, whilst in both cases these shares are comparatively high in the northern-most regions (NE, NW, and RRD), there appears to be a less strong concentration of pig production in the NU compared to the RRD than it is the case for poultry production (compare Figs. 12 and 9).

Figure 12: *District-level variation in pig holdings.*

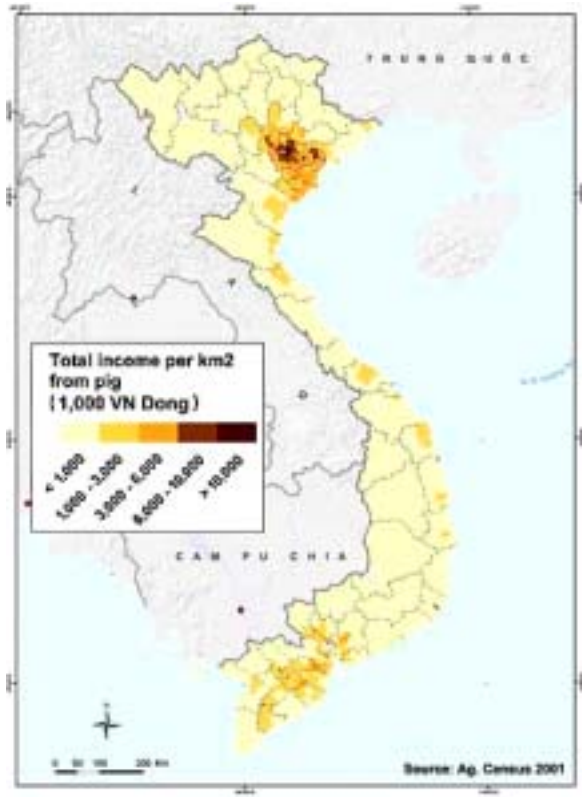
Share of total income from pigs



Total income per capita from pigs



Total income per km^2 from pigs



Data source: Ag. Census 2001

The similarities of the spatial distribution patterns of per capita income from pig and poultry are even stronger than those of income shares: three regional clusters of comparatively higher per capita pig and poultry incomes are identifiable, with the highest values in both cases in the NU and RRD, followed by the two regional clusters in the central part of the country, as well as in the Southeast (SE) and in parts of the MRD. The CH and the northern part of the North Central Coast (NCC), conversely, appear in both cases to be areas with comparatively very low per capita incomes from poultry and pig.

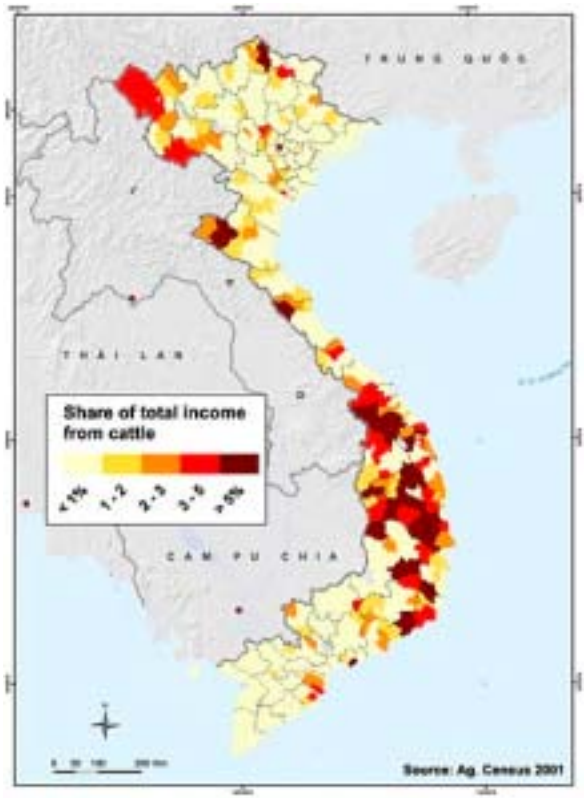
The pattern of pig production density, expressed as total pig-derived income per km^2, is also similar to income density from poultry per km^2: the highest pig production density being in the RRD, followed by a number of high-population density areas along the coast, in the MRD, and around HCMC.

Spatial variation in holdings of cattle, buffaloes and other ruminant livestock

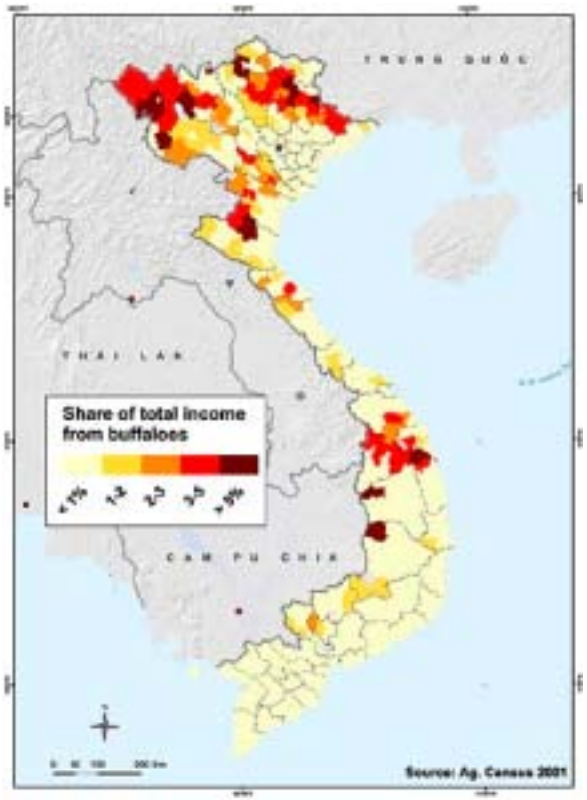
Compared to the monogastric species, a quite pattern emerges with the spatial distributions of income shares derived from cattle, buffaloes and other rumininant livestock (Fig. 13). With the exception of a rather small number of districts, cattle appear to have no over-all significance as a source of household income in the NU and in the RRD, where pig and poultry is an important source of income. Significant cattle holdings appear to be limited largely to the CH and the SCC, and along the coast of the northern part of the SE.

Figure 13: *District-level variation in ruminant holdings.*

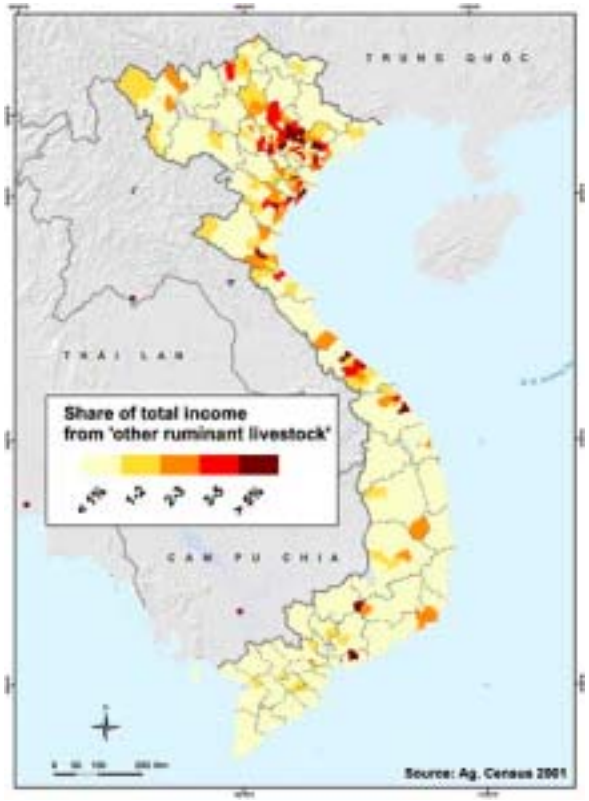
Share of total income from cattle



Share of total income from buffaloes



Share of total income from 'other ruminant livestock'



Data source: Ag. Census 2001

Buffaloes as an income source are of some significance in parts of the NU, particularly in some of the poorest areas (compare to Fig. 8), as well as in the northern and mountainous part of the CH. In several districts of those regions, the district level share of the total household income that comes from buffaloes is above 5%.

Other ruminant livestock such as goats and sheep is of some importance as a source of household income appears to be fairly limited in Vietnam. Holdings of small ruminant livestock appear to be concentrated particularly in the northern and northeastern parts of the RRD, and in a number of districts along the NCC. Overall, small ruminants appear to be of limited importance in the uplands.

