CPWF Project Report

A Water Poverty Analysis of the Niger Basin, West Africa

Niger Basin Focal Project: Work Package 1.

John Ward, David Kaczan and Anna Lukasiewicz

CSIRO Sustainable Ecosystems

CGIAR Challenge Program on WATER & FOOD

July 2009

Acknowledgements

The authors would like to acknowledge the support of the Niger Basin Focal Project leadership, Andrew Ogilvie, Jean Charles Clanet, and that of the CPWF leadership, Simon Cook. We also wish to acknowledge the financial support of the CSIRO Water for a Healthy Country National Research Flagship.

Most importantly, the authors wish to thank those who contributed to this research during its formative stage, or provided invaluable logistical assistance: Luc Ferry, 'Gil Mahé, Mary Bello, Jacob Poudiougo and Bekaye Diarra (our intrepid driver and guide), the people of Mali and the people of Burkina Faso.

Program Preface:

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase water productivity for agriculture—that is, to change the way water is managed and used to meet international food security and poverty eradication goals—in order to leave more water for other users and the environment.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface:

This report documents the findings of Work Package 1 for the Niger Basin Focal Project: A water poverty analysis. Research outputs presented here include maps of high poverty incidence and water related vulnerability. The statistical analysis revealed considerable spatial variation in water related poverty in addition to significant differences in the intra and inter-national factors associated with poverty. Poverty was measured as levels of child mortality, child morbidity and an asset wealth index to improve sensitivity in a primarily subsistence economy. Whilst the absolute quantity of water resources was important in some areas, the social and economic capacity to use and access this water was often more important.

CPWF Research Report series:

Suggested citation:

Ward, J., Kaczan, D. and Lukasiewicz, A. 2009. CPWF Project Report: Niger Basin Focal Project: Work Package 1. The CGIAR Challenge Program on Water and Food, Colombo, Sri Lanka.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. Executive Summary

Research Rationale

- The primary research focus of Work Package 1 was to quantify the magnitude, location and possible water related causes of poverty in the Niger Basin, West Africa. Water poverty occurs as the combined effect of factors such as increasing and competing water demand, changes in hydrological regimes due in part to climate change, increasing population, environmental degradation, reduced water quality, impediments to water access, conflict, corruption and changing levels of water productivity. These relationships are dynamic and likely to vary spatially and temporally. Past policy responses have relied on poverty assessments that are generally not spatially explicit; and hydrological models based on historical flows that may be redundant under regimes of climate change. Hence policy initiatives that rely solely on hydrologic probabilities, or fail to account for the different causal relationships of spatially differentiated poverty may be inappropriate or ineffective.
- Institutional arrangements for poverty alleviation and the unit of analysis where decisions are made and implemented can occur at the Whole of Basin, National, administrative district and community scale. The first research objective was to identify methodologies capable of integrating impact analysis and policy formulation that reliably differentiates poverty at regional, national and basin wide scales. A second research objective was to map poverty and vulnerability at scales that aligns water productivity, water access and poverty data. Through this data alignment, a third objective was to reveal and describe opportunities for politically feasible water policy formulation. A final objective was to provide evidence based analysis that guides instrument design and policy development in the direction of the causes of poverty and threats to livelihoods at scales that reflect the social units that are most exposed.
- To achieve these objectives we considered four core questions:
    i. How can we define, measure and spatially reference water related poverty, particularly in economies where a majority of provisioning or livelihood activities remain non-monetized?
    ii. Do the explanatory relationships of water poverty differ at different spatial scales of decision making? If so, what is an appropriate scale or unit of analysis, to capture the heterogeneity of poverty, identify areas of critical need and quantify the diversity of explanatory variables?
    iii. What is the most appropriate scale to reliably inform policy innovation, formulation and intervention that is feasible and most likely to be effective in poverty alleviation?
    iv. When constructing vulnerability or water poverty indices, is there a reliable alternative to subjectively determined weightings of composite variables? Is

there a rapid and feasible alternative when expert opinion or participatory processes are unreliable or infeasible?

A Socio-economic Overview of the Niger Basin

- The population of the Niger Basin countries is approximately 277 million, of which approximately 94 million live within the extent of the river basin (UN Population Division 2006). Population growth of the basin countries is high, with a long term average (1975-2005) of between 2.5 and 3.5% (UNDP 2007) (section 2.1.1).
- The demographic profile is female biased and young, with 44% of the basin's population under 15 years of age. The proportion of the basin's inhabitants living in urban areas is around 30%, although this is less so for the regions in the upper Sahel (Niger Basin Authority 2005) (section (section 2.1.1).
- The proportion of people living below the poverty line (US$1.25 per day) is high throughout the Niger basin countries and especially acute in Burkina Faso (70.3 %), Guinea (70.1%) and Niger (65.9%). The United Nations Human Development Index, a composite ranking based on national income, life expectancy and adult literacy rate, ranks all of the Niger Basin countries in the lowest quintile of countries. Burkina Faso is ranked 176th, Niger is 174th and Mali 173rd of 177 countries worldwide (section 2.1.1).
- A disproportionate number of the Niger Basin's poor live in rural areas. Burkina Faso and Niger have 90% of their workforces employed in agriculture, Mali 80%, Cameroon 70% and Guinea 76%. A large proportion of food production occurs within subsistence-based economic systems, and is thus not recorded under conventional national accounting measures such as GDP (section 2.1.1).
- Life expectancies of all the Niger Basin countries are in the bottom 15% of all countries worldwide. Childhood mortality rates (death prior the age of five) are extreme, up to 250 per 1000 live births, and are often two to three times higher than neighboring countries in northern and southern Africa. The region is characterized by a high prevalence of endemic and epidemic communicable diseases. Malaria is noted as the largest cause of mortality and contributes significantly to childhood deaths. Across the study region countries, 53% of people used an improved source of drinking water in 2004, and only 37% had access to adequate sanitation facilities, statistics that are low by world standards (section 2.1.2).
- Much of the Niger Basin's economic activity relies on functional agro-ecosystems. Climatic variability reduces the exploitable environmental value of the Basin's agricultural regions, however a 30% long term reduction in rainfall in the Sahelian regions since the 1970s may be indicative of a new, drier, climatic regime. Reductions in rainfall have led to a reduction in surface flows of between 20-50%. However, it is important to recognize that such dry spells have occurred before and the current climate's permanency is a subject of debate. Regional climate models predict warming

of up to 4°C over the next century, although are less conclusive regarding rainfall trends (section 2.1.3).

Defining Poverty in the Niger Basin

- We consider water related poverty as a function of three vectors: community vulnerability, situational vulnerability and hazard threat (section 4.1).

   i. **Community vulnerability:** the capabilities, assets and activities of the community. In the poverty model constructed here community vulnerability is represented by health variables, socio-economic variables, infrastructure and assets.

   ii. **Situational vulnerability:** represented here primarily by the water related variables. How well assets, capabilities and activities can withstand exposure to shock and stress of a changing water situation.

   iii. **Hazard threat:** the events that challenge the community/situation. These are represented by natural disaster risk, climatic variables, population density and environmental damage.

- The Niger Basin is characterized by high socio-economic heterogeneity, a high proportion of subsistence livelihoods and a relatively large non-market, hybrid economy. Given this, a univariate monetary measure of poverty (for instance, household income) is unlikely to capture the full extent of the problem. We use two health variables (child mortality and child stunting) and a composite wealth index. The univariate, absolute nature of the first two variables avoids the problem of subjective weighting of composite indices (section 4.3).

- A stated goal of the Water Poverty Analysis was to identify those areas particularly affected by high poverty rates. Demographic Health Survey (DHS) data, standardized across country borders, was used to map poverty estimates in the Niger Basin. The estimates for child mortality and child stunting are presented in Figure E-1 and Figure E-2 (section 4.3).

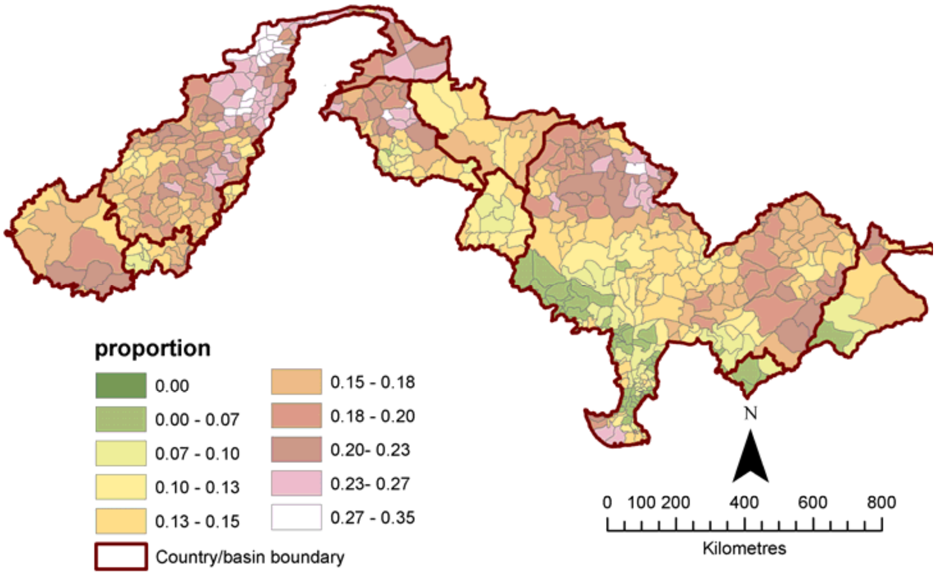


Figure E-1: Estimated child mortality (percentage of children who die before age 5) across the active Niger Basin (based on births recorded since 1980).

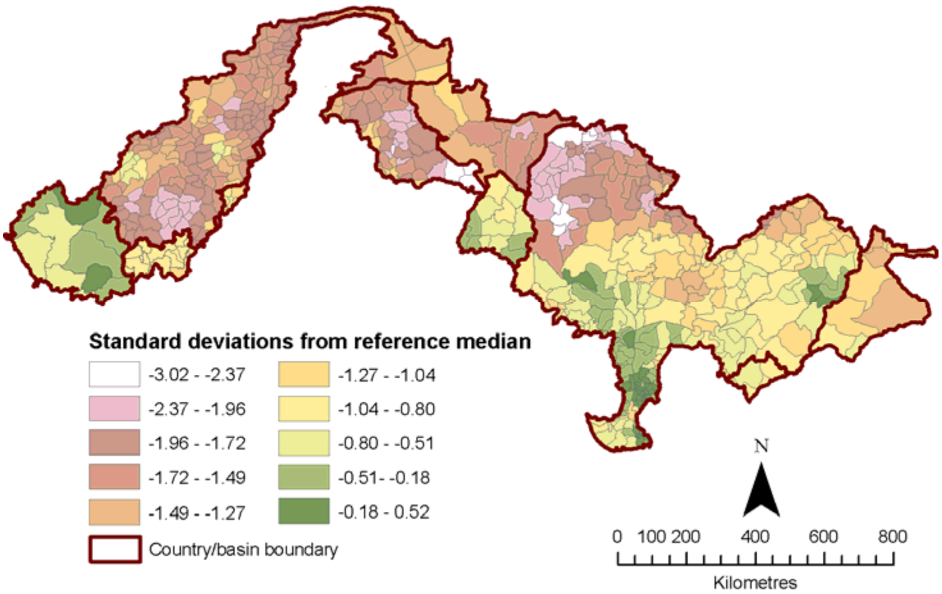


Figure E-2: Estimated child morbidity (age-height ratios) across the active Niger basin

Poverty at a Basin Scale

- At a country level, the most common measure of water stress (total available renewable water resources per capita) indicates that most of the Niger basin countries are not suffering water stress now or projected to 2025. Burkina Faso is the exception. Furthermore, both water stress and composite water poverty indices do not correlate with traditional national measures of poverty (HDI, social vulnerability index or genuine savings indicator). We hypothesized this was a matter of scale: in this case landscape matters and national scale statistics are not sufficiently precise to detect important regional variation.

- There is significant heterogeneity in the contributors to poverty across the Niger Basin. Most variables (of both a water related and non water related type) are significantly associated with poverty in only some of the countries or in sub regions of this varied Basin (section 0).
- The total quantity of available water resources appears significant in North West Nigeria, east Nigeria and central Mali. Overall however, this variable was associated with poverty only occasionally, suggesting that socio-institutional factors of water use are more important than water availability (section 0).
- Increased irrigation development is correlated with reductions in child stunting in central Mali, North West Nigeria, central and eastern Nigeria and North Burkina Faso (section 0).
- The quality of water used by households appears to be as important, or more so, than the total quantity of water available in the environment. The use of unprotected well or surface water is generally positively correlated with increased child mortality and increased stunting. In North West Nigeria and east Nigeria, a 10% decrease in the number of people using unprotected water is correlated with an up to 2.4% decrease in child mortality (section 0).
- Increased time spent in education is strongly correlated with a decrease in child mortality and child stunting. In much of the Mali Inner Delta, a one year increase in the average level of education is associated with a 3% decrease in child mortality. (section 0).
- Variables demonstrated to be spatially correlated or non-stationary are those likely to be more suited to geographically targeted policy intervention. The differences in estimated coefficients are likely to be symptomatic of the different ways in which a variable influences people in different places (section 0).
- There was considerable disparity between results for child mortality and child stunting, despite the widely accepted relationship between these variables. This highlights the need for poverty analysis that incorporates a number of alternative poverty metrics for cross validation, as is used here. We considered robust only those results that were supported by both the mortality and morbidity analyses (section 0).

Poverty at a Regional Scale

- Poverty estimates for the Niger Basin (Figure 11and Figure 12), were analyzed for spatial correlation to find ‘poverty hotspots’, or areas where policy intervention is most required. The child mortality and child stunting hotspots are presented in Figure E-3 and Figure E-4 (section 4.7). The wealth poverty index is not suitable for inter-national comparison, however as most hotspots are confined within the boundaries of one country, it is used in subsequent regression analysis.

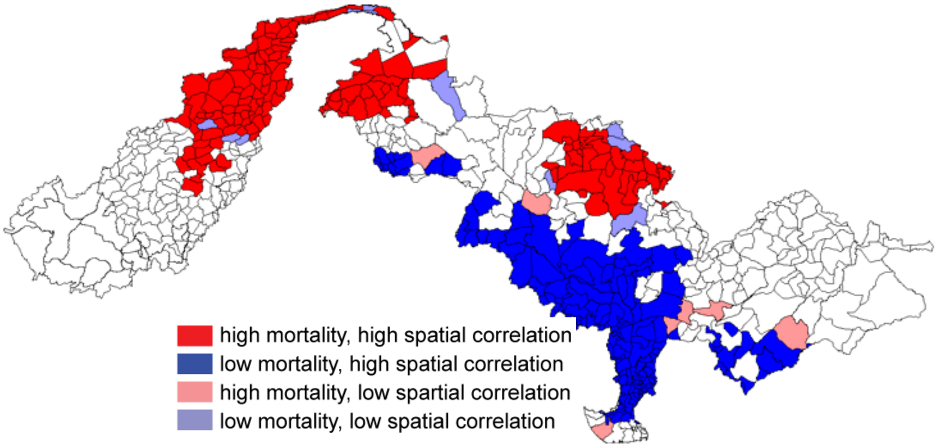


Figure E-3: Clusters of child mortality (proportion of children who die before age 5 yrs).

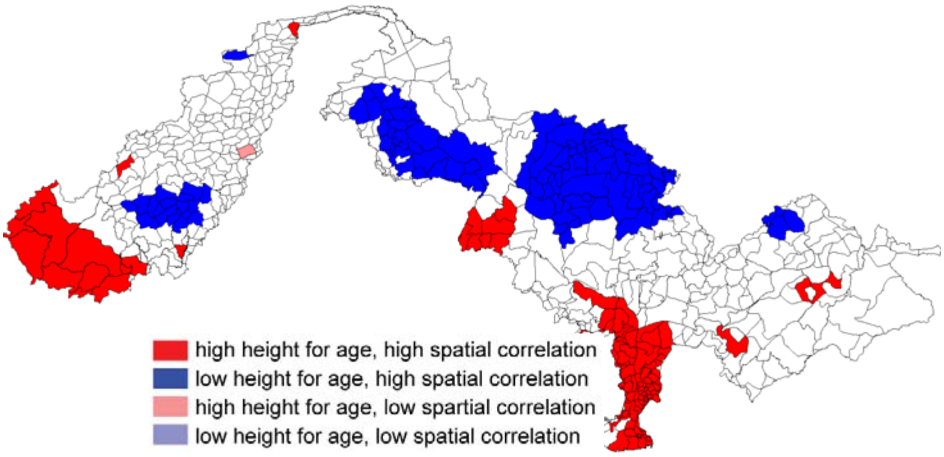


Figure E-4: Clusters of child morbidity (height for age ratios).

- There is broad convergence in the spatial correlation between poverty measures. Eastern Burkina Faso and North Western Nigeria are identified by all three measures (mortality, stunting and wealth) and Southern Mali by two (morbidity and wealth). Central Mali and the Inner Niger delta appears to be an extensive mortality hotspot, although it was not detected using stunting or wealth. Finally, Eastern Nigeria and neighboring northern Cameroon are identified as a hotspot when using the wealth index. Communities situated in regions of intersecting hotspots for all three metrics employed here are those expected to face the greatest poverty and vulnerability challenges (section 4.7).

- Each poverty hotspot was analyzed for potential causative factors. There appears to be considerable differences in the way poverty manifests in different regions of the Niger Basin (section 4.7.1).

  i. **North West Nigeria:** Water quality was the primary water-related factor that is correlated with poverty in North West Nigeria. A 1% decrease in the number of people who access their primary drinking water from unprotected well or surface water is associated with a 1.1% decrease in child mortality. Weaker evidence was found linking water access to child mortality: An average reduction of ten minutes taken to access the primary water source is correlated with a 1.7% decrease in child mortality rates. Similarly, a 1% increase in a district's irrigated area corresponds with a 0.04 standard deviation improvement in height-for-age ratios.

Education is the strongest non-water correlate: A one year improvement in average schooling attainment is associated with a 0.6% decrease in child mortality rates, all other factors held constant (section 4.7.1).

ii. **Central Mali and the Inner Delta:** This region is an important area of the Niger Basin as it contains the Ramsar listed Inner Delta – a highly productive flood plain covering an area of over 80 000 km^2. This region features average child mortality rates of 240 per 1000 live births.

The relationship between water and poverty is ambiguous in this region. Non-water variables were more clearly correlated with poverty. For instance, a one year increase in average schooling levels is associated with a 3.1% decrease in child mortality rates (section 4.7.1).

iii. **East Burkina Faso:** The use of unprotected water is correlated to poverty in this region, and suggests that quality is more important than quantity or access in this region. Environmental degradation, as measured by the World Wildlife Fund's 'Human Footprint' score significantly explained wealth and child mortality. An increase in environmental damage was associated with an increase in child mortality and a decrease in wealth (section 4.7.1).

iv. **East Nigeria and North Cameroon:** The use of unprotected water sources is significantly correlated both with reduced wealth and increased child mortality. A 1% decrease in the use of unprotected well and surface waters is associated with a 0.16% decrease in child mortality. Evidence was also found for a positive impact of dams and irrigation on poverty levels, as expected. Education is associated with reduced poverty in the wealth and mortality models, and a 1 year increase in average education levels is associated with a 0.7% decrease in child mortality (section 4.7.1).

- A key finding in this section of the report is that the absolute quantity of water available per capita is rarely successful in predicting poverty levels. Water quality, was more clearly associated with these measures of poverty. At most poverty hotspots there were significant correlations between the proportion of people drinking from unprotected water sources and the incidence of poverty. This direct relationship is to be expected for the child health poverty measures. These results also highlight the need for more accurate water accounting: the TARWR measurement does not translate reliably to higher resolution regional analysis in this study (section 4.7.2).

- The area of irrigated land was associated with decreases in poverty in only two cases, north west Nigeria (by one poverty metric) and in Eastern Nigeria and Northern Cameroon (by two metrics). This suggests either that irrigation's contribution to rural welfare is low in the Niger Basin, or that the levels of irrigation are too small at present to cause discernable improvement in livelihoods at this scale of analysis. The literature suggests that irrigation will be crucial for the future economic wellbeing of the basin, along with improvements in the productivity of rain-fed agriculture. However, it may be that the benefits of irrigation do not yet accrue to the people engaged in its practice, or that they do so at levels too small to register in these statistics (section 4.7.2).

Vulnerability mapping

- Vulnerability is a multifaceted problem, and some aggregation of causal factors is necessary to identify those areas most severely affected by their water limitations. The report presents vulnerability composites based on the coefficients determined in the poverty analysis (see Figure E-5 and Figure E-6). This aims to identify areas where the various forms of water limitation (quantity, quality, access and/or infrastructure) are contributing to the state of poverty generally, and hence are likely to contribute to a loss of livelihood in the future (section 5).
- It is important to note that this vulnerability analysis makes the assumption that the potential causal factors of poverty are also predictors of vulnerability. Vulnerability analysis is an attempt to predict livelihood outcomes in the future following changes in social and environmental situations. Due to the limitations of this project, we were unable to consider changes in the variables over time, which would provide a more direct insight into vulnerability. Instead these vulnerability maps are based on a 'snapshot' of current conditions in the basin and thus use poverty as a proxy for vulnerability.
- Immediately apparent is the differing regions of water vulnerability and community vulnerability. We consider situational (water) vulnerability to be the risk of a loss of livelihood due to a change in water resources (quality, quantity and access). We consider community vulnerability to be the risk of a loss of livelihood due to non-water related factors. Situational (water) vulnerability is most evident in the large poverty hotspot of North West Nigeria. A similar hotspot is evident in the Inner delta in Mali, highlighted using the mortality metric (section 5).

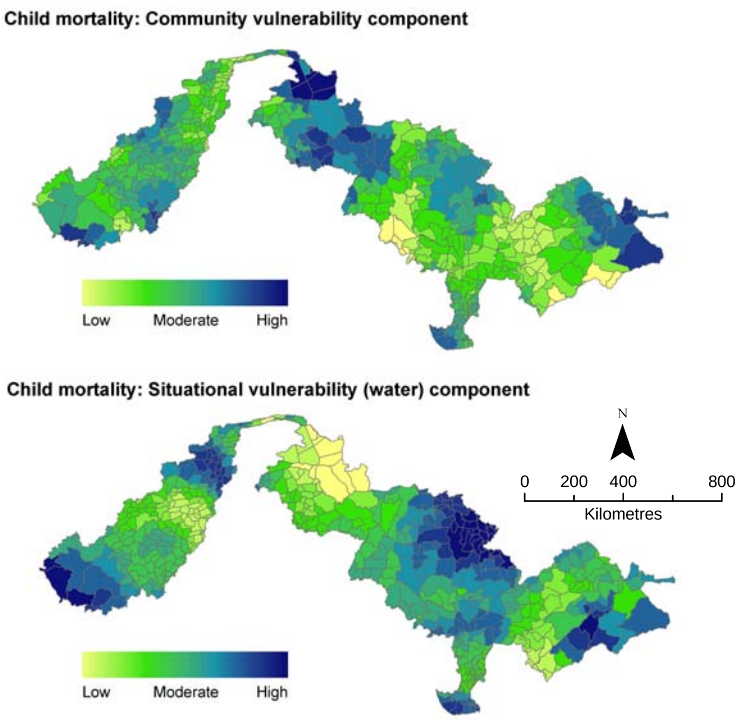


Figure E-5: Community vulnerability and situational (water) vulnerability estimated across the active Niger Basin, based on the child mortality metric.

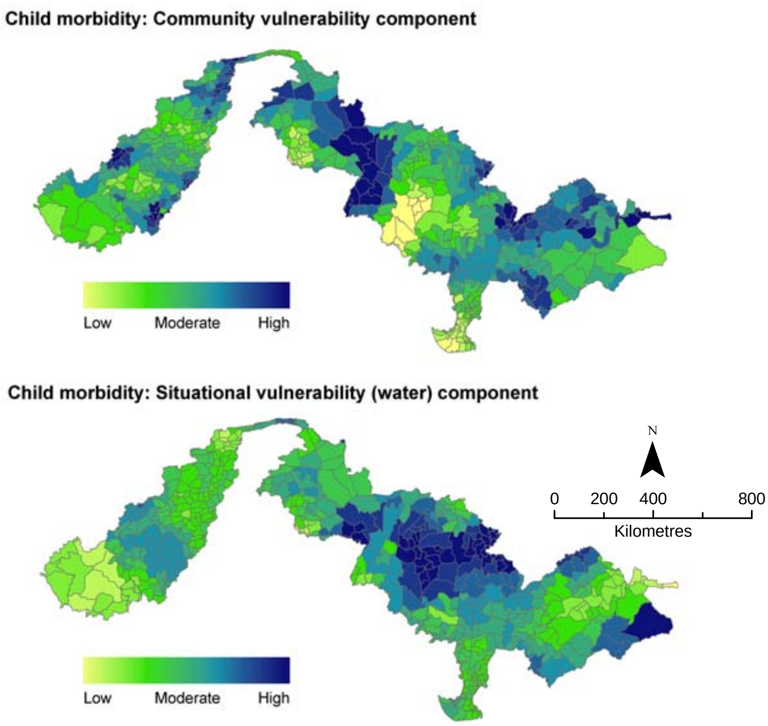


Figure E-6: Community vulnerability and situational (water) vulnerability estimated across the active Niger Basin, based on the child morbidity (stunting) metric.

Recommendations

- Poverty in the Niger Basin is widespread but highly differentiated across regions. Policy intervention should use mapping techniques such as those presented here to identify regions of greatest concern.

- The evidence provided here is based on statistical correlations only. Case studies and policy trials are required to demonstrate evidence based causality with confidence. There is a need for further research to focus on the issues of water poverty in the specific regions indentified in this broad study report.
- The application of spatial statistics in the form of geographically weighted regressions, at whole of basin, national or administrative district, is important to correct for potentially biased estimates.
- Any analysis of poverty should utilize multiple metrics of poverty, given that there is no strict consensus on what poverty is or involves. Our assessment demonstrates that related indicators can still provide quite disparate results. Findings that are supported by multiple measures of poverty are likely to be more reliable.
- The total available renewable water resources measure (per capita) is a poor descriptor of a country's water situation. At a national level it is not correlated closely with many of the key development and poverty indicators. At a sub-national level, we find that it is often secondary in importance to the quality of water-infrastructure, such as protected sources of drinking water, in predicting livelihood outcomes.
- Education is the most consistent non-water predictor of poverty.
- The vulnerability maps, estimated at a high resolution scale, can be viewed as evidence based, easy to interpret participatory tools, rather than a final product. The cadastral representation of the vectors of poverty at administratively feasible scales enable the community, policy makers and administrators to visually evaluate the relative effectiveness of alternative policy incentives and actions, the distribution of resources and investment priorities.
- Combining the research from the other Challenge Work Packages with the coefficients used to construct the vulnerability maps, is intended to provide a reliable basis for agencies to explore the social dimension that enables adaptive water system management. Agencies are thus able to concentrate on cases that describe incremental but large change and investigate social sources of renewal and re-organization.
- Estimating the covariance of those significant, spatially referenced factors that comprise community and situational vulnerability, combined with GIS mapping would enhance the usefulness of deliberative tools. This would be especially salient to evaluating portfolio approaches to poverty reduction, targeted sequencing of instruments and prioritization of investments across several factors.
- Using a case study approach central Mali examining proposed new dams and the effect on the inner delta indicate that building new dams on the Niger is not an efficient way to improve aggregate agricultural output and is unlikely to reduce poverty. Previous benefit cost analysis indicates that gains are more likely to be made by improving existing infrastructure, continuing extant institutional reforms associated with proven

productivity gains and by retaining and promoting the traditional economic activities of the inner delta.

- The report describes a static analysis of poverty. Ground truthing to more reliably establish causality and longitudinal data analysis to account for temporal effects are important validation approaches.
- Combining the developments on Bayesian networks, used to analyze poverty in the Mekong River basin, with the evidence based spatial weighting developed here merits further investigation.

2. Introduction

The Niger BFP (Basin Focal Project) is a research project funded by the Challenge Program on Water and Food (CPWF). The Program aims to provide an in-depth analysis of the socio-economic and agro-ecological situation in the basin through four main themes: poverty, water availability and access, water productivity and the institutional environment. Results from analysis of these four issues will be integrated so as to explore the links between these issues and poverty. It is the goal of the Niger Basin Focal Project and the Challenge Program on Water and Food to identify opportunities for improving the livelihoods of the Niger Basin's people through research.

The Niger River has a total length of approximately 4,100 km, making it the third-longest river in Africa (after the Nile and the Congo/Zaire Rivers). Its theoretical basin covers 2,170,500 km², although the active (hydrologic ally connected) basin is smaller, at approximately 1,500,000 km².

The Basin's extent lies over ten riparian countries, namely Nigeria (25.7% of the total basin area), Mali (25.5%), Niger (24.8%), Algeria (8.5%), Guinea where the sources are located (4.3%), Cameroon (3.9%), Burkina Faso (3.4%), Benin (2.0%), Ivory Coast (1.0%) and Chad (0.9%).

The river traverses agro-ecological zones of considerable diversity. The source waters originate in the wet monsoonal uplands of Guinea and provide the bulk of river flows. The Niger flows through the generally flat Sudanian and Sahelian regions of Mali. This region includes the Niger Inner Delta, a large area of wetlands and floodplains recognized for both its ecological and agricultural importance. The Niger then passes through the southern region of the Sahara desert, before turning to the south east and flowing towards Nigeria. A major tributary, the Banue River, joins the Niger in Central Nigeria.

The population of the Niger Basin is considerably impoverished and vulnerable to future environmental change. The primary objective of the research described in this report was to determine the extent, location, causes and typology of water poverty in the Niger River Basin more precisely. Specifically, the primary aim of the research was to determine the extent of poverty that is due to water related causes.

Despite a general consensus of the need to reduce poverty ongoing debate and conjecture remain about the description and measurement of poverty. As a corollary there exists a typology of poverty interpretations, associated with scales of policy formulation and institutional application. Daily household income, the sustainability of livelihoods, vulnerability to exogenous perturbations and the capacity of communities to adapt are some of the dimensions by which poverty is characterized. The description and measurement of poverty is similarly diverse, a response to the availability and reliability of data, the resources perceived to act as primary change agents and the locus and scale of policy formulation that directly effects poverty alleviation.

The literature review undertaken as part of this research revealed an extensive array of poverty definitions, metrics and composite indices. The lack of a comprehensive indicator that reliably captures the multi factorial characteristics of water related poverty has led to a raft of measurement techniques, constructed from weighted composite of statistics. Widely used examples include the Human Development Index (an amalgamation of life expectancy, school enrolment/literacy and income), the Water Poverty Index (a total of 17 indicators, see Lawrence et al. 2002)) and the Social Vulnerability Index (a total of 9 indicators, see Vincent (2004)). Although indices capture the multifaceted nature of a complex issue, they amalgamate disparate pieces of information with often arbitrary weights. Indices provide a viewpoint for a particular purpose, and implicitly represent the personal values of their architects (Molle and Mollinga, 2003). Yet indicators retain their prominence: they simplify and rationalize complex problems, they allow for easy comparisons, they suggest scientific legitimacy and they are easily communicated.

Adding another poverty index or measurement criteria to the literature is not the aim of this research. Instead, we rely on three common poverty variables and assess the role of water and non-water related variables in explaining the observed distribution in each for the countries of the Niger River basin. Jointly assessing the similarities, correspondences and discrepancies of spatially referenced, multiple metrics implies that conclusions drawn are founded on a more comprehensive evaluation - in contrast to the challenges and limitations of creating another 'single-use' index. The three poverty measures utilized are child mortality, child morbidity and the Demographic Health Survey's (DHS) Wealth Index

The poverty work package synthesized literature based insights from three main research domains: poverty analysis, vulnerability assessment and it's reciprocal, resilience and adaptive capacity. The research described in this report focuses on evidence based poverty analysis, which it is argued provides a basis for deliberative vulnerability analysis and exploration of adaptive management.

The review identified methodologies that enable spatial, temporal and institutional differentiation of poverty at multiple scales, primarily to mitigate the noted concerns of data aggregation to macro scales, which may compress critical information and disguise poverty heterogeneity across the Niger River basin. The review provided the basis to evaluate current practices, protocols and methodologies that best describe the relationship between priority poverty areas, surface water resource condition and region specific water management. Methodologies were ranked according to the capacity to reliably describe and spatially represent poverty at scales that are commensurate with available hydrologic and agricultural data, expressed as land and catchment condition. Aligning and mapping poverty and biophysical data at commensurate units of analysis enables other related Niger work packages to differentiate poverty, livelihoods and vulnerability to water related stresses across the basin.

Policy decisions are often made at state or national level, and regional perspectives or understanding of poverty cannot be presumed to be aligned or concordant with basin differentiation of poverty, livelihood vulnerability or institutional diversity (Hyman et al. 2005). More effective policy that influences water productivity may be reliant on mixes of sequenced instruments tailored to address temporally and spatially diverse poverty patterns. An equally important focus of the review was to guide methodological development and application that imputes variables at scales that simultaneously aligns water productivity, access and poverty data. Alignment indicates opportunities for water policy formulation that is administratively and politically feasible across the Niger basin countries. The analysis was intended to guide water management policy formulation in the direction of the causes of poverty, threats to livelihoods and increased vulnerability at scales that reflect priority social units that are most threatened or exposed. With such analysis, measures of water productivity and access, when significant, can be incorporated into aspects of policies that support sustainable livelihoods and become an integral part of mainstream development support.

Poverty is a measure of current status: vulnerability involves a predictive dimension, providing a means of conceptualizing what may happen to an identifiable population or exposure unit under conditions of particular risks and hazards. Precisely because it should be predictive, vulnerability analysis should be capable of directing development aid interventions, seeking ways to protect and enhance peoples' livelihoods, assist vulnerable people in their own self-protection, and support institutions in their role of poverty reduction (Cannon et al 2000).

There are two main streams of literature characterized under the rubric of vulnerability (*inter alia* Sen and Dreze 1898) and livelihood assessment (Chambers and Conway 1992, Scoones 1998). The natural hazard food security literature generally relies on a positivist top down approach, focused on the objective quantifiable impact assessment of hazards. Emphasis is placed on a particular environmental stress and vulnerability refers to the risk of exposure of an ecosystem to that stress. An alternative bottom up approach arises from the political economy epistemology, where vulnerability refers to the functional relationship between the economic and political institutions of particular social units of exposure and the stressor effects. These competing paradigms of biophysical and social vulnerability have resulted in conflicting theoretical constructs and terminology, non-commensurate data sets and animated and fragmented debate. Similar to the early development of the sustainability literature, vulnerability science appears to be beleaguered by theoretical schisms and convergence is subsumed by definitional debate. The antagonism has compromised the emergence of a coherent, robust and widely accepted set of methodological protocols and approaches.

Sen (1981) and Sen and Drèze (1989) introduced the notions of entitlements, endowments, capabilities and potentialities as elements of a systematic analysis of vulnerability. Entitlements are the food that a household can marshal through production, exchange or extra legal conventions such as kinship relations or community reciprocity. Endowments are the assets a household controls including stores of food or cash, investments in productive assets, and claims on other households, communities, the state, or international community. Whilst entitlements are sets of alternate commodity bundles, capabilities are sets of alternate functioning commodity bundles. Sen (1981) argues that capabilities to achieve food security and well being are predicates of and shape entitlements. They are predicated on the total rights of individuals to pursue well being, and relate to the institutional and social relationships whereby individuals or groups can command endowments and entitlements and provision themselves. Institutional relationships, expressed as capabilities, provide the functional link between entitlements and the capacity to pursue well being, to the political economy. The combined influence of capabilities, entitlements and assets create a buffer or coping range between production and consumption, between well being and contingencies and hazards.

Vulnerability analysis attempts to identify those social (or exposure) units who are most exposed to a perturbation, are most at risk to reductions in well being, who posses a limited coping range or capability and are least adaptive or resilient to change. (Ribot 1996) posits that impact assessment points to a typology, magnitude and distribution of the consequences of perturbations, hazards and shocks, such as climate change, altered resource access and entitlement change. When determined independently of the social causes of vulnerability, impact assessment does not necessarily lead to policy relevant insights or recommendations. In this context, (Downing, 1991, Ribot 1996), vulnerability analysis traces out the multiple causes of critical outcomes (drought, famine, hunger) in contrast to the examination of multiple outcomes of a single event. The vulnerability assessment of the Niger Basin was intended to bridge the gap between impact analysis and policy formulation, by informing agencies of the antecedent causes of vulnerability rather than the symptoms.

We propose that the poverty measures (child mortality, child morbidity and the wealth index) are functions of community vulnerability, situational vulnerability and hazard threat. Community vulnerability encompasses the capabilities, assets and activities of the community. Situational vulnerability is how well these assets, capabilities and activities can withstand exposure to shock and stress. As this study focuses on water poverty in particular, situational vulnerability is represented by water related variables. Hazards are the threats, stresses and perturbations that communities or social units are exposed. In contrast to the majority of previous water poverty analyses emphasizing composite indices, we derive evidence based estimates of the poverty relationships from existing data.

The intention of this method was to mitigate the criticisms associated with the arbitrary weighting of variables. Spatially weighted linear regression was used to determine the significance and magnitude of explanatory components that influence poverty. This inductive approach is superior by introducing a framework of testable hypotheses employing coefficient estimates based on data interpretation and analysis. Contingent on the selection of variables, determined primarily on commensurate data availability, it makes no *a priori* assumptions about what may or may not influence water related livelihoods.

Vulnerability maps were constructed from the spatially weighted regression coefficients and estimated at a high resolution scale. These are intended to be viewed as evidence based, easy to interpret participatory tools, rather than a final product. The cadastral representation of the vectors of poverty at fine scale enable the community, policy makers and administrators to visually evaluate the relative effectiveness of alternative policy incentives, the distribution of resources and investment priorities.

Adaptive governance of social and water based systems in the Niger is not a primary focus of the poverty package. However a top down positivist approach to poverty mitigation has attracted criticism for assuming static, passive responses by human populations to hazards and stressors, failing to capture the capacity to mediate, resist and adapt. Resilience refers to the ability of a society or ecosystem, through either governance structures or institutions, to withstand exogenous stressors or perturbations. Such governance arrangements connect individuals, communities, organizations, agencies, institutions at multiple organizational levels. Bridging organizations sometimes emerge which transform management organizations into learning environments, drawing on various knowledge systems for the development of a common understanding and policies. These bridging organizations may lower the costs of collaboration and conflict resolution, enabling the possibility of adaptive co-management and improve the efficacy of policy adoption. Folke et al. (2005) propose that such arrangements reduce vulnerability and poverty, transforming crises into an opportunity to transform into a more desired state.

Combining the research from the other Challenge Work Packages with the coefficients used to construct the vulnerability maps, is intended to provide a reliable basis for agencies to explore the social dimension that enables adaptive water system management. Agencies are thus able to concentrate on cases that describe incremental but large change and investigate social sources of renewal and re-organization.

The causal variables of vulnerability may not be limited to the individual household; communities, enterprises, cooperatives, regions river basins and the state may also be vulnerable to a multiplicity of causal agents warranting similar analysis. Interdependence of social units infers that changes in household vulnerability can have ramifications on the vulnerability of constellations of social collectives and the state, often in cascading, rapid and uncertain ways. Understanding each institutional element in terms of the vulnerability of other social groups and their relations may be a crucial component of policy development. Effective policy to reduce poverty and vulnerability may need to be formulated and implemented with embedded institutions and multiple scales in mind.

The population of the Niger Basin is considerably impoverished and vulnerable to future environmental change. The socio-economic profile of the basin as described in the literature is presented in section 2. The remainder of the report is structured as follows:

Section 3: A synthesis of literature based insights from three main research domains: poverty analysis, vulnerability analysis and water accounting. A primary focus is to identify methodologies that enable spatial differentiation of poverty at multiple scales.

These methods overcome data aggregation which otherwise compress critical information and hence disguise poverty heterogeneity.

Section 4: The poverty analysis. Metrics of poverty
This section examines the correlates of poverty by mapping hypothesised causes across the basin and estimating statistical relationships. This analysis demonstrates the differentiated impact that causal factors have in geographically dispersed locations.

Secondly, the poverty analysis identifies those regions which are most severely impoverished (poverty 'hotspots'), and attempts to determine the extent to which water related and non water related variables are responsible in each case.

Section 5: A simple model of vulnerability based on the findings of section 4 is presented. Vulnerability is a multidimensional concept, and its quantification entails aggregating a variety of contributing factors. We present approximate maps of both situational vulnerability (that caused by hypothesized non-water related deficiencies), and situational vulnerability (that hypothesised to be caused by water related deficiencies).

Section 6: The Niger Basin contains a multitude of ethno-linguistic groups that adds considerably to the complexity of managing natural resources such as water. At the resolution of analysis undertaken in section 4, it was not possible to examine ethnicity as a possible informal institutional determinant of livelihood outcomes. However we were able to undertake a simple assessment of poverty differentiation based on ethnic divisions, which is presented here.

Section 7: We recognize that the associational evidence presented in the poverty analysis does not prove causality and that only field studies and policy trials can establish such links. As a starting point in this process, we provide some insight into the water-poverty nexus with two literature based case studies: the Office du Niger and the Inner Delta (both located in Mali).

2.1. Poverty and Vulnerability Profile of the Niger Basin

Widely available national level statistics are generally relied on to establish an assessment of a country's status according to multiple criteria and indices. Despite different agency approaches and focus, there is a strong and enduring consensus as to West Africa's acute poverty. The following profile of the region discusses the issues highlighted by such indices from literature based insights. Indicators of economy, health, education and the environment were utilized in turn to compile the summary profile. The degree of spatial heterogeneity and general variability within a country however ensure that such a profile is a broad overview only. Refining this perspective to account for regional variation is the primary objective of this report's quantitative analysis. Table 1 summarizes several of these indicative data for the nine Niger River Basin countries compared to OECD and non-OECD statistics.

2.1.1. Demographics and Country statistics

Table 1: National economic statistics for countries of the active Niger basin

	Population (millions)[a]	GDP (PPP, per capita) ($US 2007)[a]	Gini coefficient[a]	% of population below poverty line (US$1.25/day)[b]	Unemployment (%)[a]	External debt to GDP ratio[a]	Economic Aid ($US 2007 per capita)[a]
Benin	8.08	1,500	36.5	47.3	-	0.10	46
Burkina Faso	14.33	1200	39.5	70.3	77	0.08	46
Cameroon	18.06	2,300	44.6	32.8	30	0.06	23
Chad	9.89	1600	-	61.9	-	0.10	38
Cote D'Ivoire	18.01	1,800	44.6	23.3	40	0.34	3
Guinea	9.97	1000	38.1	70.1	-	0.33	18
Mali	12	1,200	40.1	51.4	30	0.19	58
Niger	12.89	700	50.5	65.9	-	0.23	40
Nigeria	135.03	2,200	43.7	64.4	5.8	0.02	48
OECD* mean	n/a	37 496	30.9	n/a	5.83	1.68	10.39
Non OECD* mean	n/a	10 898	42.2	n/a	14.59	0.38	18.65

Source: [a] - CIA World Fact book (2007)

[b] – World Bank (2009)

*OECD mean based on the 27 high income countries as defined by World Bank

Economic development in West African nations has been either slow or static for the past fifty years. When ranked by GDP (using purchasing power parity, per capita), all nine countries of the Niger Basin fall in the bottom quarter of national incomes. Economic growth in 2007 averaged 5.5% (weighted by proportion of basin population), with higher growth in Nigeria, very low growth in Cote d'Ivoire and Guinea, and negative growth in Chad. Non OECD growth rates worldwide averaged a similar 5.3% for 2007. The population of the Niger Basin countries is approximately 277 million, of which approximately 94 million live within the extent of the river basin (UN Population Division 2006). Population growth of the basin countries is high, with a long term average (1975-2005) of between 2.5 and 3.5% (UNDP 2007). The demographic profile is female biased and young, with 44% of the basin's population under 15 years of age. The proportion of the basin's inhabitants living in urban areas is around 30%, although this proportion is smaller in the Sahelian regions (Niger Basin Authority 2005).

The proportion of people living below the poverty line (US$1.25 per day) is high throughout the Niger basin countries and especially acute in Burkina Faso (70.3 %), Guinea (70.1%) and Niger (65.9%). A disproportionate number of these poor people live in rural areas. The labor force is often concentrated in industries associated with agriculture, although agriculture as a share of GDP is often disproportionately low. This is partially due to low productivity, a problem common across Sub-Saharan Africa where the average cereal yield is 1230 kg/ha, compared with over 3000 kg/ha in South America and Asia (Hanjra and Gichuki 2008). Furthermore, a large proportion of food production occurs within subsistence-based economic systems, and is thus not recorded under conventional national accounting measures such as GDP. Burkina Faso and Niger have 90% of their workforces employed in agriculture, Chad and Mali 80%, Cameroon 70% and Guinea 76%. Conflict and institutional instability have discouraged investment and the landlocked Sahel nations suffer from geographic isolation, growing desertification and extremes in climate variability, all of which constrain the agrarian sector (Niger Basin Authority 2005). Foreign aid forms a large part of the Niger basin GDP: 15.7% in Mali, 15.3% in Burkina Faso and 11.6% in Niger. In Burkina Faso, aid revenues form approximately 40% of the government's annual budget, a potentially important factor of national revenue instability (UNDP 2005).

2.1.2. Health and Education

The United Nations Human Development Index, a composite ranking based on national income, life expectancy and adult literacy rate, ranks all of the Niger Basin countries in the lowest quintile of countries (see Table 3) (UNDP 2007). Burkina Faso is ranked 176th, Niger is 174th and Mali 173rd of 177 countries. Life expectancies of all the Niger Basin countries are in the bottom 15% of all countries worldwide (see Table 2). Childhood mortality rates (death prior the age of five) are extreme, up to 250 per 1000 live births, and are often two to three times higher than neighboring countries in northern and southern Africa (Balk *et al.* 2003). The region is characterized by a high prevalence of endemic and epidemic communicable diseases. Malaria is the largest cause of mortality and contributes significantly to childhood deaths. Across the study region countries, 53% of people used an improved source of drinking water in 2004, and only 37% had access to adequate sanitation facilities, statistics that are low by world standards (UNICEF 2004). HIV infection prevalence is considered high (between 1.1 and 7.1%); however infection rates are less severe than those in southern Africa. HIV is also a major contributor to childhood mortality (Balk *et al.* 2003).

Table 2: National health statistics for countries of the active Niger basin

	Life expectancy at Birth (years)[a]	Under 5 mortality rate (%)[a]	HIV aids - adult prevalence rate (%)[b]	Health expenditure as a proportion of GDP (%)[a]	Proportion of population undernourished (%)[a]
Benin	55.4	19.1	1.8	3.5	12
Burkina Faso	51.4	15.0	2	6.3	15
Cameroon	49.8	14.9	5.4	3.6	26
Chad	50	20.8	3.5	2.9	35
Cote D'Ivoire	47.4	19.5	7.1	3.8	13
Guinea	54.8	15.0	1.5	4.1	24
Mali	53.1	21.8	1.7	5.2	29
Niger	55.8	25.6	1.1	3.3	32
Nigeria	46.4	19.4	3.9	4.6	9
OECD* mean	78.3	0.52	0.22	8.7	0
Non OECD* mean	66.1	6.76	3.34	5.1	18.8

[a]: Source: UNDP, 2007

[b]: Source: UNAIDS, 2006

Statistics measuring levels of educational attainment also highlight the development challenges facing the region. Adult rates of literacy are some of the lowest in the world, and female literacy levels are significantly less than those for males (see Table 3). However, these figures are a significant improvement over the previous decade (UNESCO 2008). Primary education participation rates have increased in all the basin countries, with Niger, Mali, Chad and Benin increasing net enrolment ratios by over 10%. However, Burkina Faso, Niger, Cote d'Ivoire, Mali and Nigeria still each have over a million children out of school. Poverty and education attainment are highly correlated, hence it is unsurprising that rural children are disproportionately represented by these low statistics (UNESCO 2008). Education is a key factor limiting people's ability to find employment outside of agriculture, hampering the growth of the industry and service sectors (Simonsson 2005).

