A GEOSPATIAL APPROACH TO ASSESSING THE SYNERGIES OF AGRICULTURE-BASED POVERTY ALLEVIATION PROGRAMMES: ADRA'S PROGRAMME IN THE GA WEST DISTRICT OF GHANA

Baffour Awuah

ACADEMIC DISSERTATION

To be presented, with the permission of the Faculty of Agriculture and Forestry of the University of Helsinki, for public examination in lecture Hall 4, Block B, Latokartanonkaari 7, Department of Forest Science, Viikki on 25 January 2013, at 12 noon.

Unigrafia
Helsinki 2013
Supervisors

Professor Timo Tokola - University of Eastern Finland, Joensuu (Main)
Professor Pauline Stengberg - University of Helsinki
Professor John Sumelius - University of Helsinki

Pre-examiners

Professor Ari Pappinen - University of Eastern Finland
Doctor Veli Pohjonen - Docent of Silviculture, University of Helsinki

Opponent

Professor Paavo Pelkonen - University of Eastern Finland

ISBN 978-952-10-8582-6 (pbk.)
ISBN 978-952-10-8583-3 (PDF)

Unigrafia
Helsinki 2013
ABSTRACT

Achieving the sustainable goal of using agriculture as a human intervention to alleviate poverty requires a measurement technique that can describe, explain, and predict with optimum accuracy the spatial distribution of social, economic, developmental, and environmental factors driving agriculture and poverty alleviation. The link between poverty and agriculture distributed in space and time is multi-dimensional and complex. It cannot be quantified using a single routine measurement, but by a combined stochastic and deterministic optimization approach.

This study seeks to develop a systematic procedure with the capability to inter-relate complex datasets derived from multi-dimensional factors to evaluate an agriculture-based poverty alleviation programme. This project involves utilising geospatial analysis associated with poverty mapping, as well as other known sustainability parameters. The study focus was on ADRA’s (Adventis Development and Relief Agency) programme in the Ga West district of the Greater Accra Region in Ghana. A logical grouping of captured data was organised in a broad classification of functions, data, and topological associations and their relationships. This formed the datasets for levels of analysis (Plot, Watershed, Farm household, Developmental). Guided by the reference values, the datasets and the breakdown of sustainable criteria into variables, different modelling procedures and methods were selected from the geospatial analysis regime. A total of 16 attributes derived from the analyses were combined for geoprocessing work flow, i.e., eight socio-economic and developmental attributes representing the state of human activities or anthropogenic pressures associated with the programme, while the ecological/environmental attributes represented by 8 biophysics environmental state of the study area. Empirical analysis was completed with the development of a Spatial Sustainability Index (SSI), and the eventual creation of a Sustainable Poverty Alleviation Map (SPAM). The results show only 12.5% of the farm households achieved near sustainable level (0.7 - 0.9, out of 10.0). A majority of the problems related to sustainability identified in the research area were based on environmental indicators, which apparently stemmed from socio-economic factors. The study demonstrated that human-environmental interactions (especially using agriculture to alleviate poverty) is complex, and mutually affect each other in diverse ways. For example, increased crop income as revealed by this study adversely affected soil fertility and water quality, which in turn negatively affected human and environmental health that could promote or cause poverty. Therefore, to assess and understand these complex interactions, the study adopted an analytical regime that identified how, why, and what happens where, and makes use of geographical information that links features and phenomena at the study area to their respective locations and relationships. Events, patterns/trend and relationships in time and space were very crucial.

This dissertation contributes to the evolving debate on spatial analysis and poverty, agriculture, poverty alleviation, poverty mapping, geospatial and crop management, and sustainable development. The main contributions are the methods used for handling the data that are brought to bear in the debate, i.e., the irregular or noisy dynamics of the processes involved, the random nature of measuring events, the importance of the environmental dimension in poverty mapping, and the effective and efficient use of geospatial analysis to operationalise sustainability.