Summary of observations

In summary, the following points characterize spatial patterns in livestock holdings in Vietnam, from a perspective of livestock's importance as a source of household income.

- Overall, livestock's contribution to household income is greatest in the northern regions, particularly in the NU, followed by the RRD, and declines steadily moving south.
- Overall, livestock has a comparatively higher importance as a source of income in less accessible areas.
- Livestock is an important source of income particularly in the poorest areas of the country.
- In Vietnam overall, pig production is the most important income contributor within the livestock sector (over 15% in several districts, particularly in the northern part of Vietnam). Pig holdings are of greatest importance in the NU and in the RRD, but also in large parts of the NCC.
- Poultry is the second most important livestock-derived source of income (over 5% in many districts, particularly in the northern part of Vietnam).
- Pig and poultry derived per capita income (as district level averages) is highest in some of the poorest areas of the country.
- The densely populated RRD is the region with the highest pig and poultry production per km^2.
- Cattle are an important source of income in the CH, and parts of the SSC, in many districts averaging over 5% of total household income.
- Income from buffaloes appears to play a significant role mainly in parts of the NU, and in the northern part of the CH.
- Small ruminant livestock (sheep and goats) appear to be concentrated mainly in northern part of RRD and in some areas along the central coast.

Spatial aspects of livestock holding by income group

The previous section described the general spatial patterns of the importance of different types of livestock as a source of household income. In this section, in order to explore the differences in livestock holdings among different income groups, the spatial patterns of livestock holdings are examined by income group. The district-level summary statistics released by the General Statistics Office (GSO) from the 2001 Agricultural Census do not provide disaggregated information on income composition by income level, and hence could not be used for such an analysis. The analysis presented in this section is based on provincial and regional statistics derived from the VHLSS 2002.

Here again, income is defined as total income including home consumption, barter, etc. and measures total production (not net income).

Spatial variation in livestock holding by income group

Charting the share of the total income that is derived from livestock by region and income quintile reveals that there is a north-south decline in the importance of livestock as a source of income in all income groups. This tendency is much clearer for the lower and middle income groups, and less evident for the highest income quintile (Table 1).

Table 1: *Share of total income from livestock by region and income quintile.*

Region	Income quintile				
	1	2	3	4	5
	poorest		middle		richest
North East	15.9	17.7	16.1	13.5	8.3
North West	13.0	14.2	13.5	12.4	9.6
Red River Delta	11.6	14.2	12.9	11.4	6.8
North Central Coast	12.9	14.8	13.0	10.6	4.9
South Central Coast	9.0	9.9	8.0	6.6	4.5
Central Highlands	6.4	8.7	8.7	7.3	9.3
South East	2.6	3.6	4.2	4.8	4.9
Mekong River Delta	2.5	3.9	4.8	5.5	5.7

Data source: VHLSS 2002

Table 1 also shows how the importance of livestock overall tends to decrease with rising income, although in all regions, the very lowest income quintile shows a slightly lower dependence on livestock compared to the second income group. Two other exceptions to the general trend are evident: first, the CH, where livestock earnings appear to be at least as important for the highest income group as for lower income group, and second, the MRD, where there appears even to be an inversion of this trend, where the importance of income from livestock slightly increases with rising income levels.

Charting instead only the share of total income derived from poultry discloses even clearer patterns (Table 2): a clear north-south decline of the importance of poultry in income composition, and a very clear decline in significance of poultry as an income source with rising income levels. This latter tendency appears strongest in the northern part of the country, and the trend declines sharply moving further south.

Spatial variation in poultry holding by income group

A depiction of the poultry-derived income share by income quintile and province (Figure 14) reveals great intra-regional variations. Clearly, and not surprisingly, the main urban areas Hanoi, HCMC and Hue, as well as Hai Phong exhibit a comparatively lower importance of poultry in the income composition. Also, while in most parts of the country the declining importance of poultry with rising income level is manifested, there is a number of provinces in the southern part of the country, where this trend follows is reversed. A clear example where a province shows a higher share of poultry-derived income compared to other provinces in the region, is Long An province

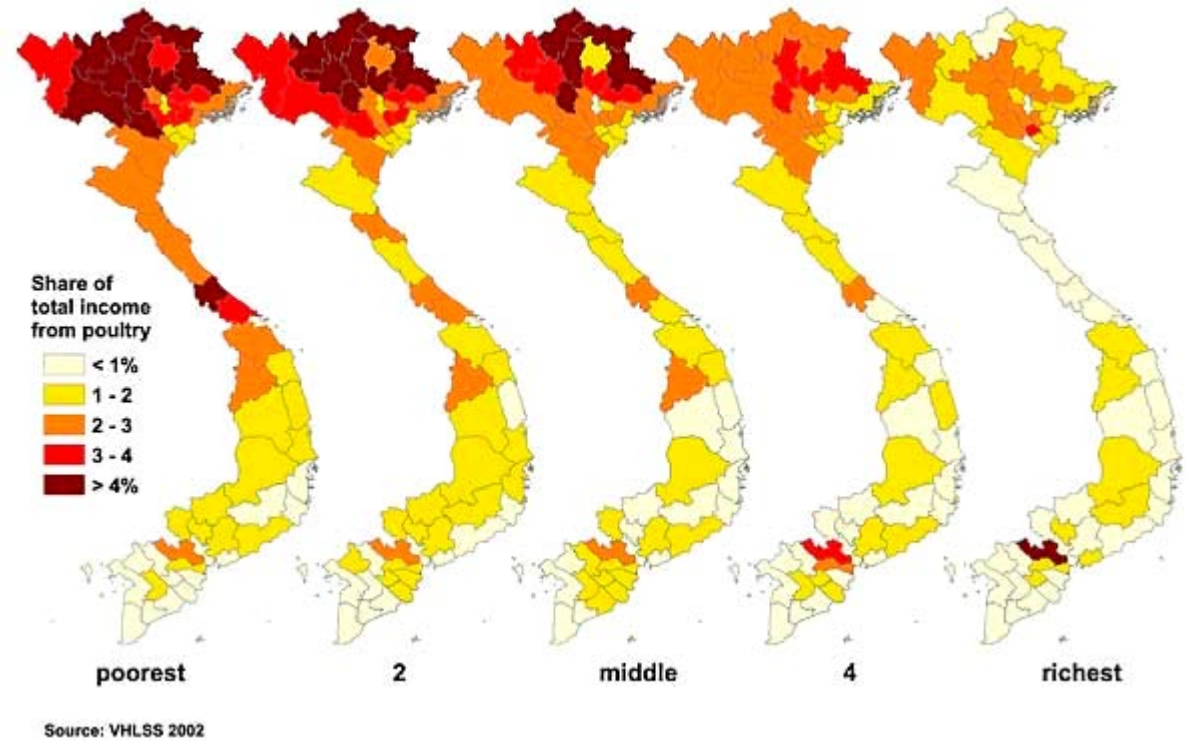
in the MRD. Long An is a partially peri-urban province southeast of HCMC in which the share of the total household income that comes from poultry holding increases moving from lower to higher income groups. Overall in the MRD, however, dependence on poultry is generally low and changes little between income groups.

Table 2: *Share of total income from poultry by region and income quintile.*

Region	Income quintile				
	1	2	3	4	5
	poorest		middle		richest
North East	4.7	4.5	3.9	2.7	1.8
North West	4.0	3.6	2.7	2.5	1.8
Red River Delta	2.5	2.3	1.9	1.7	1.2
North Central Coast	2.7	2.3	2.0	1.8	0.9
South Central Coast	1.4	1.2	1.0	0.8	0.5
Central Highlands	1.5	1.6	1.4	1.0	1.0
South East	0.8	0.9	0.9	0.7	0.6
Mekong River Delta	0.9	1.1	1.2	1.1	0.9

Data source: VHLSS 2002

Figure 14: *Share of total income from poultry by province and income quintile.*



Data source: VHLSS 2002

Spatial variation in pig holding by income group

Different patterns become evident when charting and mapping the share of income generated from pig holdings by income quintile (Table 3 and Figure 15). Unlike poultry, it appears that the poorest benefit somewhat less from pig holding than households that fall into the next higher income quintiles. From a geographic perspective, it is also interesting to observe the differences in the two northern mountain regions, where pig holding appears generally more important in the NE compared to the more rugged and mountainous NW. The importance of pig-derived income appears to be of increase for the higher income groups in the NW, as compared to the opposite trend, where it clearly declines for increasing income quintiles, in the NE.