Table 3: Human Development Index and national education statistics for countries of the active Niger basin

	Human Development Index Rank (of 177 countries)[a]	Adult literacy rate[b]	Female adult literacy rate[b]	Education expenditure as a proportion of GDP[a]
Benin	163	34.7	23.3	3.5
Burkina Faso	176	21.8	15.2	4.7
Cameroon	144	67.9	59.8	1.8
Chad	170	47.5	39.3	2.1
Cote D'Ivoire	166	50.9	43.6	4.6
Guinea	160	29.5	18.1	2
Mali	173	46.4	39.6	4.3
Niger	174	28.7	15.1	2.3
Nigeria	158	60.6	60.1[a]	-
OECD* mean	n/a	> 95	> 95	5.5
Non OECD* mean	n/a	79.5	75.5	4.5

[a]: Source: UNDP, 2007

[b]: Source: CIA World Factbook, 2007

2.1.3. Resources and the Environment

The chronic and extreme poverty summarized by the national statistics contrast with the significant natural wealth found in the basin. The supranational managing authority, the Niger Basin Authority (2005) argues that developments in water infrastructure and management systems to harness the wealth of the River Niger are lacking. The potential for agricultural production is estimated at 2.5 million hectares, of which only 20% is currently developed. There are three large dams between the River's source in Guinea and Niamey, the capital of Niger (the Sélengué, Sotuba and Markala dams in Mali). Total hydroelectricity potential is estimated at 30 000 GWh, of which 20.6% is currently developed. In Mali, for instance, the electricity network is limited to the capital and 26 towns only (Marie *et al.* 2007). Further hydroelectric potential may be utilized to meet future extension and demand growth. Fish production is also important, and the biodiversity content supported by the river is high. For example, 250 species of freshwater fish may be found here of which 20 are unique (Zwarts *et al.* 2005). The Sahelian countries' Economic output is highly dependent on the Niger River.

Although it is recognized that the basin has much untapped potential, the social and environmental consequences of the proposed large scale investments in river impoundments are yet to be fully analyzed (Zwarts *et al.* 2005). Large scale developments often bring much needed investment and economic activity to a region, but planners are advised to consider the severity of unintended negative externalities of reduced fish populations and breeding (Adams 2000).

Climatic variability reduces the exploitable environmental value of the Basin’s agricultural regions, and a 30% long term reduction in rainfall in the Sahelian regions since the 1970s may be indicative of a new, drier, climatic regime (Niger Basin Authority 2005; Bates et al. 2008). However, it is important to recognize that protracted dry spells have occurred before and the current climate’s stability or degree of permanency is a subject of ongoing debate. The inherent variation in the region’s climatic system may simply mean that a ‘representative’ rainfall figure is itself unrealistic (Hulme 2001). Reductions in rainfall have also lead to a reduction in surface flows of between 20-50%. The increase in climate variability has left the Sahel region and its people more vulnerable to desertification and land degradation, a process that is a function of both climate change and human activity and land management. The impact of climate change on the population of the Niger Basin is potentially severe; however the lack of consensus in modeling predictions means that governments must consider a number of possible scenarios (Mitchell *et al.* 2004).

Vulnerability to climate change is a key issue considered in this report due to the large agricultural dependence of these countries. Summary of climate modeling predictions for 2100 are presented in Table 4. Predictions, based on a variety of global models and compiled by Mitchell (2003) at a national scale, suggest a 3-4°C temperature increase under a high emissions scenario (A2) and a 1.9-2.6°C temperature increase under a low emission scenario (B1). Predictions concerning precipitation are more varied between models. However, temperature increases will increase evaporation regardless of any change in the seasonality and magnitude of precipitation (IPCC, 2001; Bates et al. 2008).

Table 4: Precipitation and Temperature predictions for 2100, based on an average of 4 Global Climate Models (CGM2, CSIRO2, HadCM3, PCM) for special emissions reporting scenarios A2 and B1.

Country	**1961-90 mean precip. (mm/yr)**	**Predicted mean precip. change (mm/yr) (2100)**		**1961-90 mean temp. (°C)**	**Predicted mean temp. change (°C) (2100)**	
		A2	**B1**		**A2**	**B1**
Benin	1039.6	13.0	7.0	27.5	3.5	2.1
Burkina Faso	748	-5.1	15.1	28.2	3.9	2.3
Cameroon	1603.8	-8.0	-12.5	24.6	3.2	1.9
Chad	320.9	-3.5	12.5	26.5	4.0	2.4
Cote D’Ivore	1348.1	-29.0	12.6	26.3	3.3	2.0
Guinea	1651.3	-42.3	20.3	25.7	3.5	2.0
Mali	282.1	-12.4	7.6	28.2	4.4	2.6
Niger	150.6	15.3	18.2	27.1	4.2	2.5

Source: Mitchell, 2003.

Despite reduced rainfall, the Niger Basin Sahel countries of Mali, Burkina Faso and Niger have increased the quantity of cultivated land by 9.51 million hectares over the past 40 years (FAO, 2007) (although not all of this area falls within the Niger Basin). Further increases in the basin's cultivated area will not be enough to maintain food security in the face of a rapidly increasing population. Increasing yields will be required, on top of those already achieved (Marie *et al.* 2007). Since 1966 rice productivity has doubled and corn productivity has increased by 50% in Mali for instance, although the more important crops of sorghum and millet have been subject to lesser improvements. Water extraction for agricultural purposes increased by 10.6 million megalitres between 1985 and 2000 across all the Basin countries (FAO 2007).

Table 5: National land and water statistics for countries of the active Niger River Basin.

	Cultivated area (1000 ha) (2003)	Surface water: total renewable (10^9 m^3/yr) (2007)	Groundwater: total renewable (10^9 m^3/yr) (2007)
Benin	2917	26.1	1.8
Burkina Faso	4900	8.0	9.5
Cameroon	7160	280.5	100
Chad	3630	41.5	11.5
Cote d'Ivoire	6900	78.3	37.8
Guinea	1750	226	38
Mali	4700	90	20
Niger	14500	31.2	2.5
Nigeria	33400	279.2	87

Source: FAO, 2007

The fishing industry is important to the people of the Basin, with an annual total catch of between 50-150 thousand tonnes. This provides both a vital protein source and direct employment for approximately 600 thousand people, with the majority working in the inner Niger delta (Marie, *et al.* 2007). The inner delta is a key natural asset across the region, providing sustenance for approximately one million people and ecological services for the entire basin (Zwarts *et al.* 2005). There is a strong correlation between the size of the River's floods and the size of the fish harvest, an important consideration for river management and development (Zwarts *et al.* 2005).

3. Hazard and Natural Disaster Literature

3.1.1. Vulnerability according to different disciplines

Vulnerability is studied in numerous disciplines, such as finance, security, public health, economic development, natural hazards and climate change (Janssen *et al.*, 2006). This diversity of disciplines leads to confusion over the definition and use of vulnerability as a concept (Preston & Stafford Smith, 2008).

The term has roots in geography and natural hazards literature and represents a conceptual cluster for integrative human-environment research (Füssel, 2007). Vincent (2004) identifies it as the "ability to anticipate, resist, cope with and respond to a hazard"; while the International Fund for Agricultural Development sees it as the probability of an acute decline in access to food or consumption that leads to an "inability to meet basic survival needs" (Cook & Gichucki, 2007). Kasperson *et al.* (2001) define vulnerability as the "differential susceptibility to loss from a given insult". Cutter (2003) explains that vulnerability helps to understand circumstances that lead to risk and the conditions which reduce the ability to respond to environmental threats. Thus vulnerability is composed of (a) risk (exposure), (b) hazard, (c) resilience, (d) differential susceptibility and (e) recovery/mitigation (Cutter, 2003). For instance, the IFAD definition of vulnerability captures exposure to a hazard and the lack of adaptive capacity (Cook & Gichucki, 2007). Other vulnerability definitions focus on marginality, susceptibility, adaptability, fragility and risk (Vincent, 2004). Kasperson *et al.* (2001) point out that entitlement; coping mechanisms and resilience are most important – thus focusing on the susceptibility to the imposed risk. Vincent (2004) also highlights the importance of resilience and coping capacity by saying that vulnerability is a function of economic, social, political, environmental and technical assets.

According to Fussel (2007), most conceptualisations of vulnerability agree on the following components: the system; the attribute of concern; the hazard and a temporal reference. For instance, Downing and Patwardhan (2004) created a nomenclature of the vulnerability of social systems based on: threat, region, sector, population group, consequence and time period; while Metzger *et al.* (2005) classified the vulnerability of ecosystems to global change by: ecosystem service, location, scenario of stressors and the time period.

Fussel (2007) suggests that the reason why there is so much confusion over different conceptualisations of vulnerability among the disciplines is a "failure to distinguish between sphere and knowledge domain". Table 6 shows Fussel's concept of vulnerability that encompasses both social and biophysical aspects and divides them into internal or external spheres. Taken together, these four constitute the vulnerability profile of a particular system or community.

Table 6: Fussel's conceptual model of vulnerability

	Domain	
Sphere	Socioeconomic	Biophysical
Internal	Household income, social networks, access to information	Topography, environmental conditions, land cover
External	National policies, international aid, economic globalisation	Severe storms, earthquakes, sea-level change

Source: Fussel, 2007

Adger (2006) argues that vulnerability is a dynamic concept and its measurements must reflect both social processes and material outcomes within systems and these are complicated with many linkages. Vulnerability also manifests at multiple scales which means that policy interventions promoting resilience need to address the multi-level nature of vulnerability (Adger, 2006).

There exist two main epistemological approaches in the study of vulnerability (Vincent, 2004): the top-down biophysical risk exposure approach (known as the risk-hazard model, RH) and the bottom-up social vulnerability approach (known as the pressure-and-release model, PAR). Despite varying terminologies, epistemologies and methodologies, the polarization in vulnerability between these two models is growing (Vincent, 2004) and studies are reduced to either the identification of physical exposures or a focus on local social dynamics (Cutter, 2003). These two models are briefly explained below.

3.1.2. Risk hazard models

The risk hazard (or natural hazard) model follows a positivist paradigm and focuses on the objective study of hazards. It emphasises particular environmental stresses and vulnerability in this sense refers to the risk of exposure to a hazard (Vincent, 2004). Preston and Stafford Smith (2008) define the risk-hazard model as one aiming to "understand the impact of a hazard as a function of exposure to the hazard event and the dose-response (sensitivity) of the entity exposed." The model emphasises biophysical vulnerability and focuses on the modelling of global impacts and place-based case study approaches (Vincent, 2004). Risk-hazard models suffer from a number of limitations including the ways in which the systems in question amplify or attenuate the impacts of the hazard; the distinctions among exposed subsystems and components that lead to significant variations in the consequences of the hazards; the role of the political economy, especially social structures and institutions, in shaping differential exposure and consequences (Turner *et al.*, 2006); and the lack of accepted methodology or conceptual framework which make comparisons of case studies impossible. The approach is useful, however, for assessing risks to certain valued elements that arise from their exposure to hazards of a particular type and magnitude (Fussel, 2007).

3.1.3. Pressure and release models

The pressure and release model (PAR) was developed first by Wisner, *et al.* (1994). PAR comes out of human ecology and political economy literatures, uses interpretive social science paradigms and is based on relativist and constructivist ontologies. It stems from the argument that the discourse of hazard management failed because it did not engage with political and structural causes of vulnerability within society due to a perceived dominance of engineering approaches (Adger, 2006). Hazards are mediated by institutional structures and therefore the affects on the poor and marginalized are more pronounced (Adger, 2006). Vulnerability refers to a particular group or social unit of exposure (especially to economic, political and social structures and institutions (Vincent, 2004). Preston and Stafford Smith (2008) define PAR as those models where "risk is explicitly defined as a function of the perturbation, stressor, or stress and the vulnerability of the exposed unit". PAR emphasises social vulnerability and mediating hazard exposure by looking at local-level case studies where the focus is on developing theoretical insights into processes and interactions (Vincent, 2004). The model takes its starting point from a risk-hazard framework, defining risk as the combined product of hazard and vulnerability (Fussel, 2007). The limitations of the PAR model include limited detail on the structure of the hazard's causal sequence, including the nested scales of interactions and a tendency to underemphasize feedback beyond the system of analysis (something that integrative RH models include) (Turner, *et al.*, 2006). It also under-emphasizes the dynamic relationships and feedbacks among biophysical hazards and processes and social vulnerability processes (Preston & Stafford Smith, 2008).

The PAR model has more recently been augmented by the Access model (Wisner, *et al.* 2004). The Access model attempts to explain at a micro-level the impact of a disaster as it unfolds, with particular reference to the resources accessible to individuals that can be deployed to mitigate disaster. Risk is thus generated as a result of the difficulties that some social groups have in accessing certain resources over time (Bankoff, *et al.* 2004).

3.2. Poverty literature

3.2.1. Concepts of poverty

The literature is replete with an abundance of differing concepts and definitions of poverty. Poverty has been traditionally measured as individual or household income, often calibrated to a standard reference, but this has been criticized as an inadequate reflection of the many dimensions of poverty. Poverty measures can either be objective or subjective, and furthermore, may be absolute or relative. A third variant of poverty concept classifications is that between physiological and sociological poverty.

Objective measures of poverty are based on a "normative judgment of what constitutes poverty and what is required to lift people out of their impoverished state" (Cook & Gichucki, 2007). Objective measures focus on material status and its proxy indicators, such as income or wealth (often measured monetarily), health (for example child mortality) or nutrition (for example calories).

Subjective measures of poverty are of more recent heritage and emphasize individual utility in terms of how much people value goods and services. These have led to the development of participatory poverty assessment methodologies (Cook & Gichucki, 2007). Subjective poverty measurements reveal both material and psychological aspects of poverty. Studies have shown that wellbeing is often considered in material terms (e.g. good health, steady source of income) and non material terms (e.g. safety, being part of a community and freedom of choice) (World Bank, 2008).

Absolute measures of poverty are defined by reference to a certain quantitative measure which is used to define the poor from the non-poor. These measures are often based on the cost of purchasing a minimum 'basket' of goods that is required for human survival. An example of an absolute poverty measure is the 'dollar per day,' which classifies individuals as poor or non-poor based on a fixed point. The status determined by an absolute measure of poverty is unaltered by changes in other individual's poverty status.

Relative measures of poverty attempt to understand poverty in terms of distributions of resources in a society (Townsend, 1979). They compare the lowest segments of a population with upper segments, usually measured in income quintiles or deciles (Lok-Dessalien, 1998). Relative poverty and absolute poverty can sometimes move in opposite directions. An individual may become wealthier in absolute terms but be overtaken by more successful contemporaries, leading to *relative* impoverishment.

Physiological measures of poverty focus on the basic physical needs of life, such as income, food, clothing and shelter. Poverty-reduction strategies based on the physiological approach attempt to increase the income or consumption of the poor and hence their attainment of basic needs (Cook & Gichucki, 2007).

Sociological measures of poverty focus on the underlying structural inequalities, inherent disadvantages and other factors that constrain the poor by denying them access to resources they need to lift themselves out of poverty (such as credit, water, common property resources and information) (Cook & Gichucki, 2007). It is characterized by a focus on a lack of opportunities (rather than material goods).

Also important to note is the distinction between monetary measures of poverty and index measures of poverty. The former simply measure income in dollars, whilst the latter considers a range of selected socio-economic indicators added together. Monetary approaches assume that subjects are operating in a monetary economy, and their income as defined by dollars is a sufficiently accurate metric of consumption. Index measures are broader in scope but are influenced by the choice of indicators and the convention employed to establish relative weightings.

3.3.Livelihoods literature

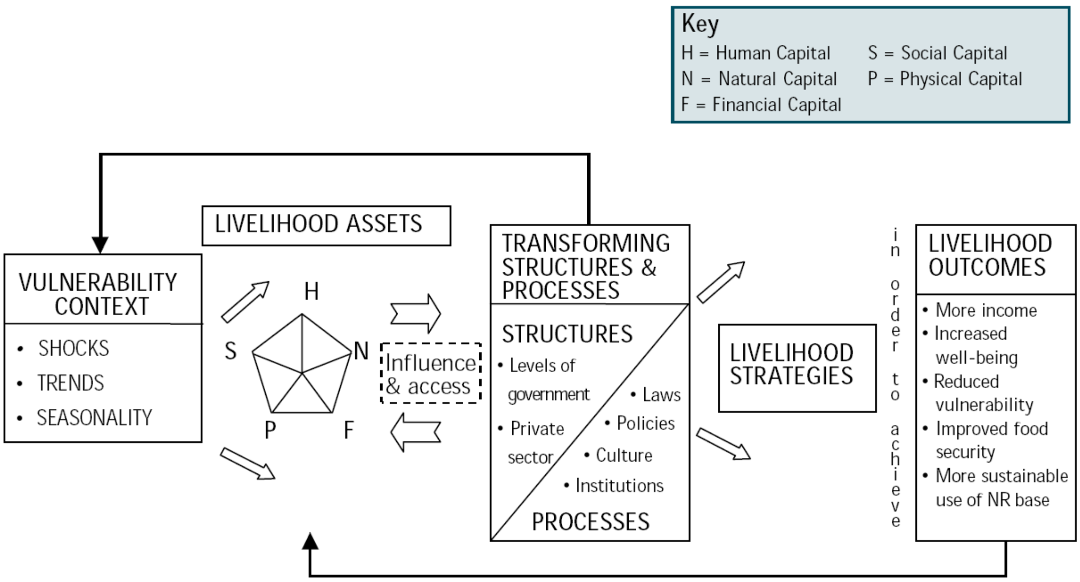
3.3.1. Entitlements and endowments approach

Sen (1981) and Drèze and Sen (1989) developed the entitlement and endowment approach to expand the concept of poverty from a strict food-per-capita approach to a consideration of power relationships. Entitlements are “the set of alternative commodity bundles that a person can command in a society using the totality of rights and opportunities that he or she faces” (Sen, 1984, p. 497). Apart from entitlements, people also have endowments (assets and resources, including labor power). Sen (1981, p. 2) divided entitlements into four categories - “production-based entitlement” (growing food), “trade-based entitlement” (buying food), “own-labour entitlement” (working for food) and “inheritance and transfer entitlement” (being given food by others). Although the concept has limitations (detailed by Sen himself and other critics, see for instance Devereux, 2001), it remains a powerful analytical tool and has informed livelihoods approaches to poverty. Vulnerability to food insecurity, for instance is often explained through the entitlement theory as a set of linked economic and institutional factors (Adger, 2006). Entitlements deliver particular capabilities that in Sen’s and Sen and Dreze’s framework are the basis for wellbeing. Such capabilities also include notions of rights of access and liberty (Sen, 2001). Sen's theoretical construct is reflected in practice by the approach of the United Nations' Human Development Report and in related development metrics such as the Human Development Index (HDI, see section 3.6.2) (Fukuda-Parr, 2003).

3.3.2. Livelihoods

Chambers (1983) and Chambers and Conway (1992) represent seminal writings in the heritage of the livelihoods approach. The sustainable livelihoods framework was largely initiated by Chambers and Conway (1992). The United Nations Conference on Environment and Development expanded on these concepts and pragmatically viewed the achievement of sustainable livelihoods as a broad goal for poverty eradication (Krantz, 2001). Livelihoods take into account the many dimensions of poverty discussed above and radically differ from conventional evaluations of poverty by focusing on peoples' lives rather than on resources or defined project outputs (Ashley & Hussein, 2000). Chambers and Conway (1992) defined a sustainable livelihood as one comprising of "the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base". The assets referred to include tangible assets and resources as well as intangible assets such as claims and access (Krantz, 2001). Specifically, the five types of assets are: social, human, physical, financial and natural.
Figure 7 illustrates schematically the multiple interacting dimensions that potentially influence the livelihoods of the poor, including these five livelihood assets.

Figure 7 The Sustainable Livelihoods Framework



(Source: DFID, 1999)

The livelihoods approach asserts that whilst economic growth is important for poverty reduction, there is no automatic relationship between the two since poverty eradication depends on the capabilities of the poor to take advantage of expanding economic opportunities (Krantz, 2001). This assertion embraced by the livelihood approach highlights the general lack of subjective measures of poverty that characterize traditional poverty approaches. The participatory nature of the livelihoods approach also recognizes that the poor posses the necessary knowledge of their own situation and must be involved in the design of poverty eradication measures. Livelihoods are most often measured at the household level (Ashley & Hussein, 2000).

3.4. Climate change literature

There are climate change-specific definitions of vulnerability. Moss et al (2001) specify three dimensions of vulnerability to climate change – physical-environmental; socio-economic and external assistance. The IPCC (2001) definition of vulnerability is the degree to which a system is susceptible to and unable to cope with the adverse effects of climate change. Key parameters of this are stress, sensitivity and adaptive capacity (Adger, 2006).

The literature on climate change is usually pursued through case studies which are based upon a simple linear relationship between hazard and impact. Vulnerability to climate change in these scenarios refers to biophysical vulnerability (Vincent, 2004). Other case studies look at the impacts of climate change on humans by investigating issues such as malaria incidence, food security, water availability and coastal flooding. However, these studies assume humans are passive recipients of global environmental change (Vincent, 2004). Traditional assessments conceptualize climate change as changes in the mean state of the climate system (i.e. average annual means) which are then applied in models to estimate mean impacts. Preston & Stafford Smith (2008) argue that these assessments do not consider either inter-annual or multi-decadal climate variability and the distinction between climate change and climate variability is largely artificial.

Sperling (2003) warns that climate change vulnerability is nested within numerous existing vulnerabilities. Besides the degree of climate change one must consider the rate of climatic changes. Rapid rates of change may pose greater challenges then the actual magnitude of the changes (Parmesan & Yohe, 2003) but the vulnerability to rates of change has not been studied extensively.

Assessments of vulnerability are usually based on the characteristics of a vulnerable system, the type and number of stressors, their root causes, effects on the system and the time horizon of assessment (Fussel, 2007).

3.4.1. Components of climate change vulnerability

Climate change vulnerability assessments are composed of three components: exposure, sensitivity, and resilience. Exposure refers to the measure of the probability that a certain risk will occur – it is related to the presence of risk as well as the people in the location of the risk; sensitivity determines the degree to which a group will be affected by environmental stress and is influenced by socioeconomic and ecological conditions; resilience (which has roots in natural sciences, especially ecology) is the extent to which an individual or a community can utilize coping and adaptation strategies (Holling, 1973; Kasperson *et al.*, 2001). Resilience is referred to as adaptive capacity by Preston and Stafford Smith (2008) who define it as the ability of a system to change in a way that makes it better equipped to manage its exposure and/or sensitivity to climatic influences.

3.4.2. Justifications for adaptation to climate change

The implementation of adaptation policies and measures will only occur in the presence of either persistent vulnerability (i.e. the exposure to climatic variabilities and hazards on a periodic basis) and/or emergent risk (climate change can either introduce new risks or substantially shift existing risks) (Preston & Stafford Smith, 2008). There is disagreement between the social and biophysical schools on whether adaptation research should focus on social determinants that contribute to current vulnerability (social school) or look at future biological changes that will affect future vulnerability and exposure (biophysical school) (Preston & Stafford Smith, 2008). This divide is reminiscent of the polarisation between the risk-hazard and pressure-and-release models of vulnerability with the biophysical school leading towards the former and the social school towards the latter. Regardless of which deserves more attention, according to Nkomo *et al.* (2006), the continent of Africa (and therefore the Niger River Basin) is currently exposed to a high and persistent degree of vulnerability to climate change and faces the highest emergent risks described in the table below:

Table 7: Current and future vulnerabilities for Africa

Current and Future Vulnerabilities	Explanation
Climate variability	manifesting in extreme events
Water	lack of access to water low water productivity declines in river flows
Health	heavy disease burden caused by vector-borne diseases influenced by climatic elements
Agriculture and food security	recurrent droughts soil degradation water supply increasing population
Environmental conflicts and migration	resource scarcity-induced conflicts ranging from civil wars to skirmishes between livelihood groups (sedentary farmers v pastoralists)

3.4.3. Limits and barriers to adaptation

A limit to adaptation is an absolute and unsurpassable barrier; while a barrier is a constraint caused by societal values or the way that a society is organized (Hulme *et al.*, 2007). Barriers can be overcome – limits can not. Limits often arise from biophysical constraints and represent inherent uncertainties in estimating future climate change and societal change (Preston & Stafford Smith, 2008). Barriers, however, are tied to measures of wealth (such as access to financial credit, access to technology and education as well as access to knowledge) and are the reason why developing countries are regarded as having low adaptive capacity (Preston & Stafford Smith, 2008). Not all barriers are material – they can also be social, cultural or cognitive (Adger, *et al.*, 2007). Cognitive barriers include differences in world views; perceptions of vulnerability, adaptive capacity and risk as well as competition with other issues on the political agenda (Adger, *et al.*, 2007). Access to knowledge about climate change becomes essential in overcoming cognitive barriers since traditional coping mechanisms of many societies are backward-looking and based on historical experience and observations (Sperling ed., 2003)

Preston and Stafford Smith (2008) identify four core components to Adaptation to climate change:

- Incentive / stimulus – adaptation is a response to some stimulus
- Agent – who adapts, each adaptation measure will have individuals or institutions responsible for decision-making.
- Capability / Entitlement – how adaptation is achieved, available resources (social and material capital), entitlements. Synonymous with adaptive capacity
- Goal – what is to be achieved; adaptation cannot be pursued in a policy vacuum.

There are also many types of adaptation and each faces specific and potentially unique limits and barriers. Adaptation can be general or specific, autonomous or planned, positive or negative (Preston & Stafford Smith, 2008). The IPCC distinguishes between anticipatory and reactive adaptation (anticipatory reduces vulnerability), private and public adaptation, and autonomous and planned adaptation (Tol *et al.*, 2008).

3.5. Water Indices

3.5.1. Water wealth

Water-related poverty occurs when people are either denied dependable water resources or lack the capacity to use them. Thus not all poor people lack adequate water resources and not all those who live in dry areas are poor (Cook & Gichucki, 2007). Black and Hall (2003) define the water-poor as:

- Those whose livelihoods are persistently threatened by either drought or flood
- Herders, fishermen, farmers who depend on water availability
- Those whose livelihood base is subject to erosion, degradation, confiscation without due compensation
- Farmers unable to improve agricultural productivity because of high risk & uncertainties of markets & rainfall which could be reduced by a little water at the right time
- Subsistence farmers who are constrained from higher value products (fruit, vegetables, meat)
- Those living with high-levels of water-associated disease without means of protection

Cook and Gichucki (2007) define water wealth as "a function of water availability and water productivity of the agricultural water management system that enables people to derive a livelihood from it". This definition takes into account three variables:

- Water system – determines availability and reliability of water
- Agricultural system – converts water into a livelihood support through food, income or other attribute. This is defined by water productivity
- Livelihood system – modifies access according to social relations, institutions or organizations

3.5.2. Falkenmark Water Stress Index

The Falkenmark Water Stress Index was developed by the Swedish water expert Falkenmark in 1989 and is one of the most commonly used indicators for water stress. It was modified in 1998 by Ohlsson and Appelgren to include measures of social capital (Cook & Gichucki, 2007). The Index is based on the estimation that a flow unit of one million cubic metres of water can support 2,000 people in a society with a high level of development (derived by calculating the total annual renewable water resources per capita) (Assimacopoulos, 2004). Interpretation of water availability using the index is explained in Table 8.

Table 8: The Falkenmark Water Stress Index

Water Availability m³/capita/year	Explanation
>1,700m³	threshold above which water shortage occurs only irregularly or locally
1,700m³ - 1,000m³	water stress appears regularly
<1,000m³	water scarcity is a limitation to economic development and human health and well-being
<500m³	water availability is a main constraint to life

Adapted from Assimacopoulos (2004).

The Falkenmark Index is useful as a coarse scale comparative metric but suffers from a number of limitations, as argued by Cook and Gichucki (2007) and Assimacopoulos (2004).

The Falkenmark Index is limited by the fact that it:

- makes no difference between impact and condition
- fails to take water quality into account
- only considers the renewable surface and groundwater flows in a country
- does not account for temporal and spatial water variability
- does not consider a country's ability to use the resources.

3.5.3. Water Poverty Index

The Water Poverty Index was developed by the Centre for Ecology and Hydrology (CEH) in Wallingford, UK and has received substantial academic attention (Sullivan, 2002; Lawrence *et al.*, 2002). It attempts to reveal the relationships and connections between water scarcity and social and economic aspects for selected geographic, hydrologic or political regions. By employing consistent variables and parameters countries can be comparatively ranked according to five water related components:

- Resources
- Access
- Use
- Capacity
- Environment

Components are standardised with a value between 0 and 1 and are derived from two to five indicators. The overall index is generated as a sum of the component values, between 0 and 100. A value of 100 is only possible if a country ranks best in all of the five components. (Assimacopoulos, 2004).

Cook and Gichucki (2007) argue that the rigid definition of relative weights required of the Water Poverty Index limits its value as an analytical tool. The subjective and arbitrary assignment of indicator weighting values further limits analytical applications. Introducing participatory processes of varying degrees of rigour and formality can improve reliability and the scope for ordinal comparison.

3.5.4. Total Actual Renewable Water Resources (TARWR)

TARWR is a *theoretical* measurement of water availability defined by national boundaries which estimates the total available water resources in cubic metres per person per year in each nation (World Water Report, 2006).

TARWR is calculated by:

- adding all internally generated surface water annual runoff and groundwater recharge derived from precipitation falling within the nation's boundaries
- adding external flow entering from other nations which contributes to both surface water and groundwater,
- subtracting any potential resource volumes shared from the water which comes from surface and groundwater system interactions, and
- subtracting, where one or more treaty exists, any volume required by that treaty to flow from the country to downstream reaches under other national jurisdictions (World Water Report, 2006).

TARWR suffers from a number of limitations. It:

- does not account for temporal and spatial water variability
- fails to take water quality into account
- does not identify the volumes of 'green' water needed to sustain ecosystems or provide water resources for direct rain-fed agriculture, grazing, grasslands and forests
- does not account for the volumes of water that are potentially available from non-conventional sources (reuse, desalination, non-renewable groundwater).

3.5.5. Water Availability Index

The Global Water Availability Assessment model created by Meigh *et al.* (1999) takes the temporal variability of water into account. This monthly Index includes surface water as well as groundwater resources, and compares the total amount to the demands of all sectors, i.e. domestic, industrial and agricultural demands. The index is normalised to the range −1 to +1 (Assimacopoulos, 2004).

The Index is calculated using the formula:

$$WAI = (R+G-D) / (R+G+D)$$

Where R is surface runoff, G is groundwater resources and D is the sum of demand across all sectors (Assimacopoulos, 2004).

3.5.6. Basic Human Needs Index

The Basic Human Needs Index, developed by Gleick (1999), quantifies the amount of water that a person needs for basic water requirements which include drinking, cooking, bathing, sanitation and hygiene, as 50 litres per person per day (see Table 9). This measurement is used to estimate the number of countries where the average domestic water use is below this threshold (Assimacopoulos, 2004). The 50 litres per person per day figure is broken down according to the basic need as follows:

Table 9: Basic Human Needs Index components

Need	Litres
Drinking Water	5
Sanitation Services	20
Bathing	15
Food Preparation	10

Source: Gleick, 1999

Gleick (1996) qualifies a number of assumptions in the derivation of thee values. Drinking water is defined as the true minimum to sustain life in moderate climatic conditions and average activity levels and food preparation does not include the water required to grow food. Gleick (1996) estimates that the amount of water required to grow the daily food needs of one person is 2700 liters.

Limitations of this approach include:

- does not account for temporal and spatial water variability
- fails to take water quality into account
- regional water scarcity is not depicted
- country data about the domestic water use are insufficient and unreliable
- the needs of other water users, such as the industry, agriculture or nature itself, are not included (Assimacopoulos, 2004)

3.5.7. Water Scarcity Index

The Water Scarcity Index combines information about water abstractions and water availability. It is defined as gross freshwater abstractions as a percentage of either the total renewable water resources or the internal water resources (Assimacopoulos, 2004). Heap *et al.* (1998) added the variable of desalinated water resources to this indicator as it is prominent in some regions (although insignificant on the global scale). The Index is calculated according to the formula:

RWS = W-S / Q

Where RWS is the water scarcity index, W are the annual freshwater abstractions, S are the desalinated water resources and Q is the annual available water. The severity of water stress is presented in Table 10:

Table 10: Severity of water stress in the Water Scarcity Index

Measurement	Stress Level
RWS < 0.1	no water stress
0.1 < RWS < 0.2	low water stress
0.2 < RWS < 0.4	moderate water stress
0.4 < RWS	high water stress

Source: Assimacopoulos, 2004.

The limitations of the water scarcity index are:

- It does not account for temporal and spatial water variability
- It fails to take water quality into account

3.6. Poverty indices and mapping

3.6.1. Social Vulnerability Index

The Social Vulnerability Index was developed by Vincent (2004) and calculated for countries in sub-Saharan Africa. This Index builds on human-ecological and political-economic approaches and uses economic, social and environmental categories to define the level of social vulnerability. It is a composite index made up of economic well-being and stability (measured by the standard of living and the change percentage of the urban population); demographic structure (measured by dependent population and the proportion of the working population with HIV/AIDS); institutional stability and the strength of the public infrastructure (measured by health expenditure as a proportion of GDP, number of telephones and corruption); global interconnectivity (trade balance) and dependence on natural resources (percentage of the rural population) (Vincent, 2004).

3.6.2. Human Development Index

The HDI uses three separate indicators – life expectancy at birth, educational attainment and GDP per capita at purchasing power parity values (Lawrence, 2002) to form a composite, broad measurement of social and economic progress. It is an easily comparable measurement, widely used by the United Nations and the World Bank.

Nevertheless, the HDI suffers from a number of limitations, the most substantial being the high correlation between components,, reducing the usefulness of its sub-indices. The data needed to calculate the index for many countries is outdated or incomplete, and subject to varying levels of informal collation, and therefore requires either interpolation, extrapolation or substantial estimation.

3.6.3. The Gini Co-efficient

The Gini co-efficient measures relative poverty – specifically income equality. It is the most commonly used measure of inequality and can be easily represented by the area between the Lorenz curve and the accepted level of income equality. If income is distributed equally, then the Lorenz curve and the line of total equality are equivalent and the Gini coefficient is zero (World Bank, 2008b). One of the disadvantages of the Gini coefficient is that it is not additive across groups, i.e. the total Gini coefficient of a society is not equal to the sum of the coefficients of sub-groups (World Bank, 2008b).

3.6.4. Gross Domestic Product

GDP measures a country's economic national income and output. It is the total market value of all final goods and services produced within the country in a given period of time. It is often mistaken for an indicator of a standard of living but it measures economic activity expressed by monetized values, not the quality of life or well being (see discussion about poverty, above). This limitation spurred the creation of the Human Development Index and the entitlements and livelihood approaches. By focusing on the formal economic sector, the GDP ignores subsistence production which is fundamental to many West African populations. It also ignores the value of non-monetized domestic and voluntary effort, the value of defensive expenditures and the depreciation of natural capital assets as well as the degree of inequitable wealth distribution, (which is measured by the Gini co-efficient).

3.7. Spatial approaches

Vulnerability manifests itself geographically in the form of hazardous places (floodplains, remnant waste sites and so spatial solutions are required when comparing the relative levels of vulnerability between places, or between different groups of people (Kasperson, *et al.*, 2001). Spatial analyses can also reveal intra-country differences as biophysical factors (such as floods, land-use potential, and groundwater) or socio-economic factors (like access to markets) are localized and will be obscured at the national level (Cook & Gichucki, 2007).

Davis (2003) discusses spatial analysis as the spatial identification of the poor and identifies several mapping techniques. He does, however, point out there is little study on bias and error in the different poverty mapping methods or the differences in practical outcomes between the different mapping techniques.

Adger (2006) discusses the great innovation in mapping vulnerability, which attempts to capture dynamic and spatial distribution of individual variables and the interactions between them. He warns however, that specific variables may not directly measure vulnerability and interpretation (manifesting as "a leap of faith") is required to establish relationships between key variables and elements such as ecosystem services or well-being (Adger, 2006).

Small-area Estimation

The method advocated by the World Bank is the small-area estimation method, which combines survey and census data to estimate indicators for disaggregated geographical units (like municipalities or rural communities). The method relies on a household-level method (where household-level censuses and representative household surveys are used to obtain data) or the community-level data method where average values from communities or small towns are used instead of households (Davis, 2003).

Davis (2003) describes an alternate mapping technique as the creation of multivariate weighted needs-based indices. Davis(2003) describes three techniques which are summarized below– principal components, factor analysis and ordinary least squares.

Principal Components

The principal components method has been used in South America (notably by the Mexican government). The technique creates a marginality index using a large number of variables from established surveys and then statistically reduces their number (or dimensionality) by extracting the linear combinations that best describe the observed variance. A single index of variables and the relative variance explained is then created (Davis, 2003).

Factor Analysis

The purpose of factor analysis is to describe the relationships between variables in terms of a few underlying but unobservable factors, or constructs. It is a more computationally demanding method than principal components since it groups variables by either correlations or co-variance, with each group representing an underlying structure. However, Davis, (2003) argues that a disadvantage to the method is that once identified, the underlying factors require interpretation – it is thus a subjective process.

Ordinary Least Squares

This method is employed by the Nicaraguan government and also relies on a marginality index which was used to rank all segments of a national census in order to target poverty interventions. The marginality index used four variables which were then weighted by the coefficients derived form ordinary least square regression analysis of the determinants of extreme poverty (Davis, 2003).

Livelihood Poverty Mapping

Kristjanson *et al.* (2005) spatially mapped livelihood assets (natural, social, human, physical, financial) at the meso-community level in the Kajiado District of Kenya. They identified specific indicators from poverty literature that were representative of each livelihood asset and were related to poverty (for instance, livestock density represented financial capital, with the assumption that higher livestock density equals lower poverty). Kristjanson *et al.* (2005) found that this approach was useful, although they had difficulties mapping the significance of ecosystem services and they found that access to water was not highly associated with poverty (in a very dry climate). Despite such limitations, the livelihood approach was useful in mapping the incidence of poverty.

The Niger River Basin country values of the water and poverty situation indicators described above are listed in Table 11. The mean values for the indicators of OECD and non-OECD countries are described for comparison. Indicator values are the most recent available at the time of writing.

3.8. Comparison of water vulnerability and poverty indices

Table 11 Poverty and water situation indicators for countries of the Niger Basin.

	GDP (PPP, per capita)	Population below poverty line (US $1.25/day)	Life expectancy at Birth	Under 5 mortality rate	Total Available Renewable Water Resources	Water Poverty Index	Basic Human Needs Index	Social Vulnerability Index	HDI	Gini Co-efficient
	2007	2007	2007	20007	2005	2002	2000	2004	2007-8	2007
	$US/capita	%	years	%	m3/yr/capita	100-lowest poverty 0-highest poverty	50L-minimum basic needs	Index value (higher – more vulnerable)	Index value (higher – more developed)	100-complete inequality, 0-complete equality
Benin	1,500	47.3	55.4	19.1	3,820	39.3	15	0.584	0.437	36.5
Burkina Faso	1,200	70.3	51.4	15.0	930	41.5	17	0.658	0.370	39.5
Cameroon	2,300	32.8	49.8	14.9	17,520	53.6	33	0.640	0.532	44.6
Chad	1600	61.9	50	20.8	4,860	38.5	11	0.618	0.388	-
Cote d'Ivoire	1,800	23.3	47.4	19.5	4,790	45.7	28	0.584	0.432	44.6
Guinea	1,000	70.1	54.8	15.0	26,220	51.7	26	0.562	0.456	38.1
Mali	1,200	51.4	53.1	21.8	7,460	40.6	6	0.585	0.380	40.1
Niger	700	65.9	55.8	25.6	2,710	35.2	20	0.725	0.374	50.5
Nigeria	2,200	64.4	46.4	19.4	2,250	43.9	24	0.621	0.470	43.7
OECD* mean	37, 496	n/a	78.3	0.52	39,085	39.7	n/a	n/a	0.939	10.39
Non OECD* mean	10 898	n/a	66.1	6.76	26,802	23.6	n/a	n/a	0.686	18.65

Compiled from Lawrence *et al.*, 2002; Vincent, 2004; World Bank, 2009; UNESCO, 2006; Gleick, 1999; CIA, 2008, UNDP, 2007. *OECD mean based on the 27 high income countries as defined by the World Bank (2007)

Benin is not water-stressed according to the Falkenmark Index, its TARWR is in the middle of all the listed countries, and it scores moderately high on the Water Poverty Index, yet it's people receive 30% of the basic daily water needs (Basic Human Needs Index). The Gini co-efficient is relatively low (relative to the other countries) and the HDI and GDP indicate high levels of relative poverty, suggesting that a majority of the population may not have the capacity to use the available resources.

Burkina Faso has the lowest relative water availability (measured by TARWR) of the nine countries and regular water stress according to Falkenmark), and meets only 34% of basic human needs (although this is 4% more than Benin, which has better water availability) (note: minimum human needs defined as 50 liters per capita per day). It also has a relatively average score on the WPI, suggesting there is no wide-spread water poverty. It is the second most vulnerable country listed (SVI) and has the second lowest HDI in the world. However it does have greater income inequality than Benin, suggesting a small middle or rich population.

Cameroon does not suffer water stress (Falkenmark) and has the second highest TARWR of all the countries listed and consequently its WPI is the highest in the group. Cameroon meets 66% of its daily water needs (BHN), the highest score out of the group. Income inequality is highest in the group, as is GDP and the HDI score but SVI is at 11 – making Cameroon the third most socially vulnerable in the group.

Chad is not water stressed (Falkenmark, TARWR) but provides only 22% of daily basic water needs, the second poorest performer in the group. It's also the second poorest out of the group according to the WPI. It has a low HDI and low GDP (although it's moderately high relative to other countries in the group). The Gini co-efficient is missing for Chad.

Côte d'Ivoire does not suffer water stress (Falkenmark, TARWR) and it has the third highest WPI. Despite this, it supplies 56% of BHN. It has the 4th highest HDI score in the group, third highest GDP and the highest income inequality (Gini co-efficient) along with Cameroon.

Guinea has the highest TARWR and Falkenmark score out of the group but also the second highest WPI (after Cameroon). It supplies 52% of BHN, the third best performer in the group. It has the third best HDI score and is least socially vulnerable according to the SVI. It also has the second lowest GDP and Gini co-efficient, suggesting a uniform poverty (but not water poverty) across the country.

Mali is not water stressed (Falkenmark, TARWR) its WPI is in the middle range of the group and yet it supplies only 12% of BHN, the worst performer in the group. It is the fifth poorest country in the world (according to HDI), has the third lowest GDP in the group but is has a comparatively high SVI.

Niger is the fourth poorest country in the world (HDI), has the lowest GDP and highest income disparity in the group and yet it supplies 40% of BHN, which is higher than Mali, Chad, Burkina Faso and Benin. This is despite having the highest water poverty (WPI) out of the group. It is the most socially vulnerable (SVI) as it has the highest Gini co-efficient.

Nigeria is not water stressed (Falkenmark, TARWR) and has the third highest WPI out of the group. It meets 48% of BHN, the fourth highest in the group. It has the second best HDI score out of the group, moderate GDP and high income inequality (Gini co-efficient).

3.8.1. Summary of Indices

Whilst the index measures presented in Table 11 provide an overview of the poverty and water situations faced by different countries, they do not provide much evidence as to the relationship between water and poverty. Table 12 presents the correlations of measures for all countries on the African continent. Correlations are generally moderate to weak at the national scale. The TARWR has no significant correlations with any poverty or vulnerability measure. The quantity of water (the first-order scarcity) has no observable bearing on the poverty and vulnerability levels of a country. Correlation with the Headcount Ratio is negative and significant as expected, but relatively weak. There is moderate correlation (-0.47) between the SVI and WPI but neither water indicator shows any significant correlation with the GSI. Thus at a national level, there is little evidence for a strong association between a country's water situation and its development performance on the African continent. Note that the TARWR correlation with the WPI is to be expected given that the latter incorporates a form of the total water resources statistic.

Table 12: Correlation matrix of the Falkenmark Index, the Water Poverty Index (WPI), the Headcount Ratio (proportion of people living under US$1 per day, PPP), the Human Development Index (HDI), the Genuine Savings Indicator (GSI) and the Social Vulnerability Index (SVI). The sample comprises all African countries for which data is available (excluding small island states).

	Falkenmark	WPI	Headcount Ratio	HDI	GSI
Falkenmark[1]	-	-	-	-	-
WPI[1]	0.30*	-	-	-	-
Headcount Ratio[2]	0.26	-0.34*	-	-	-
HDI[3]	-0.21	0.67*	-0.58*	-	-
GSI[4]	-0.18	-0.08	-0.17	0.16	-
SVI[5]	0.07	-0.47*	0.48*	-0.48*	-0.02

* - statistically significant correlation ($p < 0.05$)
[1] Lawrence, *et al.* (2002); [2] World Bank (2009); [3] UNDP (2007); [4] Hamilton and Celemens (1999); [5] Vincent (2004).

3.9. Summary

This section has briefly reviewed the vulnerability, climate change, poverty and water-poverty specific literature.

Quantifying vulnerability is conceptually challenging, as suggested by a fractured and divided literature. The two main schools of thought (the biophysical conceptualization to vulnerability and the social conceptualization to vulnerability) use different terminologies and emphasize different aspects, making comparisons difficult. The biophysical school focuses on exposure to hazards while the social school emphasizes social risks, institutions and capacities. The biophysical/social divide carries over into the climate change literature where the biophysical focus leads to studies of the changes in environments while the social school focuses on human impacts. Both provide valuable insights but integration is lacking.

Definitions and measurements of poverty have been expanded from an objective focus on economic growth and income measurements to embrace sociological and physiological dimensions. As a corollary, analysis has evolved from a singular focus on income to a pluralistic focus on livelihoods, individual and community entitlements and endowments.

Vulnerability to water related climate change is determined by exposure, sensitivity and adaptive capacity, the latter two being affected by existing poverty and livelihood constraints. The African continent is considered one of the most vulnerable because wide-spread, existing chronic poverty reduces adaptive capacity and increases sensitivity.

There exist numerous indices for water and poverty, which build upon one another or measure similar components. Insights from a review of the indices literature, indicate that country-level indices fail to account for temporal (seasonal) and spatial (local) variabilities, thus potentially masking areas of increased poverty. The different spatial methods described in the following sections are intended to provide better intra-national resolution of existing indices.

Consistent with recent water poverty analyses of other River Basins in the Challenge Water for Food Programme, this report relies on Cook and Gichucki's (2007) concept of water wealth being water access and water productivity. It incorporates the livelihood approach to poverty (and therefore embraces complex poverty definitions) and focuses on the capacity of people to use available water resources rather than purely biophysical measurements of water availability. For instance, neither the Kristjanson *et al.* (2005) nor Vincent (2004) algorithms rely on water access or productivity, and water does not enter the statistical analysis or assessment as an explanatory variable of poverty.