Keywords: agriculture, geodatabase, geospatial analysis, geostatistics, GIS, poverty alleviation, poverty mapping, sensitivity analysis, sustainability.
ACKNOWLEDGEMENTS

“He who climbs a good fruit-tree deserves good push”: This is a popular old adage among the Ashanti tribe in Ghana. This thesis got this far because some individuals saw its potential and did everything to give me the necessary assistance (Economic, Moral and intellectual) against all odds. With limited space, I will mention few noted ones.

My coming to Finland and for that matter the University of Helsinki was facilitated by Professor Emeritus Simo Poso, who encouraged and advised me to continue my education at the university. I render my sincere thanks to him for the opportunity offered to me to taste the exciting academic life in Helsinki. This exciting academic life in Helsinki would have been short-lived but for the timely assistance and encouragement of my Supervisor, Professor Timo Tokola (Geoinformatics). His sense of patience, encouragement and direction was superb; “thank you sir”. I also enjoyed a fruitful supervisory assistance from Professor John Simelius (Agriculture Economics), and brief but useful advice from Dr. Michael J. de Smith (University college of London). Many thanks go to Professor Pauline Stenberg for holding the fort and directing me to a successful completion. I cannot forget my colleagues at the former Department of Forest Resource Management (now part of Forest Science department), especially Ikka Korpela (Research fellow) and Juhana Nieminen (GIS) for their support and giving me a feeling of a sense of belonging at the department. I also thank the pre-examinaers for their useful suggestions. I appreciate the two Master students (Oppong Francis and Agyei Asamoah Emanuel) from the Universities of Cape-Coast and, Science and Technology (Ghana), respectively, for their contribution in the intensive data collection.

The immense economic support enjoyed from ADRA made it possible for me to keep the research going. Special thanks in this regard go to the late Mr Kaare Lund (Norway), Mr Akwasi Agyamang and Mr Vandapuje (Ghana). I thank the Nordic Informatics Network, and Helsinki Technical University for the opportunity offered to expand my scope in geoinformatics through many courses and seminars.

My final acknowledgement goes to my big family and friends. Unfortunately my late mother, Madam Mather Awuah, and Uncle John Kwadwo Awuah did not leave to see this day. Their wisdom advice built my confidence and gave me a clear picture of the world and how to cope with the difficult and unexpected situations I am bound to face in life as a human being. Thanks to Eva Keriden, Florence Owusu, Frank Ampofo and Professor (Dr.) Roald Jari Guleng who stood by me in time of difficulties, sickness, and pain. To all of you, I am happy that the push you gave me has not been in vain but ended with a delicious and succulent fruit.
# TABLES OF CONTENT

ABSTRACT ........................................................................................................... 3

ACKNOWLEDGEMENTS ....................................................................................... 4

TABLES .................................................................................................................. 9

FIGURES ............................................................................................................... 10

ACRONYMS .......................................................................................................... 12

1 INTRODUCTION AND BACKGROUND .......................................................... 13

1.1 AGRICULTURE AND SUSTAINABLE DEVELOPMENT .................................... 14
    1.1.1 The Role of Agriculture in Poverty Alleviation ........................................ 14
    1.1.2 Agriculture-based Poverty Alleviation Programme as Sustainable Development ................................................................. 16

1.2 OBJECTIVES .................................................................................................. 18

1.3 CONCEPTUAL FRAMEWORK ......................................................................... 19
    1.3.1 Outline of the Systems Approach to Evaluation ...................................... 19
    1.3.2 Criteria and Indicators used for Project Evaluation ................................. 20
    1.3.3 Geospatial Analysis of Poverty ................................................................. 21
    1.3.4 Poverty Mapping and Interpolation ........................................................... 23