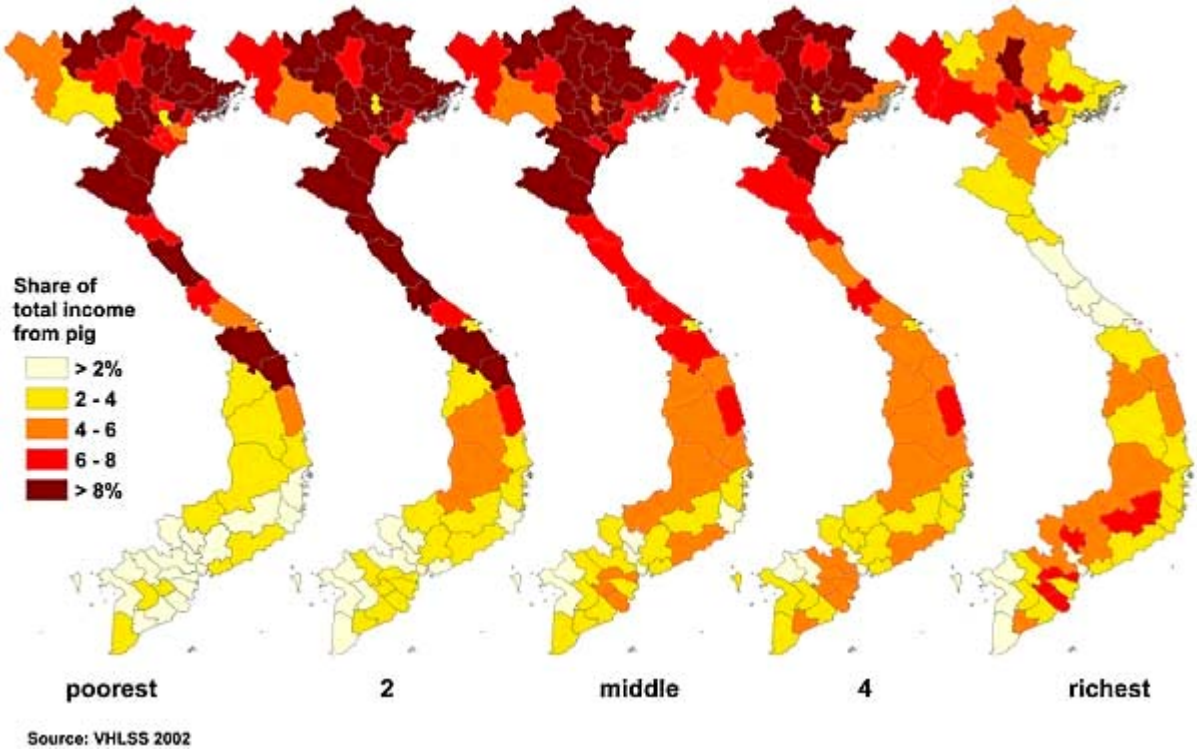
While for much of the northern part of the country, particularly the NCC and the RRD, the importance of pigs as an income source tends to decline with rising income level, the opposite is evident for much of the southern part of Vietnam, where pigs seem to be of considerably lower importance for the lower income households, compared to those that are better-off.

Table 3: *Share of total income from pig by region and income quintile.*

Region	Income quintile				
	1	2	3	4	5
	poorest		middle		richest
North East	8.8	10.5	10.0	8.6	5.1
North West	6.7	7.1	6.5	6.8	6.0
Red River Delta	7.3	9.9	8.9	7.5	3.9
North Central Coast	8.3	9.5	8.4	6.8	2.7
South Central Coast	6.2	6.2	5.5	4.3	2.8
Central Highlands	2.9	4.0	4.3	4.7	5.6
South East	1.6	2.2	2.5	3.1	3.4
Mekong River Delta	1.4	2.4	3.0	3.4	3.9

Data source: VHLSS 2002

Figure 15: *Share of total income from pig by province and income quintile.*



Data source: VHLSS 2002

Spatial variation in cattle holding by income group

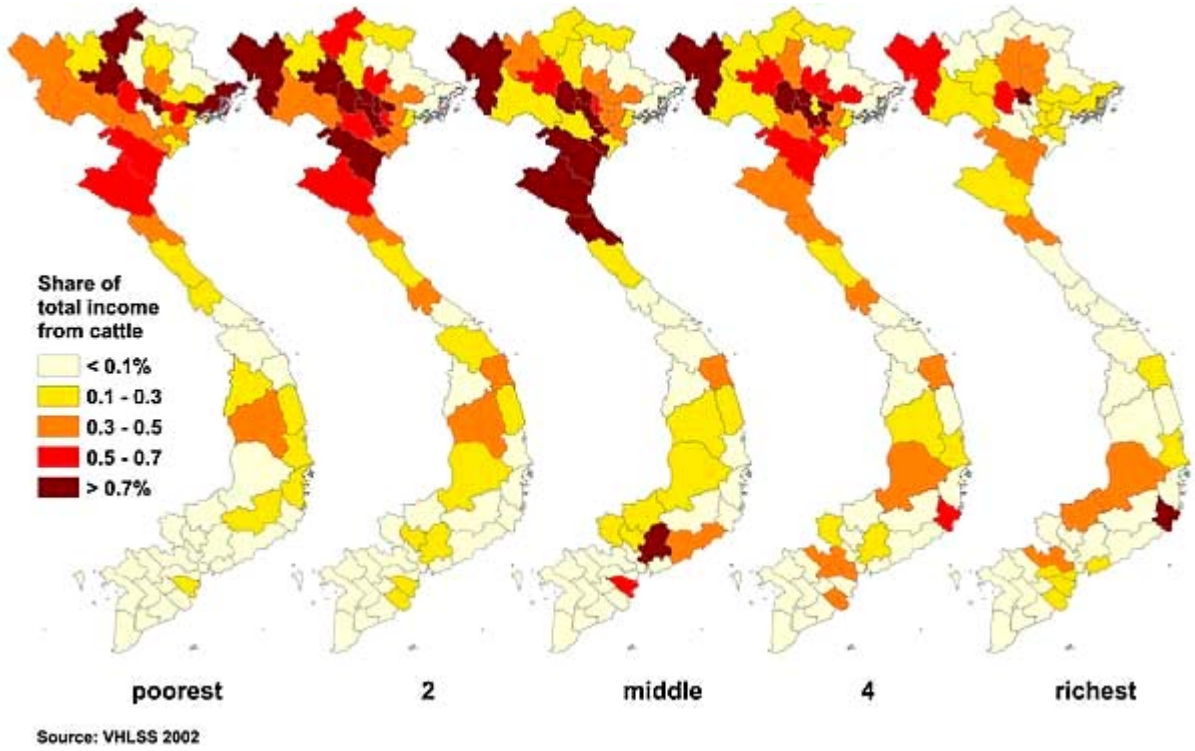
Spatial and income-related trends in the proportion of income derived from cattle are less clear (Table 4 and Figure 16). According to the VHLSS 2002, cattle play only a very minor in generating household incomes. They tend to be least important as a source of income for the highest income groups, particularly in the northern part of the country, and are most important, though still on average well below one percent of total income, for the medium income groups. Overall cattle appear to be a somewhat less important contributor to income for the poorest than for the medium range income quintiles. According to 2002 VHLSS data, cattle are more important in the northern part of the country than in the CH and the south, which appears somewhat contradictory to the information derived from the 2001 Agricultural Census (see Figure 5).

Table 4: *Share of total income from cattle by region and income quintile.*

Region	Income quintile				
	1	2	3	4	5
	poorest		middle		richest
North East	0.37	0.49	0.34	0.38	0.23
North West	0.41	0.64	0.55	0.85	0.26
Red River Delta	0.38	0.60	0.51	0.54	0.14
North Central Coast	0.40	0.50	0.64	0.33	0.18
South Central Coast	0.13	0.15	0.12	0.10	0.06
Central Highlands	0.17	0.20	0.14	0.20	0.15
South East	0.01	0.05	0.25	0.09	0.16
Mekong River Delta	0.03	0.04	0.08	0.10	0.09

Data source: VHLSS 2002

Figure 16: *Share of total income from cattle by province and income quintile.*



Data source: VHLSS 2002

Summary of observations

To summarize the observed spatial patterns of income contribution from different livestock to total household income by income quintile, to following few main points can be listed:

- There is generally a decrease in the importance of livestock in total income composition from north to south, and this trend is stronger in poorer or medium income households than in better-off households.
- An overall decrease in the importance of livestock in the income composition with increasing income can be observed, but this tendency becomes less moving southward and, in the south, the trend is actually reversed.
- Poultry is the most important livestock-based source of income for the poorest income quintile.
- Pigs are the most important livestock-based source of income for the medium income quintiles.
- According to the VHLSS 2002, cattle only play a very limited role as a source of household income.