The remainder of this report focuses on methods to estimate spatially referenced determinants of water poverty in the Niger River Basin.

4. Poverty Analysis

4.1. Defining and measuring poverty

The literature review revealed an extensive array of poverty definitions and metrics. The lack of a comprehensive indicator that reliably captures the multi factorial characteristics of water related poverty has led to a raft of measurement techniques, each with advantages and disadvantages. Adding another poverty index or measurement criteria to the literature is not the aim of this research. Instead, we rely on three common poverty variables and assess the role of water related variables in explaining the observed distribution in each for the countries of the Niger River basin. Jointly assessing the similarities, correspondences and discrepancies of spatially referenced, multiple metrics implies that conclusions drawn are founded on a more comprehensive evaluation - in contrast to the challenges and limitations of creating another 'single-use' index. The three poverty measures utilized are child mortality, child morbidity and the Demographic Health Survey's (DHS) Wealth Index.

Child mortality: Child mortality, defined by the proportion of children who die before their fifth birthday, represents a fundamental, non-monetary measure of poverty. Child mortality rates in West Africa are the highest in the world, and vary considerably across the region (Balk *et al.* 2003). Child mortality is likely to be a function of a household's ability to obtain essential services, nutrition and shelter. Secondly, it is, to some extent, more unidirectional than other measures: child mortality is caused by poverty, but does not in itself cause poverty to the same extent as do other socio-economic factors. For example, low education levels are simultaneously a cause and effect of poverty, as is the incidence of disease and availability of consumptive goods. Child mortality also is not entirely independent; however, it has a much reduced reciprocal effect than these other measures. Thirdly, the use of non-monetary measures is very important in the Niger Basin, where a large proportion of the economic system depends on barter, social custom and self sufficiency, factors that are largely unaccounted for in monetary based poverty measures. Finally, child mortality provides a relatively direct method of quantifying water poverty, because poor water quality, caused by limited availability, limited access and poor infrastructure, is the direct cause of some of the most prevalent, fatal childhood diseases.

Income poverty measurements also ignore the multidimensional character of poverty, failing to account for other desirable goals of development such as gender equality, intra-household distribution and environmental health (Setboonsarng, 2005). Thus although the correlation between income and child mortality is well established (Klasen, 2006), the use of child mortality as a primary poverty metric offers a more integrated approach that intersects cultural, economic and policy boundaries.

Child morbidity: There are many measures of child morbidity, however we utilize the ratio of observed height for age compared to a median national value (the value of relative stunting). This indicates long term, cumulative effects of inadequate nutrition and poor health, including that before birth (Setboonsarng, 2005). Compared to weight for age, height for age is less sensitive to short term seasonal variation in calorie intake, making it more appropriate when comparing data collected at different times. The nutritional health of a child is a development goal in itself and again represents an inclusive 'quality of life' approach to measuring poverty. Child morbidity is not only an outcome of poverty; it is a determinant also (which is a partial point of difference with child mortality). Good health is requisite for improved productivity, and malnutrition in childhood is recognised as having long term effects on the labor capacity and intellectual performance of adults (Setboonsarng, 2005). It may also offer an increased resolution compared to child mortality.

Wealth Index: A wealth index, such as the DHS Wealth index used here, demonstrates the material standing of households (Measure DHS, 2008). Wealth level (a stock measurement) is less volatile than expenditure and consumption (rate or flow measures) and is more readily measured (Rutstein and Johnson, 2004). Wealth represents long term access to consumer and productive goods, indicating simultaneously the level of poverty and the capacity to earn a livelihood. A detailed description of the DHS Wealth Index is presented in Rutstein and Johnson (2004).

For each household, the DHS wealth index considers: housing materials, water supply, sanitation facilities, electrical goods, vehicle type, persons per sleeping area, land ownership, domestic servants and other consumer goods. Principle components analysis was used to assign indicator loadings, revealing composite segments or components, which are then summed to give a standardized wealth index. This measure thus avoids the problem faced by many indices in that it is not reliant on arbitrary, analyst-determined weightings. However, the metric is influenced by the choice of variables included (Rutstein and Johnson, 2004).

A shared advantage of child mortality and child morbidity is that they are single, well defined variables that act as a proxy for a large number of aspects of life quality (Mosley and Chen, 1984). They are not influenced by the value judgments of researchers trying to combine variables. The principle components derived wealth index is also free of this common problem, but is influenced by the researcher's choice in variables. It is included as a comparison to the simpler poverty measures for this reason, as well as its economic focus compared to a health focus.

The contribution of water access and productivity is assessed with respect to these three variables independently. The dependent variables, either water related or other environmental and social variables (controls) are explained below.

4.2. A conceptual framework combining water related vulnerability and sustainable livelihoods

"A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from shocks and stresses and maintain and enhance its

capabilities and assets both now and in the future, whilst not undermining the natural resource" (Chambers and Conway, 1992).

The livelihoods concept, as described here by Chambers and Conway, can be represented by a three dimensional matrix of social and environmental variables (see Figure 8). These three dimensions are:

- **Community vulnerability:** the capabilities, assets and activities of the community. In the poverty model constructed here community vulnerability is represented by health variables, socio-economic variables, infrastructure and assets.

- **Situational vulnerability:** how well these assets, capabilities and activities can withstand exposure to shock and stress. As this study focuses on water poverty in particular, situational vulnerability is represented primarily by water related variables.

- **Hazard threat:** the events that challenge the community/situation. These are represented by natural disaster risk, climatic variables, population density and environmental damage.

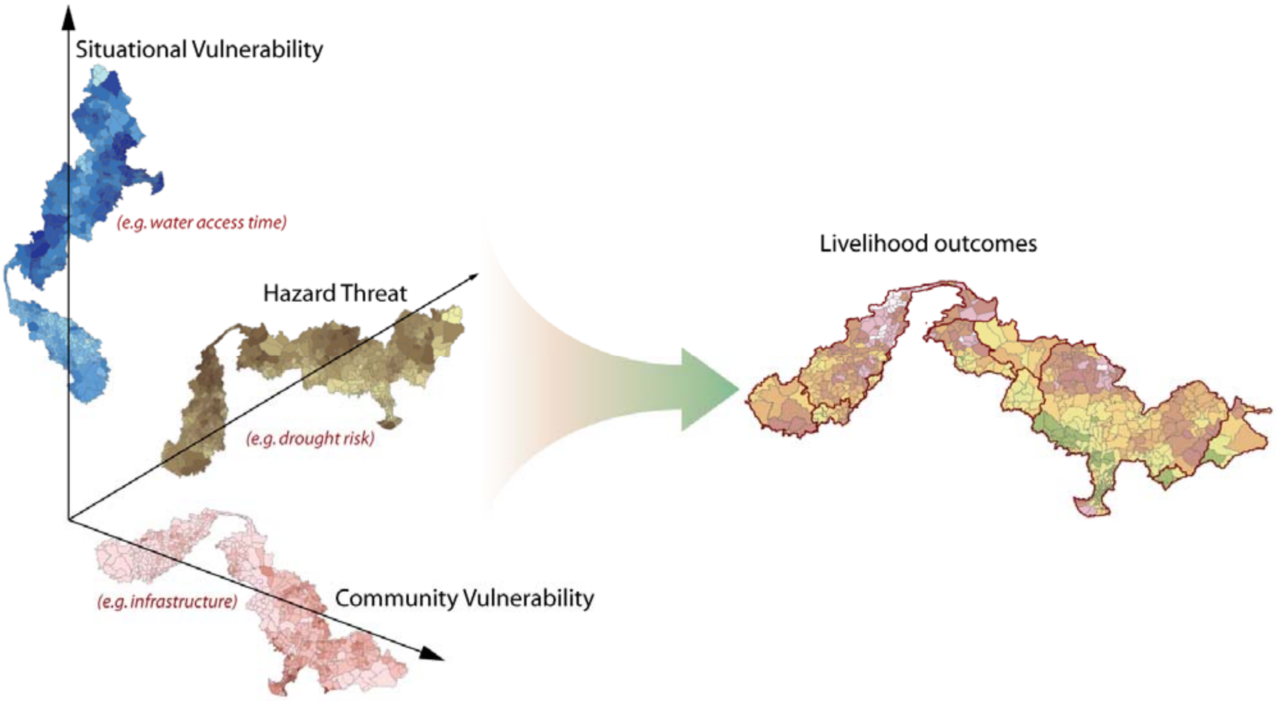


Figure 8: Conceptual framework: the three dimensional 'matrix' of social and environmental variables that contribute to vulnerability and poverty.

Vulnerability and poverty are subtly different. Poverty is a measure of current status: vulnerability involves a predictive dimension, providing a means of conceptualizing what may happen to an identifiable population or exposure unit under conditions of particular risks and hazards. However, they are conceptually interdependent: poverty contributes to vulnerability, and vulnerability to poverty, and so the analysis incorporates elements of both to provide a more comprehensive and practically applicable result.

We anticipate that the poverty measures (child mortality, child morbidity and the wealth index) are functions of community vulnerability, situational vulnerability and hazard threat. Hence, for each analysis region, *i:*

$$poverty_i = f(community_i, situation_i, hazard_i)$$

Where each of the three livelihood 'dimensions' is the sum of its component variables.

In contrast to the majority of previous water poverty analyses emphasizing composite indices, we derive evidence based estimates of the poverty relationships from existing data.

The approach mitigates the problem of an arbitrary weighting of variables. Spatially weighted linear regression was used to determine the significance and magnitude of explanatory components that influence poverty. It should be noted that this inductive approach is superior by introducing a framework of testable hypotheses. Contingent on the selection of imputed variables, determined primarily on commensurate data availability, it makes no *a priori* assumptions about what may or may not influence water related livelihoods. The coefficient estimates are based on data interpretation and analysis.

The first research hypothesis states that the vector of significant variables at the basin scale differs from the vector at the national scale which also differs from the administrative unit scale. That is Ha states that:

For poverty measure $Y_{\text{(basin, national, administrative)}}$

$SV_{\text{basin}} \neq SV_{\text{national}} \neq SV_{\text{administrative unit}}$

Where:

Y represents either child mortality or child morbidity at the scale of basin, national and administrative unit respectively[1].

SV represents $[\alpha + \beta'(X_i) + \ldots\beta''(X_j) + \varepsilon]$ where the parameter α is a constant, β represents the regression coefficients of a vector of unknown variables (X_{ij}) to be estimated and ε is a stochastic error term assumed to be normally distributed across all observations

For variable set $X_{i\text{-}j}$:

i-j $\subseteq$ variable vector I-J; are significant ($p<0.05$), and account for spatial auto correlation

However the coefficients estimated from the evidence based approach indicate association which in itself is not equivalent to poverty causation. Field studies focusing on individual variables will be required to establish more conclusive evidence of causal relationships. The evidence of association, when considered over a large and diverse area, however, is non trivial.

[1] Analysis of the poverty metric asset value was constrained to intra-national data.

4.3. Measuring Poverty: the Dependent Variables

Ordinary least squares regression was used to investigate the statistical significance of changes in factors (independent variables) that explain the observed spatially explicit change in the three poverty measures (dependent variables) The unit of aggregation is the 3rd level administrative district, giving a sample size of 650 data points across the active basin (see Figure 9). The choice of this spatial scale is deliberate, and attempts to balance the practicality of sourcing reliable data and the most appropriate resolution for policy making. Poverty statistics are most prevalently compiled at a national scale, a level of data compression that disguises important poverty heterogeneity across the landscape. Providing increased resolution is thus the objective of a spatial poverty analysis. Secondly, policy tends to be developed at a national scale but requires local implementation. Existing sub national administrative boundaries are the most likely units for policy implementation and thus analysis corresponding with such units improves the applicability of research to policy. Thirdly, poverty reduction targets and strategies can be tailored to match the varying set of circumstances that exist in different areas. The variation in socio-economic characteristics that exists across the landscape can be most accurately quantified with fine grained spatial resolution, and most effectively addressed when this high resolution is concordant with administrative jurisdiction. In selecting the 3rd administrative level, technical considerations were also important such as ensuring an adequate sample size to avoid violating OLS assumptions regarding degrees of freedom.

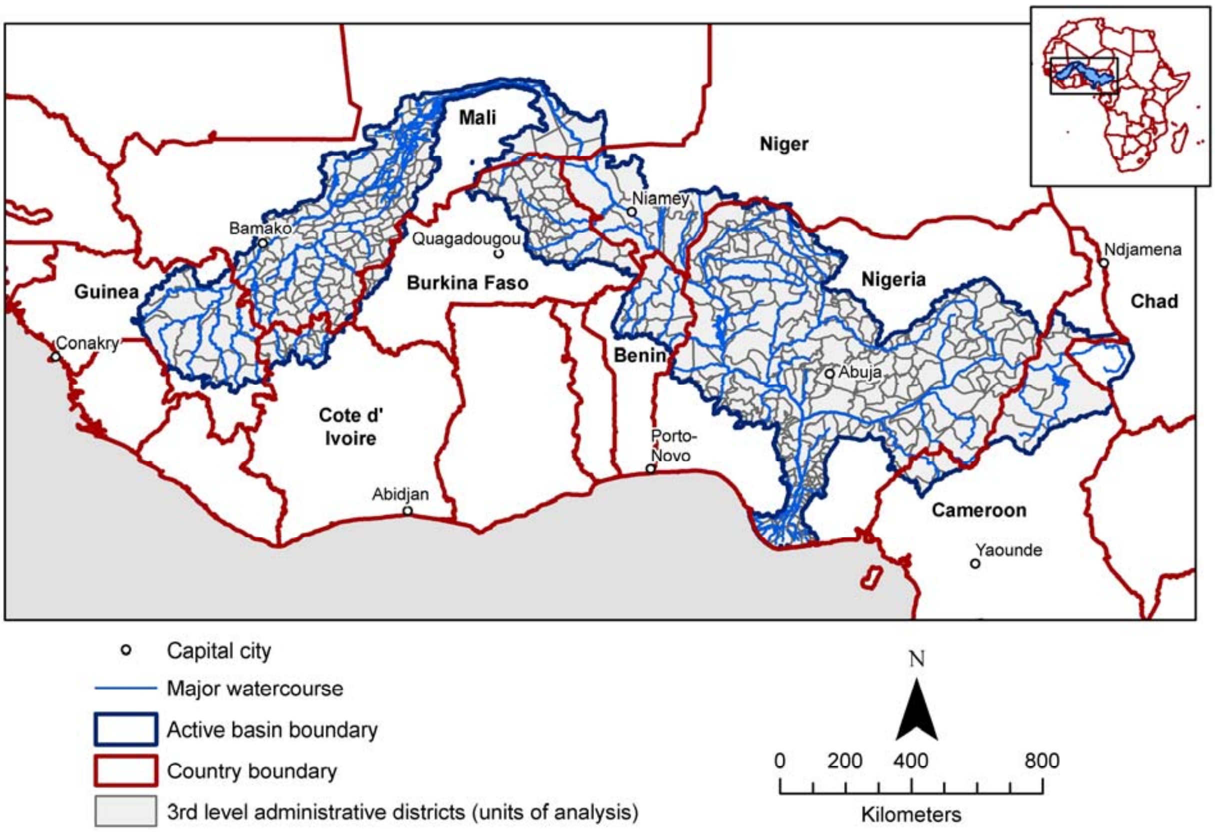


Figure 9: Study region showing the active Niger Basin, major tributaries, basin countries and 3rd level administrative districts.

The three independent variables (child mortality, child morbidity and the wealth index) are derived from Demographic Health Survey (DHS) data. The DHS program collects nationally representative human health and socio-economic data and is funded by the United States Agency for International Development. Closely matching survey instruments are deployed approximately every 5 years in 50 countries, covering all the countries of the Niger Basin. Surveying utilizes are two stage sample design, the first stage selects clusters from regional units, and the second then randomly selects households from within each cluster. Two comprehensive questionnaires are used in the interviewing of residents: a basic household questionnaire and a detailed individual questionnaire for women of reproductive age (15-49 years). The results are standardized for comparison internationally, and published with an approximate cadastral reference (Aliaga and Ren, 2006).

National surveys were undertaken in all countries in the study region within the last 10 years. Geographic data was not collected with the most recent Chad survey, and so Chad has been excluded from our analysis (approximately 1% of the total basin). Data for individuals/households (depending on the variable) were averaged at each survey 'cluster' and mapped across the basin using ArcGIS (see Figure 10 for cluster locations). Inverse Distance Weighting (IDW) interpolation was used to estimate intermediate values in data deficient areas or those not surveyed. In accord with Robinson and Metternicht, (2006) the interpolation procedure and choice of parameters was influenced by the characteristics of the data set. Inverse distance weighting (IDW), splining and krigging (spherical) were the three common interpolation techniques evaluated. Splining produced distorted results and krigging could not be performed for some countries due to data limitations. IDW was used with a variable search radius (12 data points) and exponent value of 2 (suitable for non-parametric data sets), The influence of data points that traversed international borders was restricted to simulate national policy opportunities and reveal differences in spatially constrained poverty metrics. A cross-validation procedure was used to guide selection of model parameters (based on Hofierka, et al. 2007; ESRI, 2001).

Zonal statistics were then gathered for each 3rd level administrative district, and imputed into the regression analysis. In the interpolation calculation, cluster points in or near to the basin contribute to the overall variable GIS layer. It is important to note that inconsistent data coverage exists across the basin and areas without a high density of cluster points may be less accurately estimated.

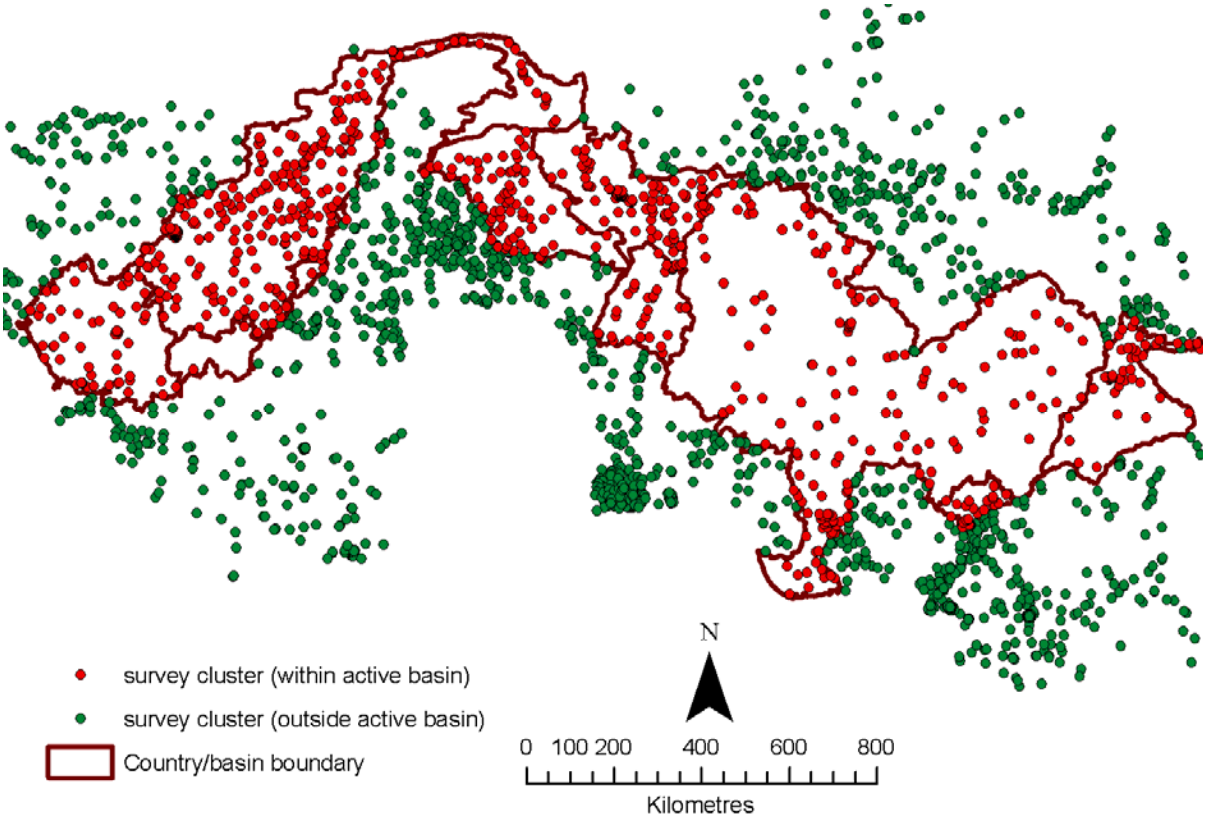


Figure 10: Survey cluster points within or close to the basin, in relevant countries.

The child mortality treatment: To ensure that the assumption of independence is maintained, cluster averages were taken at the family level. A cluster is a site of surveying (e.g. a particular village), randomly selected by Measure DHS and contains 20-30 households on average. The proportion of children born since 1980 who died before age 5 was computed for each woman surveyed, and from these proportions the average child mortality rate for that cluster point was calculated. 1980 was used as a cutoff date for births to maintain a large sample size (n = 62, 656 children in the active basin), although a 1990 cutoff provides similar results. Clusters with fewer than 5 households were removed from the active dataset. Based on the 1980 data cutoff a cluster averaged 78 children. Figure 11 shows the distribution of child mortality across the active Niger basin, where green indicates the least severe child mortality incidence and white indicates the most severe incidence of child mortality.

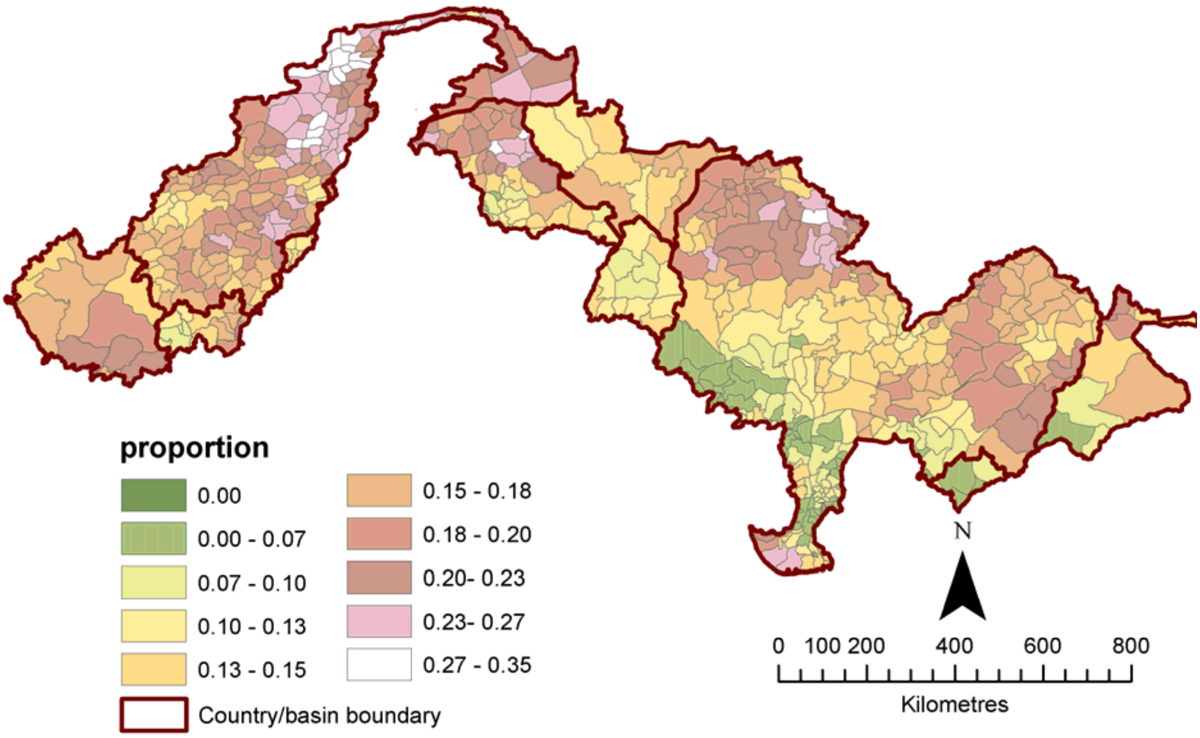


Figure 11: Estimated child mortality (percentage of children who die before age 5) across the active Niger Basin (based on births recorded since 1980).

The treatment for the quantification of child morbidity was similar to that of child mortality where applicable. The average age-height ratio was calculated for all clusters and then interpolated across the landscape. Children up to an age of 5 years were included in the calculation and clusters with fewer than 5 households were removed. Height for age ratios were recorded as standard deviations from the reference median, as assessed using the CDC (Center for Disease Control and Prevention) reference curves. It is important to note that increased child morbidity means a higher prevalence of stunting, and thus is described by a *decrease* in the average height for age values. Figure 12 shows the distribution of child morbidity across the active Niger basin, where green indicates the least severe child stunting and white indicates the most severe.

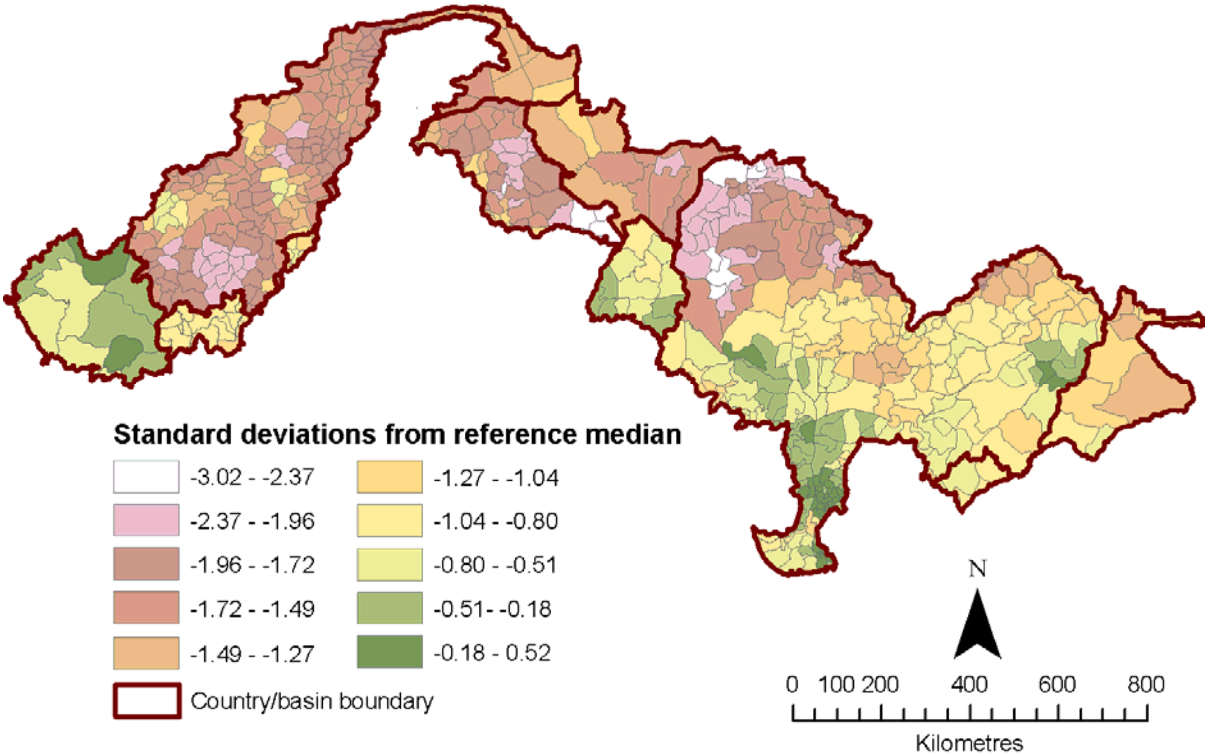


Figure 12: Estimated child morbidity (age-height ratios) across the active Niger basin.

The Wealth Index treatment differs from the previous two measures of poverty because this variable cannot be assumed to be comparable across national boundaries (Rutstein and Johnson, 2004). The index is a relative, unit-less measure which is constructed from a principle components analysis based on the type and quantity of goods present in a household (see Rutstein and Johnson, 2004 for details). Despite the intra-national limitations the metric provides a non-monetary, spatially explicit indicator of vulnerability at the same spatial resolution as the morbidity and mortality variables (which were calculated from the same sample). Furthermore, as demonstrated in the regression analyses described later, poverty hotspots tend to be localized within countries and so international comparison is not required. Figure 13 shows the distribution of the wealth index across the active Niger basin, where green indicates the wealthiest and white indicates the poorest. Note that a very poor region of Nigeria may not be as poor in absolute value as a very poor region of Mali, due to the differences in mean wealth between these countries and the problem of international ordinal comparison.

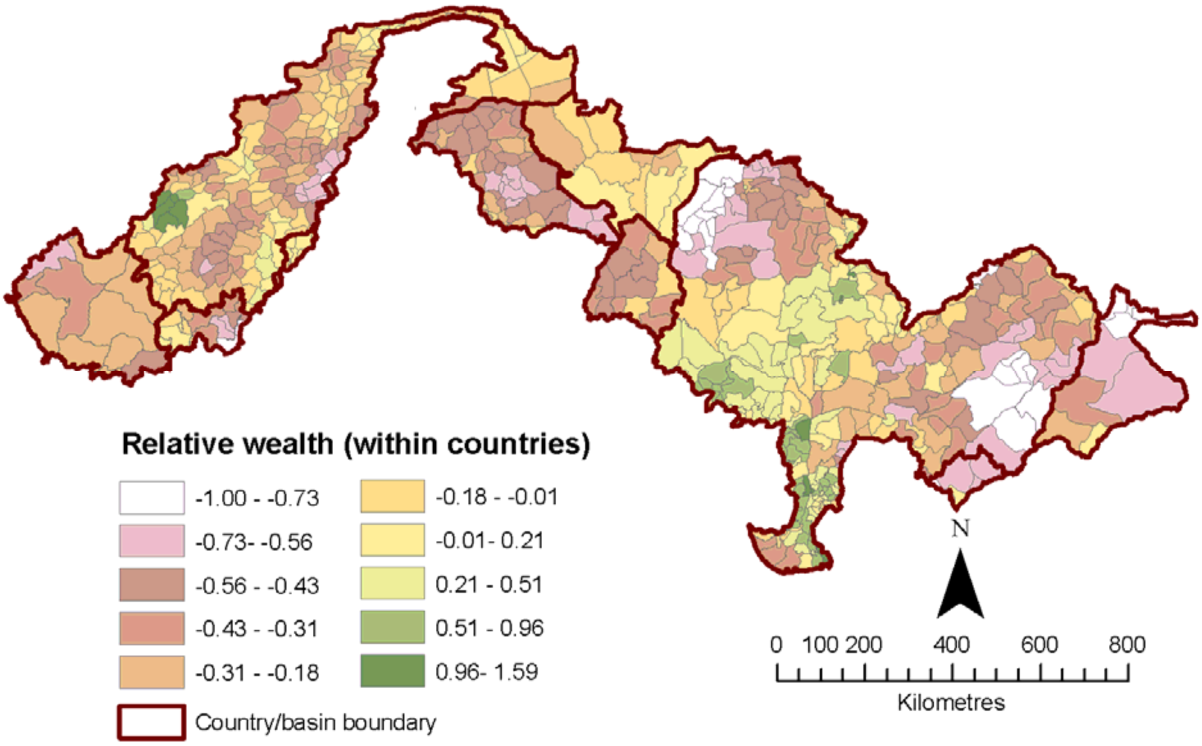


Figure 13: Estimated relative wealth across the active Niger basin, as indicated by possessions, land ownership, housing material, employees etc. Values are relative within countries, not between countries.

4.4. Estimating the variance of observed poverty: the independent variables

The dependent variables are the measures of poverty: child mortality, child morbidity (stunting) and the wealth index. The independent variables are specific elements of community vulnerability, situational vulnerability and hazard threat. A description of each is provided in Table 13, Table 14 and Table 15 respectively. Water-related variables were of primary interest to the Challenge Program. Non-water variables were selected to represent different forms of capital: physical infrastructure (electricity, telephones, roads), human (population density, education), financial (livestock density) and natural (productivity, forest cover, environmental degradation, malaria). These were selected based on the findings of Kristjanson, *et al.* (2005) and Vincent (2004). Variables were compiled in a geographic information system (GIS) and sampled to calculate the mean values in each administrative unit. Variables compiled from DHS data were interpolated using the same methods as the dependent variables (see section 4.3). A suite of agro-climatic zone dummy variables were also included initially, but were found to add little extra explanatory power.

Table 13: Aspects of community vulnerability included in model (independent variables)

Name of variable	Explanation
Population density (2005)	Population density of administrative district in 2005 (people/km^2). **Source:** CIESIN (2005)
Population (2005)	Population of administrative district in 2005 (number of people). **Source:** CIESIN (2005)
Telephones	Proportion of a district with a telephone in the home. The average is taken at the household level. Survey clusters with less than 5 households have been removed. Estimation based on an inverse distance weighting interpolation across landscape. **Source:** Measure DHS (2008)
Electricity	Proportion of a district with electricity in the home. The average is taken at the household level, i.e. all households who have been surveyed in a cluster contribute to the average value of that cluster. Clusters with less than 5 households have been removed. Estimation based on an inverse distance weighting interpolation across landscape. **Source:** Measure DHS (2008)
Problem Soils	Problem soils (most prevalent in district) (categories). Wetlands; Infertile Soils; Sandy Soils; Open Water; Shallow Soils; Cracking Clays; Desert Lands; Steep lands; Miscellaneous. **Source:** FAO (1997)
NPP (produced)	Net primary productivity (NPP). Net amount of solar energy converted to plant organic matter through photosynthesis (grams of carbon per 0.25° cell) **Source:** Imhoff, *et al.* (2004)
NPP (used)	Human appropriation of net primary productivity (HANPP). Humans appropriate net primary productivity through the consumption of food, paper, wood and fiber (grams of carbon per 0.25° cell) **Source:** Imhoff, *et al.* (2004)
NPP (percent used)	Human appropriation of net primary productivity as a percentage of the net primary product. The percentage of NPP that is appropriated for human consumption. Places with percentages >100 are net importers. **Source:** Imhoff, *et al.* (2004)
Slope	Slope (category) (most prevalent in district). 0-2%; 2-5%; 5-8%; 8-16%; 16-30%; 30-45%; >45%; Water. **Source:** FAO (2000)
Land cover	Dominant land cover (categories) Urban and built up land; Dry land crops and pasture; Irrigated cropland and pasture; Cropland/Grassland mosaic; Grassland/woodland mosaic; Grassland; Shrub land; Savannah; Evergreen Broadleaf Forest; Wooded wetland; Barren or Sparsely vegetated; Water. **Source:** US Geological Survey (2003)
Original vegetation type	Dominant vegetation categories: Lowland rain forest; Guineo-Congolian rain forest; Swamp forest; Mediterranean sclerophyllous forest; Mosaic of lowland rain forest, Isoberlinia woodland and secondary grassland; Sudanian woodland with abundant Isoberlinia; Sudanian undifferentiated woodland with islands of Isoberlinia; Sahel Acacia wooded grassland and deciduous bushland; Semi-desert grassland and shrubland; Semi-aquatic vegetation (inner delta); Mangrove. **Source:** White (1983)

Access	Average direct distance from district to an administrative centre or large populated place ('00 km). **Source:** FAO (2007a)
Education	Average years of education. The average is taken at the individual level. . Estimation based on an inverse distance weighting interpolation across landscape. **Source**: Measure DHS (2008)
Forest cover	Most common type of forest cover present in the district based on monthly NDVI remote sensing data (categories). Ocean; Closed Forest; Open or Fragmented Forest; Other Wooded Land; Other Land Cover; Water. **Source:** Global Forest Resources Assessment (2000)
Forest cover proportion	Proportion of district occupied by closed, open or fragmented forest. **Source:** Global Forest Resources Assessment (2000)
Cattle density	Average density of stock across the district (units/km^2). **Source:** FAO (2007b)
Chicken density	Average density of stock across the district (units/km^2). **Source:** FAO (2007b)
Sheep density	Average density of stock across the district (units/km^2). **Source:** FAO (2007b)
Goat density	Average density of stock across the district (units/km^2). **Source:** FAO (2007b)
Pig density	Average density of stock across the district (units/km^2). **Source:** FAO (2007b)

Table 14: Aspects of water situational vulnerability (independent variables)

Name of variable	Explanation
Piped water	Proportion of a district whose main water source is piped water. The average is taken at the household level. Clusters with less than 5 houses have been removed. Estimation based on an inverse distance weighting interpolation across landscape. **Source:** Measure DHS (2008)
Surface water	Proportion of a district whose main water source is surface water. The average is taken at the household level. Clusters with less than 5 houses have been removed. Estimation based on an inverse distance weighting interpolation across landscape. **Source:** Measure DHS (2008)
Unprotected water	Proportion of a district whose main water source is surface water or unprotected well water. The average is taken at the household level. Clusters with less than 5 houses have been removed. Estimation based on an inverse distance weighting interpolation across landscape. **Source:** Measure DHS (2008)
Water Access	Average time taken to collect water from the primary water source. The average is taken at a household level. Estimation based on an inverse distance weighting interpolation across landscape. **Source:** Measure DHS (2008)
Dams	Average direct distance from district to a dam ('00 km). **Source:** FAO (2006)
Irrigation intensity	The density of irrigation in the most intensely irrigated part of the district (based on $100km^2$ cells) (percent) **Source:** FAO (2007c)
Irrigation	Is the percentage of a district that is under irrigation. **Source:** FAO (2007c)
Precipitation	Precipitation (millimetres/yr) **Source:** FAO (2007d)
Evapotranspiration	Evapotranspiration (millimetres/yr) **Source:** FAO (2007e)
TARWR	TARWR (total available renewable water resources) of Niger sub basins. Includes actual inflows into sub basin, plus internal water resources (rainfall). All relevant parameters (water volume) measured at the sub basin level (bigger than administrative districts), and are assumed constant across sub basin. (Specified with and without area and per capita component (Mm^3/yr; Mm^3/yr/km^2; m^3/yr/km^2/person and m^3/yr/person). **Source:** FAO (2000)

Table 15: Aspects of hazard threat (independent variables)

Name of variable	Explanation
Natural Disaster mortality risk	Frequency of major natural disasters. Is the relative risk (index value 0-60) of natural disasters. The hazards of interest include cyclones, droughts, earthquakes, floods, landslides, and volcanoes. Areas with less than 5 persons/km^2 and without significant agriculture are given a zero value. **Source:** Center for Hazards and Risk Research (2005)
Drought economic risk	Economic loss (GDP) due to drought. Calculated both as a proportion of GDP and as the total loss. Global decile scale based on historical experience. Areas with less than 5 persons/km^2 and without significant agriculture are given a zero value. **Source:** Center for Hazards and Risk Research (2005)
Drought mortality risk	Mortality due to drought. Global decile scale based on historical experience. Areas with less than 5 persons/km^2 and without significant agriculture are given a zero value. **Source:** Center for Hazards and Risk Research (2005)
Drought frequency	Frequency of drought. Global decile scale based on historical experience. Areas with less than 5 persons/km^2 and without significant agriculture are given a zero value. **Source:** Center for Hazards and Risk Research (2005)
Human footprint	Normalized scores from the Human Influence Index, a measure of environmental damage. Relative values range from 0 (least influence) to 100 (most influence) for the biome found in that district. **Source:** SEDAC (2005a)
Human Impact	Index of direct human influence on terrestrial ecosystems. Based on population density, access (roads, railways, rivers, coasts), landscape transformation (land use, land cover) and electric power infrastructure. Values range from 0 (least influence) to 64 (most influence). **Source:** SEDAC (2005b)
Malaria	Estimated prevalence of malaria parasite in children 2-9 years. Data is from surveys and modelling based on climate, altitude, vegetation cover and agro-ecological zones. **Source:** MARA (1998)
Malaria distribution	Estimated prevalence of malaria parasite in children 2-9 years. Data is based on *theoretical suitability* of local climate and thus the potential distribution of stable malaria transmission in the average year. **Source:** MARA (1998)
Population change	Rate of change in population (percent per year). Calculated using population figures for 1995 and 2000, assumed linear trend. **Source:** CIESIN (2005)

4.5. Accounting for Spatial Patterns and Auto-correlation

Many poverty, resource and environmental studies concern dispersion, patterns and distributions across multiple dimensions including ethnic, social, economic, political and geographic space. A comprehensive analysis of poverty requires a methodological convention that accounts for spatial dispersion of the multiple factors that influence poverty. An important analytical issue when dealing with spatial data is the assumption of spatial stationarity or cadastral stability of the data. Non-stationarity (i.e. significant spatial correlation) is observed when neighboring geographical points display a non-random or correlated spatial pattern. Spatial dependence can be expressed in either the error terms of the explanatory variables (i.e. a spatial pattern is detectable in the residuals) of the regression equation or the presence of a substantive spatial process operating on the dependent or poverty variables. Both of these spatial relationships violate the classical linear OLS regression assumption of independent data observations, and as a corollary data must either be remodeled with spatial weighting terms or partitioned into correlated spatial units and re-estimated on a smaller scale (Bateman et al. 2006, Neupane *et al.* 2007). Failure to account for spatial auto-correlation of the dependent poverty variable can lead to inefficient or biased estimates and hence unsubstantiated or misleading inference (Neupane *et al*. 2007).

In ordinary least squares regression analysis, spatial autocorrelation can be addressed either through incorporation of a spatial error model or through use of a spatial lag model (Anselin, 2003, 2005). Spatial association can be measured globally or locally. Global measures assume that the processes that give rise to spatial dispersion or patterning are constant over the entire basin. Anselin (1995, 2005) has developed localized indicators of spatial correlation (LISA) to account for spatial clustering at defined local scales. LISA measures identify clusters in the pattern of spatial associations within a large study area. These spatial clusters can be areas of high relative poverty (hotspots) or low relative poverty (cold spots). In the Niger River Basin case these clusters signify statistically significant regions of high or low poverty according to the three metrics and when mapped may identify a spatial poverty pattern of interest to policy makers, aid agencies and water managers.

Anselin (1995) proposes two interpretations of spatial auto-correlation at the local level. The first is that local spatial autocorrelation provides an indicator of the propensity of similar values to cluster in specific areas throughout the whole map, while the second can be treated as a diagnostic for local instability of values. The first interpretation may reveal specific policy actions to influence poverty at a localized administrative scale, the second may indicate sensitivity of poverty measures to stimuli or perturbations. The analysis reported here uses both global and localized approaches to assess the spatial auto-correlation of poverty at supra-national (whole of basin) and sub national scales.

The following equation describes the model used to estimate the observed variation of the three poverty variables:

$$Y_i = \alpha + \beta^{'} X_i + \varepsilon_i \qquad (1)$$

Where: Y represents the measure of poverty for spatial administrative unit *i*, the parameter α is a constant, β' represents the regression coefficients of a vector of unknown parameters to be estimated and ε_i is a stochastic error term assumed to be normally distributed across all observations.

Spatial correlation occurs if there is a non-random pattern across the error term ε_i in equation (1) or the presence of substantial spatial patterning of the poverty measures.

Spatial auto-correlation reveals spatial patterns by assessing the tendency that cells close together are more similar than cells that are far apart. Typically this is addressed through the Moran's I statistic. Neupane *et al.* (2007, pp. 476-477) describe the method to estimate Moran's I as follows.

Let the observed values of poverty Y_i, $i \in \{1, \ldots n\}$ are recorded as a set of *k* cells (indexed by i) in the spatial distribution. Non-stationarity or spatial autocorrelation arises when the values of x_i display a non-random pattern over the distribution. Non-randomness can imply that there is a clustering of like data values associated with proximate cells. Thus, the measurement of spatial auto-correlation requires consideration of both location and poverty data and is given by the cross product statistic represented by:

$$P = \sum \sum w_{ij} y_{ij} \quad (2)$$

Where: *P* is the cross product statistic, w_{ij} is a measure of the spatial relationship of cells i and j and y_{ij} is a measure of the relationship in poverty attribute space. Anselin (2005) and Bateman *et al*. (2006) suggest there is limited formal guidance in the selection of the spatial weight matrix w_{ij}. As matrix selection is a non-trivial analytical decision, a sensitivity analysis of different weighting options applied to the poverty measures was undertaken, and assessed based on the explanatory power of the spatially weighted regressions.

Bateman *et al*. (2006), Benson *et al*. (2005) and Neupane *et al*. (2007) employ a 1st order Queen contiguity configuration for W_{ij} using raster data, which is not suitable for the polygons representing the Niger basin administrative units. The spatial relationship (W_{ij}) was defined as a K^{th} order nearest neighbour configuration (i.e. the variable value of the K^{th} order nearest neighbour administrative units *j* of each administrative unit (i) of interest). The K^{th} nearest neighbour weighting configuration with the lowest value of Moran's I in the spatial lag residual was considered optimal (see Anselin, 2005) (Table 16).

Derivations were estimated using a spatial lag model for the administrative cells specific to the whole of basin, each country and each hotspot for the three poverty measures.

Table 16: K^{th} nearest neighbour weighting configuration for each hot spot to account for spatial auto correlation

	spatial weight matrix (K^{th} nearest neighbor)		
Hotspot	Mortality	Morbidity	wealth
Basin	K1	K2	K2
Burkina Faso	K4	K4	K2
Mali	K2	K1	K2
Nigeria	K3	K2	K2
Mali Hotspot	K1	K3	K2
Burkina Hotspot	K3	K1	K3
Nigeria Hotspot	K1	K2	K3
Cameroon Hotspot	K1	K1	K2
Delta Hotspot	K2	K3	K3

Moran's I statistic is the metric used to indicate the degree of spatial auto correlation, derived as (also see Boots 2001):

$$I = (k/w)\left[\sum_{i=1}^{k}\sum_{j=1}^{k} w_{ij} y_i y_j \Big/ \sum_{i=1}^{k} y_i^2\right], \qquad (3)$$

Where: $W = \sum_{i=1}^{k}\sum_{j=1}^{kn} w_{ij}, y_i = (x_i - \overline{x})$

where x is the poverty metric (child mortality, child morbidity or wealth index) and $\overline{x}$ is the mean poverty score over all the administrative units in the Niger River basin. The local Moran's I is derived by localizing the global measure. The formula for the localized Moran's I is:

$$I_i = \left[y_i(\sum_i y_i^2 / k)\right]\sum_j w_{ij} y_j \qquad (4)$$

In order to examine clusters of high (hotspots) or low (coldspots) poverty we analyzed the data using local spatial data methods (4) as described by Anselin (2005). These procedures involved determining whether the observed measure of poverty at the scale of administrative unit display a non-random pattern over the entire basin in addition to those for each of the basin countries. The latter is crucial in policy formulation as this is the unit of analysis where policy can be formulated and implemented at a scale that accounts for heterogeneity and yet maintains administrative feasibility.

The presence of local positive (Ii>0) spatial auto-correlation indicates a cluster of poverty values around administrative unit *i* that are similar to those of the neighbors of *i* that deviate strongly (either positively or negatively) from $\overline{x}$. In this case $\overline{x}$ represents the mean measure of poverty for the K4 nearest neighbors surrounding cell *i.* Negative spatial autocorrelation (Ii<0) describes the same situation except the sign of the rating at cell *i* is opposite to that of its neighbors. However, if either X_i or the poverty metric in the neighborhood are close to the mean poverty values, no spatial autocorrelation is indicated (Boots 2001). The global and local Moran's I for the poverty data over the entire Niger River Basin were calculated using the statistics program 'R' and the package 'spdep' (R Development Core Team, 2009; Bivand, 2009).