Analysis of spatial relationships among livestock, poverty and the environment

In the preceding chapters, spatial relationships among patterns of livestock holding, poverty, aspects of accessibility and some environmental characteristics have been visually explored by comparing the spatial distributions of the different variables on separate maps. Those illustrations clearly indicated the existence of such relationships in space.

However, such relationships appear clearer in some parts of the country than in others, whereas there might, for example, be little relationship between livestock holding patterns and poverty incidence in one region, a clear relationship may be evident in another region. The intensity and nature of such relationships might well differ even within certain regions.

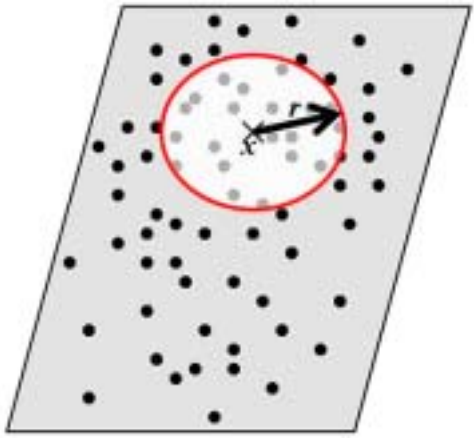
In this chapter, such relationships will be explored and quantified by means of spatial statistical analysis. From a methodological point of view, two important points are to be considered when attempting to analyze such spatial relationships: first, such relationships may be of a non-linear nature, and second, such relationships may vary over space.

Applying a 'global' traditional linear regression model, for instance, would produce parameters under the assumption that relationships apply equally across the whole study area: regional and local variations would remain hidden. Therefore, in this explorative spatial analysis, the application of local spatially weighted regression models are used to explore geographically varying relationships.

As demonstrated here, such local regression models have the advantage of allowing for spatial variation in relationships and enable us to quantify and visualize this variation. The application of such a model does, however, not make it possible to describe and quantify non-linear relationships. This means that, through permitting spatial variation in relationships, we still assume these relationships to be linear, though only locally.

Local spatially weighted regression model

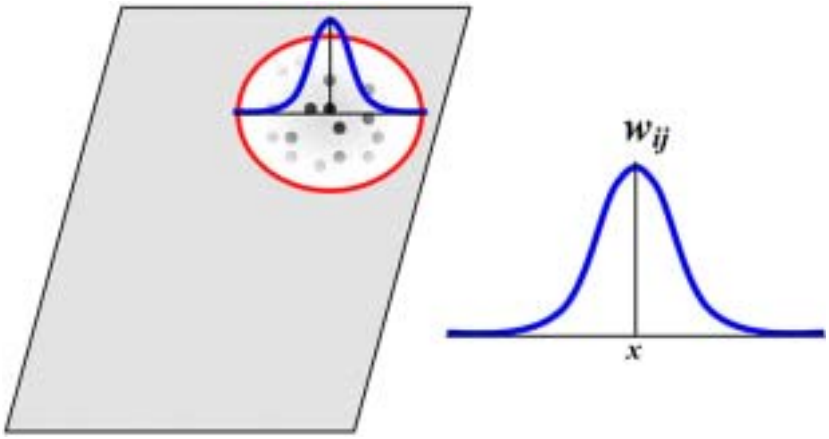
Figure 17: *Local 'regression window' in space.*



Local spatial regression models have been applied in a variety of fields including geography and geophysics (Murray and Baker 1991), and have been developed into

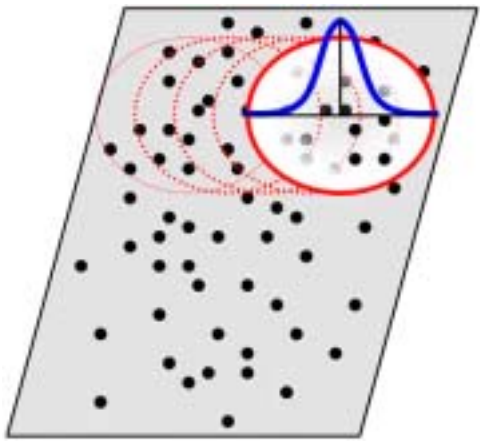
Geographically Weighted Regression (GWR) models by Fotheringham *et al*. (2002). Unlike traditional regression models, which produce one set of parameters for the whole data set, local spatially weighted models provide local parameters for every 'regression point'. These 'regression points' x_i are the respective locations of each sub-set of the whole data base (Figure 17). The local regression model takes into account all data that fall inside a specified 'regression window', defined by the bandwidth r from a regression point x. (Figure 17). The parameters produced by a local regression model describe relationships at point x_i, based on the patterns observed within the regression window. However, rather than giving all observations within the regression widow the same importance in the local regression, observations are weighted using a specified distance decay function – typically a Gaussian decay function, so the weights w_{ij} for observations x_{ij} are the higher the closer (measured as Euclidian distance) they are to the regression point x_i (Figure 18).

Figure 18: *Gaussian distance decay weighting in local 'regression window'.*



By 'moving' the regression window across space (Figure 19), numerous separate local regression models are estimated, one for each regression point, based on the observations within the defined window, until all regression points have been covered.

Figure 19: *Moving local spatially weighted 'regression window' across space.*



Since this method is based on a conventional regression framework, the technique produces the standard regression outputs, regression coefficients, t-statistics and R^2 values, which can all be mapped, showing how they vary over space. This makes this

technique particularly useful for detecting, visualizing and analyzing relationships that vary spatially.

Furthermore, the estimated parameters can be summarised for sub-regions, and the improvement from a global model can be tested (Fotheringham *et al*. 2002).

A standard global regression model, written as:

$$y_i = a_0 + \sum_j x_{ij} a_j + \varepsilon \quad (1)$$

can be extended to a local regression model, written as:

$$y_i = a_0 + \sum_j x_{ij} a_{ij} + \varepsilon \quad (2)$$

where

y is the dependent variable,

x is the independent variable,

a is the regression coefficient,

i is an index for the location,

j is an index for the independent variable, and

ε is the error term.

For each local regression at a regression point i, the observations are weighted depending on the distance from the regression point to the observation j. The Gaussian distance decay function applied in this analysis can be written as:

$$w_{ij} = \exp\left[-\frac{1}{2}\frac{d_{ij}}{r}\right]^2 \quad (3)$$

where

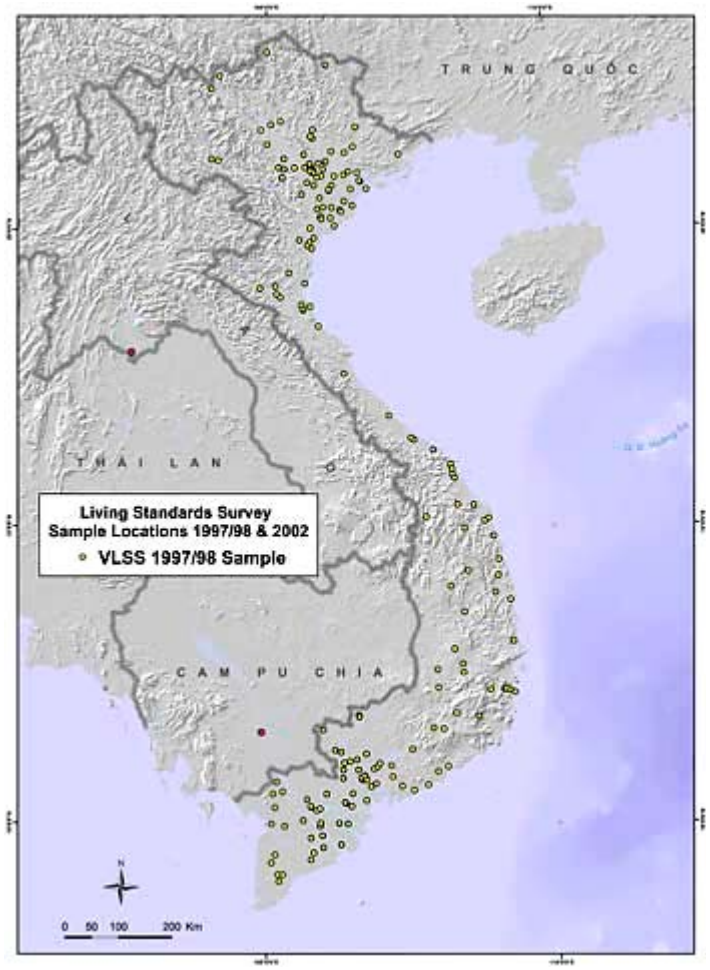
w_{ij} is the weight at regression point i for observation j,

d_{ij} is the distance from regression point i to observation j,

r is the bandwidth or the radius of influence around each observation.

In addition, we can test whether a local model really describes relationships better than a global model by comparing global and local values of R^2. Fotheringham *et al*. (2002) further propose a Monte Carlo test to determine whether spatial variations in the estimated coefficients are statistically significant. The test involves randomly adjusting the geographic locations of the observations numerous times and, for each randomization, running a GWR and then comparing statistically the parameter estimates for the randomly distributed observations with the parameter estimates of the actual geographic distribution.

Figure 20: *Survey locations VLSS 1997/98.*



Data source: VLSS 1997/98

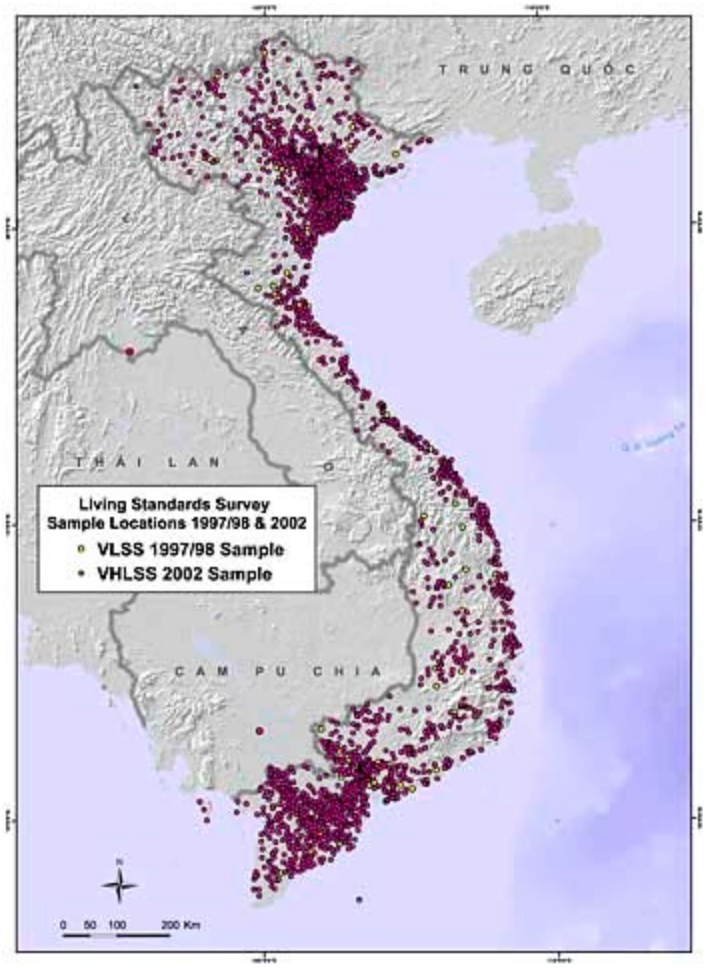
Description of applied spatially weighted local regression model

For the purpose of this analysis of livestock holding patterns, accessibility and environmental variables, a combination of living standards survey data, which provide good information on livestock holdings and income levels for each surveyed household, and data derived from GIS data sets, which provide good detailed information on accessibility environmental variables, were used.

There are two relatively recent nationally representative household level living standards surveys available:

- The 1997/98 Vietnam Living Standards Survey (VLSS) includes 6,000 households, which are geographically referencable to nearly 200 locations (communes). Figure 20 shows the distribution of these communes.
- The Vietnam Household Living Standards Survey (VHLSS) 2002 covered nearly 45,000 households, which are spatially referencable to over 2200 locations (communes) in the country. For all of the 45,000 surveyed households information on income was collected, while for a sub-set of 15,000 households information on expenditures was also collected. Figure 21 shows the location of the communes (of which there are over 2200) where the survey was implemented.

Figure 21: *Survey locations VHLSS 2002.*



Data source: VHLSS 2002

While the 2002 VHLSS obviously offers a much higher degree of spatially disaggregated representation, the 1997/98 VLSS contains much more detailed data for each surveyed household.

For the purpose of this analysis, it was considered that the more recent VHLSS, with the better spatial representation, would be more appropriate, and the entire data set, covering 45,000 households, was used for this explorative analysis, which is based on information on income only.

Three different local spatially weighted regression models were estimated: the log of total household per capita income a) from livestock as a whole ('livestock model'), b) from poultry ('poultry model'), and c) from pigs ('pig model'). For each of these models the same set of independent variables were used. Each model included the share of the total income from the respective income source as an additional independent variable. The different independent variables, as well as the dependent variables used in the different models, are listed in Table 5.

Table 5: *Dependent and independent variables used in the different local regression models.*

Dependent variables (one for each model)	Independent variables
Log of total household per capita income from: a) livestock as a whole b) poultry c) pigs	i) Share of the total household income derived from a) livestock as a whole, b) poultry, c) pigs (one per respective model) ii) Cost-distance to nearest urban area with a population of at least 10,000 inhabitants iii) Market density in the vicinity of 30km iv) Percentage of commune area that is flat land v) Area of 'good forest' per person in commune

The variables were standardized to a common value range in order to allow an easier interpretation of the individual coefficients, and pair wise correlation analysis was performed to check that no high collinearities existed. For that reason, variables on elevation (e.g. mean elevation in commune, standard deviation of elevation in commune, range of elevation values in commune, etc.) had to be excluded, since they were highly correlated (coefficient of above 0.7) with access (cost-distance) to major urban areas. Since most of the explanatory variables are not particularly meaningful for urban households, the models were restricted to rural households.

Each model was estimated for every rural VHLSS 2002 survey site (a total of 1721), generating for each location a full set of individual regression outputs. Rather than defining the regression window by distance, for each local regression the closest 150 rural survey locations were included, and individually weighted according to the distance from the respective regression point. This clearly results in a variable bandwidth, which adapts itself according to the spatial density of the survey locations: the higher the data point density, the smaller the resulting bandwidth. This variation of the methodology outlined above makes sense particularly for study areas in which the density of the data points varies significantly across space, as it is the case for the VHLSS survey locations in Vietnam (see Figure 21).

The resulting 1721 sets of regression output for each model were then mapped according to each regression point's location, resulting in maps depicting, for example, the local regression coefficients a, the local t-statistics and the local indicator of goodness-of-fit R^2 for each local model.

In the following section, the resulting coefficients for each explanatory variable of the three different models are presented. For illustrative purposes the individual statistics for each survey location were spatially interpolated to generate a continuous surface that could be color-shaded for ease of interpretation. The maps show the survey locations as black dots (.) where the coefficients are significant at the 95% level, and as a black crosses (+) where the coefficient estimates are not significant at the 95% level.

In the legends to the color ranges, the respective global estimates of the coefficients are indicated with an 'L' for the 'livestock model', with a 'P' for the 'poultry model', and a 'H' (for hog) for the global coefficients estimated in the 'pig model'.