4.6. Estimations of spatial auto correlation and spatial lag

Child Morbidity and Mortality: A spatially explicit whole of Niger Basin analysis

The first step to estimate the significance of spatial auto correlation imputes the northing (y), easting (x) and spatial coordinate interaction (xy) as explanatory variables regressed against the dependent variables. For child morbidity (stunting), a pseudo adjusted R^2 value of 0.466 and an $F_{(3,646)}$ value of 187.654 ($p \leq 0.05$ for all significance tests unless stated otherwise) indicates a significant spatial pattern. Moran's I = 26.75 ($p \leq 0.001$) indicates significant spatial auto-correlation.

The same process for child mortality resulted in a pseudo adjusted R^2 value of 0.485 and an $F_{(3,646)}$ value of 202.45 indicating a significant spatial pattern. The plots of residuals illustrated in Figure 14 suggest that additional non-cadastral variables are likely to explain the observed variance of both variables.

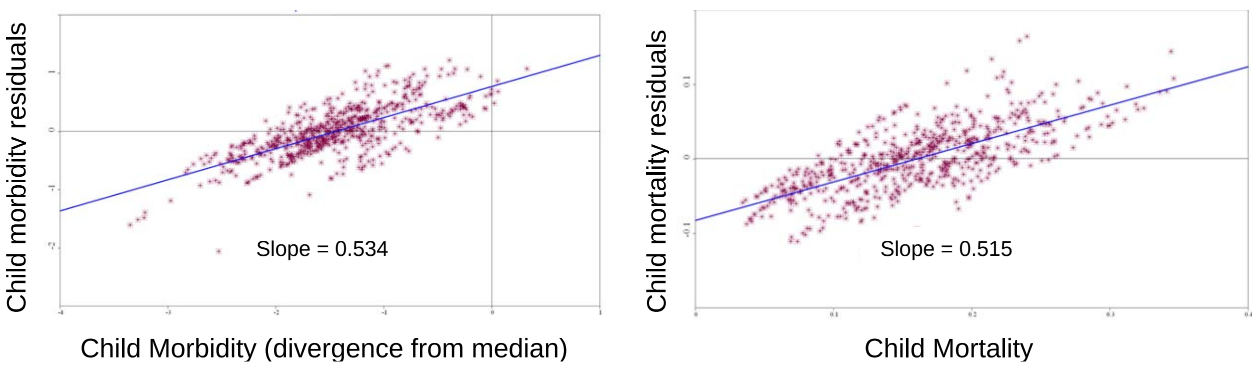


Figure 14: OLS residuals of spatial coordinates plotted against child morbidity and child mortality for the Niger Basin

The magnitude of the robust Lagrange multiplier (Anselin 2003, 2005) indicates that a spatial lag model is superior to a spatial error model in accounting for the spatial autocorrelation in both cases. This was found to be true of all regressions undertaken in this study.

Consider *n* observations of spatially referenced child mortality, denoted by the vector y and *n* observations of *m* independent variables, denoted by the matrix X (Bateman *et al*. 2006).

$$y = X\beta + \varepsilon \qquad (5)$$

Where β is a vector of coefficients and ε is a vector of normally distributed random errors.

Spatial dependence can be controlled by including the mean of child mortality variable in adjacent administrative units for each of the *n* observations as an explanatory variable. The same approach was applied to child morbidity. Vector y was linearly transformed to *Wy* by applying the spatial weighting matrix *W*. Incorporating *Wy* into (5) gives:

$$y = X\beta + pWy + \varepsilon \qquad (6)$$

Where *p* represents the spatial coefficient of the spatially adjacent mean of the poverty variable.

Anselin (1995) notes that a maximum likelihood framework explicitly accounts for the problem of simultaneity, avoiding biased and inconsistent OLS regressions. The statistics program 'R' and the package 'spdep' was used to calculate the spatial lag regression estimates (R Development Core Team, 2009; Bivand, 2009).

	Child Height for Age Ratio [a] (s.d)		**Child Mortality Rate [a] (proportion)**	
(Constant)	-0.46988	***	0.08706	***
Population density (people/km^2)	2.15E-05		-1.54E-07	
Population (people)	-1.35E-07		1.79E-08	
Telephones (proportion)	0.19023		-0.01968	
Electricity (proportion)	0.10096		0.02092	***
NPP (produced) (tonnes/0.25° cell)	3.21E-13	**	-3.44E-14	**
Access ('00 km)	-0.03990		0.01354	
Education (years)	0.01642	**	-0.00459	***
Forest Cover (proportion)	0.10203	**	-0.00592	
Cattle density (units/km2)	-0.00201	**	0.00015	
Chicken density (units/km2)	-0.00005		0.00000	
Sheep density (units/km2)	0.00057		-0.00002	
Goat density (units/km2)	0.00059	*	-0.00004	
pig density (units/km2)	0.00086		0.00001	
Unprotected water (proportion)	-0.24028	***	0.04232	***
Water Access (minutes)	-0.00032		-0.00027	**
Dams ('00 km)	0.06691	***	0.00977	***
Irrigation (percent)	0.01695	***	0.00032	
Precipitation (mm/yr)	-0.00009	**	-0.00001	*
TARWR (m3/yr/km2/person)	0.00005		0.00000	
Drought Economic Risk (decile)	-0.00698		0.00064	
Human footprint (1-100 index)	-0.00138		-0.00032	
Malaria prevalence (parasite ratio)	0.00086		-0.00529	
Moran's I for residuals	**0.001**		**0.004**	
Akaike information criterion	**256.03**		**-2617.4**	
Aprox. Adj. R^2	**0.701**		**0.667**	
Spatial weights matrix	**1 nearest neighbor**		**2 nearest neighbors**	
Sample size	**650**		**650**	

Whole-of-Basin Assessment: Geographically Weighted Regression

The spatial lag model described above provides an indication of the extent to which individual variables explain child mortality and morbidity across the entire Niger River basin. The analysis identified and estimated spatially unbiased coefficients of the explanatory variables of two of the three metrics of poverty. By formally accounting for significant spatial correlation and patterning, spatial lag regression quantified the sensitivity of the poverty variables to potential policy stimuli or interventions. In practice, different explanatory variables have different effects in different geographic locations, and a global statistic may not be a good approximation for any one locality. Global spatial regression models assume that the spatial process that accounts for child mortality is constant across the basin, and thus potentially obscure heterogeneity in explanatory variables (Fotheringham *et al*. 2000). As an alternative, geographically weighted regression (GWR) can provide a more nuanced assessment of poverty, where poverty metrics at different localities are influenced by a variable that differs in magnitude and even sign across the study area.

The inspiration for this approach arises from time series analysis that jointly include both autoregressive and moving average models to assess the behaviour of a dependent variable observed at regular intervals (Bateman *et al.* 2006). We exclude time from the poverty analysis and employ this approach. The global regression model can be written as:

$$y = \alpha_0 + \sum_j x_{ij}\beta_j + \varepsilon \qquad (7)$$

Where *y* represents the dependent poverty variable, the parameter α_0 is a constant, *x* is the value of independent variable *j* at administrative unit *i*, β is the regression coefficient of *j* and ε is a stochastic error term assumed to be normally distributed across all observations. This can then be expressed as a local regression model:

$$y = \alpha_{0i} + \sum_j x_{ij}\beta_{ij} + \varepsilon \qquad (8)$$

Where individual regression models are built for each locality *i*, using data from neighbouring points. The extent to which proximate administrative units contribute to a particular local analysis depends on the distance from *i*. We use a fixed, Gaussian shaped kernel with a spatial bandwidth of 0.8 data units, as determined using AICc minimisation. This optimisation procedure and the following outputs were obtained using the GWR 3.0.1 Software (Fotheringham *et al.* 2003).

Table 17: shows the specification of the GWR models constructed to explain child mortality and child morbidity (stunting). The global adjusted R^2 values are 0.871 and 0.867 respectively, a small improvement over the spatial lag model (0.840). Figure 15 presents the local pseudo R^2 values for the mortality model, which range from 0.65 to 0.99. R^2 values for the morbidity model (not shown here) have similar values between 0.60 and 0.98. Both models comprise of variables chosen on the basis of their significance in the spatial lag model. Other variables were found to be significant in local GWR model also,

although high levels of multicollinearity prevented their inclusion in the final model presented here.

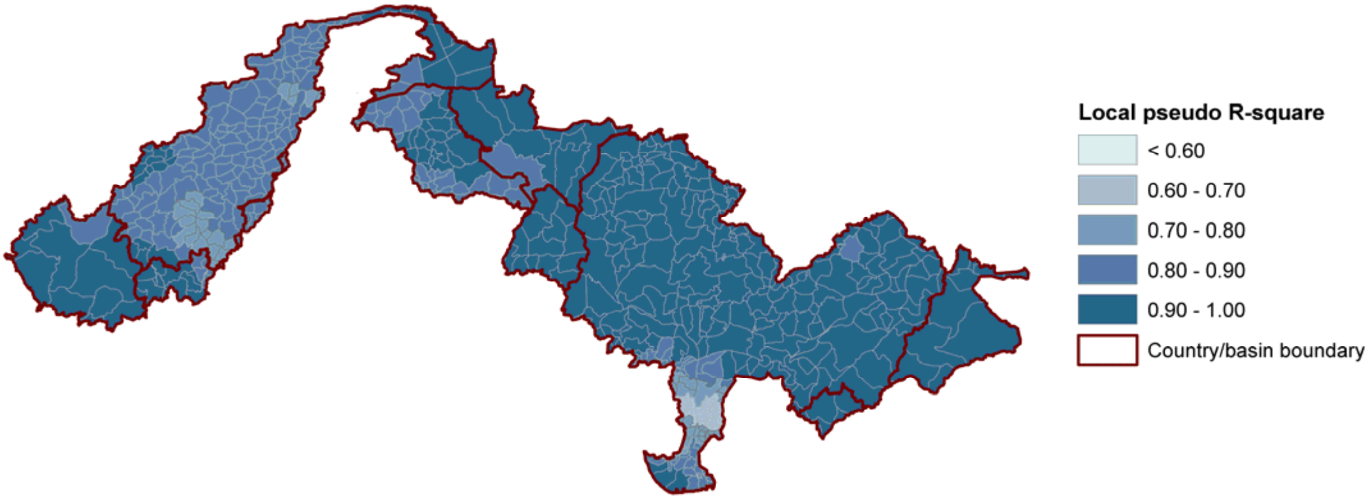


Figure 15: Local pseudo R^2 from the geographically weighted regression model of the determinants of child mortality in the Niger Basin. Darker areas are more comprehensively explained.

GWR regression calculates a coefficient for each variable at each geo-referenced cell in the landscape, complicating conventional presentation of regression results. As an alternative, we firstly give an indication of the significance of each coefficient's variation across the study area, calculated using a Monte Carlo estimation (100 iterations) (Table 17:). This indicates whether the spatial variation in each variable is significant or is simply a random distribution. Variables that are not significant may still have an influence on child mortality/morbidity (as seen in the hotspot analysis) however there is insufficient evidence to conclude that their effect is heterogeneous through space. Most livestock variables were found to be significantly varied. Water variables such as TARWR, water access, water quality and irrigation, and additionally, education, access to towns and environmental damage (human footprint) were also significant ($p < 0.05$).

Table 17: Variables used in the geographically weighted regression model of child mortality and child morbidity.

Variable	Spatial non-stationarity test sig. level (p-value)	Spatial non-stationarity test sig. level (p-value)
	Child mortality	**Child morbidity (stunting)**
Intercept	**< 0.001**	**< 0.001**
Cattle density	**< 0.001**	**< 0.001**
Sheep density	0.98	0.33
Chicken density	**< 0.001**	**< 0.001**
Goat density	**< 0.001**	**< 0.001**
Pig density	**< 0.001**	**< 0.001**
Human footprint	**0.01**	0.24
Access	**0.01**	0.22
Education	**0.01**	**< 0.001**
Dams	0.54	**< 0.001**
Water Access	**< 0.001**	**< 0.001**
Unprotected water	**< 0.001**	**< 0.001**
TARWR	**< 0.001**	**0.06**
Irrigation intensity	**< 0.001**	**< 0.001**
Adj. R^2	0.871	0.867
Sample size	650	650

Figure 16 and Figure 17 illustrate mapped representations of the non-standardized variable coefficients across the Basin. Districts where the variable is not significant (at α=0.1) are colored blue, districts where that variable has a significantly negative effect on child mortality/morbidity are colored yellow and orange, and districts where that variable has a significant positive effect on child mortality/morbidity are colored green.

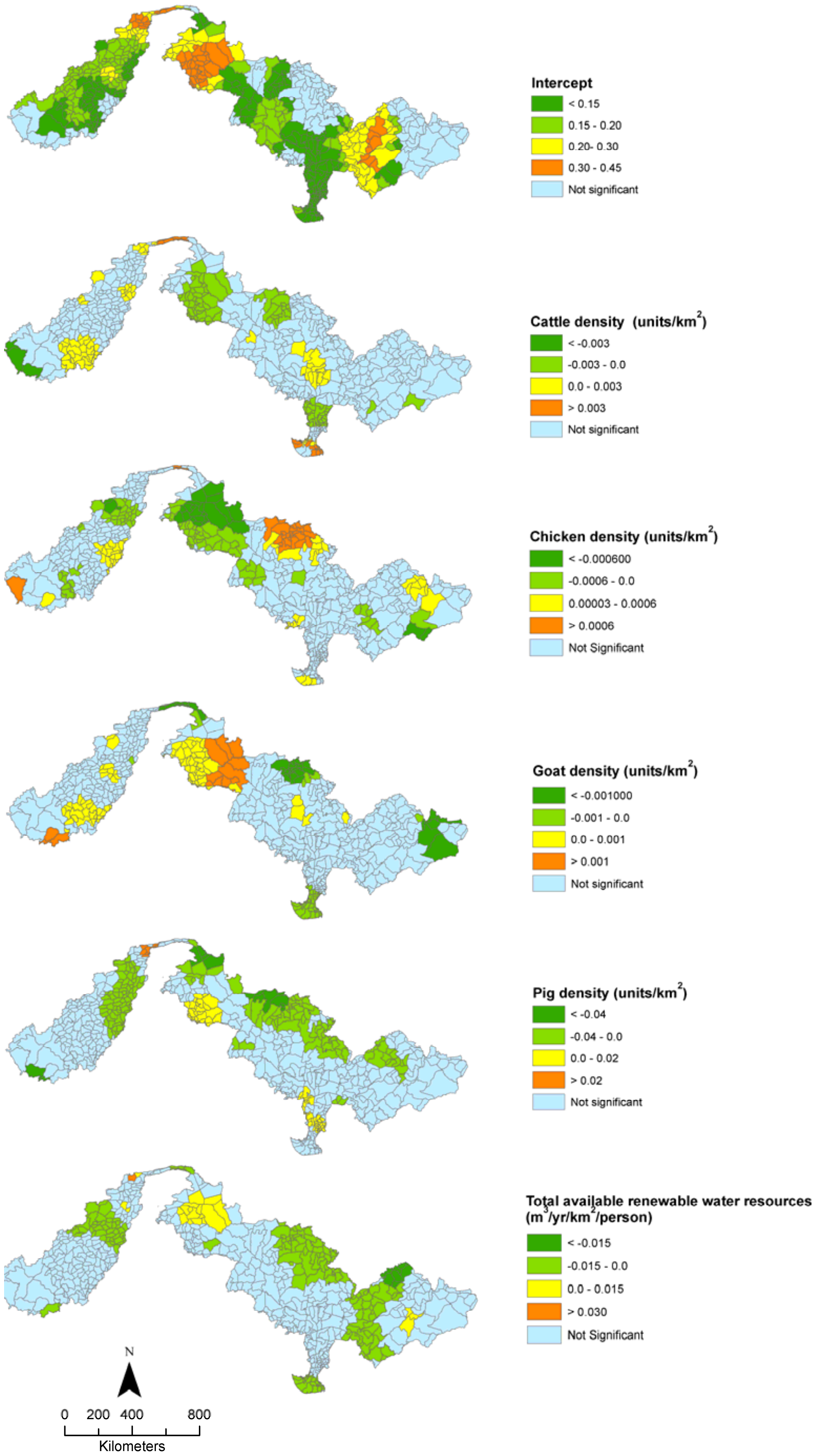


Figure 16: Maps of all significant independent variables used to model the incidence of child mortality (proportion of children who die before 5 years of age) using GWR regression

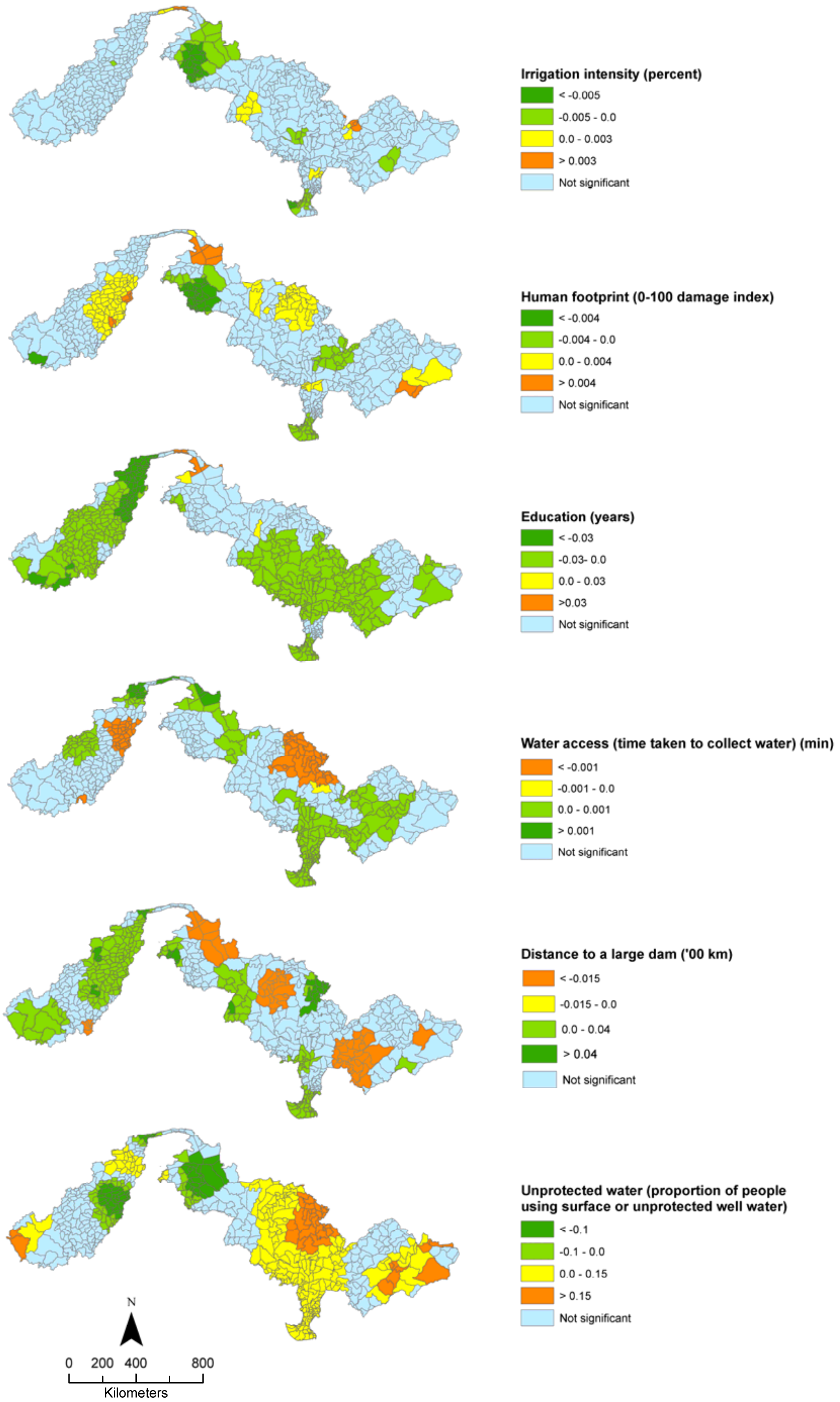


Figure 16 (continued)

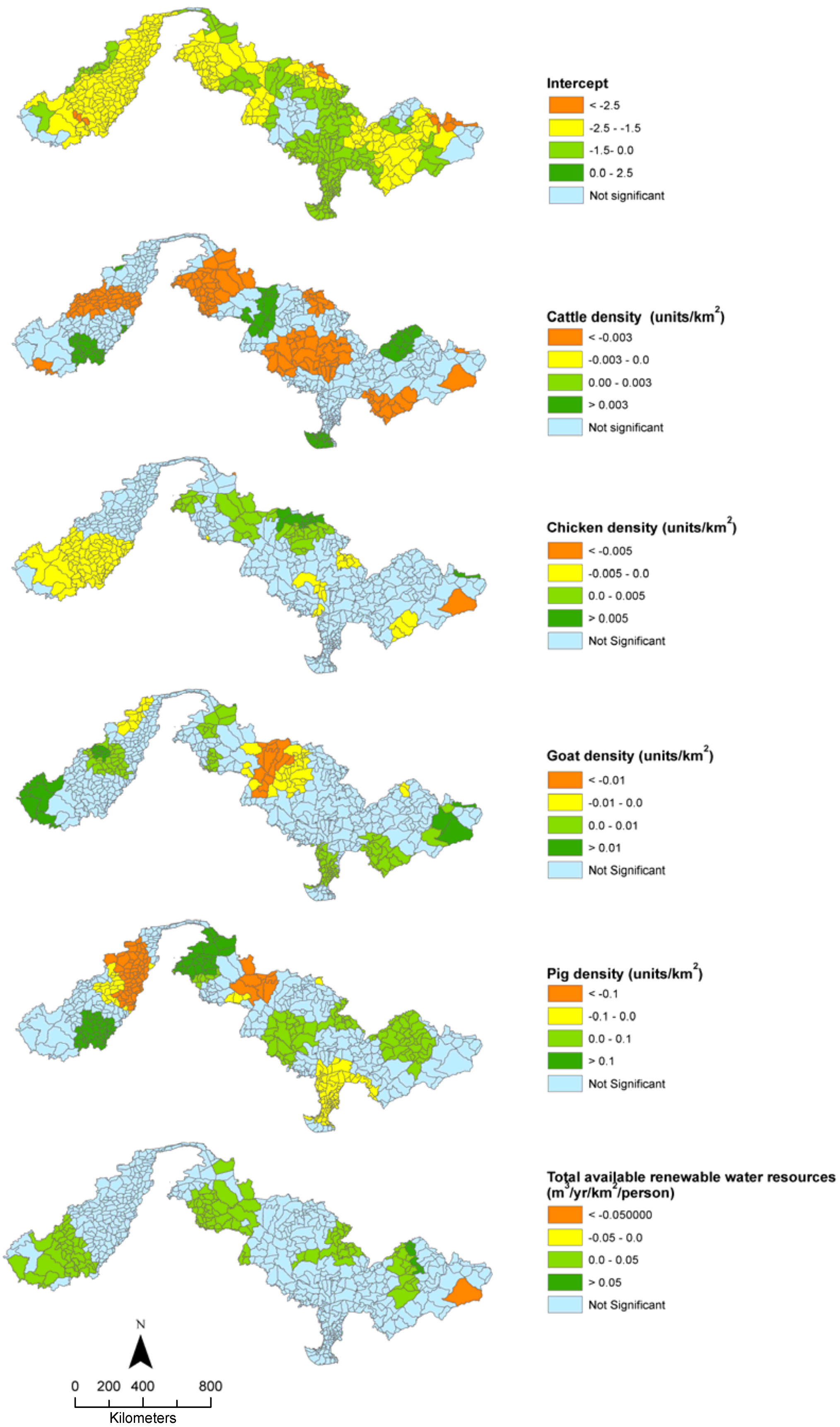


Figure 17: Maps of all significant independent variables used to model the incidence of child morbidity (height for age ratios, standard deviations from reference median) using GWR regression

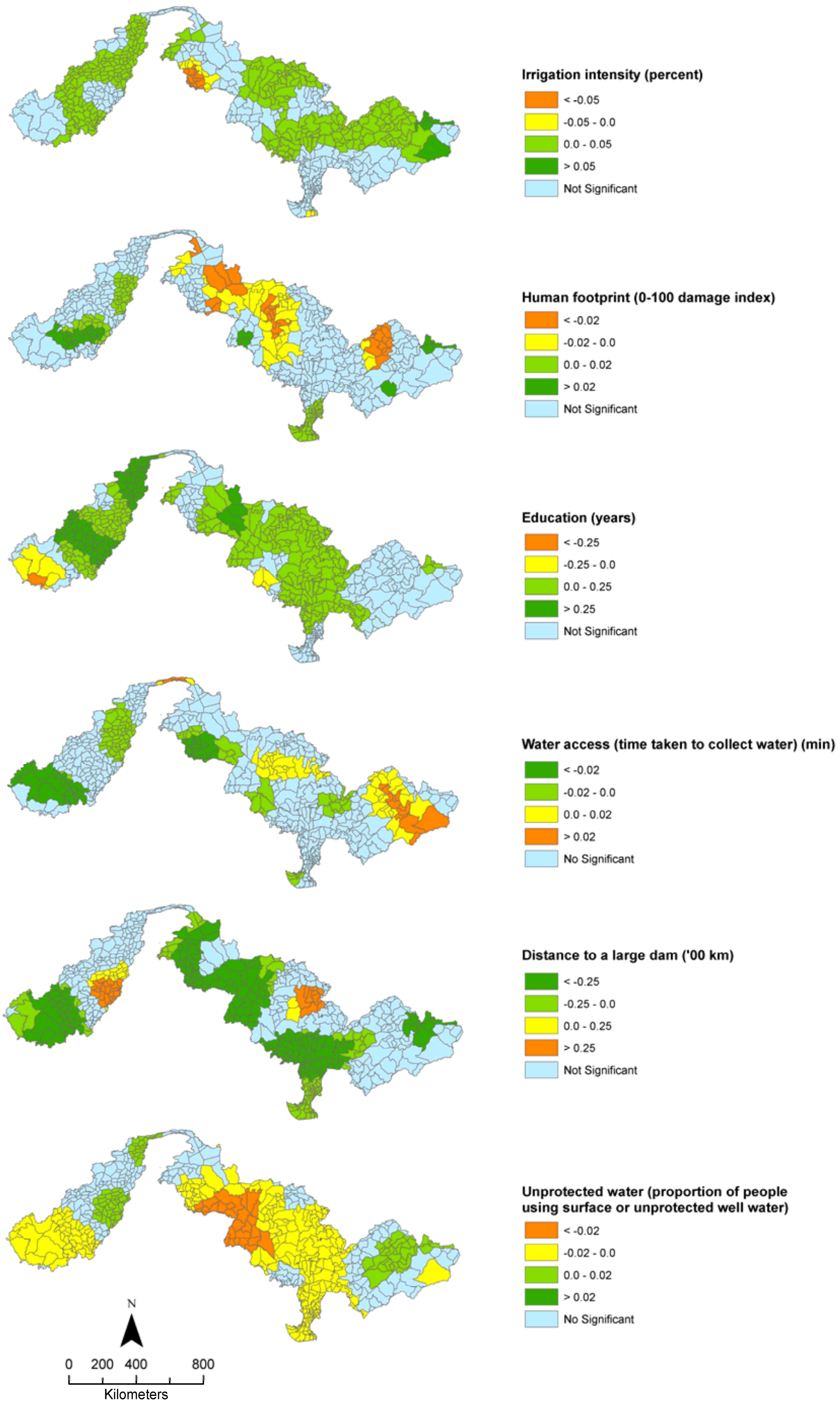


Figure 17 (continued)

The intercept term shows how the prevalence of childhood mortality and child morbidity would differ from the overall mean if all other variables were held constant. Thus, *ceteris paribus*, child mortality is more severe in east Burkina Faso, central Mali around the inner delta, and east Nigeria. East Burkina Faso and east Nigeria are similarly highlighted on the stunting intercept map, which also features a hotspot in north west Nigeria. These regions correspond with the hotspots identified by localized indicators of spatial autocorrelation described in section 5. Lower incidences of child mortality are found in southern Mali, Benin and south and central Nigeria, whilst lower incidences of stunting are found in south and central Nigeria.

The first important implication of these modeling results is the disparity that exists between the two poverty metrics. Despite a widely accepted correspondence between rates of child mortality and stunting (see for instance Black, *et al.* 2008), spatially explicit results at the scale of the Niger Basin administrative district show considerable variation. The result emphasize that the multiple expressions of poverty warrant analysis that incorporates a number of poverty metrics for cross validation. To improve the reliability of policy guidance and interpretation, we prioritise analytical results that are consistent for both observed mortality and morbidity.

Greater availability and supply of bulk water resource (measured by the TARWR) are correlated with improvements in the child mortality and stunting rates for many parts of the Basin, as expected. A higher quantity of available water should allow for increased agricultural production and hence increases in incomes, although as other sections of this report demonstrate, there exist inhibitory factors. Importantly, the negative correlation between water availability and both metrics is present in north west Nigeria (identified as a poverty hotspot in section 5), providing evidence of quantitative water limitations in this region. The negative water availability/poverty relationship is demonstrated in Central Mali and east Nigeria also, and of these, the east Nigeria region is supported by both metrics. There appears to be a contradictory aberration to this trend in southern Niger for the mortality variable. This poor, dry region has an unusually high TARWR value due to the proximity of the Niger River. The associational relationship between water and mortality in this area is contrary to most of the basin but does not contradict the overall conclusion. Alternately, the morbidity analysis of southern Niger is consistent with the results observed for other parts of Niger Basin. In the light green areas of Figure 16, an additional cubic meter of water (per person, per km^2, per year) is associated with a reduction in child mortality of up to 1.5%. The green areas identified here are those for which there is evidence of significantly elevated water poverty.

An increase in irrigation intensity, representing the highest density of irrigation area in a district, is correlated with reductions in child stunting in central Mali, parts of Burkina Faso, north west Nigeria, central and eastern Nigeria and North Burkina Faso. This variable is very closely correlated with the more intuitive ‘area of irrigation’ variable but provides additional sensitivity to the extent of irrigation development. Increased irrigation intensity is associated with an increase in morbidity in south east Burkina Faso, in contrast to positive coefficients observed for mortality data. As a corollary, opposing evidence limits guidance regarding the role of irrigation in poverty policy.

East Burkina Faso is characterized by a number of micro dams which allow for small scale irrigation development and rainfall capture and management. The evidence presented suggests that this type of water related development has resulted in an above average reduction in poverty, measured by both child mortality and morbidity, although it is possible that dams are acting as a proxy for other causative factors not included in the model.

The use of unprotected well or surface water is generally positively correlated with increased child mortality and increased stunting. In the important areas of north west Nigeria and east Nigeria, a 10% decrease in the number of people using unprotected water is correlated with up to a 2.4% decrease in child mortality. Contrary results are found for both metrics in southern Mali and in the inner delta. Groundwater and open channels of surface water are important in these regions. In the absence of contamination, the unprotected wells (south Mali) and the accessibility of surface water (inner delta) are likely to be assets. In other parts of the basin the general relationship of increased poverty associated with increased use of unprotected water holds however, as indicated by both the global model and the two local models.

The density of the five types of livestock considered (cattle, sheep, goats, pigs and chickens), except sheep have some significant spatial non-stationarity for both metrics. Increased cattle densities are associated with a decrease in childhood mortality in the Sahel belt of east Burkina Faso and also in south central Nigeria, although this is not supported by the morbidity data. There is slightly more agreement between metrics for goats, however, which are a positive asset in the desert regions of Mali and Niger according to both metrics. However, they are also associated with increased childhood mortality in east Burkina Faso and with increased stunting further east in north west Nigeria. This suggests a reciprocal relationship between goats and cattle: goats are suitable stock in areas less suited to cattle, likely due to their increased drought tolerance (Silanikove, 1999). Contingent on the partial agreement from the child morbidity data, we advise a cautious interpretation of these findings.

The effect of chicken density and poverty is also characterized by spatial variability. There is agreement on their positive contribution to reduced mortality and morbidity in east Burkina Faso and south Niger. The results for pigs have little relevance for the majority of Muslim areas of North Nigeria, Niger and Mali, however there is agreement in their positive association with decreased poverty in east and central Nigeria (near Kaduna and Bauchi, for instance) which have moderate concentrations of pigs.

An increased time that spent in education is strongly correlated with a decrease in child mortality, a consistent finding in all three methodologies and all three dependent variables employed in this study. The positive influence of education is especially pronounced in Nigeria and Mali. In much of the Inner Delta, a one year increase in the average level of education is associated with a 3% decrease in child mortality.

The variables demonstrated to be statistically non-stationary are those suitable for a targeted policy approach. The differences in coefficient estimates are likely to be symptomatic of the ways in which a variable influences communities subject to variance due to spatial location. A targeted policy approach to poverty reduction, tailored to account for spatial heterogeneity is likely to be more successful than policy that is based on the national or basin average. Those variables that are significant but are stationary across the study area can be approached with larger scale policies with less attention to regional differences. This section has also demonstrated the potential for different measures of poverty to lead to divergent poverty reducing actions. Conclusions that rely exclusively on a single terrain poverty model are likely to be an insufficient basis for robust policy design and intervention. The discussion has drawn attention only to those conclusions that are substantiated by both of the metrics of child related poverty; child mortality and stunting. This is an important finding when designing water related poverty reduction given the tendency of past poverty research to often utilize only one dependent variable metric at a time.

4.7. National and sub national poverty analysis: estimates using LISA spatial clusters

Policy decisions are often made at state or national level, and regional perspectives or understanding of poverty cannot be presumed to be aligned or concordant with the differentiation of poverty, livelihood vulnerability or institutional diversity across the entire Niger basin (Hyman *et al*. 2005). More effective policy that influences water access or productivity may be reliant on mixes of sequenced instruments tailored to address temporally and spatially diverse poverty patterns. An important focus of the research was the development and application of methods capable of imputing variables at scales that simultaneously align water management and poverty data, revealing opportunities for water policy formulation that is administratively and politically feasible across the Niger basin countries. A primary research objective was the provision of evidence based analysis that guides water management policy formulation in the direction of the causes of poverty and threats to livelihoods at scales that reflect priority social units that are most threatened or exposed. With such analysis, measures of water access and productivity can be incorporated into aspects of policies that support sustainable livelihoods and become an integral part of mainstream development support.

A finer resolution of poverty analysis was introduced as an alternative to a whole of basin analysis, enabling the identification of poverty hotspots at a sub-national scale. Positive spatial dependence is observed when neighboring points have values more similar than those expected from a random distribution, and may take the form of either correlated error terms or a spatial lag. Both of these spatial relationships violate the assumptions of linear OLS regression. To avoid biased estimates due to spatial autocorrelation, the data must either be remodeled with spatial weighting terms or statistically segregated into spatially homogenous units and re-estimated on a smaller scale. This section of the report describes the latter strategy.

Anselin (2005) has developed localized indicators of spatial correlation (LISA) to account for spatial clustering at defined local scales, described earlier in section 4.5. LISA quantifies clusters in the pattern of spatial associations of poverty. These spatial clusters can be areas of high spatial correlation characterized by either high relative poverty (hotspots) or low relative poverty (cold spots). The analysis also highlights regions of high or low poverty measures associated with insignificant spatial patterning. Regression models reliant on spatial lag corrections are not required for those areas with low spatial correlation attributes. An example of the four possible categories is illustrated in Figure 18. In the Niger River Basin, clusters signify statistically determined regions of high or low poverty according to the three poverty metrics. Mapped LISA clusters identify a spatial poverty pattern of interest to policy makers, aid agencies and water managers. Consistent with the spatial lag and GWR regression models, the spatially referenced poverty estimates rely on LISA clusters based on a Morans' I estimated from the values of the K^{th} nearest neighbor.

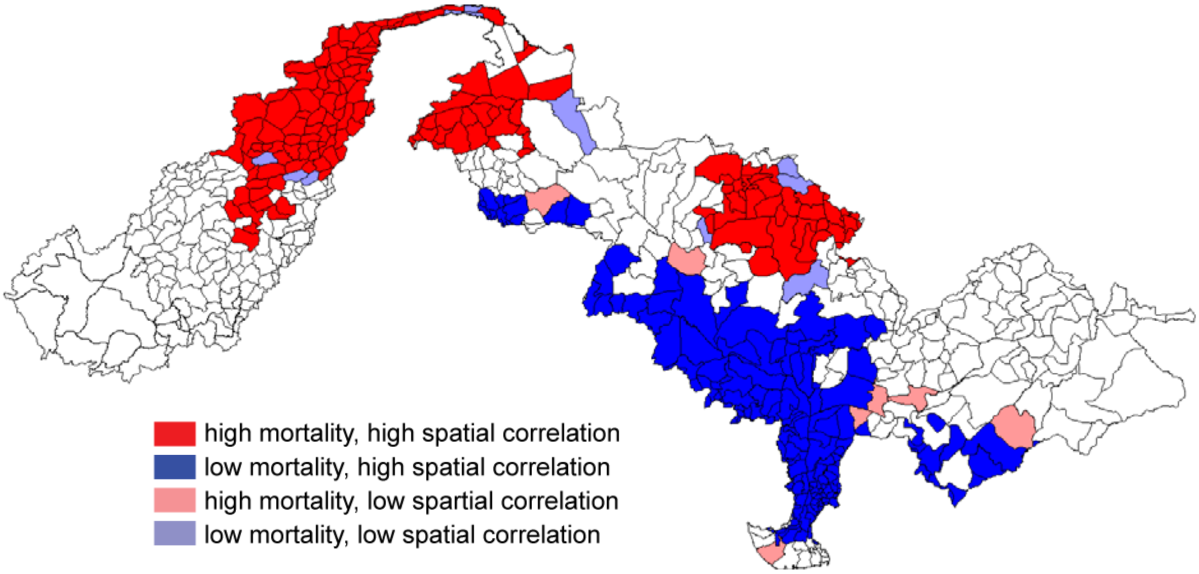


Figure 18: LISA clusters of child mortality (proportion of children who die before age 5 yrs) across active Niger Basin. Moran's I value of 0.679 indicates moderate spatial autocorrelation in this variable.

Figure 18 shows child mortality hotspots (colored red) in central Mali, and importantly in the inner Niger delta. This stretches over a large area, between Bla, Niono, Bandiagara, Goundam and further along the Niger river to the East. North East Burkina Faso exhibits a hotspot between Oursi, Dori and Titao. North Western Nigeria shows a hotspot between Sokoto, Katsina and Gusau.

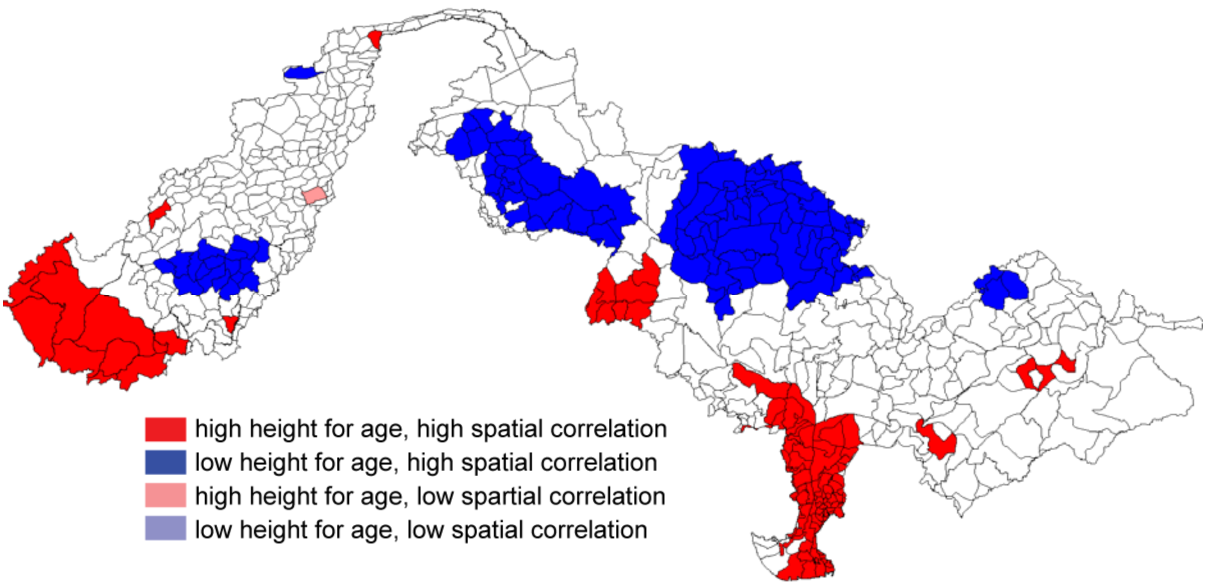


Figure 19: LISA clusters of child morbidity (height for age ratios) across active Niger Basin. Moran's I value of 0.833 indicates high spatial autocorrelation in this variable.

Figure 19 shows hotspots of child morbidity (colored blue) clustered into three regions. Southern Mali, around Kignan, Klela, Sanso, Sikasso and Bougouni; Eastern Burkina Faso from Gorom-Gorom and Djibo down towards Diapaga and Kantchari; and North Western Nigeria and South Western Nigeria from Dosso and Birnin Konni to Katsina and Funtua. As child morbidity is measured by stunting, low values (height for age) indicate worse conditions.

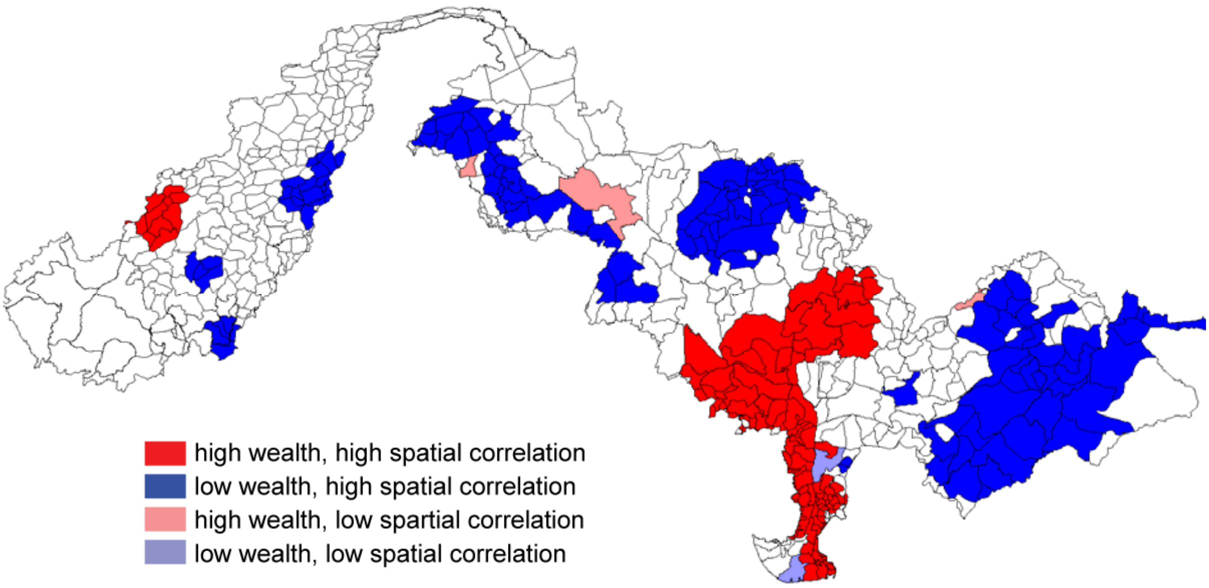


Figure 20: LISA clusters of relative wealth across active Niger Basin. Moran's I value of 0.767 indicates moderate spatial autocorrelation in this variable.

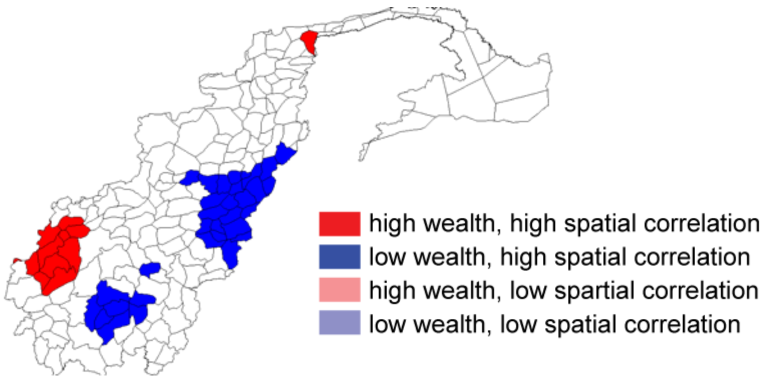


Figure 21: LISA clusters of relative wealth across active Niger Basin in Mali only. Moran's I value of 0.767 indicates moderate spatial autocorrelation in this variable.

Figure 20 and Figure 21 show hotspots of low relative wealth or asset value (colored blue). Because the wealth index cannot be compared internationally (Rutstein and Johnson, 2004), a separate analysis for Mali was undertaken; however it shows very similar results. A hotspot occurs in Southern Mali, between Niena, Kolondieba and Sikasso; and in Burkina Faso between Aribinda, Oudalan and further south to Bogande. There is a hotspot in north Western Nigeria, again around Sokoto, extending south to Zugu and East to Isa. Another extensive cluster of low relative wealth is found in eastern Nigeria, bordering an area of low wealth in North Cameroon. Although the wealth index does not compare accurately across international borders this region is analyzed as one unit due to the similar levels of GDP in both countries. Furthermore, separate analysis of the Cameroon hotspot would be hampered by a small sample size.

There is broad convergence in the spatial correlation between poverty measures. Eastern Burkina Faso and North Western Nigeria are identified by all measures and Southern Mali by two (morbidity and wealth). Central Mali and the Inner Niger delta appears to be an extensive mortality hotspot, although it was not detected by the other assessment methods. Finally, Eastern Nigeria and neighboring northern Cameroon are identified as a hotspot when using the wealth index. Communities situated in regions of intersecting hotspots for all three metrics employed here are those expected to face the greatest poverty and vulnerability challenges.

4.7.1. Estimating the factors of poverty at a sub-national scale

The research hypothesis suggests that each hotspot is subject to differing local conditions and thus observed poverty is caused by a different vector of poverty explanators. Section 4.6 described the initial analysis at the whole of basin scale. Although spatially explicit models were used to account for spatial autocorrelation, the non-stationary nature of the explanatory variables observed using GWR analysis (section 0) suggests that such global models would be insensitive to detail that is crucial to targeted policy development, given the size and complexity of the Niger Basin. As an alternative to the GWR analysis, the following section describes an analytical framework that focuses on the specific poverty hotspots identified in Figures 14-17.

It is the aim of this research to both identify and spatially reference areas of poverty and to investigate the extent to which water is contributing to this poverty. It is hypothesized that different factors drive poverty in different places, so individual regressions are applied to each hotspot. Each table describes a different hotspot. The regressions contain a spatial lag term to account for spatial autocorrelation (as was required in section 4.6).

Analytical results and summaries are described in Table 18 to Table 27. Each table shows three regression models, explaining child mortality, child morbidity and the wealth index in turn. All variables were initially included in the models, with variables removed on the basis of high multi-collinearity (variance inflation factors >10).The electricity and telephone variables were excluded from wealth index models (as they are themselves components of the index).

Model fits are described in terms of a pseudo R^2 value and a log likelihood score. Note that a robust model of the southern Mali poverty hotspot proved unobtainable due to the small sample size, and so has not been included in the section below.