Linkages in 'livestock model'

Table 6: *Regression results from the global run of the 'livestock model'.*

Global livestock model			R^2: 0.5604	
Independent variable	**Coef.**	**Std. Err.**	**t**	**P>|t|**
Share of income from livestock	0.579309	0.003436	168.6	0
Market density	0.024598	0.002612	9.42	0
Cost distance to main urban areas	-0.0501	0.003807	-13.16	0
Flat land per person	0.017532	0.001748	10.03	0
Prevalence of forest	-0.0374	0.008613	-4.34	0
Constant	34.34872	0.14186	242.13	0

Data source: VHLSS 2002

Figure 22 shows the spatial variations in the coefficients of the five independent variables used in the local livestock model and Table 6 presents summary statistics of the global livestock model. In the global livestock model all independent variables were significant at the 95% level, suggesting these global coefficients to be meaningful:

- higher shares of total income coming from livestock relates to higher household per capita income from livestock;
- higher market densities relate to higher household per capita incomes from livestock;
- higher access costs to major urban areas relate to lower household per capita income from livestock;
- more flat land in the commune relates to higher household per capita income from livestock; and
- more forest per person relates to lower household per capita income from livestock.

While there is, probably not very surprisingly, little spatial variation in the local coefficients of the variable 'share of total income from livestock', there appear to be stronger variations in local coefficients for the other variables, to a varying degree of significance, though. While all variables are significant in the global run of the model (see Table 6), all variables show insignificant coefficients for local runs in several areas of the country.

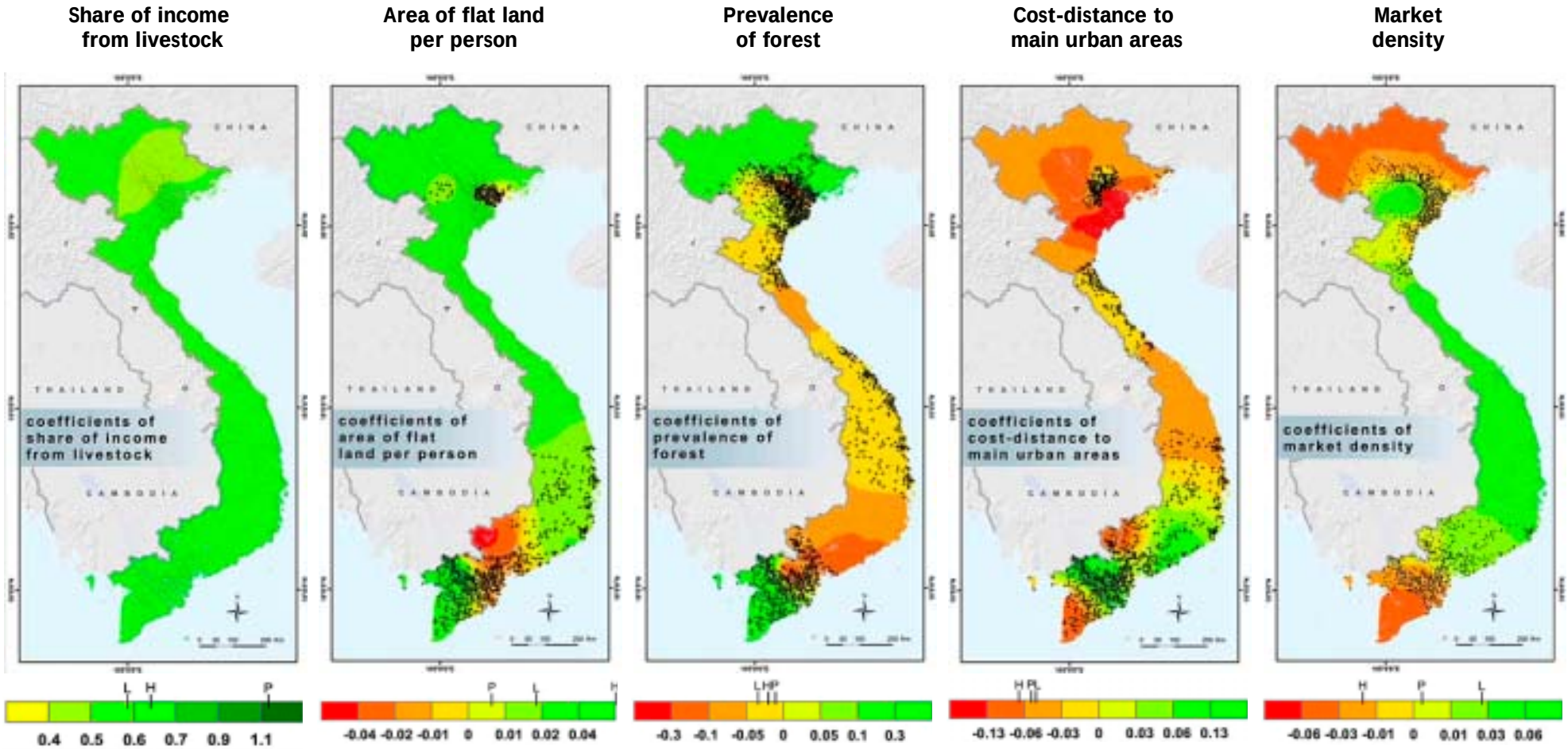
Looking at the map depicting the local coefficients of availability of flat land shows much of the country in the range of the global value, with the exception of parts of the SE towards the Cambodian border, where an inverse trend appears to be significant. It has to be remembered here, though, that the calculated theoretical availability of flat land per person does not reveal the actual distribution of this land in the commune.

The map illustrating the local coefficients of 'prevalence of forest land' shows three major areas where the coefficients are significant: much of the NU with positive coefficients, indicating a tendency to higher incomes from livestock in areas with more forest, and parts of the NCC, SCC and CH, all with varying degrees of negative coefficients, indicating the opposite – lower incomes from livestock in better forested

areas. It is also noteworthy that the global coefficient is just slightly negative (see also Table 6).

With regard to the variables related to access to markets and other services. Two tendencies can be seen. First, cost-distance to main urban areas is globally, as well as locally negatively related to per capita income from livestock, meaning that the further away from major urban areas, the smaller the income from livestock. Second, a higher market density relates positively to per capita income from livestock in much of the country, but a reverse trend is indicated in the NU and the MRD, which might indicate that in those areas, where the market density is generally low, livestock are often marketed in ways other than through official permanent markets.

Figure 22: *Local regression coefficients for independent variables of 'livestock model'.*



Data source: VHLSS 2002

Data source: SRTM Topographic - USGS 2004

Data source: FIPI 1999

Data source: Author's modelling

Data source: Vietnam National Market Census 1999

L regression coefficient value in the global 'livestock model'
H regression coefficient value in the global 'pig model'
P regression coefficient value in the global 'poultry model'

. dots represent data points where the regression coefficients were significant at 95% confidence level

+ crosses represent data points where the regression coefficients were not significant at 95% confidence level

Linkages in 'pig model'

Table 7: *Regression results from the global run of the 'pig model'.*

Global pig model			R^2: 0.5628	
Independent variable	**Coef.**	**Std. Err.**	**t**	**P>|t|**
Share of income from pigs	0.633889	0.004613	137.41	0
Market density	-0.01658	0.002954	-5.61	0
Cost distance to main urban areas	-0.07839	0.004223	-18.56	0
Flat land per person	0.050831	0.001981	25.67	0
Prevalence of forest	-0.02144	0.011054	-1.94	0.052
Constant	35.83265	0.156076	229.59	0

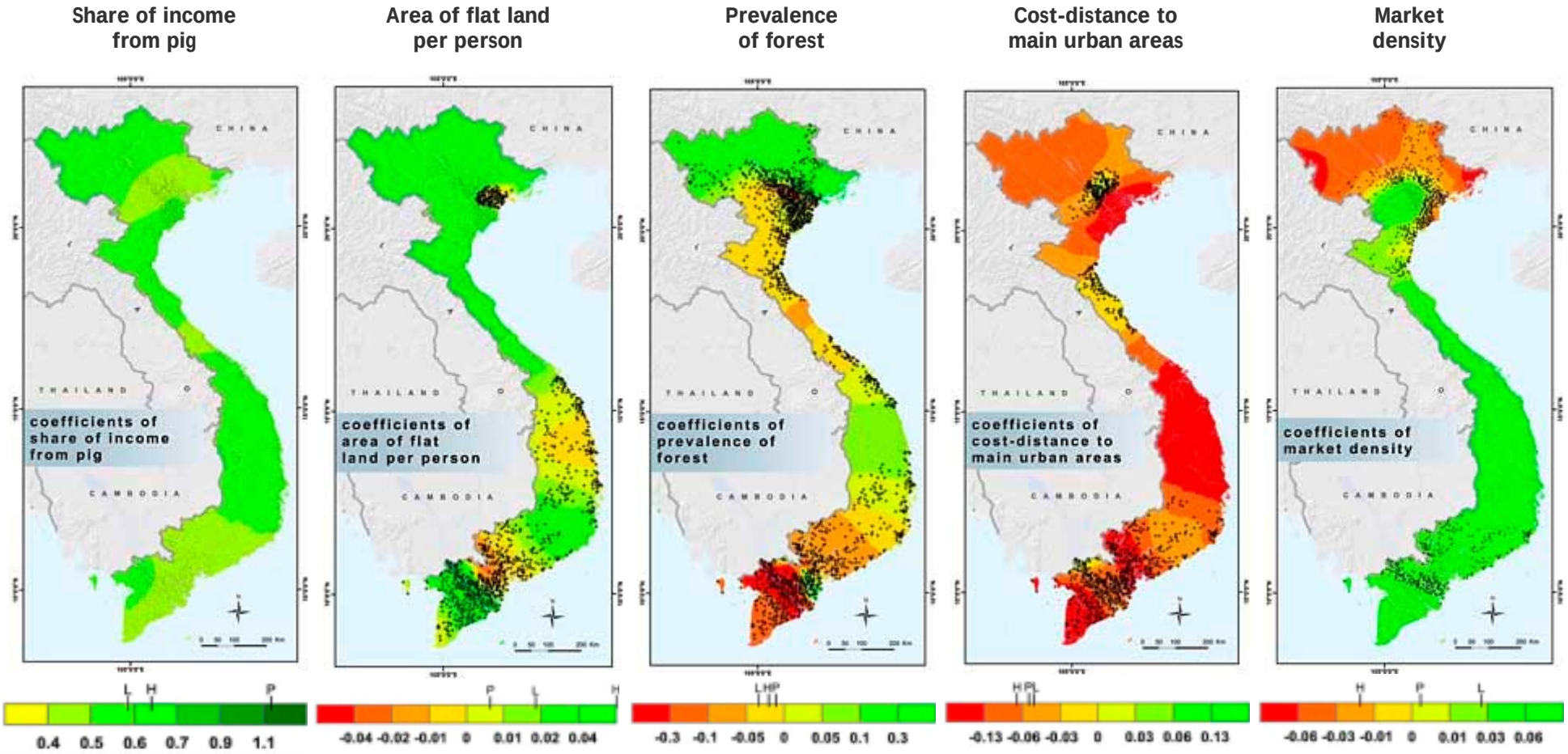
Data source: VHLSS 2002

Table 7 summarizes the regression outputs of this global pig model. All variables except for the prevalence of forest are significant at the 95% level; the forest variable being slightly less significant, throwing it into the 90% significance category. These global coefficients reveal a similar picture to the 'global livestock model'. One noticeable difference, though, is the negative sign for the market density coefficient: whilst the global livestock model produced a positive coefficient, indicating higher total household per capita income from livestock to be related to higher market densities, the global pig model suggests the opposite – that higher total household per capita income from pigs occurs in areas with lower market densities. Such a negative relationship might suggest the importance of pigs as a source of income, particularly in areas with lower market densities. Another indication, perhaps, that pigs are, at least in areas with lower mark densities, often marketed at a less formal level.

Figure 23 presents the spatial distributions of regression coefficients resulting from the local pig model. Comparing Figure 23 with Figure 22 (local livestock model) reveals a rather similar picture, not surprisingly, given the importance of pig production as a source of income within the livestock sector (see Figure 5).

As already indicated by the results of the global model, the main difference can be found in the variable market density. Whilst this coefficient is negative in the global pig model, the map reveals that the local model indicates significantly positive coefficients for most parts of the country – even the MRD, which is negative in the local livestock model. In the NU, however, the coefficients are more strongly negative in the local pig model than in the local livestock model, again possibly pointing at the importance of informal markets in those areas that are generally less accessible, and are characterized by poorer market and transport infrastructure.

Figure 23: *Local regression coefficients for independent variables of 'pig model'.*



Data source: VHLSS 2002

Data source: SRTM Topographic - USGS 2004

Data source: FIPI 1999

Data source: Author's modelling

Data source: Vietnam National Market Census 1999

L regression coefficient value in the global 'livestock model'
H regression coefficient value in the global 'pig model'
P regression coefficient value in the global 'poultry model'

. dots represent data points where the regression coefficients were significant at 95% confidence level

+ crosses represent data points where the regression coefficients were not significant at 95% confidence level

Linkages in 'poultry model'

The third of these local regression models looked at relationships between the independent variables and total household per capita income from poultry. Table 8 presents the summary regression output for the global poultry model.

Clearly these variables are less well able to explain the total household per capita income from poultry than they were with income from livestock overall, and from pigs, in the previous two models. Both, the R^2 is markedly lower than before, and two of the five variables, market density and prevalence of forest, are not significant in the global poultry model.

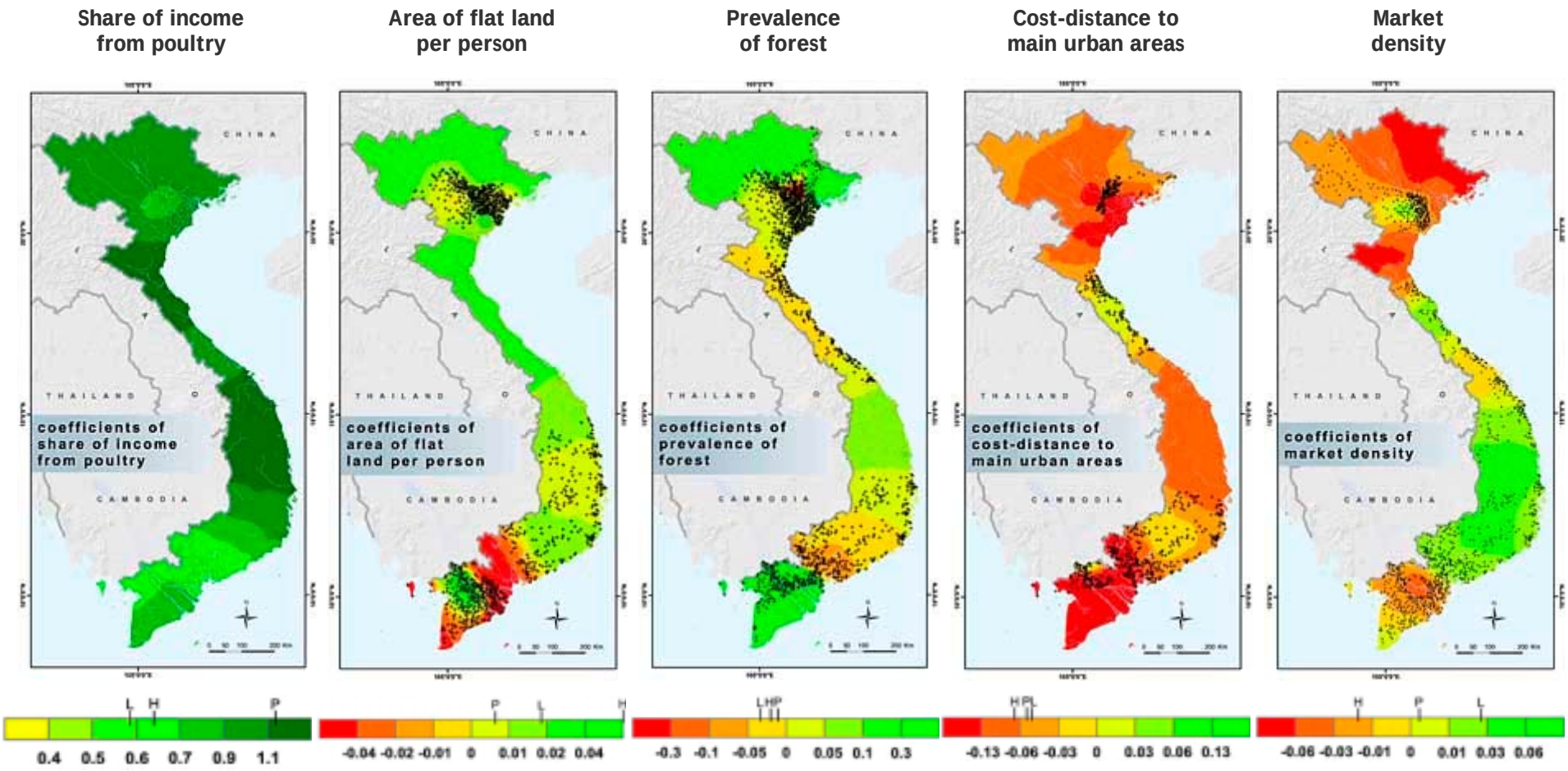
Looking at the coefficients of the local models, however, depicted in Figure 24, reveals the significance of all independent variables in some parts of the country, particularly in the NE. Market density, for example, in the local poultry model reveals a similar pattern to the other two models, with significantly negative coefficients in the NU, and positive significant coefficients in parts of the CH and the SCC.