North West Nigeria

This region is considered impoverished according to all three metrics employed, with below average wealth and child health and above average child mortality rates. Models are all significant and have hive explanatory power (approximate pseudo R^2 0.89 – 0.92. The impoverished status of this region accords with mapping by the World Resources Institute (2007), whilst SEDAC (2006) also finds the region afflicted by poor nutrition.

Table 18: Summary of health, education and water statistics for the north west Nigeria hotspot.

	Mean	Standard deviation
Population (in total, millions)	11.49	-
Child (<5 yrs) mortality (%)	19.64	3.18
Average education (years)	1.25	1.06
Average TARWR (m^3/yr/km^2/person)	7.76	38.40

Water quality is significant (p< 0.1) for two metrics: A 1% decrease in the number of people who access their primary drinking water from unprotected well or surface water is associated with a 1.1% decrease in child mortality. Other water variables are found significant in one model only, providing weaker evidence of their importance. These include the commonly utilized **TARWR** statistic (total available renewable water resources) and the variable representing proximity to large dams (correlated with a slight decrease in child mortality and an increase in wealth respectively). An increased time taken to gather water **(water access)** is associated with higher child mortality. An average reduction of ten minutes taken to access the primary water source is correlated with a 1.6% decrease in child mortality rates. **Irrigation** is suggested to play a role based on the morbidity model, with a 1% increase in a district's irrigated area corresponding with a 0.04 standard deviation improvement in height-for-age ratios.

Education is influential on all three poverty metrics: more time in formal schooling is correlated with wealth, better health and reduced mortality. A one year improvement in average schooling attainment is associated with a 0.6% decrease in child mortality rates and an 0.08 standard deviation increase in child height for age ratios, all else being equal.

The majority of poverty determinants did not exhibit concordance of significance across models, the conditional requirement we use for reliability. They provide information regarding potential poverty correlates of second tier quality only. **Chickens** are associated with improved wealth whilst **sheep** are associated with diminished health. The prevalence of **telephones** is associated with an improvement in height-for-age ratios.

The association between child health and education is common to most poverty hotspots analyzed in this study, and is concordant with the findings of Kandala et al. (2007). Their spatial analysis revealed mother's education, place of residence (rural or urban), breastfeeding, wealth level and others as significant predictors of diarrhea, fever and cough in Nigerian children. In contrast to the results presented here Kandala et al. (2007) did not identify the north western region as an area of relatively high disease, instead identifying the north eastern area worst inflicted (concordant with another hotspot discussed below). The choice of dependent variable is thus an important influence on results, and this difference may be due to the different temporal scales relevant to long term stunting (measured over years) and short term respiratory and diarrheal inflictions (measured over weeks).

Table 19: Variables explaining wealth, morbidity and mortality in North Western Nigeria region.

	Wealth Index		**Child Height for Age Ratio (s.d)**		**Child Mortality Rate (prport^n)**	
(Constant)	-0.32330	**	-2.90450	***	-0.07228	*
Population density (people/km^2)	0.00017	***	-0.00018	**	0.00001	
Population (people)	-		-		-	
Telephones (proportion)	-		1.32720	**	0.05563	
Electricity (proportion)	-		-		0.01361	
NPP (produced) (tonnes/0.25° cell)	-		-		-	
Access ('00 km)	-		0.52565		0.03358	
Education (years)	0.07467	**	0.08867	***	-0.00655	***
Forest Cover (proportion)	-0.16014		0.22228		0.01170	
Cattle density (units/km2)	-0.00217		-0.01003	**	-0.00076	**
Chicken density (units/km2)	0.00130	***	-		0.00024	
Sheep density (units/km2)	0.00003		-0.00381	**	0.00021	
Goat density (units/km2)	-		0.00257		0.00006	
pig density (units/km2)	-		-0.01177		-0.02104	***
Unprotected water (proportion)	-0.73068	***	-0.34122		0.10797	***
Water Access (minutes)	-0.00046		-0.00408		0.00171	***
Dams ('00 km)	-0.23005	***	0.03517		0.00041	
Irrigation (percent)	0.00645		0.04289	*	0.00126	
Precipitation (mm/yr)	0.00083	***	0.00064		0.00008	*
TARWR (m3/yr/km2/person)	-0.00014		-0.00034		-0.00015	**
Drought Economic Risk (decile)	0.00346		-0.01672		-0.00159	
Human footprint (1-100 index)	-		-		0.00109	
Malaria prevalence (parasite ratio)	-0.43230	*	0.44091	*	0.03178	
Moran's I for residuals	**-0.014**		**-0.059**		**0.017**	
Akaike information criterion	**-92.14**		**6.77**		**-327.14**	
Aprox. pseudo adj. R^2	**0.95**		**0.92**		**0.89**	
Spatial weights matrix	**3 nearest neighbors**		**2 nearest neighbors**		**1 nearest neighbor**	
Sample size	**34**		**65**		**71**	

* = statistically significant at 90%, ** = 95%, ***=99%. Note that a positive child morbidity coefficient means increasing height for age ratios and thus an improvement in health.

Central Mali and the Inner Delta

This region is an important area of the Niger Basin as it contains the Ramsar listed Inner Delta – a highly productive flood plain covering an area of over 80 000 km^2. It provides fish (70 000 – 90 000 tonnes per year), pasture and other means of living for over one million people (Zwarts, et al. 2005). Large numbers of nomadic herders and their migratory livestock arrive in most dry seasons, particularly during drought years (Niger Basin Authority, 2005). The Central Mali poverty hotspot extends far to the south to Bla and past Tombouctou in the north, representing a total of approximately 3 million people, or one quarter of Mali's population. LISA cluster analysis of the wealth index and of child morbidity did not find impoverishment to be significantly spatially correlated (Moran's I $p \geq 0.05$). However, the region has a high prevalence of child mortality, up to 350 per 1000 births in some localities, and with a mean of approximately 240. For consistency, modeling using the other poverty measures has been undertaken using the region as defined by child mortality.

Table 20: Summary of health, education and water statistics for the central Mali and inner delta hotspot.

	Mean	**Standard deviation**
Population (in total, millions)	3.00	-
Child (<5 yrs) mortality (%)	24.05	4.62
Average education (years)	0.64	0.64
Average TARWR (m^3/yr/km^2/person)	0.85	1.17

All three models, presented in Table 21, are significant and pseudo adjusted R^2 ranges from 0.81 for the wealth index to 0.60 for the mortality model.

The relationship between water and poverty is ambiguous in the central Mali hotspot. There are no significant relationships concordant between at least two dependent variables. Weaker evidence is provided by variables significant in only one model. Improved **access** to water is significantly associated with morbidity; however it has a sign contrary to expectations. It is possible that the unique environment of the inner delta contributes to this unexpected result: some of the poorest communities in this region live along the delta's waterways with close access to water but poor access to services. This hypothesis is supported by the significance of the **unprotected water** variable. Poor water quality is associated with lesser wealth, as expected.

We hesitate to draw conclusions from variables which do not enjoy concordance between models, regardless of their significance level, and would encourage the reader to do likewise. An important finding in this exercise is the discrepancy that exists between different poverty measures, despite the concordance that exists between study regions in this case (determined by the mortality LISA cluster only). Several variables (irrigation and malaria prevalence) have significant but alternative signs between models.

Education was found to be significant in all three models. A one year increase in average schooling levels is associated with a 3.1% decrease in child mortality rates.

Table 21: Variables explaining wealth, morbidity and mortality in Central Mali region.

	Wealth Index		Child Height for Age Ratio (s.d)		Child Mortality Rate (prport^n)	
(Constant)	-0.16539		-1.71010	***	0.14522	***
Population density (people/km^2)	0.00137	**	0.00040		-0.00004	
Population (people)	0.00000		0.00000		0.00000	
Telephones (proportion)	-		0.74888		-0.10982	
Electricity (proportion)	-		-0.39659		0.10017	
NPP (produced) (tonnes/0.25° cell)	-		-		-	
Access ('00 km)	0.04319		0.17222		-0.01578	
Education (years)	0.22160	***	0.20625	*	-0.03104	**
Forest Cover (proportion)	-0.17428		0.04348		0.00325	
Cattle density (units/km2)	0.00001		0.00443		0.00055	
Chicken density (units/km2)	-0.00024		0.00031		-0.00029	
Sheep density (units/km2)	-0.00081	*	-0.00172		0.00025	*
Goat density (units/km2)	-0.00107		-0.00457		0.00013	
pig density (units/km2)	-0.01497		-0.06780		-0.00559	
Unprotected water (proportion)	-0.20029	***	0.32213		-0.00789	
Water Access (minutes)	-0.00282		0.02090	**	0.00038	
Dams ('00 km)	-		-		-	
Irrigation (percent)	-0.00631	***	0.01206	*	-0.00090	
Precipitation (mm/yr)	-		-		-	
TARWR (m3/yr/km2/person)	0.00871		0.01864		-0.00406	
Drought Economic Risk (decile)	0.01388	*	0.03840	*	0.00311	
Human footprint (1-100 index)	0.00120		0.00667		0.00059	
Malaria prevalence (parasite ratio)	-0.18819	**	-0.26380		-0.06278	*
Moran's I for residuals	**-0.025**		**-0.002**		**-0.011**	
Akaike information criterion	**-144.31**		**37.22**		**-321.88**	
Aprox. Pseudo adj. R^2	**0.81**		**0.63**		**0.60**	
Spatial weights matrix	**2 nearest neighbors**		**3 nearest neighbors**		**1 nearest neighbor**	
Sample size	**83**		**83**		**83**	

Note that the 'hotspot region' is defined by incidence of child mortality only, as other measures do not find this region highly impoverished (see section 4.7) * = statistically significant at 90%, ** = 95%, ***=99%. Note that a positive child morbidity coefficient means increasing height for age ratios and thus an improvement in health.

East Burkina Faso

Explanatory power and overall model significance was satisfactory for the wealth and morbidity models (pseudo adj. R^2 = 0.82 and 0.75 respectively). The sample size for this region was smaller than others considered (26-34 data points), potentially causing some of the difficulties experienced in analyzing this hotspot. The mortality model in particular manages to explain only 26% of the variance in the dependent variable and is not considered reliable here due to a trend in the residuals (suggesting that a significant explanatory variable is missing from the model). Also of relevance, the mortality hotspot detected here is largely different to the hotspot detected using the wealth and morbidity measurements, and is located further to the north (see Figures 14-16). The conclusions regarding the potential causes of poverty are drawn primarily from the morbidity and wealth models.

Table 22: Summary of health, education and water statistics for the east Burkina Faso hotspot.

	Mean	Standard deviation
Population (in total, millions)	1.37	-
Child (<5 yrs) mortality (%)	18.33	4.71
Average education (years)	0.50	0.42
Average TARWR (m^3/yr/km^2/person)	1.07	3.00

The use of **unprotected water** is the clearest result regarding water related poverty in this region. An increase in the proportion of people accessing their primary water source from unprotected wells or streams is associated with a decrease in wealth and a decrease in height-for-age ratios. This suggests that quality of water is more of a factor than quantity or access in this region. Variables representing the latter factors provided insights contrary to expectations and except in the case of water access are not supported between models (a conditional requirement for reliability). The time taken to access water had an unexpected sign, with those taking greater time associated with improved child health and wealth. The **risk of drought also** had an unexpected sign, challenging the assumption that drought prone areas area necessarily poorer.

Environmental degradation, as measured by the World Wildlife Fund's 'Human Footprint' score significantly explained wealth and child mortality. An increase in environmental damage was associated with an increase in child mortality and a decrease in wealth. Burkina Faso faces extensive risk of desertification (Leenders, *et al.* 2004), particularly in the dry north eastern regions. Vegetation prevents erosion and water loss and scattered tree cover is thought to improve agricultural productivity in this region. However, Rasmussen *et al.* (2001) argues that land degradation in this area, although severe, is variable and reversible.

Education is a fourth variable that is significant in more than one model. Extra schooling is associated with increases in wealth and a reduction in child morbidity, however is associated with an increase in child mortality. This contrary result is derived from a very weak model, as previously explained, and we do not draw conclusions from this finding.

Table 23: Variables explaining wealth, morbidity and mortality in East Burkina Faso region.

	Wealth Index		**Child Height for Age Ratio (s.d)**		**Child Mortality Rate (prport^n)**	
(Constant)	-0.05808		-1.99870	***	0.16177	**
Population density (people/km^2)	-0.00043		0.00049		-	
Population (people)	-		7.70E-07		-2.90E-07	
Telephones (proportion)	-		-0.67647		-	
Electricity (proportion)	-		-		-	
NPP (produced) (tonnes/0.25° cell)	-		-		-	
Access ('00 km)	0.00503		0.09982		-	
Education (years)	0.26254	***	0.40189	***	0.05140	***
Forest Cover (proportion)	-0.25285	***	-		-	
Cattle density (units/km2)	-		-		0.00125	
Chicken density (units/km2)	-		-0.00209	**	-	
Sheep density (units/km2)	-0.00038		-0.00123		-0.00008	
Goat density (units/km2)	-0.00067		-		-0.00034	
pig density (units/km2)	-0.00119		-0.09706		-	
Unprotected water (proportion)	-0.48590	***	-1.15100	***	-0.01365	
Water Access (minutes)	0.00351	*	0.03837	***	-0.00126	
Dams ('00 km)	-0.13353	**	0.15614		-0.00242	
Irrigation (percent)	-		-		-0.00500	
Precipitation (mm/yr)	-		-		-	
TARWR (m3/yr/km2/person)	0.13582		-0.65692	***	0.00108	
Drought Economic Risk (decile)	0.00976	***	0.04691	***	-	
Human footprint (1-100 index)	-0.01362	***	-		0.00463	**
Malaria prevalence (parasite ratio)	-		-1.83810	***	-	
Moran's I for residuals	**0.006**		**0.123**		**-0.046**	
Akaike information criterion	**-86.00**		**0.67**		**-99.85**	
Aprox. pseudo R^2	**0.82**		**0.75**		**0.27**	
Spatial weights matrix	**3 nearest neighbors**		**1 nearest neighbor**		**3 nearest neighbors**	
Sample size	**32**		**34**		**26**	

* = statistically significant at 90%, ** = 95%, ***=99%. Note that a positive child morbidity coefficient means increasing height for age ratios and thus an improvement in health.

East Nigeria and North Cameroon

This region is classified as a poverty hotspot due to its low wealth index scores. Because the wealth index is constrained by national borders, it is possible that similarly poor or poorer areas may exist elsewhere in the basin without being detected when classification is based on this index alone. Thus the evidence that this region faces highly elevated poverty levels is weaker than for the other areas identified, although this does not detract from the strength of findings within the poverty hotspot itself. Although our morbidity and mortality assessment did not identify spatial correlation here, the elevated morbidity (defined by fever, cough and diarrhea) results found by Kandala *et al.* (2007) supports our treatment of this region as relatively impoverished.

Table 24: Summary of health, education and water statistics for the East Nigeria and north Cameroon hotspot.

	Mean	**Standard deviation**
Population (in total, millions)	9.23	-
Child (<5 yrs) mortality (%)	15.86	4.35
Average education (years)	2.98	1.62
Average TARWR (m^3/yr/km^2/person)	0.52	1.34

The relationship between water and poverty remains ambiguous in this hotspot with only some variables exhibiting consistent significance across models. The area of **irrigation** has a significant correlation with all three measures of poverty: as the area irrigated increases poverty decreases in this hotspot. Proximity to **large dams** also shows concurring significance. Districts closer to a large dam have reduced rates of child mortality and improved relative wealth. There are five major dams within or very close to this hotspot and are clustered towards the north. It is unknown whether dams are acting as proxy for other spatial effects or omitted variables. The **risk of drought** as measured by proportional economic loss is significant in two variables, with an increase in risk associated with higher levels of poverty. Although the unprotected water variable is significant across models its sign is not consistent with expectations in the case of child height for age ratio.

Areas of higher **population density** are associated with both higher child mortality rates and decreased wealth, a result not shared with other poverty hotspots in the basin. **Education** is associated with reduced poverty in the wealth and mortality models, and a 1 year increase in average education levels is associated with a 0.7% decrease in child mortality. There is also evidence of a detrimental impact of **Malaria** found in two models. **Environmental degradation**, as measured by the World Wildlife Find’s Human Footprint is associated with increased poverty.

Table 25: Variables explaining wealth, morbidity and mortality in Eastern Nigeria and Northern Cameroon region.

	Wealth Index		Child Height for Age Ratio (s.d)		Child Mortality Rate (prport^{n})	
(Constant)	-0.30827		-0.36913		0.02545	
Population density (people/km^2)	-0.00087	**	0.00161		0.00036	***
Population (people)	9.51E-10		-5.13E-07		9.41E-08	***
Telephones (proportion)	-		-2.00990		-0.36940	***
Electricity (proportion)	-		1.26050	***	0.04260	
NPP (produced) (tonnes/0.25° cell)	-		-		-	
Access ('00 km)	0.32076		-1.04930		0.12151	*
Education (years)	0.10320	***	0.01285		-0.00783	**
Forest Cover (proportion)	0.29402	***	-0.88656	***	0.05192	***
Cattle density (units/km2)	-0.00151		-0.00071		-0.00033	*
Chicken density (units/km2)	-		-		-	
Sheep density (units/km2)	0.00153		-0.00111		0.00038	**
Goat density (units/km2)	0.00716	***	-0.00789	***	0.00004	
pig density (units/km2)	-0.00907	***	0.01451	**	0.00066	
Unprotected water (proportion)	-0.39451	***	0.74399	***	0.16039	***
Water Access (minutes)	0.00084		0.00041		-0.00081	*
Dams ('00 km)	-0.10469	**	0.03650		0.05802	***
Irrigation (percent)	0.13607	*	0.34413	**	-0.02724	**
Precipitation (mm/yr)	-		-		-0.00016	***
TARWR (m3/yr/km2/person)	0.00034		0.02257		0.00740	***
Drought Economic Risk (decile)	-0.03295	***	0.01628		0.00447	***
Human footprint (1-100 index)	-0.01045	*	-0.02530	*	-0.00066	
Malaria prevalence (parasite ratio)	-0.03309		-0.97926	***	0.14551	***
Moran's I for residuals	**-0.147**		**-0.091**		**0.036**	
Akaike information criterion	**-45.76**		**19.17**		**-179.18**	
Aprox. Pseudo adj. R^2	**0.58**		**0.59**		**0.69**	
Spatial weights matrix	**2 nearest neighbors**		**1 nearest neighbor**		**1 nearest neighbor**	
Sample size	**38**		**38**		**38**	

* = statistically significant at 90%, ** = 95%, ***=99%. Note that a positive child morbidity coefficient means increasing height for age ratios and thus an improvement in health.

Central and South Nigeria

This region has above average wealth and below average mortality and morbidity and has been assessed here as a counterpoint to the poverty hotspots analyzed above. The purpose of this is to determine whether the variables identified as significant in areas of high poverty also apply in relatively wealthy areas.

Table 26: Summary of health, education and water statistics for central and south Nigeria hotspot.

	Mean	**Standard deviation**
Population (in total, millions)	17.20	-
Child (<5 yrs) mortality (%)	9.12	3.51
Average education (years)	7.47	2.65
Average TARWR (m^3/yr/km^2/person)	22.08	127.38

Poverty is generally lower in the south and central agro-climatic zones of Nigeria than in the north. The north has poorer infrastructure, fewer health and education services and less exposure to economic development due to its geographic isolation (Canagarajah and Thomas, 2001). Whilst the incidence of poverty decreased throughout the 1990s in the south, conditions in the north deteriorated, especially in rural areas (Aigbokhan, 2000). Whilst the north has a fragile agro-climatic environment, the southern region has much of the country's industry and export crops and the central region is more amenable to agriculture (the country's 'bread-basket'). Household expenditure has diverged between these regions during the 1980s and 90s (Canagarajah and Thomas, 2001).

The poverty status of the Niger Delta, partially included in the far south of this 'wealth hotspot', is more ambiguous. Ikelegbe (2001) describes this locality as one of the poorest and least developed in Nigeria, despite its oil wealth. Violent conflict and environmental degradation have contributed to reduced living standards (Zalik, 2004; Ikelegbe, 2006).

The wealth hotspot identification undertaken here confers with geographic zones discussed in the literature, although the partial inclusion of the Niger delta in the wealth index and morbidity layers may be inappropriate. All three models are significant and have moderate explanatory power (pseudo adj. R^2 0.62 – 0.70).

The proportion of people using **unprotected water** is correlated positively with child mortality and negatively with wealth. A 1% decrease in the use of unprotected well or surface water is associated with an 0.025% decrease in child mortality incidence. The measure of total available water, **TARWR,** was negatively correlated to wealth and age-for-height ratios, contrary to expectation. Areas of higher endowment were found to have higher poverty, all else being equal. Again this suggests that the link between water poverty and total water quantity is ambiguous. The **irrigation** variable is insignificant. Improved **access to water** is associated with wealth, but counter-intuitively, also with increased child mortality.

A number of other variables were significant, although only supported by one model (and hence considered a less reliable finding). The proportion of households with access to **electricity** is associated with a decrease in child mortality. **Access** to towns is significant in the wealth model, with districts further from large population centers more likely to be poor. In contrast to the other regional analyses **education** is only significant in the wealth model, and has a relatively lower coefficient. An increase in **environmental degradation,** as measured by the World Wildlife Fund's 'Human Footprint' index is correlated with reduced wealth levels.

Table 27: Variables explaining wealth, morbidity and mortality in Southern Nigeria region.

	Wealth Index		**Child Height for Age Ratio (s.d)**		**Child Mortality Rate (prport^n)**	
(Constant)	1.61730	***	-0.79216	**	0.04390	*
Population density (people/km^2)	-0.00006		0.00017	***	0.00000	
Population (people)	2.63E-07		-4.13E-07		2.00E-08	
Telephones (proportion)	-		0.66850	**	-0.03415	
Electricity (proportion)	-		0.07477		-0.02822	***
NPP (produced) (tonnes/0.25° cell)	-3.33E-13		4.11E-13		3.15E-14	
Access ('00 km)	-0.59663	**	-0.26894		0.00871	
Education (years)	0.02018	*	-0.00087		-0.00118	
Forest Cover (proportion)	-0.27336	***	0.14862		-0.00287	
Cattle density (units/km2)	-0.00120		0.00391		-0.00026	
Chicken density (units/km2)	0.00000		-0.00013		0.00001	
Sheep density (units/km2)	0.00049		-0.00213	***	-0.00001	
Goat density (units/km2)	-0.00034		0.00044		-0.00002	
pig density (units/km2)	0.01003	***	-0.00469		0.00026	
Unprotected water (proportion)	-1.21030	***	-0.07716		0.02558	**
Water Access (minutes)	-0.00347	*	0.00194		-0.00056	***
Dams ('00 km)	-		0.02474		-	
Irrigation (percent)	0.04604		-		-0.00035	
Precipitation (mm/yr)	-		-		-	
TARWR (m3/yr/km2/person)	-0.00035	**	-0.00034	*	-0.00001	
Drought Economic Risk (decile)	-		-		0.00074	
Human footprint (1-100 index)	-0.01340	**	0.00349		-0.00028	
Malaria prevalence (parasite ratio)	-		0.10356		0.02622	
Moran's I for residuals	**0.025**		**-0.007**		**0.081**	
Akaike information criterion	**-28.17**		**8.87**		**-563.97**	
Aprox. Pseudo adj. R^2	**0.65**		**0.62**		**0.70**	
Spatial weights matrix	**3 nearest neighbors**		**3 nearest neighbors**		**2 nearest neighbors**	
Sample size	**77**		**82**		**115**	

* = statistically significant at 90%, ** = 95%, ***=99%. Note that a positive child morbidity coefficient means increasing height for age ratios and thus an improvement in health.

4.7.2. The causes of poverty – a summary

Poverty Hotspot	Measure of poverty	Water poverty variables	Non-water poverty variables	Utility of the TARWR variable
North West Nigeria	Identified using all three metrics. Wealth index model strongest (pseudo R^2 = 0.96)	Water access Unprotected water Irrigation TARWR	Education Livestock	Moderate – child mortality only
Central Mali and the Inner Delta	Identified only in child mortality. Wealth index model strongest (pseudo R^2 = 0.82)	Unprotected water	Education Livestock	Limited – not significant
East Burkina Faso	Identified using all three metrics. Child morbidity model strongest (pseudo R^2 = 0.79). Consistency of results weak.	Unprotected water Dams	Education Environ. damage	Limited – child morbidity only, contrary signs
East Nigeria and North Cameroon	Identified only in wealth index. Child mortality model strongest (pseudo R^2 = 0.65)	Irrigation Dams	Education Population density Malaria Drought risk Environ. damage	Limited – child mortality only, contrary signs
South and Central Nigeria *('wealth hotspot')*	Identified using all three metrics. Wealth index model strongest (pseudo R^2 = 0.63)	Unprotected water	Access to towns Education Electricity Telephones	Limited – contrary signs, small effect

Changes in water quantity, as measured by TARWR, only partially predicts poverty variance in the Niger Basin. In only two of the hotspots (North West Nigeria and East Burkina Faso) was TARWR correlated significantly with poverty with the expected sign (negative). In North West Nigeria it was correlated only with the mortality metric, and in East Burkina Faso it was correlated only with morbidity. Water quality, however, was more commonly associated with these measures of poverty. At most poverty hotspots there were significant correlations between the proportion of people drinking from unprotected water sources and the incidence of poverty. This direct relationship is to be expected for the child health poverty measures: water borne diseases are one of the leading causes of death and are associated with poor development status (UNDP, 2006). However, it was expected that TARWR would be a significant factor of a region's overall wealth, given that water quantity represents an important environmental limit on the type and extent of agricultural development. This hypothesis receives weak support only. These results also highlight the need for improved water accounting at a higher spatial resolution: the TARWR measurement applied at the scale of administrative districts and poverty hot spots (the scale of targeted decision making) in the Niger basin does not reliably estimate poverty levels.

The area of irrigated land was associated with decreases in poverty in only two cases, north west Nigeria (by one poverty metric) and in Eastern Nigeria and Northern Cameroon (by two metrics).

This suggests either that irrigation's contribution to rural welfare is low in the Niger Basin, or that the levels of irrigation are too small at present to cause substantial, discernable improvements in livelihoods at this scale of analysis. Given that the present population of West Africa can scarcely be supported by rain fed agriculture in its current low-input form, ICID (2002) highlight irrigation development as a critical aspect for improved economic wellbeing of the basin population, along with improvements in the productivity of rain-fed agriculture (Castillo et al. 2007, Rockstrom et al. 2007). However, it may be that the benefits of irrigation do not yet accrue to the people engaged in its practice, or that they do so at levels too small to register in these statistics. It should be noted also that to a partial extent, livestock may represent a proxy variable for water availability. Different livestock are suited to different agro-climatic conditions, with goats more tolerant of water and feed scarcity than sheep, which are in turn more tolerant than cattle (Silanikove, 2000).

5. VULNERABILITY AS AN INTEGRATED PROBLEM

The analyses of poverty in the preceding sections of this report used three complementary metrics of poverty (child mortality, child morbidity and wealth). The analysis estimated in quantifiable terms the effect of a range of environmental and social determinants on each metric. Such disaggregation enabled evidence based conclusions to be drawn regarding the statistical significance and magnitude of contributors to explain the variance of poverty in different geographic locations in the Niger basin. However, vulnerability is a multifaceted problem, and some aggregation of causal factors is necessary to identify those areas most severely affected by their water limitations. The following section presents child mortality as a function of two vectors, based on the conceptual model of poverty presented in section 4.2. In doing so we identify areas where the various forms of water limitation (quantity, quality, access, infrastructure) are contributing to the state of poverty generally.

The geographically weighted regression (GWR) results from section 0 were combined to reconstruct the component of poverty (measured by child mortality or child morbidity) resulting from either community vulnerability or situational vulnerability. The original conceptual model presented in section 4.2 featured three components; however, the lack of significant variables in the third vector (hazard threat) has led to its exclusion here. Community vulnerability encompasses the capabilities, assets and activities of the community. Situational vulnerability is how well these assets, capabilities and activities can withstand exposure to shock and stress. As this study focuses on water poverty in particular, situational vulnerability is represented here by the water variables (Table 28).

Table 28: variables included in each vulnerability vector

Community Vulnerability	Situational Vulnerability
Cattle	TARWR
Sheep	Irrigation intensity
Chickens	Distance to dam
Goats	Water access
Pigs	Unprotected water
Distance to administrative centre	
Education	

The final GWR comprised of 13 variables, producing spatially explicit predictive models with R^2 values between 0.6 and 0.99 for both child mortality and child morbidity. A number of other variables (many of which formed the hazard threat vector) were excluded due to multicollinearity. The GWR results demonstrated that the magnitude of variable effect is spatially dependent and as a corollary, we can conclude that landscape heterogeneity matters. Hence, use of the GWR results (as opposed to a globally homogenous model, such as that in section 4.6) provides high resolution spatially referenced information, allowing more targeted policy development and implementation.

Even with only this constrained vector of variables included, the model's predictions of poverty closely match our original estimation (see Figure 22).

For each of the two dependent variables, we present vectors of vulnerability consisting firstly of all relevant variables. Secondly, we present vectors that are comprised only of those variables that are statistically significant for a particular locale. The first approach potentially includes confounding components; however as the coefficient estimates of locally non-significant variables tend to be small, any distortion is is likely to be minimal.

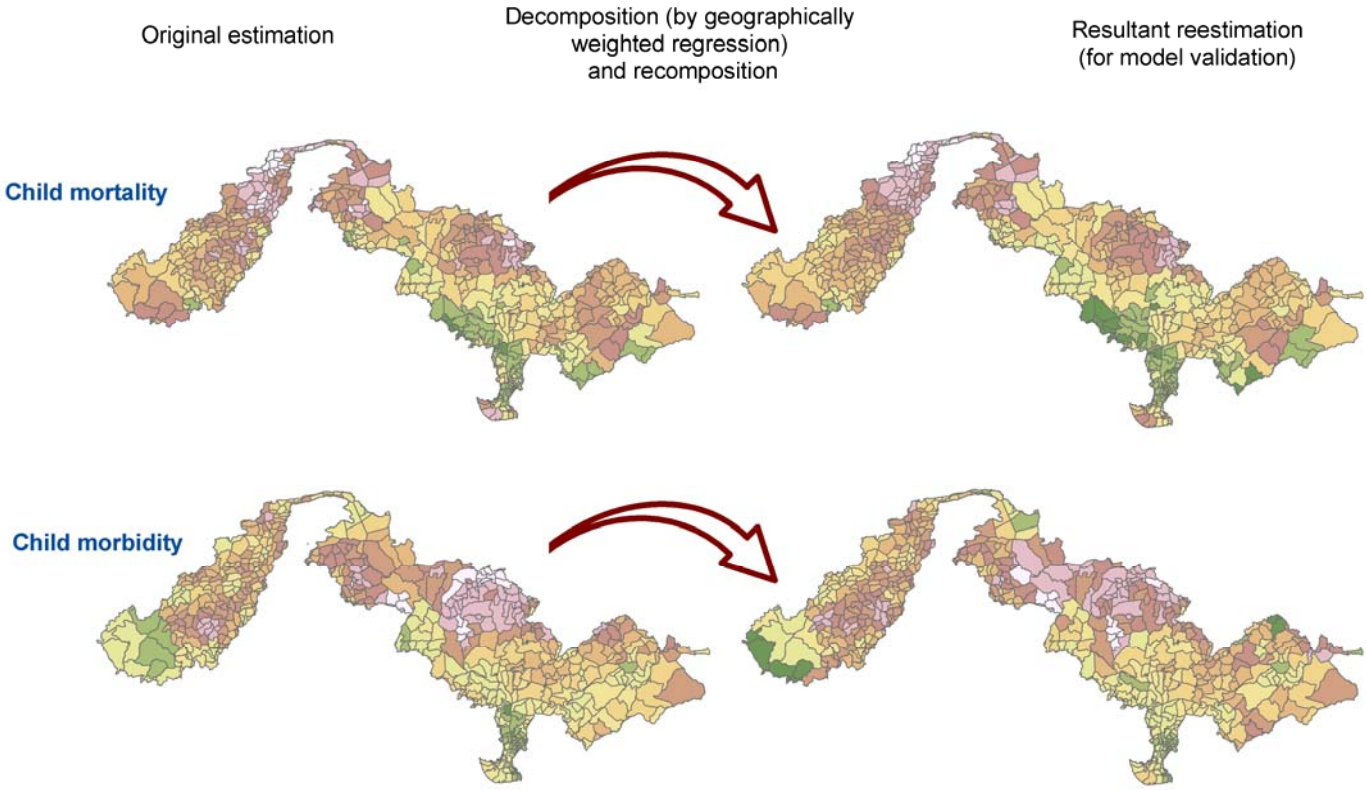


Figure 22: comparison of original estimation of dependent variables (based on Measure DHS (2008) data) with reconstituted geographically weighted regression results.

Figure 23 through Figure 26 indicate the spatial differentiation throughout the Niger basin of water vulnerability and community vulnerability. Consistent with our original hypothesis, these two vectors of vulnerability map differently across the Niger Basin. Furthermore, the difference is preserved between dependent variables, with both the child mortality and child morbidity based maps showing close correlation. As a general principle throughout this report, we consider most reliable only those areas for which there is concordance between metrics. Community vulnerability clusters in a band centered in the south west Niger and extending over the borders to parts of Mali (towards Gao) and Burkina Faso. Parts of North West Nigeria and south Mali are also highlighted.

Situational (water) vulnerability is most evident in the large poverty hotspot of North West Nigeria, although there is some correlation in north Cameroon. Of note, this only partially correlates with community vulnerability. The Inner delta in Mali is only highlighted using the mortality metric. Due to less comprehensive dataset for Guinea we are not confident of vulnerability predictions regarding this area.

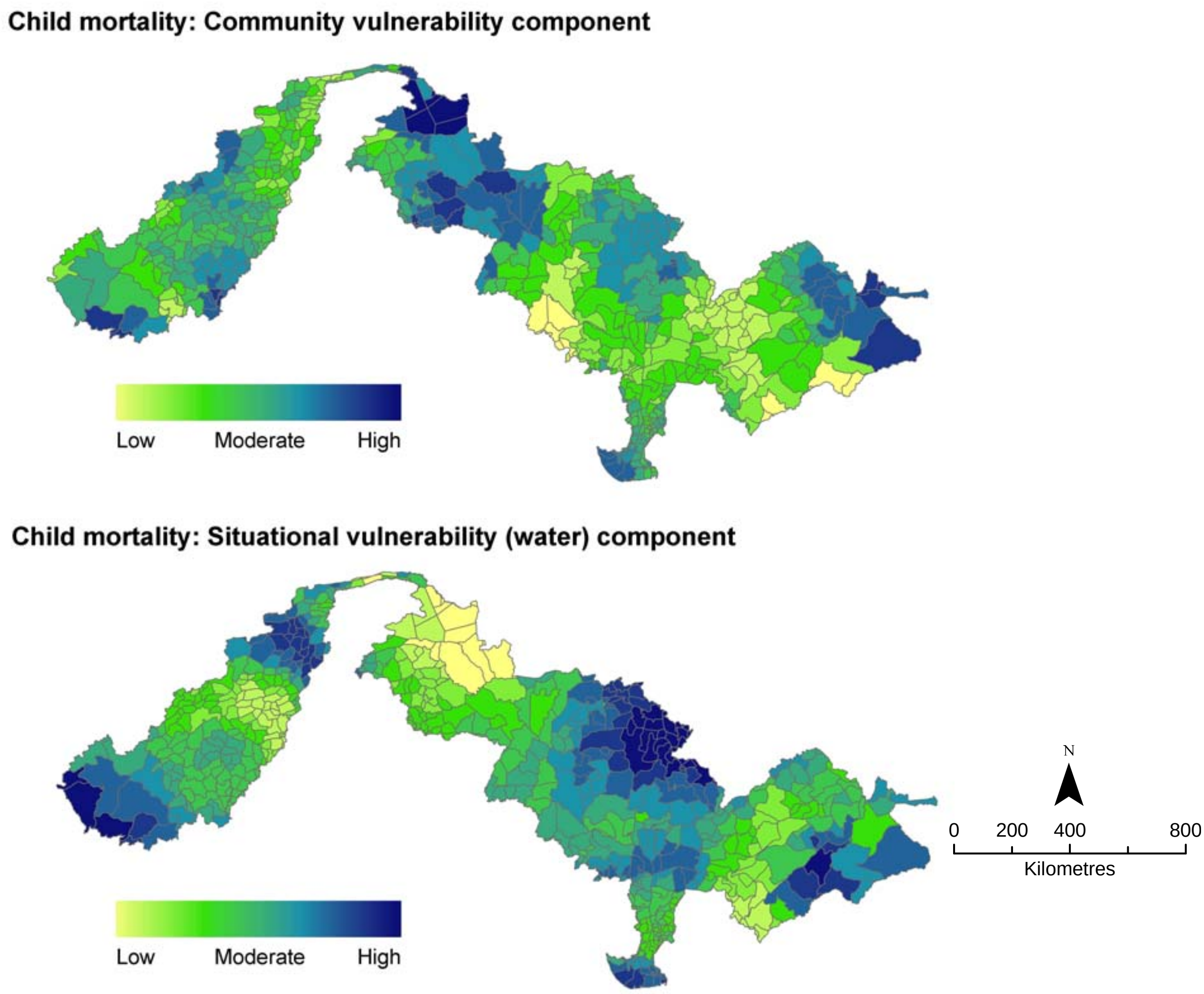


Figure 23: Community vulnerability and situational (water) vulnerability estimated across the active Niger Basin, based on the child mortality metric. All variables are included at all locales.

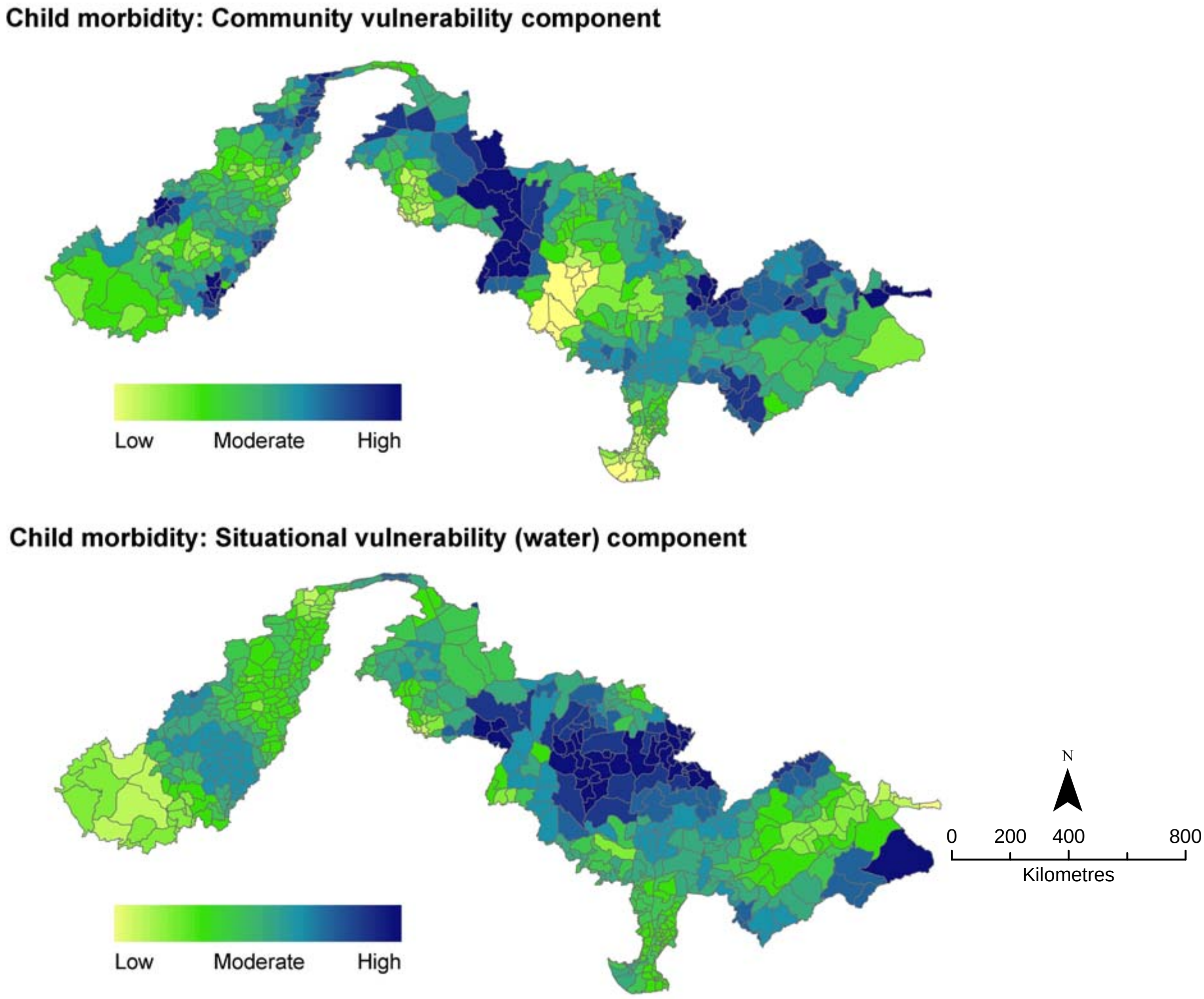


Figure 24: Community vulnerability and situational (water) vulnerability estimated across the active Niger Basin, based on the child morbidity (stunting) metric. All variables are included at all locales.

The models comprised only from locally significant variables show less distinct patterns, as expected given the mosaic 'patchwork quilt' nature of their construction. Community vulnerability in particular is difficult to interpret meaningfully and reconcile with the results from the more complete models in Figure 23 and Figure 24. However, situational (water) vulnerability appears strongly in the north west of Nigeria.

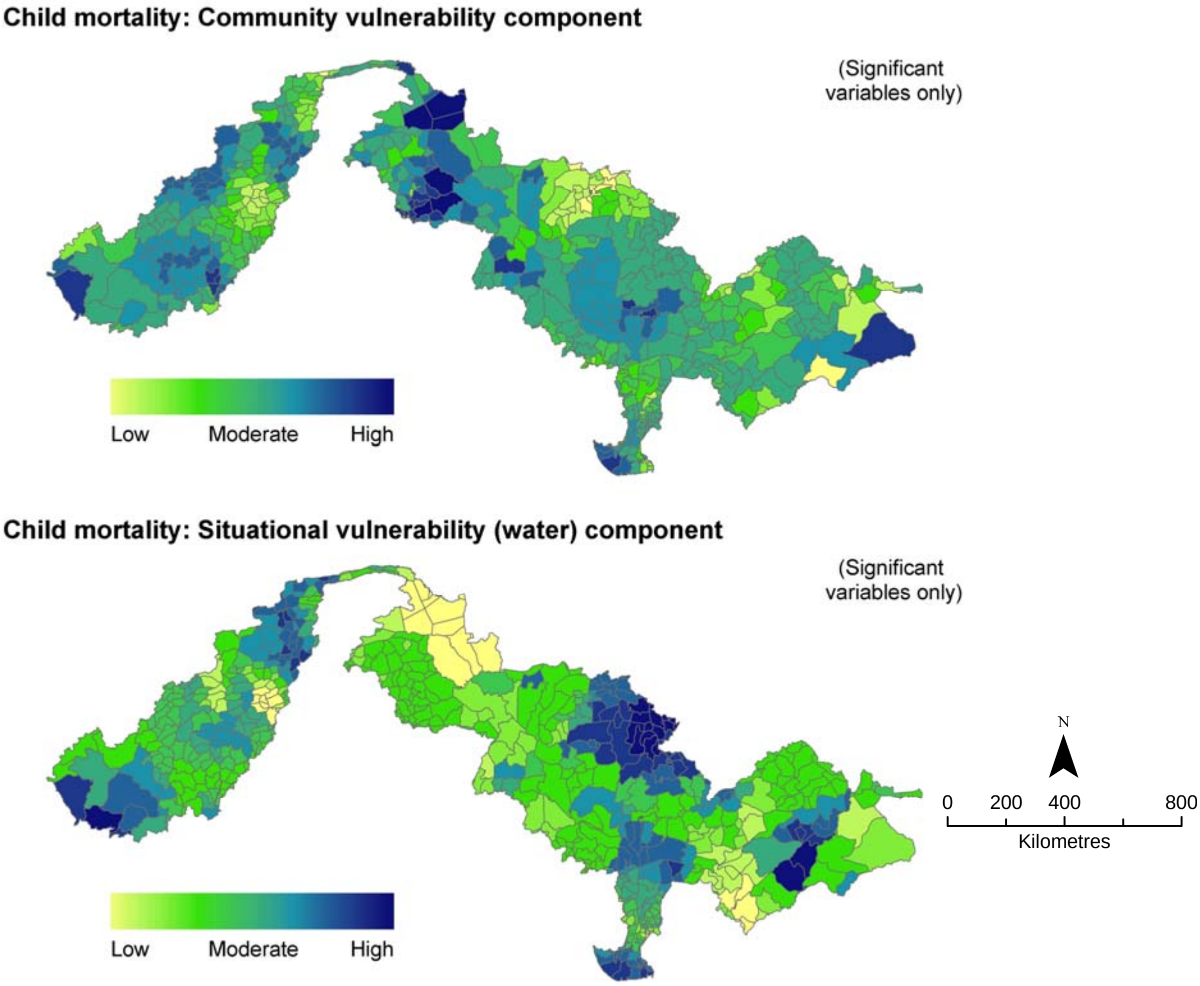


Figure 25: Community vulnerability and situational (water) vulnerability estimated across the active Niger Basin, based on the child mortality metric. For each locale, only locally significant variables were included.