Prevalence of forest, though not significantly in the global model, shows significant positive coefficients in the NU, the central part of the country, and in the MRD, indicating a positive relationship between prevalence of forest and income from poultry.

Existence of flat land in the commune reveals a similar picture to that shown by this coefficient in the local livestock model; positive coefficients in most parts of the country, but a significantly negative relationship in parts of the SE, where peri-urban industrialization is most advanced in Vietnam.

Lastly, total household per capita income from poultry is significantly negative correlated to the cost of access to main urban areas in large parts of the country. This implies that rising profitability of poultry as a source of income with closer proximity to urban markets.

Figure 24: *Local regression coefficients for independent variables of 'poultry model'.*



Data source: VHLSS 2002

Data source: SRTM Topographic - USGS 2004

Data source: FIPI 1999

Data source: Author's modelling

Data source: Vietnam National Market Census 1999

L regression coefficient value in the global 'livestock model'
H regression coefficient value in the global 'pig model'
P regression coefficient value in the global 'poultry model'

. dots represent data points where the regression coefficients were significant at 95% confidence level
+ crosses represent data points where the regression coefficients were not significant at 95% confidence level

Summary of observations

The examples presented in this chapter result from an exploratory analysis of the relationships among livestock holding patterns, accessibility and environmental variables, in which we try and elucidate the spatial variations in these relationships.

While there is certainly much scope to apply more sophisticated analytical techniques to explore such relationships locally, this example clearly shows the potential of locally spatially weighted regression in the analysis of livestock-poverty-environment linkages. There is also considerably more that could be done using this methodology, and one particular area worthy of further investigation is the use of various poverty measures as the dependent variable in the local regression models.

A few points worth re-emphasizing are:

- That there are strong spatial variations in relationships among livestock, accessibility and environmental variables.
- That in many cases the sign of the coefficients change over space in the local models, implying the limited validity of global analysis of relationships in these cases.
- That there appear to be different relationships with regard the density of formal markets, and access to urban areas; whereas better access to urban areas appears generally to have a positive influence on income from different livestock types, while sheer density of formal markets does not seem to be a decisive factor particularly in the more remote areas. This counterintuitive outcome requires further investigation.

CONCLUSIONS

Data situation

An assessment of the existence and availability of GIS data relevant to pro-poor livestock policy related mapping and spatial analysis in Vietnam revealed that, though the available data are of varying resolution, recentness and general quality, there does exist a wealth of relevant, spatially disaggregated data with which to implement interesting and useful pro-poor research.

There are, however, only limited GIS data on livestock specific aspects in Vietnam. Tabular data on livestock do exist; most notably from the 2001 Rural Agricultural and Fisheries Census, which could be georeferenced and is potentially an extremely rich source of livestock and other information.

Much of the available data are appropriate for national scale mapping, analysis and modelling, though some data sets, such as, for example, the transportation network, would require additional inputs to achieve a more up-to-date and more comprehensive data set. For regionally and smaller-scale focused work several of the available data sets would be too coarse in resolution and scale to be appropriate, and additional work would be needed to increase their resolution accordingly.

Mapping

Mapping of relevant indicators has been demonstrated to be an invaluable tool to visualize, interpret and communicate the geographic dimensions of livestock-poverty-environment issues at the national level. Furthermore, it could be of great value in communicating spatial variability in potential outcomes resulting from different modelled policy scenarios.

In this report digital mapping has been used:

- to locate poor livestock keepers,
- to identify the importance of different livestock types across space,
- to visualize and communicate information on spatial patterns and trends in livestock holdings, and
- to elucidate potential linkages, through common spatial patterns, among livestock holdings, poverty, environmental and physical variables.

Mapping helps to reveal spatial dimensions in data sets in a way that makes such information accessible to non-specialists; information that is often ‘hidden’ in tabular data bases. Visualization through digital mapping makes these data ‘accessible’ policy analysts, policy makers and other stakeholders and greatly facilitates communication and discussion.

Spatial analysis

In this report it has been clearly demonstrated that spatial analysis goes well beyond digital mapping. The visual interpretation and comparison of simple maps is a valid and valuable tool that can support policy analysis and discussion, but this can be taken much further, as demonstrated through the use of locally spatially weighted regression. A systematic spatial analysis of relevant indicators has been used:

- to identify and quantify relationships among livestock holdings, poverty, environmental and infrastructural variables,
- to detect and analyze spatial variation in these spatial relationships, and
- to develop spatial information that is relevant to policy analysis and discussion.

Spatially explicit analytical techniques, such as the one demonstrated here, hold great potential, when properly integrated and implemented, for pro-poor livestock policy analysis.

OUTLOOK

Data

While there is a wealth of GIS data and information available for general variables such as natural and physical settings, administrative division, etc. there is an obvious gap in the existence of spatial data on aspects of livestock holdings and agricultural production systems in Vietnam.

The 2001 Rural Agricultural and Fisheries Census of Vietnam includes detailed data on livestock holdings and related variables of each rural household in Vietnam, and all urban households in wards with households engaged in some agricultural activities. These data, if made available, could be geo-referenced at commune level and be used to produce very detailed and up-to-date GIS data sets on livestock holdings and production systems.

Commune-level aggregates of the relevant variables would be very useful. However, for the development of detailed production system GIS data sets, household-level information would be ideal, since much of the household-level production system patterns would be lost in commune-level aggregations.

It is therefore strongly recommended here to pursue negotiations with the GSO to gain access to the relevant variables from the 2001 Agricultural Census at least commune level, but ideally at household level.

Geo-referencing of these data would then be possible at commune level, using the location information contained in the Agricultural Census data base and matching it with administrative commune-level boundary data. These commune-level administrative boundary data are available in Vietnam, though would require some further inputs to update them to the administrative situation reflected in the 2001 Agricultural Census.

Mapping

Access to, and geo-coding of the highly disaggregated data from the 2001 Agricultural Census would allow the development of a number of valuable and detailed GIS data sets on livestock and other agricultural variables. This holds great potential for uncovering and communicating important spatial dimensions 'hidden' in the highly aggregated data sets that are currently available. A recent example of the great potential of spatially detailed mapping of Census data is the recently published Socioeconomic Atlas of Vietnam (Epprecht and Heinimann 2004), in which 1999 Population and Housing Census data have been depicted on national maps at communal level.

Some examples of the types of variables that should be considered for production of high resolution GIS data sets include:

- small-area livestock population distributions (gridded surfaces, by livestock type);
- livestock production systems;
- market prices;
- land holding patterns;
- marketed share of livestock production;
- inputs into livestock by household;
- changes and trends over time in livestock holdings; and
- econometrically modelled effects of policy adjustments on livestock holding and poverty.

Spatial analysis and modelling

As demonstrated in this report, the application of GIS should not stop at 'simple mapping' of data, but should be exploited for its great potential as an analytical tool.

The demonstrated spatial analysis is a preliminary exploration of linkages in space, which was possible within the framework of this paper. Obviously, there is great scope to refine and further develop the spatial analytical approaches that have been outlined here, and it is strongly recommended further to pursue this kind of analysis, which promises to reveal valuable information and develop important knowledge related to spatially differentiated pro-poor livestock policy analysis.

Some approaches that could usefully be applied in further spatial analysis and modelling exercises include:

- further development of the locally spatially weighted regression methodology, particularly in the use of welfare estimates as dependent variables;
- application of other spatial analytical techniques, such as local and global cluster analysis, to explore the spatial dimensions of livestock-poverty-environment linkages;
- spatial analysis of changes in livestock holdings;
- spatial modelling of effects on livestock holding and poverty resulting from changes in the infrastructural environment;
- spatial modelling of effects of policy adjustments on livestock holding and poverty; and
- identifying opportunities for geographically differentiated pro-poor livestock policy adjustments.

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