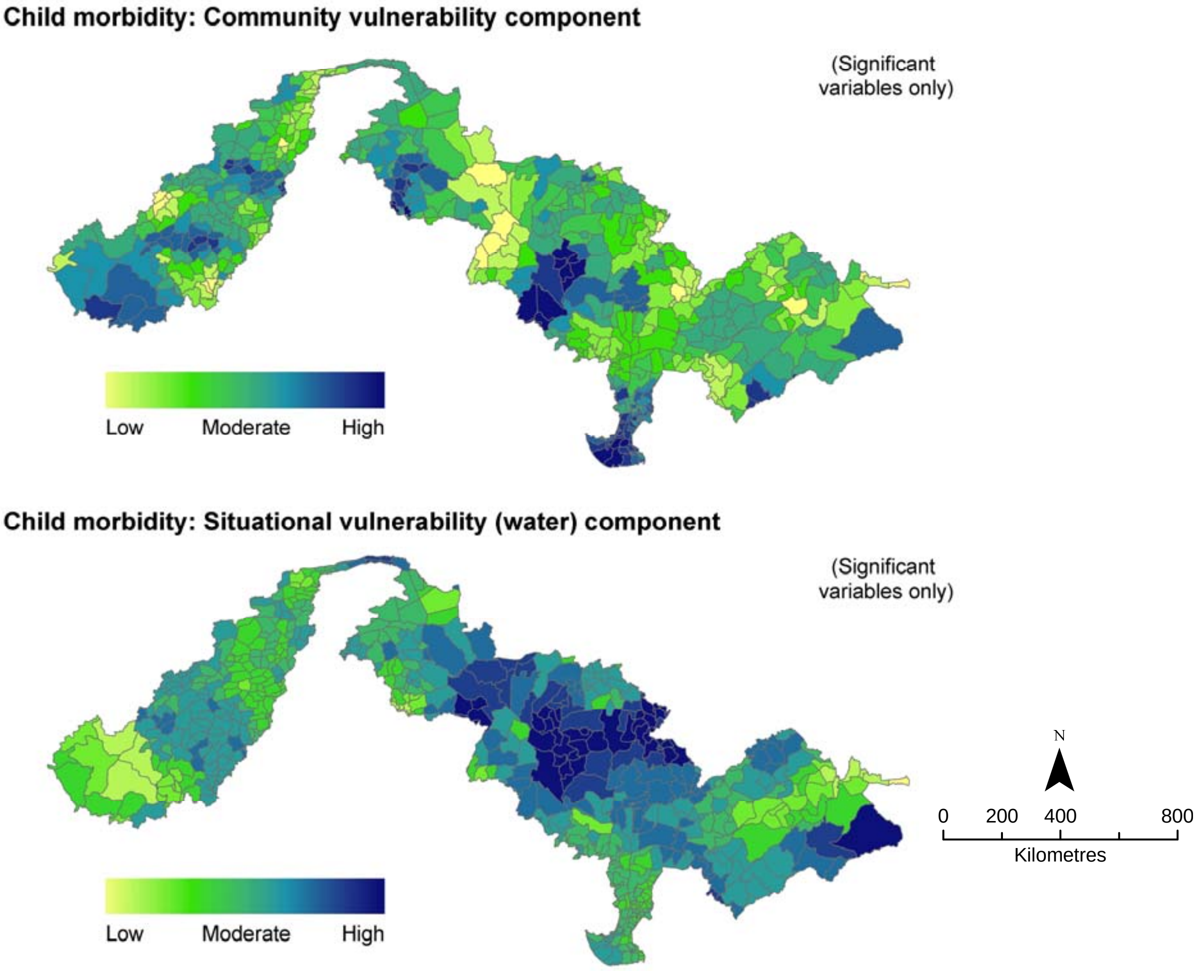


Figure 26: Community vulnerability and situational (water) vulnerability estimated across the active Niger Basin, based on the child morbidity (stunting) metric. For each locale, only locally significant variables were included.

The purpose of re-aggregation into a bi-vector representation of vulnerability is to provide an evidence based, comprehensive and interpretable representation of the water vulnerability situation. As vulnerability is a multi-dimensional, synthetic construct, collating the identified components with statistically estimated weighting coefficients is necessary for integrated and improved understanding. However, for assessing the potential impacts of different policy effects, a more tangible output is required. In Figure 27 to Figure 30, we remodel the original dependent variables, child mortality and child morbidity (stunting) and adjust particular independent variables to predict the likely effects of such a change. The models are constructed from the GWR results, meaning that the impact of an independent variable change (for instance from a particular policy approach) will manifest differently in different parts of the basin.

We consider eight policy hypotheticals: an increase in average education (by two years and by four years, see Figure 27), a decrease in the use of surface and unprotected well water (by 10% and by 20%, see Figure 28), an increase in irrigation intensity (by 10% and by 20%, see Figure 29) and a decrease in the distance to a dam (by 10% and by 20%, see Figure 30). The color scheme used to represent changes in the poverty variables are standard across all four figures, allowing for visual comparison of the different strategies.

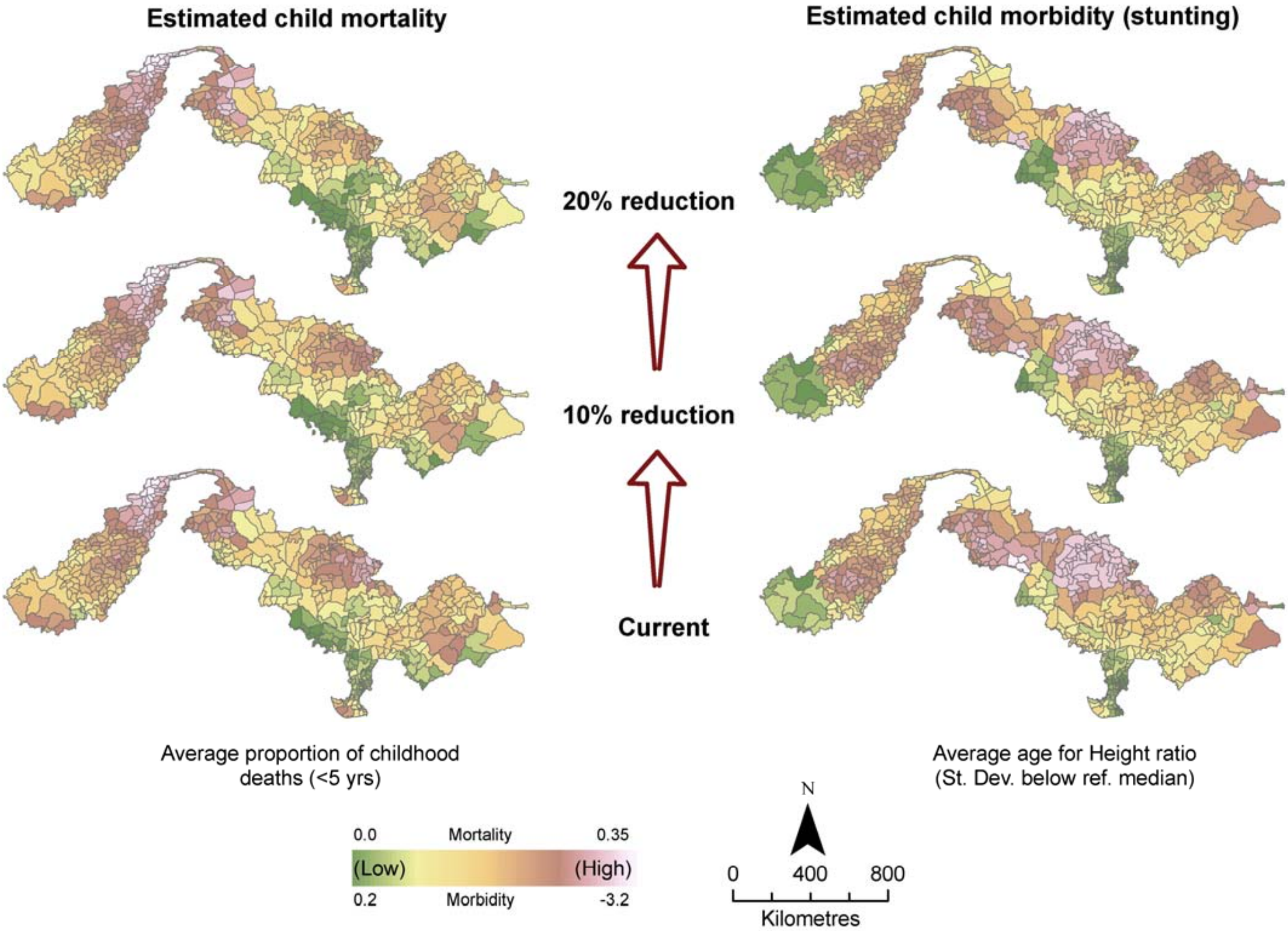


Figure 27: Predicted effect on child mortality and child morbidity (stunting) levels due to a reduction in the proportion of people obtaining their primary water supply from surface water or unprotected well water, in the active Niger Basin.

A reduction in the proportion of people using surface water or unprotected well water represents a likely improvement in the quality of water used. Our model suggests that this approach could substantially alleviate child mortality in north west and central Nigeria, although other areas are affected only very slightly.

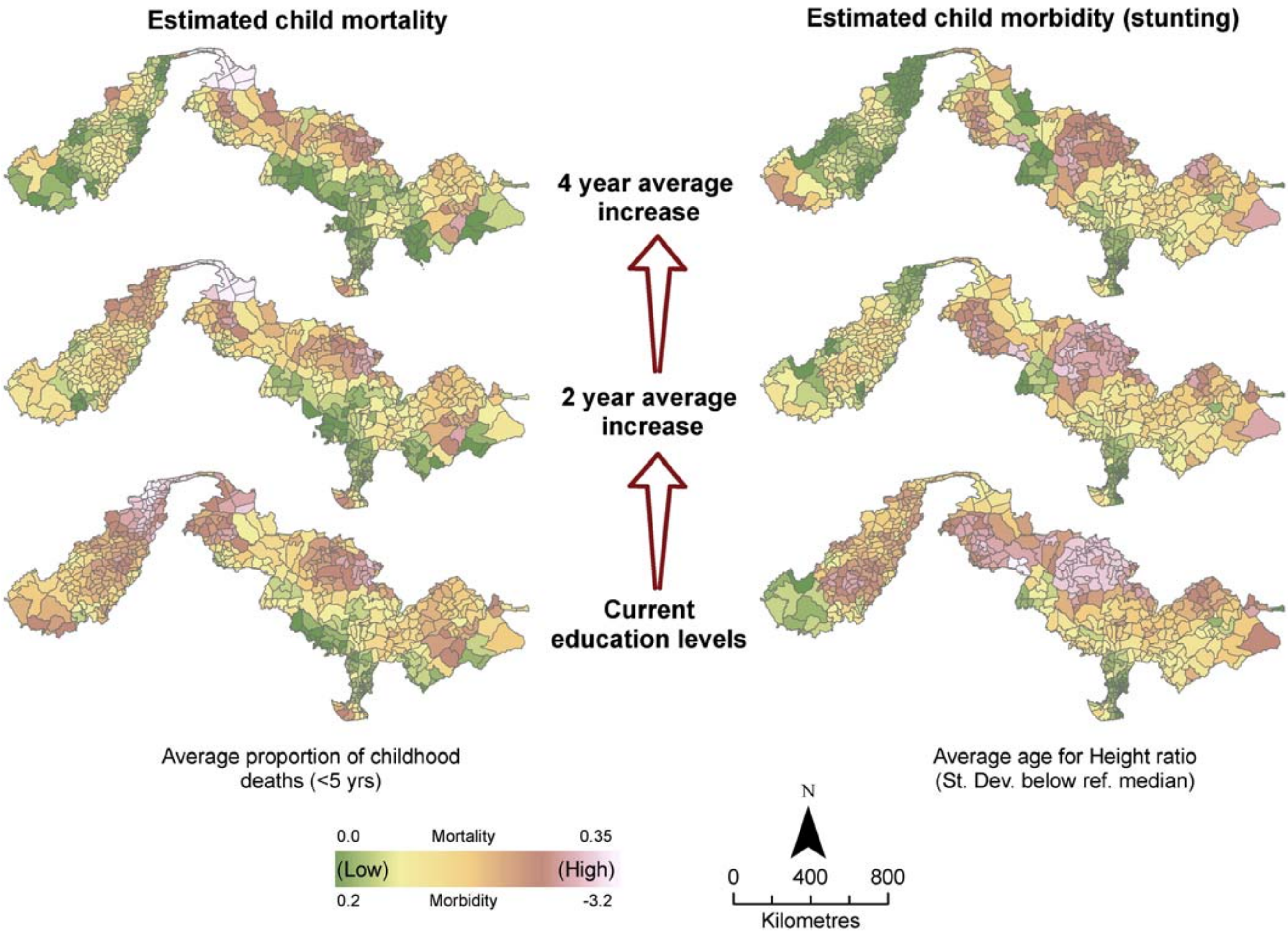


Figure 28: Predicted effect on child mortality and child morbidity (stunting) levels due to an increase in the average number of years of education, in the active Niger Basin.

Education appears to be the most universally effective means of reducing poverty, with improvements in health predicted for much of Mali, North West Nigeria, east Burkina Faso and central Nigeria. In particular, the poverty hotspot around the Inner Niger Delta appears substantially alleviated by an additional 4 years in average education.

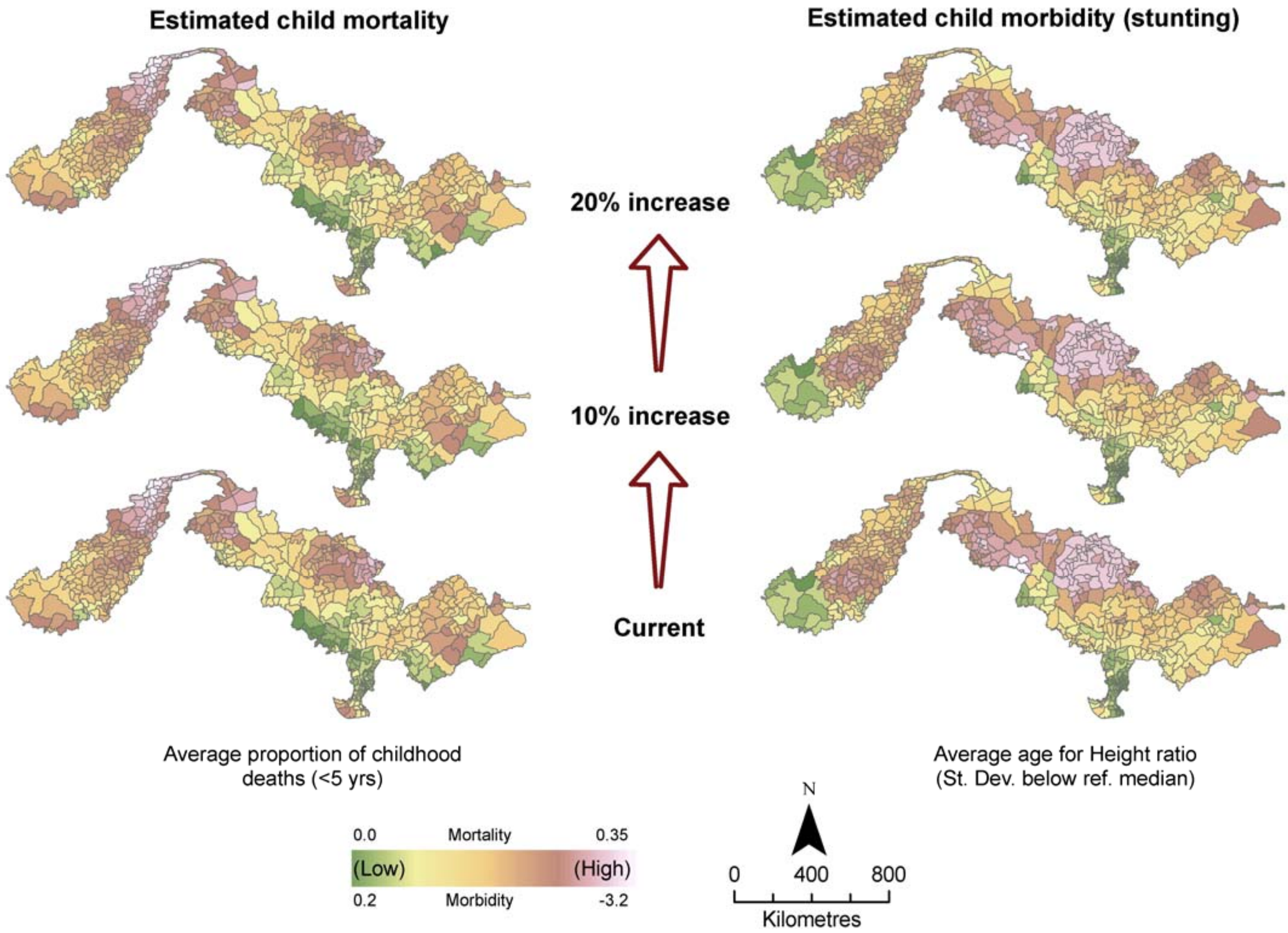


Figure 29: Predicted effect on child mortality and child morbidity (stunting) levels due to an increase in irrigation intensity in the active Niger Basin.

Figure 29 and Figure 30 show the predicted impacts from an increase in irrigation intensity and a decrease in the average distance to a dam respectively. Neither approach led to a prediction of substantial reductions in child mortality and child morbidity (stunting).

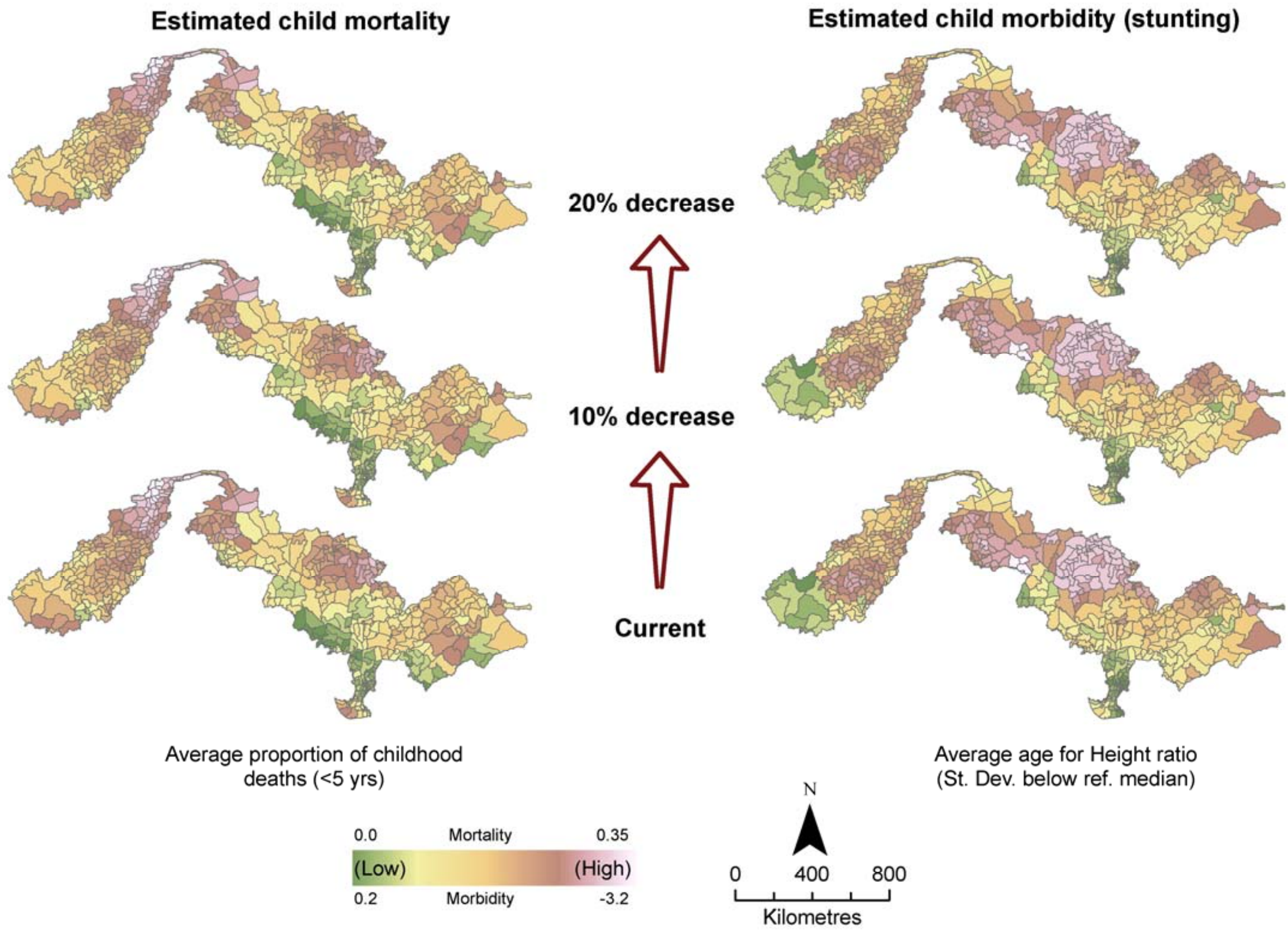


Figure 30: Predicted effect on child mortality and child morbidity (stunting) levels due to a decrease in the distance to a dam in the active Niger Basin (i.e. an increase in the number of dams).

6. Differences in Poverty Along Ethnic Divisions

The Niger Basin is home to a large number of ethnic groups, leading to a diverse array of languages, cultures, and methods of social organization and production. In some instances this diversity is a product of centuries of harmonious and mutually beneficial cooperation, in others it leads to conflict, particularly as demand for resources increases. According to the Niger Basin Authority (2005) The Niger Basin attracts migrants because of its more favorable agro-ecological regions.

It is common for differences in wealth levels between different ethnic groups to become entrenched by commercial processes. Economic power is consolidated due to the actions of social networks, sometimes causing a self perpetuating maintenance of inequality (Fafchamps, 1999). Sharing the same ethnicity and religion may facilitate trust in economic relationships, or its reciprocal, prejudice in jobs, trade and business against those who are different. Countries with high ethnic diversity often must manage difficult relationships between groups, and their failure to achieve this can impede the policy making process. Suberu, (2001) argues that *"Fractured countries have no faith in the nation building project"*. West Africans tend to socially define themselves along ethnic lines. For instance, after nationality, 40% of Mailans and 48% of Nigerians define themselves by their ethnic group, significantly more than the number who define themselves religiously (23% in Mali, for instance) (Bratton, Coulibaly and Machado, 2000). The same survey found that two thirds of Malians identified with their ethnic group first and their country second, despite the fact that Mali has made considerable progress in establishing a functional democracy and associated sense of nationhood. This figure may be much higher in less harmonious Basin countries such as Nigeria and Cote d'Ivoire.

There are considered to be hundreds of different ethnic groups in the Niger Basin, of which the Hausa, Mande, Fulani and Igbo are some of the largest (Suburu 2001). Hausa (Kanuri) is one of the major languages and ethnic groups of the region. The language is spoken by an estimated 39 million people and is dominant in Northern Nigeria and Niger. The Mande number approximately 20 million across West Africa, an ethnic group which includes the Bambara people of Mali. The Fulani, or Peulh people are traditionally nomadic pastoralists although most now live in towns or villages. They form a sizeable minority in many West African countries with a total population estimated to be between 10 and 13 million. The Igbo are one of the three large ethnic identities in Nigeria, where they are found in the South. This mainly Christian group has a population of approximately 30 million (VanderSluis, 2007). Amongst these and the hundreds of smaller identities, boundaries are often fluid with different levels of social and economic cooperation, partnership and intermarriage (Suberu, 2001). Ethnic units tend not to be rigid or well defined.

The data presented below show the three poverty metrics (child mortality, child morbidity and the wealth index) for different ethnic groups in each country. The wealth index is shown in quintiles: ethnic groups with a highly uneven distribution across these quintiles are relatively rich or poor. Child mortality is indicated by the average age of death for deceased children of women surveyed; a lower average age of death indicates that child mortality is more prevalent (Figure 31). Child morbidity (stunting) is more severe when the average height for age ratio is lowest (Figure 32).

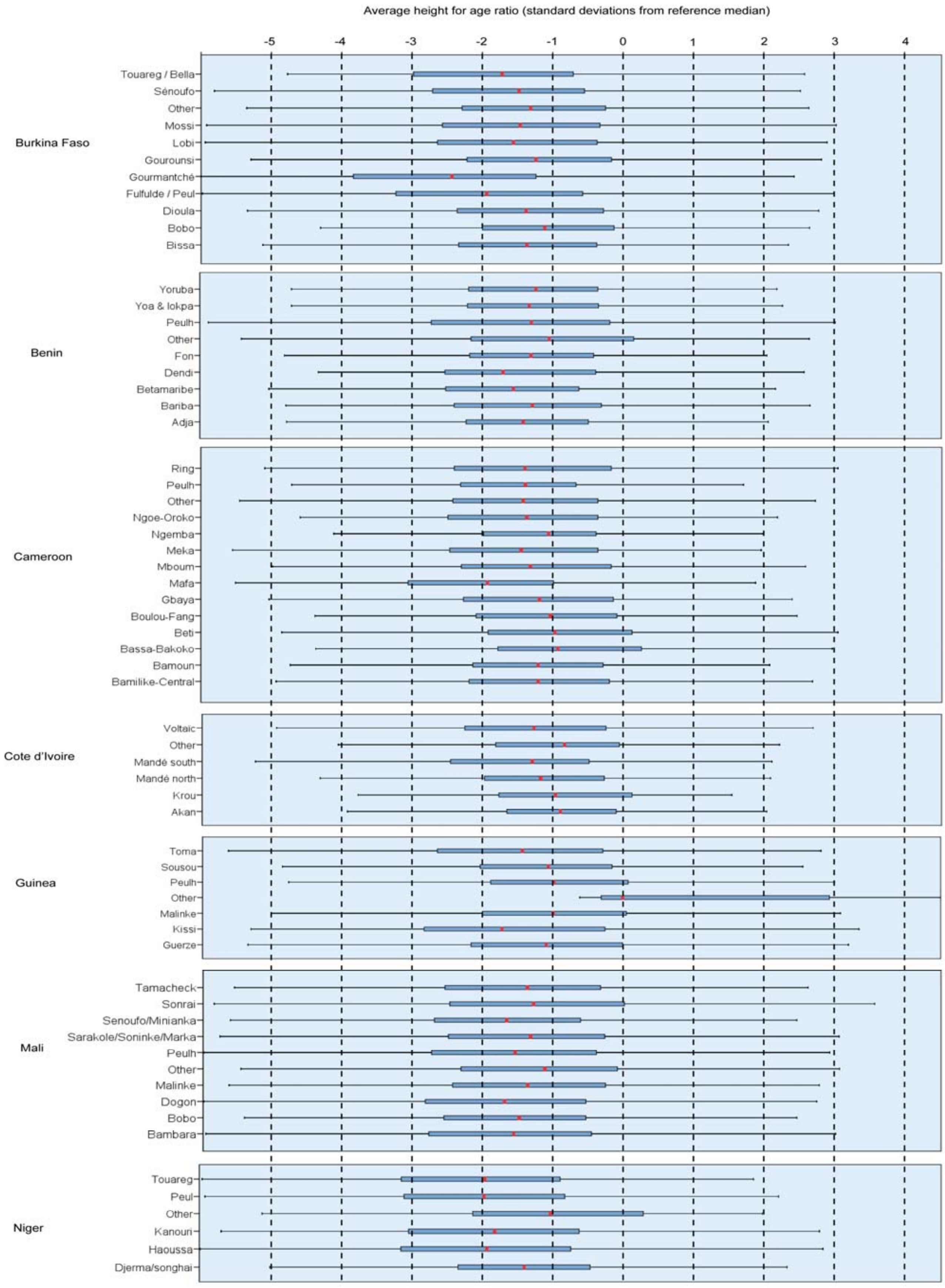


Figure 31: Child morbidity (height for age ratios by major ethnic groups in the Niger Basin countries. Box and whisker plots show minimum, 1st quartile, median (red), 3rd quartile and maximum.

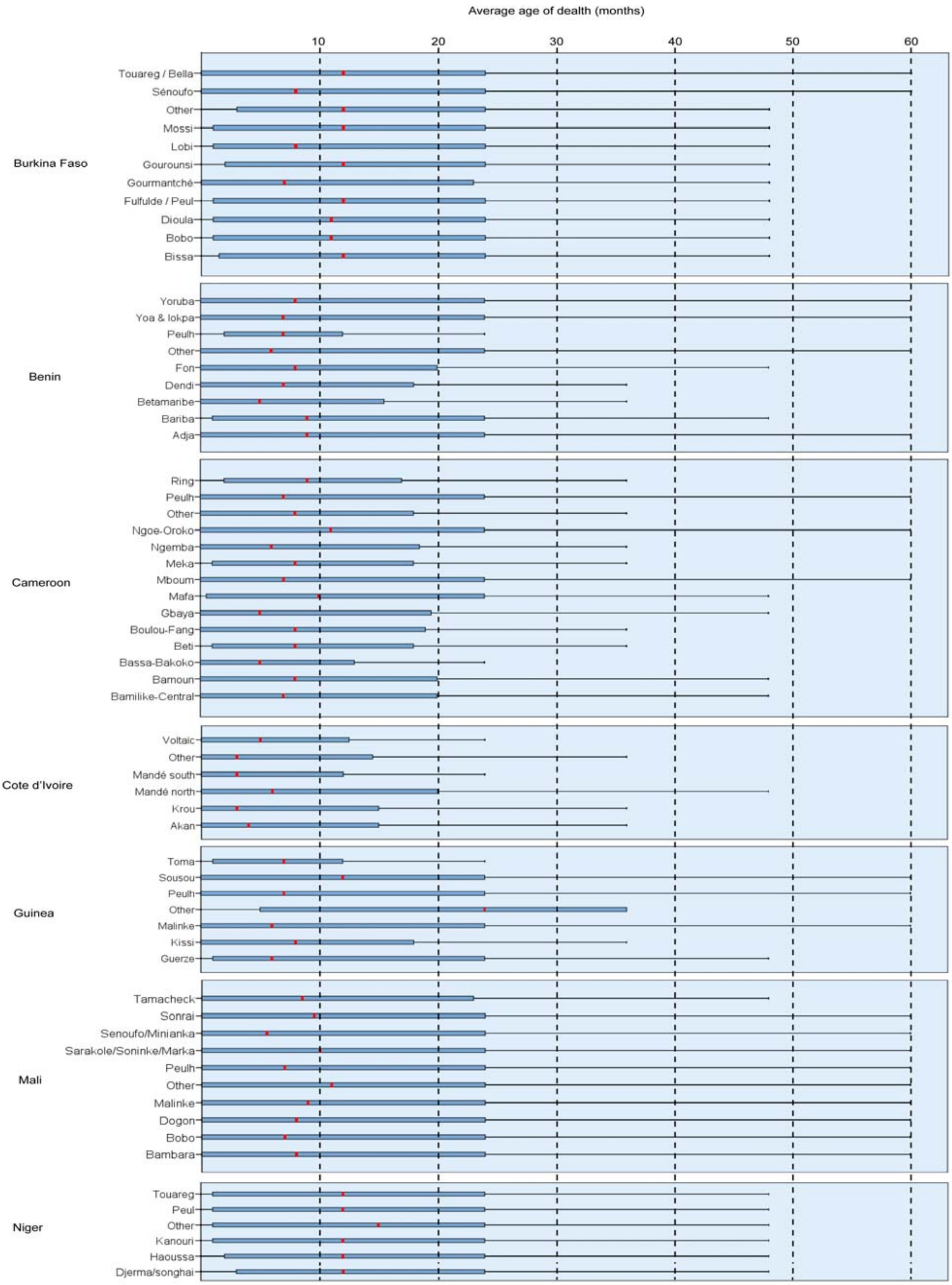


Figure 32: Child mortality across major ethnic groups in the Niger Basin countries. Calculated by averaging the age of death for children who died before 5 years. Box and whisker plots show minimum, 1st quartile, median (red), 3rd quartile and maximum.

6.1. Benin

Betamaribe, Peulh, Yoa and Lokpa people were identified as relatively disadvantaged. In the case of Betamaribe, over 60% are classified in the lowest wealth quintile. In the case of Peulh, 45% live below the lowest wealth quintile. Adja, Fon and Yoruba have a relatively flat wealth distribution, indicating lesser economic stress (see Figure 33). Figure 31 and Figure 12 show differences in child mortality and child morbidity (height for age ratios, or stunting) between the same ethnic groups. A Kruskal Wallis test indicated significant differences in the means between ethnic groups for child mortality but not for stunting (mortality: $\chi_{(8,3249)} = 15.57$, $p < 0.049$; stunting: $\chi_{(8,3725)} = 9.36$, $p < 0.313$). Betamaribe, the group identified as poorest in Figure 33, has a particularly young average age of death for those children who die before 5 years. Peulh, Dendi, Yoa and Lokpa are similarly disadvantaged.

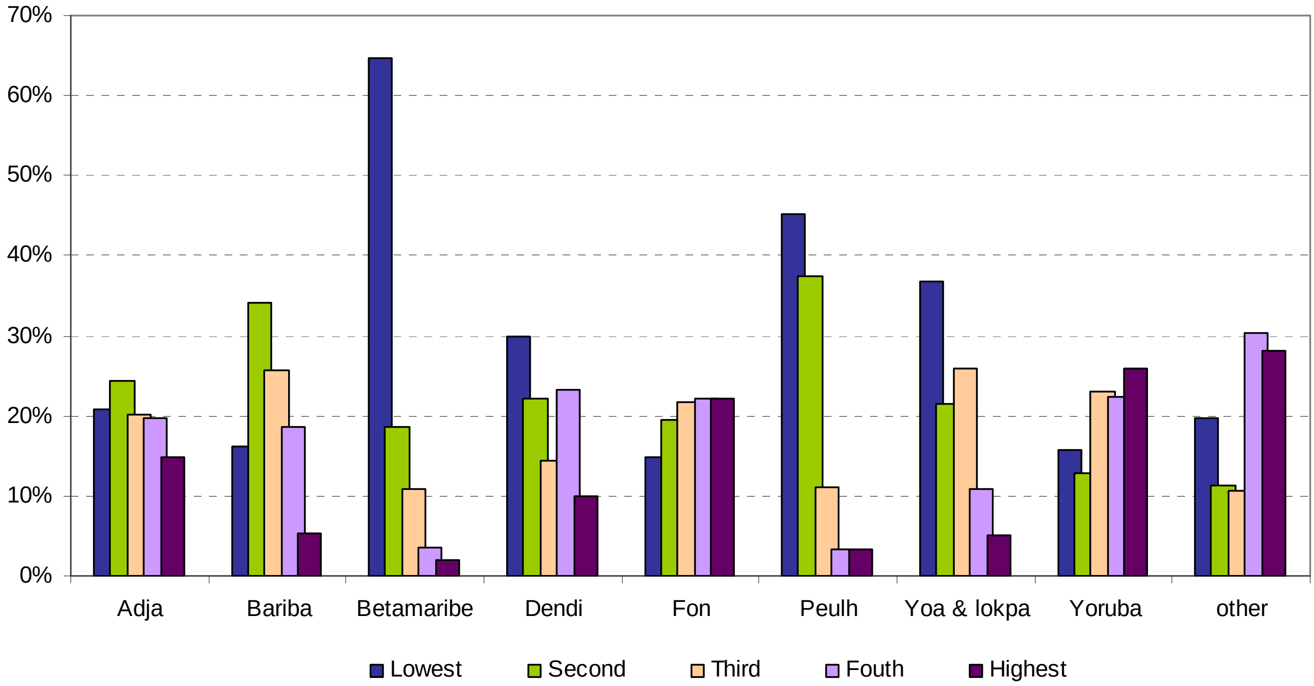


Figure 33: wealth index quintiles by ethnic groups in Benin.

6.2. Burkina Faso

In Burkina Faso, Touareg and Bella (traditionally Touareg slaves) are highly impoverished ethnic groups, along with Gourmatché, Peulh and Lobi. Touareg and Bella combined have over 40% of their national population in the poorest wealth quintile, while the other impoverished groups identified here all have over 35% in this category. Bobo and Dioula, two closely related ethnic groups that commonly intermarry, are relatively wealthy. Sénoufo fare relatively well also. These findings are reflected in the health variables, however Gourmatché show particularly severe disadvantage. Touareg/Bella have slightly contrary health statistics, with more stunting but reduced child mortality, however, these variables are broadly concordant across the other ethnic groups. Differences between groups were confirmed for both variables (Kruskal-Wallis, mortality: $\chi_{(9,7478)} = 22.2$, p = 0.08; stunting: $\chi_{(9,7903)} = 178.6$, p = <0.001).

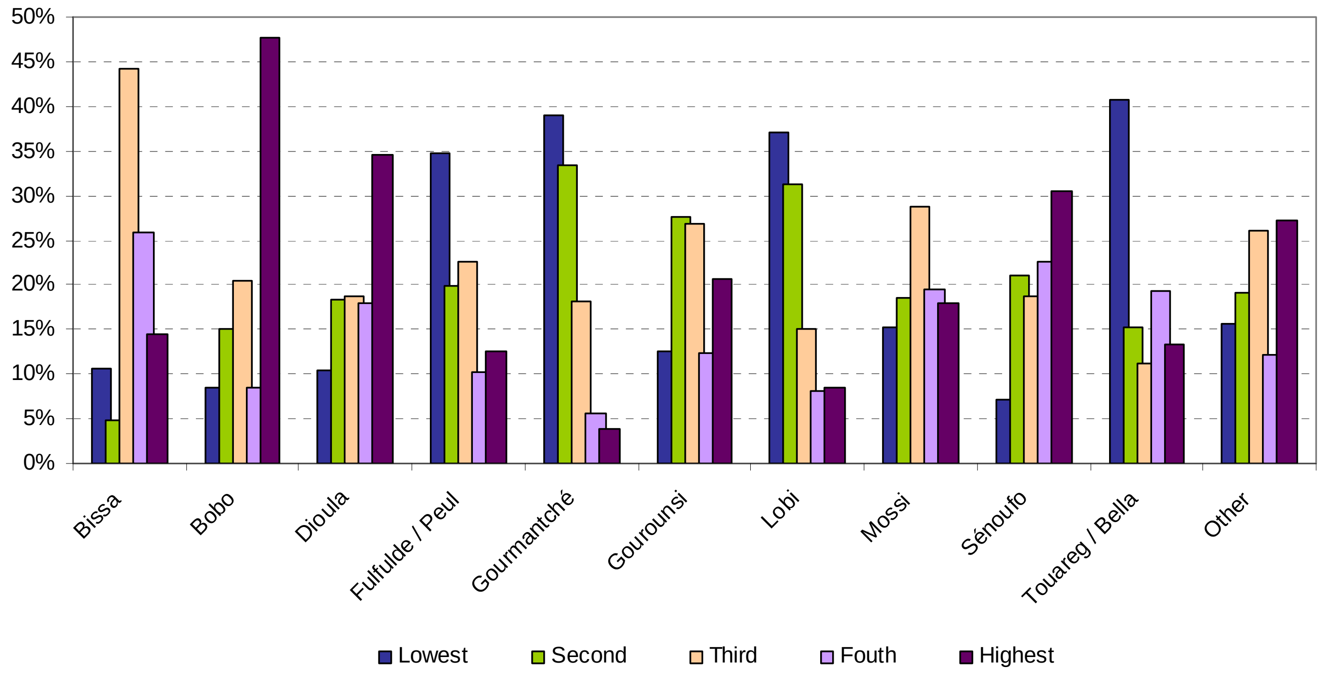


Figure 34: wealth index quintiles by ethnic groups in Burkina Faso.

6.3. Cote d'Ivoire

Akan are clearly wealthier than Ivorians of other ethnicities, with almost 40% in the highest wealth quintile. Krou also have a slightly positive skew to their wealth distribution. There are few other outstanding ethnic discrepancies however, with most quintiles holding between 10% and 30% of each ethnic group's sample. This may be due to the reduced resolution of ethnic identification in DHS surveys for Cote d'Iviore relative to other basin countries. Significant difference exists between these groups for the stunting variable but not for the mortality variable (Kruskal-Wallis, mortality: $\chi_{(5,1105)} = 3.58$, p = 0.612; stunting: $\chi_{(5,1477)} = 24.97$, p = <0.001). Mandé South people show the most severe health problems, with an average height for age ratio over 1.4 standard deviations below the global healthy reference median. As expected, Akan show much more satisfactory health statistics.

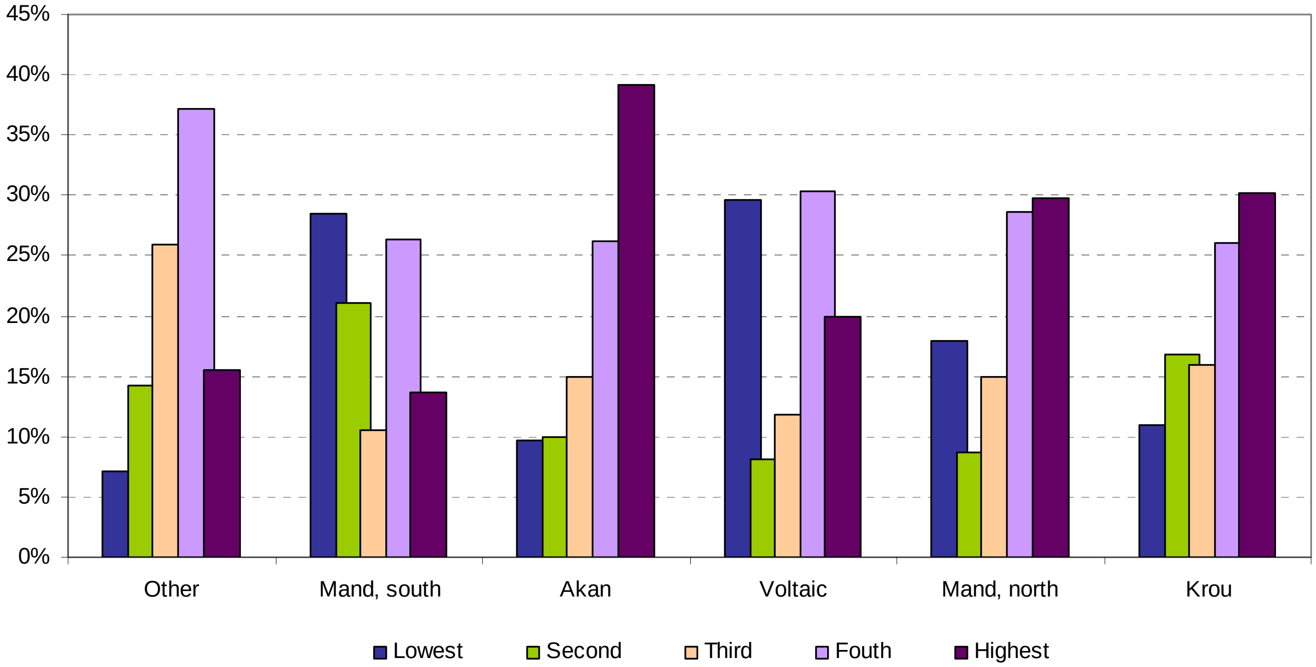


Figure 35: wealth index quintiles by ethnic groups in Cote d'Ivoire.

6.4. Guinea

Guerze, Kissi and Toma all show highly unequal wealth distributions. Over 40% of surveyed Guerze and Kissi people fell within the lowest wealth quintile, and less than 5% of Guerze and Toma fall within the highest wealth quintile. Peulh again show some economic disadvantage also. Malinke have a fairly even wealth distribution, while Sousou are relatively better off than Guineans of other ethnicities. Significant differences were found to exist amongst groups for both the mortality and stunting variables. (Kruskal-Wallis, mortality: $\chi_{(5,4815)} = 19.1$, $p = 0.02$; stunting: $\chi_{(5,2920)} = 25.12$, $p = <0.001$). Kissi and Toma show the most severe mortality and stunting statistics, with the Peulh, Sousou and Malinke samples having better than average statistics.

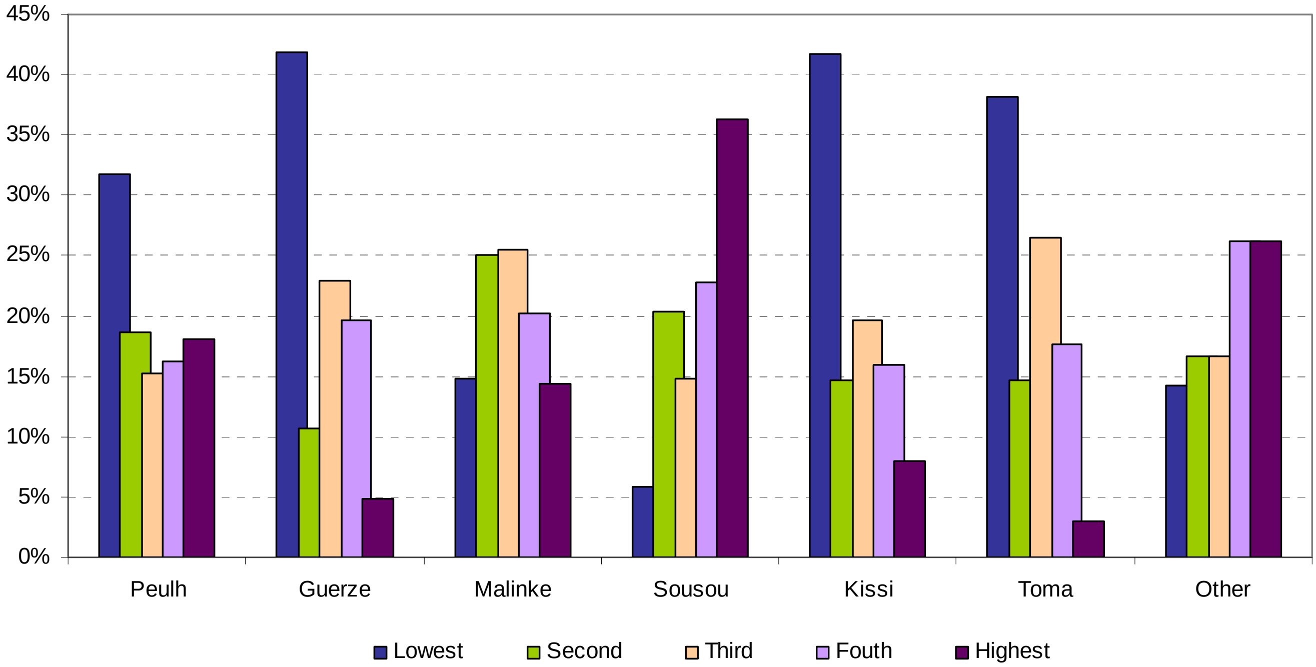


Figure 36: Wealth index quintiles by ethnic groups in Guinea.

6.5. Mali

In Mali, the Dogon and the Bobo are the two most economically impoverished ethnic groups. This stands in contrast to the Bobo people in Burkina Faso, who are relatively wealthier than other Burkinabé ethnic groups. Most ethnic groups surveyed in Mali have a relatively even wealth distribution, suggesting less ethnic-based disparity here compared to other Basin countries. Mandé people, which include the Bambara, Malinke and Soninke ethnic groups, comprise 50% of Mali's population and share a well distributed wealth curve. Sonrai, which comprise 6% of the population, are slightly wealthier. The Tuareg (< 10% of the population) are not included as a separate category for the DHS survey of Mali, however it is expected that they would show higher levels of impoverishment due to the long running intermittent conflict between Tuareg rebels and the central government. It is interesting to note, however, that a survey by Bratton, Coulibaly and Machado (2000) found that the Touareg minority held similar opinions about the quality of governance, although there exists a significant distrust of the army within this ethnic group.

There are significant differences between ethnic groups for both the mortality and stunting metrics (Kruskal-Wallis, mortality: $\chi_{(8,11182)} = 33.67$, $p < 0.001$; stunting: $\chi_{(8,8968)} = 47.9$, $p = <0.001$). Dogon, Peulh and Bambara all exhibit poor average height for age ratios, almost 1.6 standard deviations below the global healthy reference median. Bobo and Sonrai exhibit better health statistics, matching their advantageous wealth distribution.

A study by Adams, *et al.* (2002) compares child mortality also for two ethnic groups, Bambara and Peulh, comprising 35% and 10% respectively of the Malian population. Peulh primarily engage in cattle husbandry, and have more independent, smaller social units. The traditionally agricultural Bambara have larger social networks and are more cooperative. Adams *et al.* report higher child mortality amongst Peulh, a result that whist not explicitly evident here, may be seen in the other Sahelian countries. Whilst they explain the Peulh's disadvantage as a function of the harsher, resource limited Sahelian environments inhabited by this ethnic group, they also found evidence for the role of social networks to reduce child mortality.

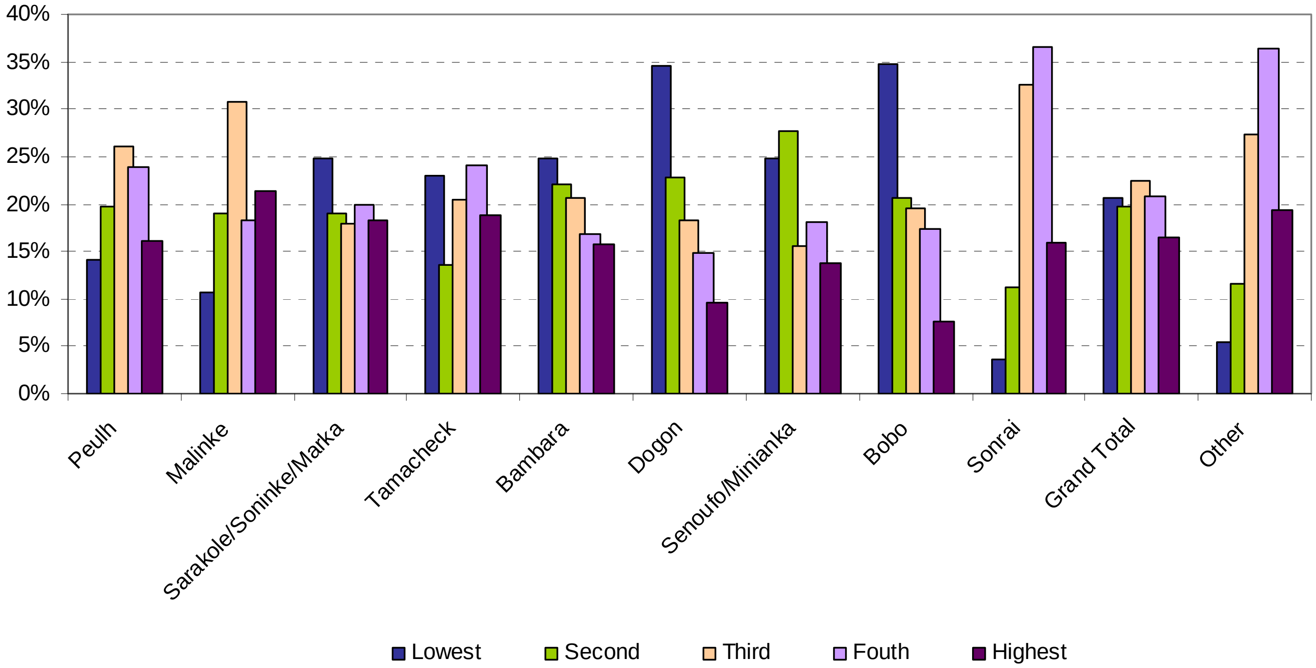


Figure 37: wealth index quintiles by ethnic groups in Mali.

6.6. Cameroon

Mboum, Mafa and Gbaya have the highest wealth discrepancies, with over 50% of Mboum and Mafa falling into the poorest quintile. Bassa-Bakoko and Beti have positively skewed wealth distributions, but generally the other ethnic groups of Cameroon have relatively even wealth. The child stunting metric exhibit significant differences along ethnicity lines but the mortality measure does not (Kruskal-Wallis, mortality: $\chi_{(8,1881)} = 7.89$, $p = 0.44$; stunting: $\chi_{(8,1630)} = 30.9$, $p < 0.001$). The correlation between these variables is much reduced in comparison to other Basin countries, with few clear trends obvious.

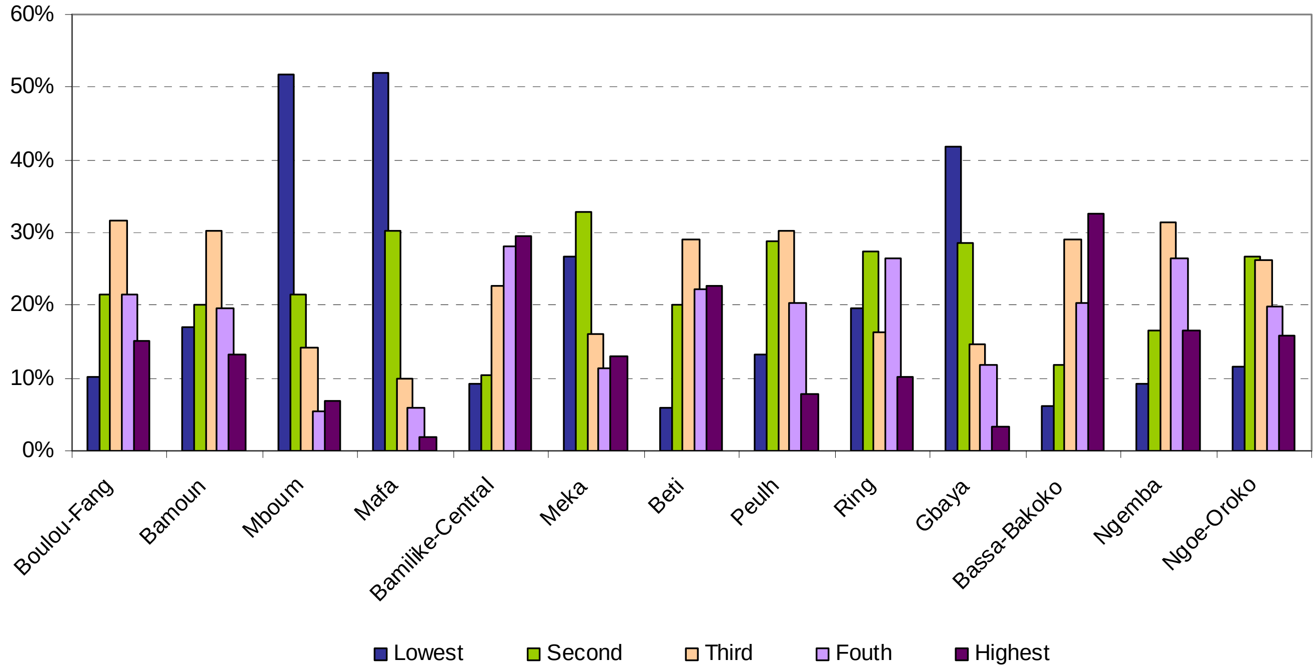


Figure 38: wealth index quintiles by ethnic groups in Cameroon.

6.7. Niger

The Djerma-Songhai ethnic group, which makes up 215 of the Nigerien population, exhibits the highest wealth discrepancy, with over 35% of people falling into the wealthiest quintile. This is, however, a modest inequality in comparison to other Basin countries. The majority Houssa (55.4% of the population) and the small minority Kanouri (4.7% of the population) exhibit slightly positive wealth distributions. The Tuareg (9.7% of the population) are an obvious discrepancy amongst ethnic groups, with just under 35% falling in the poorest quintile. Like Mali, Niger also faces ongoing intermittent conflict between the central government and armed Touareg militia (Nachega and Fontaine, 2006).

Significant differences exist between ethnic groups for both mortality and stunting (Kruskal-Wallis, mortality: $\chi_{(7,6728)} = 29.4$, $p < 0.001$; stunting: $\chi_{(7,3659)} = 66.7$, p = <0.001), with strong correlation between the metrics. Goumantché, as in Burkina Faso, show particularly severe child mortality and stunting. Average age for height ratios amongst this group are more than 2.5 standard deviations below the global healthy reference median. Kanouri and Houssa exhibit better than average health statistics. The effect of ethnicity on child nutritional status was investigated by Ndiaye (2002), who found that Touareg children were significantly smaller and slimmer than Haoussa. However, she also notes that this discrepancy has reduced over time, concurring with a move to sedentary life and an associated modification in diet.

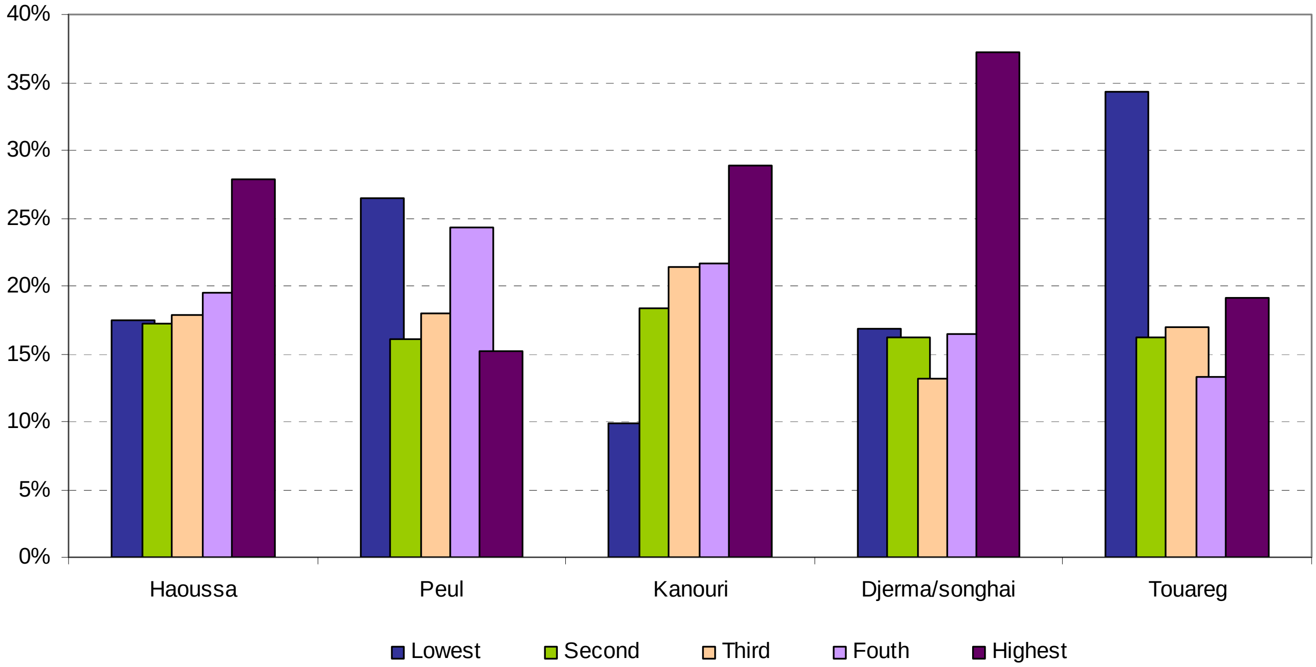


Figure 39: wealth index quintiles by ethnic groups in Niger.

7. WATER MANAGEMENT AND POVERTY IN MALI: A CASE STUDY

This case study will look at two economically, ecologically and socially important areas on the Niger River (The Inner Delta and the Office du Niger, both within Mali) to highlight the linkages between poverty reduction and water productivity. The Niger Basin area is usually divided into four zones, illustrated in the table below:

Table 29: The different hydro-ecological zones of the Niger River

Zone	Location	Rainfall
Sudano-Guinean	South of the line between Bougoni and Sikasso, spanning Upper Niger and High Bani	>1,000mm over 7 or 8 months in a year
Saudi	On or around a line between Bamako, Segu and San	1,100-600mm or less for <6 months of the year
Sahel	North of Mopti, , across Niger's inland delta and oxbow	600-100mm for less than 3 months of the year
Sahara/ Desert	North of the line between Timbuktu and Bourem	<100mm per year

Source: (Marie *et al.*, 2007)

The Inner Delta lies in the Sahel zone while the Office du Niger is in the wetter, Saudi zone. Most of the economic activities in Mali are confined to the river, with about 80% of the population engaged in either farming or fishing, 10% engaged in nomadic herding and the rest working in the industrial sector, which is concentrated on processing farm commodities (CIA, 2008). Thus agriculture (both irrigated and rain-fed), fishing and livestock represent the 3 main economic activities in Mali; all three depend on access to river water to some degree. Fishing is dependent on the river and even though it contributes only 4.2% to Mali's GDP, it provides employment for about 500,000 people (Marie *et al.*, 2007). Although livestock herding employs only 10% of Mali's population, cattle numbers have been growing in the south and remained steady in the arid north which has been a traditional cattle area. In the 1990s, there were around 7.6 million cattle in Mali (Marie *et al.*, 2007). Agriculture, the most important economic activity in Mali revolves around crops of sorghum and millet, lettuce and vegetables as well as a growing rice industry. Rice is being promoted in the Office du Niger area and commercial rice productivity in Mali has increased by 50% since the 1960s (FAO, 2007a). All three activities (agriculture, fishing and livestock) are discussed below in the sections on the Inner Delta and Office du Niger in terms of how they relate to water productivity. A brief comparison of the two areas is given in the table below:

Table 30: Brief comparison of the Inner Delta and Office du Niger regions

Region	Size (ha)	Population	Population Density (people/ha)*	Rice Production (tonnes/year)	% of national rice production	Dependence on rainfall and/or floods
Inner Delta	4,119,500	1,000,000	0.24	86,000	10% in a good year	Completely dependent on floods
Office du Niger	80,000	270,289	3.38	320,000	40% annually	Independent of floods and rainfall

*Population density calculated using given statistics
Sources: (Aghanim, 2004; Zwarts, Bvan Beukering, Kone, and Wymenga, 2005)

7.1.The Inner Delta

The Inner Delta can be divided into four parts based on a combination of hydrological, socio-economic, ecological and demographic factors (Kone et al. 2002). These divisions are outlined in the table below:

Table 31: Four zones of the Inner Delta

Zone	Location	Water sources	Hydrological characteristics
Haut Delta	Situated between Ké-Macina and an imaginary line between the Ténenkou and Kouakourou – Sofara Rivers	Niger, Bani, Diaka, Souman Bani, Mayo Sogona	Limited tributary flow
Delta Moyen	Situated in the southern part of the Inner Delta, between Haut Delta and the line of Toguéré Koumbé (on the Diaka River) and Konna (on the Niger)	Niger, Diaka and Bani	The main water flow slows to become a network of waterways of varying capacities and inundated plains. Bourgoutières comprise some 5,000km^2
Bas Delta	North of Mopti in the central Inner Delta	comprised of the following lakes: Walado Debo, Lac Debo, Lac Korientzé	The lakes together cover approximately 600km^2 when inundated
L'Erg de Niafounké	Extends from Lac Debo until Timbuktu	Niger and 2 large tributaries – Bara Issa and Koli-Koli	Extensive zone of parallel dune systems run west-south-west and east-north-east. Rivers run in a serpentine fashion towards the north

Source: (Kone *et al.*, 2002)

The Inner Delta is the largest wetland in Africa, with a mean area of 4,119,500 ha (depending on the extent of annual flooding) (Aghanim, 2004). In the decade between 1990-2000, the flooded area varied between 4000 – 15 000 km^2 in the upper Delta (Haut Delta), and between 1000 - 8000 km^2 in the lower Delta (Bas Delta) while the inundated area in aggregate amounted to between 8000 - 23 000km^2 (Mariko, Mahe, & Servat, 2003). Flooding typically begins in the south in August or September and reaches the northern margins of the Delta in December. The bourgotières are the vast grasslands that cover the floodplain and allow annual grazing of cattle.

The Inner Delta is an ecologically important area with more than 1 million migratory birds coming from over 80 countries to use the delta annually (Aghanim, 2004). It is also an important site for a variety of reptiles and amphibians (including the rock python, the Nile varan, cobras and vipers). Mammalian species including hippopotamus and the manatee are still present, although now threatened (Aghanim, 2004). There are 138 documented species and subspecies of fish, with at least 24 of these endemic to the Delta (Aghanim, 2004). The Inner Delta is on the RAMSAR list of Wetlands of International Importance.

Approximately 1 million people or 10% of the Mali population inhabit the Delta. This population is divided into some thirty ethnic groups who have traditionally engaged in separate agricultural and fishing activities. For instance, the Bozo are predominantly fishermen while the Peulh have a tradition of nomadic herding. Table 32 lists the major ethnicities and their respective economic activities. It is important to note that these divisions are not as distinct as they once were – for instance the division between herders and farmers has blurred with most herders now engaged in some farming and most farmers owning some cattle (pers. comm. Mary Bello 2008). All ethnic groups rely on additional household income earned by sending children to work in towns and cities. The extent of intermarriage and social interaction between ethnic groups varies. The Dogon do not mix and almost never intermarry with other ethnic groups (pers. comm. Jacob Poudiougo 2008).

Table 32: Major ethnicities and their traditional livelihoods in the Inner Delta

Activity	Ethnicity
Agriculture	Rhimaïbés, Bellas (former slaves of Peulhs), Bambara, Dogon, Marka, Sonrai
Herding	migratory groups of Peulhs, Tamasheq and Maures
Agriculture & Herding	Peulhs, Rhimaïbés and Bellas
Agriculture & Fishing	Bozo, Somono, Sorkos
Migratory fishing	Bozo

Source: (Kone, 2002)

7.1.1. History

The Inner Delta has been played an important role in the history of Western Africa. The extensive empires of Ghana, Mali and Songhoy as well as the theocratic States of Sékou, Ahmadou and Elhadj Omar Tall emerged from the area between the 8th and the 16th century. Today, the historic city of Djenné and the cliffs of Bandiagara are listed on UNESCO's World Cultural and Natural Heritage lists (Aghanim, 2004).

The first formal decree (the Dina) aimed at the integrated management of the Delta was introduced in 1818 by the Peulh (Fulani people). The Dina was instrumental in effecting a number of profound institutional and land use changes, including creating fishing dams for the Bozo, settling the Peulh, establishing the migratory paths and grazing areas for livestock and dividing the Delta into about 30 "Leydi"or territorialities, each of which were further subdivided into agricultural, agropastoral and fishing areas. (Kone *et al.* 2002).

The Dina established clear rules of access to natural resources. Access was unrestricted for forest resources, wild plants and some pastures, while limits to access were applied to agricultural lands, fisheries and grazing areas. These rules were enforced by the Dioro (manager of the territory who came from the Peulh family which reigned in the area). The Dina lasted from 1818 to 1862 when the Peulh were forcibly evicted by the Toucouleurs who came from present-day Senegal and Mauritania. For the next 30 years, Toucouleur farmers maintained control over the land until French conquest. Neither successor attached great importance to land management so the Dina system continued unofficially while the French natural resource agencies attempted to limit access and use to the local populations. Mali became independent in 1960 and a Government Department of Waters and Forests assumed management of natural resources. The 1980s saw increased inclusion of traditional management techniques into the policy of the state agencies, whist the 1990s saw the beginning of decentralization (Kone *et al.* 2002).

7.1.2. Economic Activities

While the Inner Delta is one of the major food production areas in Mali, yields are currently under threat by the overexploitation of the Delta's resources and introduced fishing techniques. Climate change threatens to compound this resource depletion (Bryson et al. 2008). Along with farming, fishing and livestock, transportation and tourism are other important activities but the Delta is also important for navigation and tourism. On the 31st of January 2004, Mali designated the entire Inner Niger Delta (4,119,500 hectares) as a Ramsar Site, consolidating three previously existing Ramsar Sites in Mali that were designated in 1987: Lake Horo (18,900 ha), Séri (40,000 ha), Walado Debo/Lac Debo (103,100 ha) with new areas without status (Aghanim, 2004).

7.1.3. Agriculture

The Delta supplies the major part of national rice production, which is enhanced by water from the Markala dam, enabling it to irrigate around 67 000 ha (Aghanim, 2004). Traditional methods of rice cultivation use local varieties of floating rice which can survive the three-metre-deep water flood inundation. Floating rice can span between 180 000 to 200 000 ha but has poor yields of less than 900kg/ha and these have not improved since the 1950s. It is also dependent on the flooding cycle with good floods creating a 10 000 tonnes surplus which can be sold outside of the Delta while inadequate flooding can cause rice shortages (Marie *et al.*, 2007). Average annual rice production in the Delta is approximately 86 000 tonnes (with a large yearly variation). Almost all of this is consumed locally with only 10% being sold outside of the Delta in good years (Zwarts *et* *al.*, 2005). Dependence on flooding means that the amount of usable farmland is subject to extensive year to year variation. For instance, a low flooding event in 1992 restricted agricultural activity to 332 000 ha, whereas the large inundation event of 1994 allowed 1 342 000 ha to be used (Marie *et al.*, 2007).

7.1.4. Fishing

The fishing industry within the Delta involves around 80,000 fishermen. The annual fishing production varies widely. Marie *et al.* (2007) estimated the annual catch between 50 000 -150 000 tonnes while Aghanim (2004) estimated an average of approximately 90,000 tonnes. Marie et al. (2007) specified that mean production has fallen from 130,000 tonnes per year to 50,000 tonnes in recent years as a result of lower floods and overexploitation. FAO estimated an annual yield of 85,000 tonnes in 2007 (FAO, 2007b). Declining fish stocks are directly linked to lower flooding levels in the Delta (Zwarts *et al.*, 2005).

7.1.5. Livestock

The Delta supports approximately five million cattle which migrate annually to graze on the bourgotières (Aghanim, 2004). Migrations occur according to traditional schedules along migratory routes (the cattle enter the arid, rain-fed lands as waters rise and move back on to the floodplain to graze on protein-rich grasses as water recedes) and facilitate minor economic exchanges such as the barter of milk and millet between farmers and herders (pers. comm. Mary Bello 2008). Substantial conflict occurred between herders and farmers in the 1970s and 1980s when farmers were forced to clear the bourgotières due to poor flooding to convert them to rice paddies (Marie *et al.*, 2007).

7.1.6. Tourism

Tourism is important both in the flooded areas (especially around Mopti) as well as in dry areas (such the Dogon territories). In 2001, approximately 100,000 tourists visited Mali, generating an income of CFA50 billion (US$ 108 million) (Aghanim, 2004). Tourism continues to expand despite intermittent armed conflict by the Touaregs in the north of the country.

7.1.7. Institutional Arrangements

Although the Dina formally existed for only 44 years two centuries ago, it has persisted as a traditional management system. The Dioro is still in charge of the bourgoutières and receives royalties from the owners of herds who are granted the right to graze pasture (for example, from the Peulh, Ramasheq and Maure). Access to the bourgoutières is decided at a Regional Conference on Bourgoutières held in Mopti in June and attended by all parties (Kone, 2002). This Conference grants the right and timing to different parts of the Delta. Fishing is regulated by the "master of the waters" of the native Bozo to whom migratory fishermen are obliged to pay royalties in either fish oil or coin (Kone, 2002).

The village is the key organizational structure for the people of Mali. The most powerful and respected socio-economic organization is the village council headed by the village chief (Amiri) and or the Dioro. In the case of the Inner Delta, most village chiefs are the Dioro. Wetlands International conducted a research project involving 28 villages in the south of the Inner Delta which found 162 different traditional organizations (excluding the village council). Each village had an average of six organizations (an average of 4.3 are for men and 1.7 are for women). All villages had had at least one organization for the following: agricultural activities, fishing, herding, women and young people. Table 5 specifies the organization type and lists their main activities.

Table 33: Types of organizations present in all villages

Type of organization	Activities
Agricultural	work is either paid for by village members or undertaken in collectively-owned fields
Fishing	Management of fishing (determination of fishing periods and enforcing protected zones); provision of fishing equipment to members and commercialization of fishing products
Herders	Organization of vaccination programs for animals and management of herd migrations
Women	Specializing in market gardening, small enterprises, reforestation activities, commercialization of fish, water birds, milk and wool, basket-making and pottery
Young people	Work undertaken under the supervision of the chief of village, involves paid or voluntary agricultural work, surveillance of protected forests, ponds, bourgoutières and local sacred places

Source: Kone, 2002

7.2. Office du Niger

7.2.1. Description

The Office du Niger region is one of the oldest and largest irrigation schemes in Sub-Saharan Africa. The irrigation zone of the Office du Niger is located in the Delta Mort, a flat alluvial plain bordered on the west side by a dune system, covered by sparsely wooded savanna and a number of forests. There are two old river branches (called the Falas) which now act as water supply conduits in the area, with one passing north through the Niono region (Fala de Molodo) and the other passing northeast towards the Macina region (Fala de Boky Wéré). The area can be categorized into 5 zones shown in Table 34:

Table 34: Zones of the Office du Niger

Name/Location	**Size (ha)**	**Type of crop**
Office du Niger	55,500	Rice
Ké-Macina and Bewani	1,580	Rice
Sugar cane area	5,800	Sugar cane
Opération Riz Ségou	3,000	Rice
Hors-casiers	8,000	Cultivation

Source: (Zwarts *et al.*, 2005)

Niono is the main town while Kourouma, Sokolo in the north and Kolongotomo, Boky Wéré and Macina in the east comprise the major villages (Zwarts *et al.*, 2005). The Office du Niger occupies approximately 80, 000 ha in a semiarid climate and in 2002 supported a population of 270, 289 (Zwarts *et al.*, 2005). The area also has important ecological values. Irrigated rice polders and the stagnant marshes of the Fala area are important wetland habitats where at least eight species of water birds are present in significant numbers. The remnant forests provide habitat for breeding colonies of endemic and migratory birds. Limited research has been conducted on the ecological values of the irrigation zones (Zwarts *et al.* 2005).

7.2.2. History

The Office du Niger region was established in 1932 by the French to produce cotton for the French textile industry and to grow rice for the Sahelian region of the French Empire (Aw and Dejou, 1996). The original plan was to develop about 1 000 000 ha over a period of 50 years. In the 1940s, 25 000 farmers were forcibly resettled in the area (IPTRID Secretariat, 2003). However, by 1982 only 6% of the Office du Niger had been developed, one-third of which was abandoned due to poorly maintained infrastructure (Aw & Dejou, 1996). Cotton growing ceased as the average yield of a paddy was 1.6 t/ha and the settlers were disgruntled over their poor conditions (Aw & Dejou, 1996). Settlers were forced to sell their plots to the Office du Niger (resulting in their eviction from the scheme). The Office du Niger employed 4000 staff and controlled nearly all economic activities in the area: it monopolized marketing and milling, ran the irrigation network, supplied all farming inputs, provided extension, produced farm equipment and even ran literacy courses (Diemer, 2004).

A successful rehabilitation of the area was undertaken between 1983 and 1994 with the average paddy yields tripling to 5t/ha. Previously abandoned lands were cultivated and the settler population grew by 222% (Aw & Dejou, 1996). By 2004, the average paddy yields had increased to 6.5t/ha; water use dropped from 1,500m^3/t to 250m^3/t and cultivation intensity has risen from

60% to 115% (Diemer, 2004). Water scarcity is currently a problem only in the degraded parts of the Office du Niger irrigation system, which comprise some 25 000 hectares, and in the unofficial extensions created by farmers (Stemerding, Musch, & Diarra, 2002).

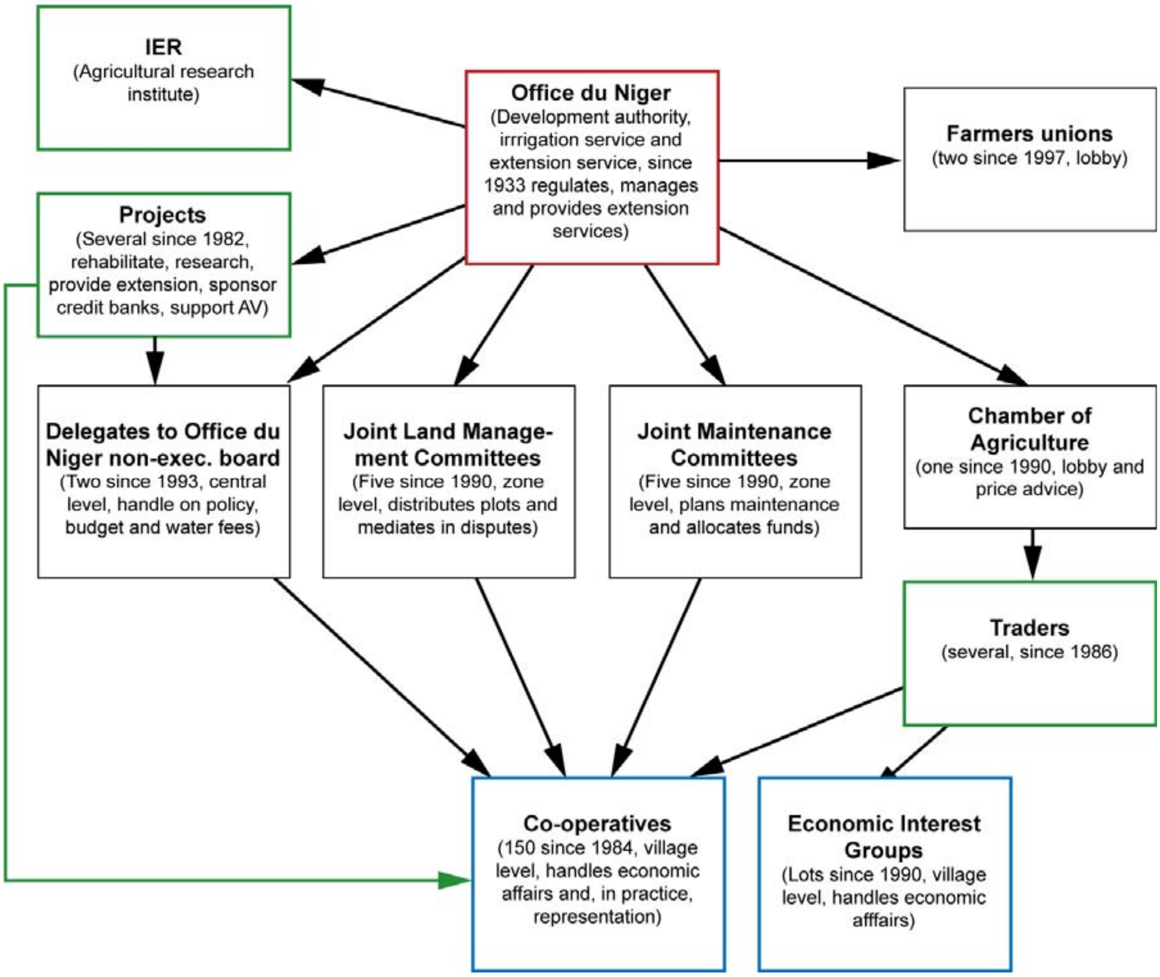
Managment reforms undertaken in the 1980s and 1990s profoundly changed the organization of the Office du Niger. What commenced as a rigid state-controlled system of micro-management was transformed into a community organization. The Office du Niger finally adapted into a system where various producer associations coexist with the private sector (Griffon, 2001).

7.2.3. Institutional Arrangements

The Office du Niger underwent extensive reforms in the 1970s and 1980s. These included the privatization of non-irrigation activities enabling farmers to sell produce and buy their imports at will (Diemer, 2004). Currently, farmers sell the majority of their produce to traders who in turn sell the farmers production inputs (seeds, agro-chemicals and fertilizers). A de facto oligopoly exists where traders have an interest in keeping rice prices low and input prices high. This is increasingly reinforced through package and credit deals for farmers where the agricultural process outside of actual production is handled by the traders (Stemerding *et al.*, 2002).

The Office du Niger was established as a financially and administratively autonomous public enterprise (Diemer, 2004). Post reform, the Office du Niger controls the distribution of land and construction and development, with other activities managed by village co-operatives (Griffon, 2001) and is responsible for the main system management (Stemerding *et al.*, 2002). The institutional setup in the Office is complex (see Figure 40), however it attempts to provide transparency and participation by farmers (Diemer, 2004).

Figure 40: Office du Niger Institutional framework of actors. Farmers organizations – blue, delegations and pressure groups – grey, Office du Niger bodies – red, other important actors – green.



Source: (Stemerding et al., 2002; modified by author)

The irrigation network is split into 5 zones run by co-management committees made up of settlers and Office staff (Diemer, 2004). There are two Joint Committees in each of the five zones, one for system maintenance and one for land management, with a roughly equal number of farmers' representatives and officials on each committee (Stemerding *et al.*, 2002). The Joint Maintenance Committees decide how and where to zone maintenance expenditure, audit accounts and supervise the implementation of maintenance plans. The Joint Land Management Committees decide on land attribution and resolve conflicts related to land use (Stemerding *et al.*, 2002).

Sovereignty rights are maintained by the Office du Niger. Irrigation infrastructure is owned by the government and the settlers are tenants – they may thus be evicted on a yearly basis if they do not pay their irrigation fees (Diemer, 2004). The Office du Niger manages both land and irrigation infrastructure. Every three years, the Office, the Ministry of Finance and two farmer representatives negotiate and sign a performance contract which details water fees, the share of fees that must be spent on maintenance in each zone, goals for increases in cultivation and details of new construction and rehabilitation. This contract also details the rights and obligations of the farmers, how the contract will be monitored and how funds will be managed (Diemer, 2004). According to regulations, 50% - 60% of the water fees must be used to maintain the irrigation network and each zone gets a share of the operating budget based on its share of contribution. The maintenance work is contracted out to private agencies.

Village cooperatives and interest groups are present at the village level and form an important part of the institutional framework. Apart from these, there are informal organizations for water management, festivities and burials, and for insurance-type self-help schemes based on the borrowing and leasing livestock (Stemerding *et al.*, 2002). However, the dominant village-level organization remains the village cooperative which is comprised of the heads of farm households of the village (usually adult men). The cooperatives' responsibilities include rice milling and threshing, marketing, provision of agricultural inputs, provision of agricultural credits and the operation and management of tertiary canals and drainage systems (Stemerding *et al.*, 2002). The cooperatives were designed to break the Office du Niger's monopoly on economic activities but they slowly succumbed to bankruptcy (Griffon, 2001) with only a few operating efficiently and most mired in debt and locked in factional strife (Stemerding *et al.*, 2002). The demise of cooperatives gave rise to economic interest groups, some of which became successful (some cooperatives became economic interest groups) however many continued to struggle and consequently more and more responsibilities became divested to the booming private sector (Griffon, 2001).

Formal institutional structures like cooperatives and interest groups have negatively impacted on women. Whilst women are traditionally involved in agriculture, these institutional structures have often ignored their land use rights as land plots are commonly registered in the husband's name. In 1995, 11 842 registered tenants were male and 68 registered tenants were female. Of the 68, most were government (ex-) employees while two were registered because their husbands could not pay the water fees (van Koppen, 1998).

7.2.4. Economic Activities

The Millennium Challenge Corporation (MCC) has signed a five-year, US$460.8 million Millennium Challenge Account Compact to reduce poverty and increase economic growth in Mali. The Alatona irrigation project seeks to develop 16,000 hectares of newly irrigated lands, representing an almost 20% increase of "drought-proof" agriculture in the Office du Niger area (Millennium Challenge Corporation, 2006). This expansion, however, is contingent on the successful construction of the Fomi Dam in eastern Guinea.

7.2.5. Agriculture

The Office du Niger mainly produces flooded rice with an average yield of 5 tonnes per hectare (Vandersypen *et al.*, 2006). The scheme is geared towards smaller farms with each farmer cultivating a plot with an average total area of 2 ha (Vandersypen *et al.*, 2006). Annual rice production is approximately 320 000 tonnes (40% of national rice production). Sugarcane and vegetables are also grown. While the irrigation zone guarantees steady rice production, it diverts a considerable quantity of water from the river (more than half of the river is diverted during low-water stages and up to 80% at peak times) which has detrimental downstream effects. Water use efficiency is comparatively low with one cubic meter of water producing 0.13 kg of rice (compared to the Asian standard of at least 0.2 kg/m^3 of water) (Marie *et al.*, 2007). Other measurements estimate that water use has been reduced to 8000 L/kg of rice (Zwarts *et al.*, 2005). Nevertheless, because it significantly contributes to national rice production, the area has been described as the "granary of Mali" (Zwarts *et al.*, 2005, p. 189).

Cultivation of other crops has expanded since the 1990s. Eschalot and maize are grown outside of the wet season which offers substantial complimentary income. Maize production increased from 140 ha in 1994 to 600 ha in 2001 while vegetable production (tomatoes, garlic cabbage) take up 2500-3500 ha (Zwarts *et al.*, 2005).

7.2.6. Fishing

To the authors' best knowledge, fish production is not a major activity in the Office du Niger.

7.2.7. Livestock

The Office du Niger attracts large migratory herds from Mali and Mauritania in the dry season. Theoretically and historically the two activities (farming and herding) have been complimentary. Traditional arrangements state that farmers cannot deny access to water to the herds but can impose conditions (for instance, they water their own herds first before allowing the migratory herd on the field). Cattle manure is an important fertilizer and a form of compensation for the use of the farms as grazing lands in the dry period. However, these arrangements became threatened when new dams allowed the sedentary farmers to plant alternative crops in the dry season thus limiting the grazing opportunities of migratory herders. This has caused increased conflict between sedentary farmers and migratory herdsmen. Increasing attention is also focused on the soil and vegetation degradation caused by cattle.

7.3. Impacts of Existing Dams

There are three main dams on the Niger River in Mali: Selingué, Markala and Sotuba. The table below lists the dam impact on key economic activities in the Office du Niger and the Inner Delta.

Table 35: Impact of the existing dams on key economic activities

	Inner Niger Delta without any dams	Impact of dams on Inner Niger Delta	Impact of dams on the Office du Niger	Impact of dams on the Selingué area
Rice (tonnes)	99,200	-13,200	+333,078	+6,000 / 7,500
Fish production (tonnes)	54,000 -133,000	-4,100	0	+4,000
Cattle	1,260,000	-60,000	+99,000	Negative, unknown
Biodiversity (waterbirds)	3,000,000 – 4,000,000	Negative impact: up to 4% less reproduction	+595,155	+20,000

Source: Wetlands International, 2008

The Selingué dam was built in 1980 to produce electricity, mainly for Bamako (the capital of Mali). Some associated irrigation and fisheries activities have occurred since the dam was built, but other side effects have been detrimental. 13 500 people living in the valley of the Sankarani lost their houses, grazing lands, orchards and other agricultural lands due to dam construction (Marie *et al.*, 2007). Furthermore, the dam has had negative ecological consequences by restricting fish migrations and altering the timing of the annual delta flood (Wetlands International, 2008).
The Markala dam was constructed to create new agricultural land by enabling gravitational irrigation in the Office du Niger area. The consequence in the immediate vicinity are primarily positive by enabling increased food production and creating a number of new wetlands used by some populations of waterbirds (Wetlands International, 2008).

Table 36: Impacts of current dams on selected areas in Mali

	Area (km^2)	People	Population change (annually, last decade)	Impact of dams
Mali (total)	1,240,000	11,995,000	2.43%	Additional and stable electricity supply; Increased food production; Loss of biodiversity, navigation, fish production
Inner Niger Delta	30,000 (inundated)	1,107,791	0.7%	Drop in cattle numbers, fish catch, agricultural production and navigation
Selingué area	13.5 (irrigated)	123,535	2.96%	Loss of agricultural and grazing lands (result of the 50km^2 lake); Newly irrigated areas and fish production
Office du Niger	740 (irrigated)	270,069	5-10%	Newly irrigated areas

Source: Wetlands International, 2008

Marie et al. (2007) and Wetlands International (2008) argue that the Inner Delta has been negatively impacted by the three existing dams and will be exposed to further detriment from the four proposed dams – especially the proposed Fomi dam in Guinea. Figure 25 shows the location of existing and proposed dams.

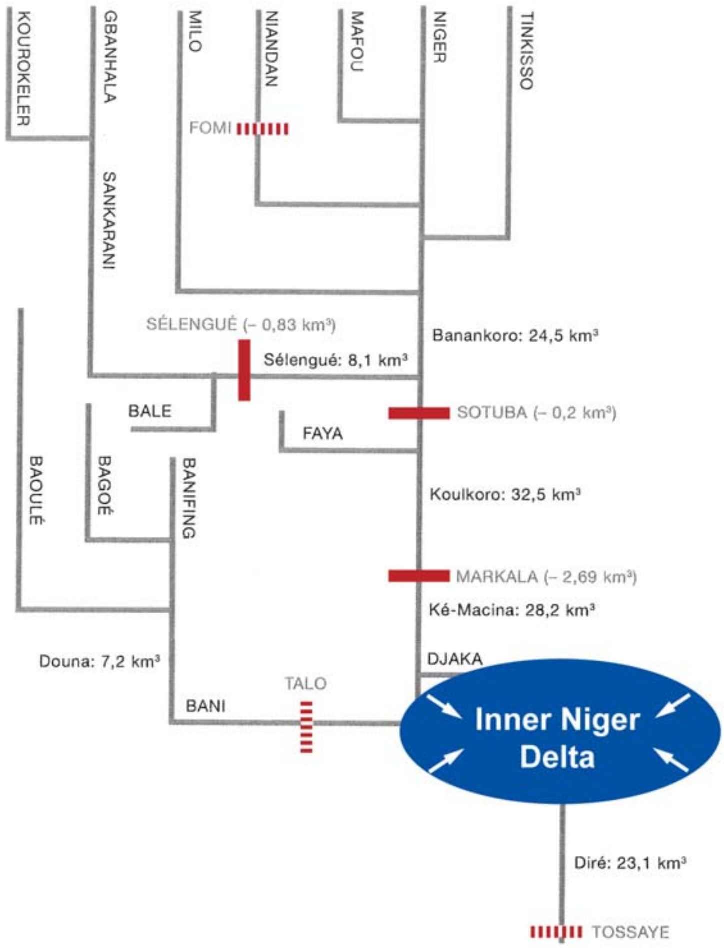


Figure 41: Water flows of the Niger River system and the impact of dams. (Red lines are existing dams, dotted lines are planned dams) Source: (Wetlands International, 2008)

The Sélingué dam and consequent irrigation by the Office du Niger has lowered the water level in the Inner Niger Delta by 20 to 25 cm which in turn decreased the flooded area of the Inner Delta by 900 km^2. This is expected to reduce the bourgoutières by 62% (Wetlands International, 2008).

The dams are also threatening traditional fishing and agricultural practices. The dams create an artificial dry season flow which contributes to conflicts between farmers and herders (explained above) but also disrupts traditional fishing techniques when the artificial flow washes away planted crops and fishing nets (pers. comm. Mary Bello 2008).

Several studies on the negative ecological impacts of dams (both existing and proposed have been conducted and some of the financial results of a cost-benefit analysis carried out by Zwarts *et al.* (2005) are shown in Table 37 (Office du Niger Dam relies on the Markala Dam).

Table 37: Annual costs or benefits of the dams for several sectors within Mali and Guinea

	Selingué dam	**Office du Niger dam**	**Fomi Dam**
Agriculture	152,439	36,260,487	6,250,000
Livestock	152,439	0	-,981,707
Fisheries	-4,268,292	-1,219,512	-9,146,341
Biodiversity	-457,317	0	-5,030,487
Transport	303,978	-152,439	-152,439
Electricity	10,670,731	0	17,987,604
Total benefits	6,707,317	34,756,097	7,621,951
Total costs	3,963,414	22,256,097	27,743,902
Net Value	**2,743,902**	**12,500,000**	**-20,121,951**

Source: Wetlands International, 2008

7.4. Impacts of Proposed Dams

Four large dams are proposed – Tossaye, Talo, Djenné and Fomi (in eastern Guinea). Table 38 summarizes their main characteristics.

Table 38: Proposed dams in Mali

Name	**Location**	**Purpose**	**Effects**
Taoussa	Between Timuktu and Gao	Electricity Farming	Dam will reshape annual swelling from the rainy season higher up the stream Guarantee 100m^3/s flow rate into Niamey through the dry season Irrigate 70 000-80 000 ha in Mali
Talo	Threshold dam on Bani River	Farming	Irrigate 24 000 ha Potential reductions in flood levels of 30 cm for those downstream, indicating a reduction of 600 to 900 hectares of arable land
Djenné	Djenné	Farming Electricity	Flood 85 000 ha Generate electricity for Djenné Little impact downstream

Source: Association des ressortissants de Djenné a Bamako, 1998; Marie *et al.*, 2007; pers. comm. Luc Ferry 2008).

The Talo Dam has been planned since 1985 and has been met with persistent and vocal opposition from the people of Djenné who protest against a lack of consultation and the potential socio-economic and ecological consequences. This includes the reduction of bourgoutières caused by lower flood levels (Association des ressortissants de Djenné a Bamako, 1998). For instance, the

Bani River (on which the Talo Dam is proposed) is a major source for Lake Debo, replenishing 30% of its volume in August and September. This replenishment in turn determines the effectiveness of the flooding at the bend of the Niger around Timboucou-Gao and above (Association des ressortissants de Djenné a Bamako, 1998).

Undoubtedly, the dam in Fomi will have considerable consequences for the Inner Delta. Its primary purpose is electricity generation but it may also create opportunities for some fish production. It is unknown at this stage whether the areas around the dam reservoir will be suitable for livestock and agriculture as well as waterbirds (Wetlands International, 2008). However the estimated effects include a 45 cm drop in the water levels of the Inner Delta which will decrease the flooded area by a further 1400 km^2. Tourism and river transport will also be adversely affected because of a reduced operating season for larger boats. Significant decreases in resident and migratory species of waterbirds are also forecast, diminishing the last breeding colonies of cormorants, ibises, herons and egrets in West Africa (Wetlands International, 2008). Importantly migratory birds are the main source of fertilizer for the inner delta. The Dam will, however, benefit the Office du Niger region (it is considered essential to its expansion), especially the areas near the river and will have the added effect of making groundwater more accessible (pers. comm. Luc Ferry 2008). Table 39 lists the estimated impacts from the proposed Fomi dam on rice, fish, livestock and biodiversity in the Inner Delta as compared to other areas.

Table 39: Additional impact of the Fomi dam on sectors in the investigated areas

	Inner Niger Delta without any dams	**Impact of Fomi dam on Inner Niger Delta**	**Impact of Fomi Dam on Office du Niger**	**Impact of Fomi dam on Selingué area**	**Impact of Fomi dam on Fomi area**
Rice (tonnes)	99 200	-34 000	0	0	-
Fish production (tonnes)	54 000 -133 000	-8 500	0	0	+ 4000
Cattle	1 260 000	-24 000 / - 48 000	0	0	-
Biodiversity (waterbirds)	3 000 000 – 4 000 000	Negative impact: Loss of 60% of key habitats (Bourgou): extinction of populations	0	0	?

Source: Wetlands International, 2008

The Office du Niger region is one of the oldest and largest irrigation schemes in Sub-Saharan Africa. The irrigation zone of the Office du Niger is located on approximately 80 000 ha of semiarid flat alluvial plain. The Office du Niger supports a population of over 270 000 and also contains a number of ecologically important sites. The scheme was initiated in the 1930s to grow cotton for the French textile industry, however until the 1980s the scheme failed to realise its potential due to low productivity and inefficient administration (Molden, 2007). A successful rehabilitation of the area was undertaken between 1983 and 1994 which saw average rice paddy yields tripling to

5t/ha. Previously abandoned lands were cultivated and the settler population grew by 222% (Aw and Dejou, 1996). By 2004, the average paddy yields had increased to 6.5t/ha; water use dropped from 1,500m3/t to 250m3/t and cultivation intensity has risen from 60% to 115% (Diemer, 2004).

This successful rehabilitation is thought to have been achieved by micro management reforms, implemented by the Malian government in return for capital investment by donor countries. Institutional reforms included the privatization of non-irrigation activities enabling farmers to sell produce and buy their imports at will. Decision making has slowly shifted from government officials to famers' representatives, improving the effectiveness of incentives and subsequent productivity. The new balance of power was formalized by 3 year performance contracts between the government and farmers. The scheme is geared towards small-scale farming with each farmer cultivating a plot of 2 ha on average. Today the Office du Niger produces mainly rice (40% of national production), as well as some sugar cane and vegetables. Eschalot and maize are grown outside of the wet season which offers complimentary income (Zwarts, et al. 2005). Expansion of irrigated agriculture in the Office du Niger is cited as a factor in regional poverty reduction. In general terms expansion can be accomplished by either improved water efficiencies reliant on existing impoundments or the construction of new dams associated with existing water efficiencies.

Zwarts et al. (2006) examined this question with relevance to the Office du Niger by estimating the present value of alternative river management scenarios. Scenarios included a no dam-no Office du Niger baseline, existing dams plus the Office du Niger and the potential construction of the Fomi dam in Guinea. Using water balance models for the Niger River and predicted inundation levels of the inner delta, estimated net benefits included the impact on fisheries, agricultural and livestock production and biodiversity. Their analysis estimates a net marginal loss per annum of M€ 8.5 for the Fomi dam scenario associated with significant wealth transfers from the inner delta to the Upper Niger. The existing dam/Office du Niger scenario resulted in a net gain of M€ 26.4 and no change in wealth transfer. Zwarts et al (2006) argue that building new dams on the Niger is not an efficient way to improve agricultural output and is unlikely to reduce poverty. They suggest that gains are likely to be made by improving existing infrastructure, continuing extant institutional reforms associated with proven productivity gains and by retaining and promoting the traditional economic activities of the inner delta.

Alternative water management proposals

To our knowledge, no studies of alternative proposals to large dams have been conducted. One alternative points to a series of smaller dams may have comparable positive effects and avoid the negative downstream effects of large dams. For example, the Dogon, who live around the central plateau region near Mopti, are traditional agriculturalists who have been able to double their agricultural production with the building of 'micro dams.' These small dams (approximately 2 meters high and 3 meters long) allow a Dogon village of 300-500 to cultivate 2 harvests by extending the wet season with minimal apparent ecological damage or effects on groundwater. The average cost of such a dam is US$6000 (pers. comm. Marc Montagner).

8. Bibliography

Adams, A, Madhavan, S and Simon, D (2002) 'Women's social networks and child survival in Mali', *Social Science and Medicine*, vol. 54, no. 2, pp. 165-178.

Adams, W (2000) 'WCD Thematic Review: The Downstream Impact of Large Dams', World Commission on Dams, 2000

Adger, W., (2006). Vulnerability. Global Environmental Change, 16, 268-281.

Aghanim, N. (2004). Mali designates Inner Niger Delta for the Ramsar List. Retrieved 7 September, 2008, from http://www.ramsar.org/wwd/4/wwd2004_rpt_mali1.htm

Ahiadeke, C (2000) 'Breast-feeding, diarrhoea and sanitation as components of infant and child health: a study of large scale survey data from Ghana and Nigeria', *Journal of Biosocial Sciences*, vol. 32. pp. 47-61.

Aigbokhan, B (2000) *'Poverty, growth and inequality in Nigeria: A case study'*, African Economic Research Consortium Research Paper 102, Nairobi.

Aliaga, A and Ren, R (2006) 'Cluster optimal size for demographic and health surveys', DHS Working Papers No. 30, ORC Marco, Calverton, Maryland.

Anselin, L (1995) Local indicators of spatial autocorrelation-LISA. Geographical Analysis 27, pp92-115.

Anselin, L (2005) 'Exploring spatial data with GeoDa: A Workbook', Spatial Analysis Laboratory, Department of Geography, University of Illinois, Urbana, Illinois.

Anselin, L.(2003). GeoDa 0.9 user's guide. Spatial Analysis Laboratory, University of Illinois, Champaign, IL.

Ashley, C., & Hussein, K. (2000). Developing methodologies for livelihood impact assessment: Experience of the African Wildlife Foundation in East Africa: Overseas Development Institute.

Assimacopoulos, D. (2004). Indicators and Indices Appendix. Water Strategy Man Newsletter, Jan-Mar(4).

Association des ressortissants de Djenné a Bamako. (1998). "The arguments from Djenné concerning the planned Talo Dam. Retrieved 16th of October, 2008, from http://www.djenneinitiative.org/argu_djenne_eng.html

Aw, D., and Dejou, C. (1996). Office du Niger: Ensuring food security for Mali. *World Bank Findings: Africa region no. 61*.

Balk, D, Pullum, T, Storeygard, A, Greenwell, F and Neuman, M (2003) 'Spatial Analysis of Childhood Mortality in West Africa, Calverton, Maryland,USA: ORC Macro and Center for International Earth Science Information Network (CIESIN), Columbia University

Bateman I, Yang, W. and Boxall, P.C. (2006). Geographical information systems (GIS) and spatial analysis in resource and environmental economics. In (Eds) Tietenburg, T. and Folmer, H; The

`

International Yearbook of Environmental and Resource Economics 2006/20007. Edward Elgar, Cheltenham, U.K.

Bivand, R. (2009). 'Package spdep: spatial dependence, weighting schemes and models' [software for use with R], accessed online [19 Aug 09] at < http://cran.r-project.org/web/packages/spdep/spdep.pdf. >

Black, M., & Hall, A. (2003). Pro-poor water governance: Asian Development Bank.

Booth, D., Holland, J., Hentschel, J., Lanjouw, P., & Herbert, A. (1998). Participation and combined methods in African poverty assessment: renewing the agenda. London: Social Development Division Africa Division.

Boots, B., 2001. Local measures of spatial association. Ecoscience 9, 168–176.

Bratton, M, Coulibaly, M and Machado, F (2000) 'Popular perceptions of good governance in Mali', Afrobarometer Paper no. 9, Michigan State University, Ghana Center for Democratic Development and the Institute for Democracy in South Africa.

Canagarajah, S and Thomas, S (2001) 'Poverty in a wealthy economy: the case of Nigeria', *Journal of African Economies*, vol. 10. no. 2, pp. 143-73.

Cardona, O (2004) 'The need for rethinking the concepts of vulnerability and risk from a holistic perspective: A necessary review and criticism for effective risk management', pp. 37-51 in Bankoff, G, Frerks, F, Hilhorst, D and Hilhorst, T (eds.) *'Mapping Vulnerability'*, Earthscan, London.

Carney, D. (1998). Sustainable Rural Livelihoods: What contribution can we make?' Department for International Development, London.

Castillo, G, Namara, R, Ravnborg, H, Hanjra, M Smith, L Hussein, M, Bene, C, Cook, S, Hirsch, D, Polak, P, Vaalee, D and van Koppen, B (2007) Reversing the flow: agricultural water management pathways for poverty reduction', in Molden, D (ed.) 'Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture', International Water Management Institute and Earthscan, Washington D.C.

Center for Hazards and Risk Research (2005) 'Core datasets - Natural disaster hotspots – A global risk analysis', The World Bank Group and The Center for International Earth Science Information Network, Columbia University, New York. Available online [29 Sep 08] at < http://www.ldeo.columbia.edu/chrr/research/hotspots/ >

Charlton, M, Fotheringham, A and Brunsdon, C (2003) 'GWR 3 – Software for Geographically Weighted Regression',Spatial Analysis Research Group, Department of Geography, University of Newcastle, UK.

CIA (2008) 'The World Factbook', Central Intelligence Agency, Washington D.C. Retrieved March, 2008, from https://www.cia.gov/library/publications/the-world-factbook/index.html

CIESIN (2005) 'Gridded Population of the World: Future Estimates (GPWFE)', Center for International Earth Science Information Network, Columbia University; United Nations Food and Agriculture Programme (FAO); and Centro Internacional de Agricultura Tropical (CIAT). Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available online [29 Sep 08] at < http://sedac.ciesin.columbia.edu/gpw >

CIESIN (2006) *'Where the Poor Are: An Atlas of Poverty'*, Center for International Earth Science Information Network, Columbia University, New York.

Cleary, D. (2003). People-centred approaches: A brief literature review and comparison of types: Food and Agriculture Organization of the United Nations.

Cook, S., & Gichucki, F. (2007). Analyzing water poverty: Water, agriculture and poverty in the basins: CGIAR Challenge Program on Water and Food.

Chambers, R. (1983) 'Rural development: putting the last first', Longman, Harlow, UK.

Chambers, R, Conway, G (1992) 'Sustainable rural livelihoods: Practical concepts for the 21st century', IDS Discussion paper 296, IDS, Brighton, UK.

Cutter, S. L. (2003). The vulnerability of science and the science of vulnerability. Annals of the Association of American Geographers, 93(1), 1-13.

Davis, B. (2003). Choosing a method for poverty mapping: Food and Agriculture Organization of the United Nations.

Devereux, S (2001) 'Sen's entitlement approach: critiques and counter-critiques', *Oxford Development Studies*, vol. 29, no. 3, pp. 245-63.

DFID (1999) 'Sustainable livelihoods guidance sheets', The Department for International Development, London, accessed online [6 Jul 2009], < http://www.eldis.org/vfile/upload/1/document/0901/section1.pdf >

Diemer, G (2004). Reform of Governance of the Office du Niger in Mali *International Network on Participatory Irrigation Management Newsletter 12*.

Dreze, J and Sen, A (1989) 'Hunger and Public Action', Clarendon Press, Oxford.

FAO (1997) 'Dominant Land Resource Types in Africa: Problem Soils of Africa', Land and Plant Nutrition Management Service, Food and Agriculture Organization, Rome. Available online [29 Sep 08] at < http://www.fao.org/geonetwork/srv/en/metadata.show?id=1046&currTab=simple >

FAO (1997) 'Slope of Sub-Saharan Africa', Land and Water Development Division, Food and Agriculture Organization, Rome. Available online [29 Sep 08] at < http://www.fao.org/geonetwork/srv/en/metadata.show?id=8&currTab=simple >

FAO (2000) 'Water Resources and irrigation in Africa', Aquastat, Food and Agriculture Organization, Rome. Available online [29 Sep 08] at < http://www.fao.org/nr/water/aquastat/watresafrica/index.stm >

FAO (2006) 'Geo-referenced database on African dams', Aquastat, Food and Agriculture Organization, Rome. Available online [29 Sep 08] at < http://www.fao.org/nr/water/aquastat/damsafrica/index.stm >

`

FAO (2007) 'FAOSTAT: Agricultural and water statistics database', Food and Agricultural Organisation of the United Nations, accessed online 26th Mar 08, < http://apps.fao.org/page/collections >

FAO (2007a) 'Auxiliary vector database component – RWDB2 Administrative Centres and Populated Places', African Water Resources Database, Technical manual and workbook, FAO, Rome.

FAO (2007b) 'Gridded livestock of the world 2007', by Wint, G and Robinson, T, Food and Agriculture Organisation, Rome. Data layers sourced from Kruska, R, CGIAR (pers. comm. June 2008).

FAO (2007c) 'Global map of irrigation areas – version 4.0.1', aquastat, Food and Agriculture Organization, Rome. Available online [29 Sep 08] at < http://www.fao.org/nr/water/aquastat/irrigationmap/index10.stm >

FAO (2007d) 'Annual total evaporation, Food and Agriculture Organization, Rome. Available online [29 Sep 08] at < http://www.fao.org/geonetwork/srv/en/metadata.show?id=30534&currTab=distribution >

FAO (2007d) 'Annual total evapotranspiration', Food and Agriculture Organization, Rome. Available online [29 Sep 08] at < http://www.fao.org/geonetwork/srv/en/metadata.show?id=30533&currTab=distribution >

FAO. (2007a). FAOSTAT: Agricultural and water statistics database. Retrieved 26th March, 2008, from http://apps.fao.org/page/collections

FAO. (2007b). Mali: Fishery country profile. Retrieved 16th of October, 2008, from http://www.fao.org/fi/oldsite/FCP/fr/MLI/profile.htm

Fotheringham, A, Brunsdon, C and Charlton, M (2000) 'Quantitative Geography: Perspectives on Spatial Data', Sage Publications, London.

Fotheringham, S, Charlton, M and Brunsdon, C (2003) 'GWR 3.0.1. Software for Geographically Weighted Regression', Spatial Analysis Research Group, Department of Geography, University of Newcastle upon Tyne, UK.

Fukuda-Parr, S (2003) 'The Human development paradigm: operationalizing Sen's ideas on capabilities', *Feminist Economics*, vol. 9, no. 2-3, pp. 301-317.

Füssel, H. (2007). Vulnerability: A generally applicable conceptual framework for climate change research, Global Environmental Change, 17, 155-167.

Gleick, P. (1999). The human right to water. Water Policy, 5(1), 487-503.

Global Forest Resources Assessment (2000) 'Global Forest Cover', US Geological Survey Earth Resources Observation and Science Centre', Washington D.C. Available online [29 Sep 08] at < http://edcsns17.cr.usgs.gov/glcc/fao/index.html >

Griffon, M. (Ed.). (2001). *Filières agroalimentaires en Afrique: Comment render le marché plus efficace?* Paris: Ministère des Affaires étrangères.

Hanjra, M. and Gichuki, F. (2008) 'Investments in agricultural water management for poverty reduction in Africa: Case studies of Limpopo, Nile, and Volta river basins', *Natural Resources Forum, vol. 32, pp. 185-202*

Heap, C., Kemp-Benedict, E., & Raskin, P. (1998). Conventional Worlds: Technical Description of Bending the Curve Scenarios: Polestar Series Report.

Holling, C.S. (1973) Reslience and stability of ecological systems. Annual Review of Ecological Systems; 4; pp 1-24.

Hulme, M (2001) 'Climatic Perspectives on Sahelian desiccation 1977-1998', *Global Environmental Change*, vol. 11, pp. 19-21

Hulme, M., Adger, W. N., Dessai, S., Goulden, M., Lorenzoni, I., Nelson, D., et al. (2007). Limits and barriers to adaptation:four propositions. Norwich, UK: Tyndall Centre for Climate Change Research.

Hyman, G., Larrea, C. and Farrow, A. (2005) 'Methods, results and policy implications of poverty and food security mapping assessments', Food Policy, 30, pp. 453–460

ICID (2002) 'Nigeria', Nigerian National Committee of the International Commission on Irrigation and Drainage, Abuja. Available online [04 Nov 08] at < http://www.icid.org/v_nigeria.pdf >

Ikelegbe, A (2001) 'Civil society, oil and conflict in the Niger Delta region of Nigeria: ramifications of civil society for a regional resource struggle', Journal of Modern African Studies, vol. 39, no. 3. pp. 437-69.

Ikelegbe, A (2006) 'The Economy of Conflict in the Oil Rich Niger Delta Region of Nigeria', Nordic Journal of African Studies, vol. 14, no. 2. pp. 208-34.

Imhoff, M, Bounoua, L, Ricketts, T, Loucks, C, Harriss, R and Lawrence, W (2004) Global Patterns in Net Primary Productivity, Global Patterns in Human Appropriation of Net Primary Productivity, Human Appropriation of Net Primary Productivity as a Percentage of Net Primary Productivity', Socioeconomic Data and Applications Center (SEDAC), available online [29 Sep 08] at < http://sedac.ciesin.columbia.edu/es/hanpp.html >

IPCC (2001) 'Chapter 4: Hydrology and Water Resources', in 'Third Assessment Report: Impacts, Adaption and Vulnerability', Intergovernmental Panel on Climate Change, United Nations Environment Programme, New York.

IPTRID Secretariat. (2003). *The irrigation challenge: Increasing irrigation contribution to food security through higher water productivity from canal irrigation systems*. Rome: Food and Agriculture Organisation.

Janssen, M. A., Schoon, M. L., Ke, W., & Borner, K. (2006). Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change. Global Environmental Change, 16, 230-252.

Kasperson, J. X., & Kasperson, R. E. e. (2001). Global environmental risk. Tokyo: United Nations University Press and Earthscan.

`

Klasen, S (2006) 'Poverty, undernutrition and child mortality: some inter-regional puzzles and their implications for research and policy', IZA DP No. 2509, Institute for the Study of Labor, Bonn.

Kone, B. (2002). Organisation socio-économique du delta intérieur du Niger. In E. Wymenga, B. Kone, J. van der Kamp & L. Zwarts (Eds.), *Delta intérieur du fleuve Niger: Ecologie et gestion durable des resources naturelles* (2nd ed., Vol. Mali-PIN Publication 2002-01): Wetlands International, Sévaré/RIZA Rijkswaterstaat, Lelystad/Alterra, Wageningen/ Altenburg and Wymenga conseillers écologiques , Veenwouden.

Kone, B., Wymenga, E., & Diallo, M. (2002). Brève description du delta. In E. Wymenga, B. Kone, J. van der Kamp & L. Zwarts (Eds.), *Delta intérieur du fleuve Niger: Ecologie et gestion durable des resources naturelles* (2nd ed., Vol. Mali-PIN Publication 2002-01): Wetlands International, Sévaré/RIZA Rijkswaterstaat, Lelystad/Alterra, Wageningen/ Altenburg and Wymenga conseillers écologiques , Veenwouden.

Krantz, L. (2001). The Sustainable Livelihood Approach to Poverty Reduction: An Introduction: Sweedish International Development Agency, Stockholm.

Kristjanson, P., Radeny, M., Baltenweck, I., Ogutu, J., & Notenbaert, A. (2005). Livelihood mapping and poverty correlates at a meso-level in Kenya. Food Policy, 30, 568-583.

Lawrence, P, Meigh, J and Sullivan, C (2002) 'The Water Poverty Index: an International Comparison', Keele Economics Research Papers no. 19, Keele University, Keele, UK.

Leenders, J, Visser, S and Stroosnijder, L (2004) 'Farmers' perceptions of the role of scattered vegetation in wind erosion control on arable land in Burkina Faso' *Land Degradation and Development*, vol. 16, pp. 327-337.

Lok-Dessalien, R. (1998). Review of Poverty Concepts and Indicators: SEPED Poverty Reduction Series.

MARA (2008) 'Mapping malaria risk in Africa – Distribution of endemic malaria, prevalence model, Western Africa', MARA/AMRA, Durban, South Africa. Available online [29 Sep 08] at < http://www.mara.org.za/ >

Marie, J, Morand, P and N'Djim, H (2007) 'Avenir du Fleuve Niger', Institute de Recherche pour le Developpment, Paris.

Mariko, A., Mahe, G., & Servat, E. (2003). The flooded areas of the Niger river inner delta using NOAA/AVHRR satellite data. *Bulletin - Société française de photogrammétrie et de télédétection, 172*, 61-68.

Measure DHS (2008) 'Country Datasets: Benin (2001), Burkina Faso(2003), Cameroon (2004), Cote d'Ivoire (1998-9), Guinea (2005), Mali (2006), Niger (2006), Nigeria (2003)', Macro International, Calverton, Maryland, USA, accessed online [29 Sep 08] at < http://www.measuredhs.com >

Millennium Challenge Corporation. (2006). Mali and Millennium Challenge Corporation: Building a Dynamic Partnership for Poverty Reduction through Economic Growth. *Factsheet, October 26*.

Mitchell, T (2003) 'Country Climate Data: TYN CY 3.0', accessed online [6 Jul 09] at < http://www.cru.uea.ac.uk/~timm/climate/ateam/TYN_CY_3_0.html >

Mitchell, T, Carter, T, Jones, P, Hulme, M, New, M, (2004) A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100)', Working Paper 55, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, UK.

Mosley, WH and Chen, L (1984) 'An analytical framework for the study of child survival in developing countries', *Population and Development Review*, vol. 10, pp. 25-45.

Nachega, J and Fontaine, T (2006) 'Economic Growth and Total Factor Productivity in Niger', International Monetary Fund Working Paper, Washington D.C

Narayan, D., Patel, R., Schafft, K., Rademacher, A., & Koch-Schulte, S. (1999). Can anyone hear us? Voices from 47 countries. World Bank, Poverty Group, PREM.

Ndiaye, A (2002) 'Child nutrition in Niger: An investigation of patterns of change', Masters Thesis, Department of Agricultural and Resource Economics, University of Arizona.

Neupane, A Boxall, P, Farlane, B and Pelletierc R (2007) Using expert judgments to understand spatial patterns of forest-based camping: A values-at-risk application', Journal of Environmental Management 85, pp. 471-482.

Niger Basin Authority (2005) 'Regional Synthesis on National Multi-sectoral Studies', Niger Basin Authority, Niamey, Niger.

Nkomo, J. C., Nyong, A. O., & Kulindwa, K. (2006). The impacts of climate change in Africa. The Stern Review on the Economics of Climate Change.

Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate impacts across natural systems. Nature, 421, 37-42.

Preston, B. L., & Stafford Smith, M. (2008). Framing vulnerability and adaptive capacity assessment. Paper presented at the Pre-Workshop Draft, Climate Adaptation Flagship Workshop.

R Development Core Team (2009). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available online < http://www.R-project.org >

Rasmussen, K, Fog, B and Madsen, J (2001) 'Desertification in reverse? Observations from northern Burkina Faso', *Global Environmental Change*, vol. 11, no. 4, pp. 271-82.

Rockstrom, J., Hatibu, N., Oweis, T.Y. and Wani S (2007) Managing water in rainfed agriculture. in Molden, D (ed.) 'Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture', International Water Management Institute and Earthscan, Washington D.C.

Rutstein, S and Johnson, K (2004) 'The DHS Wealth Index', DHS Comparative Reports no. 6, Measure DHS, Calverton, Maryland, USA.

`

SEDAC (2005a) 'Last of the Wild Data Version 2: Global Human Footprint data set (HF)', Wildlife Conservation (WCS) and Center for International Earth Science Information Network (CIESIN). Available online [29 Sep 08] at < http://sedac.ciesin.columbia.edu/wildareas/ >

SEDAC (2005b) 'Last of the Wild Data Version 2: Global Human Influence Index (HII). Wildlife Conservation (WCS) and Center for International Earth Science Information Network (CIESIN). Available online [29 Sep 08] at < http://sedac.ciesin.columbia.edu/wildareas/ >

Sen, A (1981) 'Poverty and Famines: An Essay on Entitlement and Deprivation', Clarendon Press, Oxford, UK.

Sen, A (2001) 'Development as Freedom', Oxford University Press, Oxford, UK.

Sen, A (1984) 'Resources, Values and Development', Basil Blackwell, Oxford, UK.

Sen, A and Dreze, J (1989) 'Hunger and Public Action', Clarendon Press, Oxford, UK.

Setboonsarng, S (2005) 'Child malnutrition as a poverty indicator: an evaluation in the context of different development interventions in Indonesia', ADB Institute Discussion Paper no. 21, Asian Development Bank, Manila.

Silanikove, N (2000) 'The physiological basis of adaptation in goats to harsh environments', *Small Ruminant Research*, vol. 35, no. 3, pp. 181-193.

Simonsson, L (2005) 'Vulnerability Profile of Burkina Faso', Stockholm Environment Institute, Stockholm.

Sperling, F. (2003). Poverty and climate change: Reducing the vulnerability of the poor through adaptation: OECD.

Stemerding, P., Musch, A., & Diarra, Y. (2002). *Social Dimensions of Integrated Production and Pest Management - A Case Study in Mali* (Vol. 13): FAO.

Suberu, R (2001) *'Federalism and Ethnic Conflict in Nigeria'*, US Institute of Peace Press, Washington, D.C.

Sullivan, C. (2002). Calculating a water poverty index. World Development, 30(7), 1195-1211.

Tol, R. S. J., Klein, R. J. T., & Nicholls, R. J. (2008). Towards Successful Adaptation to Sea-Level Rise along Europe's Coasts. Journal of Coastal Research, 24(2), 432–442.

Townsend, P. (1979). Poverty in the United Kingdom: A survey of household resources and standards of living. Harmendsworth: Penguin Books.

Townsend, R. (1970). Up the organization: How to stop the corporation from stifling people and strangling profits: Jossey-Bass Inc. Publishers.

Turner, B, Kasperson, R, Matson, P, McCarthy, J, Corell, R, Christensen, L, Eckley, N, Kasperson, J, Luers, A, Matello, M, Polsky, C, Pulsipher, A and Schiller, A (2006) 'A framework for vulnerability analysis in sustainability science', *Proceedings of the National Academies of Science USA*, vol. 100, pp. 8074-8079.

UN Population Division (2006) 'World Population Prospects: the 2006 Revision Population Database', accessed online [12 Dec 08] at < http://esa.un.org/unpp/index.asp?panel=1 >

UNAIDS (2006) 'Report on the global AIDS epidemic', New York.

UNDP (2005) 'Human Development Report 2005: International cooperation at a crossroads,' United Nations Development Program, New York.

UNDP (2006) 'Human Development Report 2006: Beyond Scarcity: Power, Poverty and the Global Water Crisis,' United Nations Development Program, New York.

UNDP (2007) 'Human Development Report 2007/2008: Fighting Climate Change', United Nations Development Program, New York.

UNESCO (2006) 'The State of the Resource in Water: A Shared Responsibility', United Nations Educational Scientific and Cultural Organisation, & World Meteorological Organisation, New York.

UNICEF (2008) 'State of the World's Children', United Nations Children's Fund, New York

US Geological Survey (2003) 'Land use – Land cover of Africa', Distributed by the GIS Unit, Food and Agriculture Organization, Rome. Available online [29 Sep 08] at < http://www.fao.org/geonetwork/srv/en/metadata.show?id=12755&currTab=simple >

van Koppen, B. (1998). Water rights, gender, and poverty alleviation. Inclusion and exclusion of women and men smallholders in public irrigation infrastructure development. *Agriculture and Human Values*, *15*, 361–374.

VanderSluis, M (2007) 'E-Museum: Igbo People', Minesota State University, accessed online [2 Dec 08] at < http://www.mnsu.edu/emuseum/cultural/oldworld/africa/igbo.html >

Vandersypen, K., Keita, A. C. T., Kaloga, K., Coulibaly, Y., Raes, D., & Jamin, J. Y. (2006). Sustainability of farmers' organisation of water management in the Office du Niger irrigation scheme in Mali. *Irrigation and Drainage*, *55*(51-60).

Vincent, K (2004) 'Creating an index of social vulnerability to climate change for Africa', Working Paper 56, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK.

Wetlands International. (2008). *Impact of dams on the people of Mali*. Mopti / Sévaré: Wetlands International.

White, F (1983) Vegetation of Africa - a descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa'; Natural Resources Research Report, U. N. Educational, Scientific and Cultural Organization, Paris. Available online [29 Sep 08] at < http://www.grid.unep.ch/data/download/gnv031.zip >

Wisner, B, Blaikie, P and Cannon, T (1994) 'At Risk: natural hazards, people's vulnerability and disasters' (1st Edn.) Routledge, London.

Wisner, B, Blaikie, P and Cannon, T (2004) 'At Risk: natural hazards, people's vulnerability and disasters' (2nd Edn.) Routledge, London.

`

World Bank. (2008a) 'Poverty Analysis – Overview', available online [4th Feb 09] at < http://go.worldbank.org/K7LWQUT9L0 >

World Bank (2008b) 'Poverty Analysis – Measuring Inequality', available online [4th Feb 09] at < http://go.worldbank.org/3SLYUTVY00 >

World Bank (2009) 'PovcalNet online Poverty Analysis Tool', available online [4th Feb 09] at < http://go.worldbank.org/NT2A1XUWP0 >

World Resources Institute (2007) 'Earth Trends Poverty Resource: Nigeria', Available online [04 Nov 08] at < http://earthtrends.wri.org/povlinks/country/nigeria.php >

Zalik, A (2004) 'The Niger delta: 'petro violence' and 'partnership development', *Review of African Political Economy*,vol. 31, no. 101, pp. 401-24.

Zwarts, L., Bvan Beukering, P., Kone, B., & Wymenga, E. (2005). *The Niger, A Lifeline: Effective water management in the Upper Niger Basin*. Mali / The Netherlands: RIZA, Lelystad / Wetlands International, Sévaré / Institute for Environmental Studies, Amsterdam / A 7 W ecological consultants, Veenwouden.

Personal Communications

Jacob Poudiougo – Dogon guide

Luc Ferry – Institut de recherche pour le Développement

Marc Montagner – Bilou Toguna

Mary Bello – Sahel Eco

9. Appendix A

The following section summarizes annotated transcripts of informal field interviews conducted in February and March, 2008. The research team conducted these interviews in Mali and Burkina Faso with Village elders or Chiefs, and agencies involved in agriculture, aid and water management.

All identifying details of the individuals, organizations and villages have been removed for confidentiality. This information is based on the opinions and experiences of interviewees and may represent personal biases or misunderstandings. All interview details should be considered the personal opinion of the interviewees only, not scientific fact, and the authors of this report make no assertion as to their accuracy.

Village	Village below Dogon escarpment
Date	March, 2008
Ethnicity	Dogon
Interview details	• 8 months of water trouble – Ground water used during shortages • When the chief was a younger man water was harder to access because there was no assistance with well construction • Village has 4 wells and 2 pumps. 1 pump 3 years old, broke down 3 times. Community puts on dances for tourists – money from this put into village trust and used to repair the pump. Mechanic brought in from Bamako. • 3 other villages in the vicinity, have own wells but share water in times of shortage. Fulani come to the village for water – Fulani herd the Dogon cattle, have rights to milk in return. Never any conflict over water. • Village does not receive government money – the only outsiders who come are tourists and an NGO which builds dams (they put in the pumps, no good place for

	dam near the village). They visit the village to discuss village problems, no government representatives have come. • Village priority: o Water o Health o Education • Tourist money is important. Community dances provide money for the village (currently used to fix the pump), sale of artifacts benefits only the makers and their families. Tourists do not cause any problems – do not draw on food or water resources of the village. Village money used to cater for tourists. Tourist season = July-Feb. • There is a microcredit scheme in nearby town but not in the villages. It would be useful, especially for the women. • Village pumps and wells are only used for drinking, not irrigation. There was an onion garden established but it used too much water. There is not enough water to cultivate all the fields – drip irrigation would be useful.

Organisation	Agricultural NGO
Date	March, 2008
Interview details	• Most of the dams built in the escarpment region are 2m high 3 m long • Larger dam near Sangha was built in 1958. • There is no ecological damage from the micro dams • The dams cost 4,000 Euro. the money is for concrete and sand and the masons' wages • There is no apparent effect on ground water levels • Dam doubles production by improving duration of the wet season – 2 harvests instead of 1 • 1 dam per village • After dams, the most sought-after aid is for walls for paddy fields. Without the wall, a paddy field produces 500kg of rice, with the wall – 3 tonnes (per 1 ha of land). More and more people are asking for the walls

Organisation	Relief and development NGO
Date	March, 2008
Interview details	• Religion is not a source of conflict if provision of resources is done without discrimination • Water shortages – no shortage of water immediately along the river yet but basin-level management not happening • Impediments to development of agriculture o Water – Duenza region not suitable for small hand pumps, water tables too deep o Inputs – limited access to fertilizers, a problem everywhere o Education – limited literacy and numeracy. Herders don't want to send children to school in a pastoralist culture o Access to markets and market information • Migration – seasonal migration to secondary cities during the dry season. Long term migration from rural to urban areas. Seasonal migration to Office du Niger. Migration to Cote d'Ivoire common. • Conflicts happening between farmers and herders over water • Value-added agriculture costly in land-locked Sahel countries – One international sugar refining company calculated that a sugar factory in Mali will only be profitable if fully mechanized so few benefits to Malians. • Cotton is the main export crop – global prices have huge impacts. Cotton production plummeting because it's not profitable. Sesame an option. Huge demand for sesame, good crop, doesn't need fertilizer, quality not important. Rice is good in right zones but not so much. Shea butter, watermelon grown during harvest time. So some diversification going on to escape cycle of poverty • Vulnerability – Timbouctou, Gao, Mopti, Kai – most vulnerable in terms of food security. Kai has strong culture of relying on remittances but these may not be spent most wisely. • Indications of wealth: North = tents, cattle, slaves. South: access to land, cash, inputs. Multiple spouses a sign of wealth everywhere but especially in the North. • Fertilizer is a major constraint to agricultural productivity. Fertilizer only used by

`

	cotton industry, none for smaller farmers.

Village	A town in Northern Burkina Faso
Date	March, 2008
Ethnicity	Fulani, Sori, Bella, Mossi
Interview details	• Micro dam has been here for 40 years. • Other similar dams near Dori, this is the only one in the immediate region. • Provides for market gardening and stock watering. • Many ethnic groups use this water resource. • In the wet season there is more water, but during the dry season the lake remains partially filled. Prior to the dam, there was no water in the dry season. • During the dry season, the town attracts many migrants including some from Mali. • Water is only used for irrigation and stock watering, not for drinking. Drinking water is supplied by village wells, which is clean enough to prevent much illness • There is no conflict over water. There is plenty for all current uses here. • Food is grown just for the people of this village. There is not enough for export. • There are some health problems, but biggest problem is that there is less rain than there used to be (compared to 1980s) • If there is not enough rain for the sorghum crop, they take some animals to the market and sell for millet • Lake water is free for outsiders to use but water from pump must be paid for. • Government built the pump, traditional well built by villagers. Both have water and do not run dry. • Dam also provides a source of fish.

Village	A village close to the Bagoe River.
Date	March, 2008
Ethnicity	Bambara
Interview details	• Village has 1 pump and 1 traditional well. The pump will dry out in 2 months. When the pump dries out they leave it for a few hours and water returns. Depth to water = 54 meters. The well has no more water, dried out forever. The river is far away. Preferred solution would be to get another pump. • The pump was constructed by the government because there was a school constructed and the pump goes with the school. • Rain was more plentiful when the chief was a young boy • The population has increased due to migration. • When there is not enough water, the village will take the animals to the riverbank • Village is primarily agricultural (rain-fed) but also keeps some animals • There is a mechanic in another village who can come and fix the pump if it breaks • There is no connection between the river and GW according to the villagers • Before they could grow a lot of wheat, now there is less rain, less wheat. There is not enough millet grown to meet demand after the wet season • Eucalypt wood used for house construction • All problems stem from the water. The people ask for help because they are afraid. “To live well, one must have water”. They want another pump.

Village	A watering point for herders, North Burkina Faso
Date	March, 2008
Ethnicity	Fulani, Bella
Interview details	• The Belli River and four lakes in the area are salty. This makes animals lethargic. Not a good natural water supply. • Fodder is not the problem, only water. The numbers of cattle are only limited by this, and overgrazing is not a concern. • System is not limited formally or informally, it is open access. There is no direct cost for using the water, although contributions for pumping station fuel required. • A vaccination certificate is the only documentation required for herders from neighboring countries who use the site. • Herders come from Mali, Burkina Faso and Niger. • The water has become a little more difficult to extract than in the past. • If pump does not work, nearest water source is a river 20km away. • If pump needs repairs, mechanic must come and visit. Guardian can do regular maintenance, but nearest technical support is from Ouagadougou.

	• Herders arrive in April. • Salt content has increased in the water over generation time period. • The drought in the 1970s changed the landscape, has not returned to the earlier state. Prior to this people had to cut a path through the trees. Now it is mainly open savannah. • If there is no water in the Niger River, there will still be some in the Belli River. All herders come here. • Each Saturday there is a market at Gorom Gorom, the village chiefs meet there to discuss the key issues. Commune includes Dell, Markoye, Ousi, tinakoff, Gorom Gorom. Dell alone has 14 villages. Some issues remain unresolved. When chiefs make decisions, it is "better to obey." • Niger Basin Authority is undertaking anti-desertification projects in this province and two others nearby. Replanting trees and grasses. • The respondent's dream is to "have enough water" • There is a government vet here who does a good job. Since he started there have not been any animal health problems.

Organization	Hydrologists, Research agency
Date	March, 2008
Interview details	• Potable water – problem in Bamako and Sikasso. All cities in Guinea have problems with potable water. Access to potable water is most problematic in towns. • Inner Delta – some areas have too much water (Guinea) some have too little (downwards from Delta). Problem in Delta = regulation of water vis a vis the population. Each zone is very unique • Water access – river water near the river and GW away from river. Nothing known about connectivity between GW & SW • Pollution – 1st problem is access to water, quality comes later. There is treatment for river water in cities but no treatment for effluent. No control over wells in Bamako, contamination happening. • Mining – many mines in Guinea, Burkina Faso – cyanide and mercury poisoning. People affiliated with big companies dig own holes to mine, no control. Mining is a secret operation, no reports, no scrutiny, mines guarded by military – no access. • Contamination – cloth dying, tanneries along the river – no companies, just individuals → no control. Cotton growing – no purification • Minimum flows – Nigeria wants minimum flows from the Niger – NBA ensures this in its documents. This is the only form of river regulation. • Dams – new dam in Guinea essential for extension of Office du Niger. Extension will double production. 1 million 9 hundred thousand hectares for Mali. Extension good for Office du Niger but bad for Inner Delta. Nothing known about relations between Inner Delta and Office du Niger. Dam in Guinea makes flows more regular but catastrophic for people far from the river. Will make navigation easier. Stability of the water regime (with the Dam) will make pumping of water easier. Dams followed by increase in pumps. After construction of dam in Selingue – 230 pumps put in with no regulation. 5 big projects in Mali, about 10 proposed in Guinea for irrigation and electricity. No long term impact studies on any of them. • Water problems: Urban – access and quality. Rural – irregularity in flows. Problems of regulation of precipitation in certain areas. • Adaptability – high in Mali. North: completely adapted to dry seasons. South: wet – no problems with water. Middle zone North and South has the biggest problem for agriculture due to dry/wet variability • Wetlands – important for Inner Delta. Very important ecological zone. Birds come in from Europe and Australia. • Each areas are unique – Mopti is particular only to Mopti.

Name	
Organisation	A Conservation NGO
Date	March, 2008
Interview details	• Restoration of forests – migration of birds = more fish = wood for fires, fishing = fish processing, agriculture, better quality of water. Reforestation and increasing water supply stops sedimentation. • Dams – upstream and downstream impacts of dams need to be considered. Water has generally decreased in the Delta and this was augmented by dams. Niger has a series of ponds which used to be connected. Now they're not due to sedimentation, dams and climate change. Solution = flow network improvement,

`

	reforestation, improved cultivation. Dams upstream of Delta have more impacts on ecosystem. Large dams – Delta region has many opportunities, but several regions are stressed and desertification happening so people moving to the Delta. Proper planning of dams can mitigate bad effects of upstream dams. • Many villages between Gao and Niger will have to be moved upstream of the proposed Toussi dam. • Recession of flows very short – traditional agriculture and fishing affected. Inundation is now quicker and not so extensive – great for people along the river • Power generation – dams necessary, power shortages happen everyday in Mali & Guinea. • Conflict between farmers and herders in different villages, exasperated by irrigation schemes being claimed by 1 person. Most conflicts in villages and families between farmers and fishermen. • Inner Delta - 30% do agriculture, 30% fishing, 40% herding. Out of 40 wet forests, 10 are left – 1970s drought started it. All now protected but most critical to ecological recovery. Grasslands and pasturelands decreased by overgrazing. Owner of pasture lands always most rich and politically connected. • Pasturelands – livestock moves out during flooding. Grass needs to grow, cattle leave to allow grass to grow before flooding so that it can survive the flood. • Flood channels not working due to sedimentation. River banks collapsing. • Inner Delta is a Ramsar site since 2004. 15 species of fish disappeared. • Government management – centralization doesn't work. Decentralization – rights over natural resources given to communes but the traditional ways and owners have remained

Organization	An agricultural NGO
Date	March, 2008
Interview details	• Land = Average market garden for a farmer = 0.5 ha. Big families – each man and woman have own market garden. Chief of the village distributes land. In a village 2, 3 or 5 people very rich but the rest have the same level of poverty. Rich farmers have more children, more materials for producing crops & inheritance in the form of domestic animals and land. • Money from pumped crops used for – education, clothes, health. Maintenance costs for pump = must change 4 rubber caps every 3 months. 1 cap = 300CFA → 1,200CFA every 3 months → low maintenance costs. • Farmers not exporting food, market price changes all the time. Pumps used mainly to grow potatos, cucumber, tomatoes, green beans. Sikasso region – potatoes and tomatoes. Segoué – onion and rice. Mopti - onions • There aren't many pumps located near rivers, most use groundwater. Must have a well for the pump. • Pumps used to be brought in from Kenya. 3 months for transport, quality could not be guaranteed and high price. Now pumps made and transported from China – 45 days for transport, 25% less cost and quality guaranteed.

Organisation	A conservation NGO
Date	March, 2008
Interview details	• Millennium Challenge Program – will add a new canal to Office du Niger. Originally destined for agribusiness but some plots for farmers. 5 hectares being sold without tertiary canals. • Water rights – everybody has the right to take water • Land rights – land which is not cultivated has no value. Forests are valuable for non-timber products and as shelter for livestock but this value not captured. • Ethnic identity – people identified as either herders or farmers but in reality everybody does a little bit of both. Ethnic identities can be a source of conflict but these are in the past in areas where this NGO works. • Herders – there has been a growth in herds but most of the animals don't belong to the herder. There are long standing relationships between farming and herding communities. Herders who come to water their stock are not refused water but have to abide by certain conditions. Eg. Well owner's stock has to be watered first and cattle must leave manure on the well owner's farm. Millet can also be exchanged for milk. • Groundwater – no control over GW resources. GW aquifers filled from the river • Surface water – Nigeria has controls over the taking of water from the river but no

	control over boreholes. • Dams – Dam in Selingue has beneficial effects because water is available all year. Farmers and herders are convinced that the Markala dam has no effect on the river so everything is blamed on the dam in Selingue. • Dry season flows are interrupting traditional plantings – crops planted during dry season are washed away by the artificial flooding. Fishermen also practice traditional fishing in the dry season – artificial floods destroy fishermen's nets. • Subsistence economy – not captured by GDP. The delta is outside of government control • Drinking water access – Direction Nationaux d'Hydrolique – one of the better organized ministries. Provides piped water for free for villages of 2,000 inhabitants and over. Villages must pay fees to use the well but water user groups are set up so the villagers know where the money is being spent. Villages with less than 2,000 inhabitants, have to turn to the Communé. Village needs to pay 15% of the cost of the pump or well. Money to communés comes form NGOs and 1 government stream. • Impact of wells – daughters given to a village with a well but not to one without → new well = increase in marriages. Also houses can be built and re-built during the dry season because mud bricks can be made. • Pollution – upstream and downstream pollution is not on anybody's radar. In Mopti, the river is used for everything so cholera outbreaks happen. • Solid waste – effluent from Bamako goes directly to the river or is dumped on land and then washed away to the river. Treatment plants are either incorrectly situated and drivers don't want to drive up there or they are correctly situated and overwhelmed • Mining – cyanide and mercury

Village	Village above Dogon escarpment
Date	March, 2008
Ethnicity	Dogon

Interview details	• Small village – 300 people. Dam recently installed by NGO. Effects:
	  o More fruit trees can be planted
	• Village likes tourists, good for income
	• 3 important things
	  o Health
	  o Education
	  o Nutrition
	• There was more rainwater when the chief was a young man. The village has no reliance on the Niger river at all.
	• Many people leave the village to work in Mopti, Bamako and learn French and Bambara but those who stay in villages speak only Dogon

Village	A village in the inner delta, Lake Debo. Migrates with the water level.
Date	March, 2008
Ethnicity	Bozo
Interview details	• People are totally reliant on the lake for everything. • There is not enough water in the lake, sediment is gathering • Some fish species have disappeared in the chief's lifetime. Very large fish have not been present for 30 years • People are afraid because there is less water and less fish • There used to be lots of birds around lake Debo but now there is less water → less fish → less birds • Villagers know there is a new dam downstream and are happy about it because they will have more water which means more fish. No government rep ever came to speak to these people about the dam, they find things out by radio or when they travel to Mopti • The Fulani have left, People fish small fish in order to survive. • The Bozo grow (water) rice and fish. • Water is the priority concern. Education and health is a concern but much less important than water • All drinking water comes from the river – cholera is a problem (according to our guide)

`

	• The people don't know what they can do to make the government listen • The village used to be situated on a nearby hill but moved down to the lake because there was no water up there Information from our guide • There are over 40 encampments around Lake Debo – strangers who came from other parts of the Niger river to settle around Lake Debo – Bozo and the semi-nomadic Fulani • Other Bozo who come to Lake Debo to fish must ask the chief's permission, there are restrictions placed on fishing methods which are enforceable by official government representative in Sendigue. • Lake Debo is 1.5m-2m high in summer (dry season) and 12m high in winter (wet season) • The pirogue is the most common type of transportation. Wood for the pirogue comes from Guinea and Cote d'Ivoire (2 types of wood). Needs 20kg of shea butter every 6 months to stop leaks • Fulani own the rights to the bourgou (pasture) – the river is for the Bozo • Half of the young people leave the lake to work in Mopti, Cote d'Ivoire, Nigeria – "If there are 4 young people in a family, 2 have left" • "Everybody works in the water – the men and the women, the young and the old.

Organization	An agricultural NGO
Date	March, 2008
Interview details	• Different ethnicities specialize in different things – Bambara etc are both herders and farmers but Dogons are mostly farmers. Fulani are the true herders but becoming more sedentary because of the drought. Fulani settled in Sikasso, grow cotton, sorghum and maize. Serakale ethnicity – traders. Bogou ethnicity – eat dogs. Too many ethnicities to make generalizations. • Fulani, a good indicator of wealth is the size of the herd, even though the herder could be herding for others. True Fulani will never tell you the size of his herd. There are Fulani that have over 1,000 animals. The shepherds recognize the markings on each individual animal – can visually identify each animal that belongs to his herd. If herding for someone else, a shepherd gets money and or milk as payment. Fulani often herding for farming villages. Often near a farming village there is a smaller, poorer Fulani village. Fulani migrated from San to Sikasso in 1974 and 1984. • Cattle important for everyone but most of all for the Fulani, both men and women as the women inherit part of the herd from their husbands. Chickens everywhere, sheep and goats also important. Cattle are a status symbol. For farmers a sign of wealth is the possession of draught animals (work bulls). A rich farmer would have between 1-4 work bulls. Farmers – number of sheep is significant for wealth. • Importance of animals: • Cattle – status symbol • Sheep – religious reasons (Islam) • Goats – require no shepherds • There is not enough infrastructure for holding water around Sikasso so there is movement everyday to find water. In the South there is water but not enough wells or dams. • Pasture – there is not enough pasture on Sikasso. • Migration – Cattle migrate during harvest time (April-May – Summer) go South to Cote D'Ivoire and Guinea. Normally there's enough water for animals in the South. Evidence of permanent migrations South after each major drought. In the North there are large herds and low watertables.

Organisation	A Conservation NGO
Date	March, 2008
Interview details	• Niger River divided into 4 components: ▪ Upper Niger – Guinea till Segou ▪ Inner Niger Delta – Segou till Timbouctou ▪ Middle Niger ▪ Outer Delta • River depends on what happens upstream – higher flows (height of flooding) = better livelihoods. Factors affecting flooding

	▪ Climate Change – river not depended on local rain but on rainfall in Guinea. 1984 the flooding area was 8,000 km2, used to be 51,000 km^2, this was a good year. Whole system collapsed during drought. Inner Delta supports between 3 to 4 million water birds ▪ Human Population Growth – growth rate was 0.7% to 2.7% ▪ Dams – upstream scenarios study. Proposed dam in Guinea 3 times as big as the one in Selingue. Wetlands International did scenario assessment on cattle, rice, fish production, ecology, birds and navigation – Conclusions = proposed Foumi dam will be an economic and hydrological disaster for Mali. Will result in wealth transfer from Mali to Guinea. Dam should be smaller. Big inundation stopped by big dams. • Inner Delta – 1 million people depend on natural resources of the Inner Delta ▪ 1/3 cattle herders – 5 million cattle ▪ 1/3 fishermen – 4,000-10,000 fish production ▪ 1/3 farmers – 100,000 tons of rice produce • Office du Niger = 30,000 liters for 1 ha of rice in Office du Niger – must improve irrigation. Off-season growing is a problem of Office du Niger. 1 million people negatively affected by Foumi dam do not contribute to Mali food production but do subsistence. World Bank reconsidering funding for Foumi dam (50 million euros. Rice production – salinisation due to water waste, weeds also a problem. Water management very bad in Odu Niger • GW/SW – no natural recharge in Mali. Irrigation goes into GW and creates sedimentation. In a flood year – 6% of the water is actually used. A – ministers used to fight amongst themselves but now that the river has a problem they've started to work together.