2 MATERIALS AND METHODS ......................................................................... 28

2.1 STUDY AREA ................................................................................................ 29

2.2 DESCRIPTION OF CASE STUDY PROJECT .................................................. 31

2.3 DATA COLLECTION METHODS AND ANALYSIS ........................................... 32

2.3.1 GIS Data ..................................................................................................... 32
    2.3.1.1 Blueprint Map Used ............................................................................ 32
    2.3.1.2 Satellite Imagery .................................................................................. 33
    2.3.1.3 Digital Elevation Model ...................................................................... 34
    2.3.1.4 GIS Database Structure ...................................................................... 34

2.4 PLANNING OF SAMPLING AND MEASUREMENTS .................................... 36

2.5 STANDARDS USED AND MEASUREMENT PRACTICES ............................... 38

2.6 INDICATORS AT DIFFERENT GEOGRAPHICAL SCALES .............................. 38

2.7 QUANTITATIVE ASSESSMENT OF SUSTAINABILITY AND POVERTY ......... 41
    2.7.1 Technical Efficiency and Productivity ...................................................... 42
    2.7.2 Stability .................................................................................................... 43
    2.7.3 Biodiversity Variables .............................................................................. 44
    2.7.4 Seasonal Variation of Variables ............................................................... 45
2.7.5 Risk Factors in Farming ................................................................. 46
2.7.6 Cultural Diversity Variables.......................................................... 47
2.7.7 Profitability ................................................................................... 47
2.7.8 Resilience Factors........................................................................ 48
2.7.9 Rules of Resource Management...................................................... 48
2.7.10 Satisfaction of Basic Needs ............................................................ 48
2.7.11 Spatial Distribution of Equity ........................................................ 49

2.8 SUSTAINABLE POVERTY ALLEVIATION MAP (SPAM) AND SPATIAL SUSTAINABILITY INDEX (SSI) .................................................. 49
2.10 SENSITIVITY ANALYSIS OF ATTRIBUTE/INDICATOR WEIGHTS .............................................. 52
2.11 INTERPOLATION OF REGIONAL DATA ................................................................. 52
2.12 DEVELOPMENT OF THE ANALYSIS AND ASSUMPTIONS AT SPECIFIC SCALES........ 53
  2.12.1 Crop Production Practices in the Research Area were Assumed to Lead to Soil Degradation ................................................................. 53
  2.12.2 Production Techniques Favour Development of Specific Pests and Diseases, Which is Assumed to Lead to Increased Pesticide Input with Negative Environmental Consequences ................................................ 53
  2.12.3 Soil Erosion and Production Techniques Affect River Water Quality ...... 55
  2.12.4 The Environmental Impact of Current Land Use has a Negative Effect on Human Health in Society ................................................................. 55
  2.12.5 Production Costs Increase Due to the Additional Quantities of Chemicals and Labour Input Required to Compensate for the Negative Effects of Current Land Use, while Yields Tend to Decline. Both Effects will Reduce Farm Income ................................................................. 56
  2.12.6 The Production and Economic Well-being of Communities Can be Increased with Various Incentives ........................................................................ 58
  2.12.7 There was an Even Distribution of Development Projects Across the Communities ......................................................................................................... 58
  2.12.8 The Degree of Freedom in Decision-making Processes was Low in Farm Households ......................................................................................................... 58

3 RESULTS .......................................................................................... 59

3.1 ANALYSIS OF POVERTY AT DIFFERENT SCALES .............................................. 60
  3.1.1 Hierarchy of GIS Analysis ........................................................................ 60
  3.1.2 Plot Level Analysis ................................................................................. 60
APPENDIX 1. WATER QUALITY INDEX CALCULATION BASED ON TURBIDITY, TEMPERATURE, pH, PHOSPHATE, AND NITRATE .......................... 109
APPENDIX 2. SPATIAL REFERENCE VALUES TABLE DERIVED FROM THE TICK MARKS - THE PAPER MAP (FIGURE 2.2) .......................................................... 110
APPENDIX 3. INDICATOR-REFERENCE VALUES .................................................. 111
APPENDIX 4. SPECIMEN OF SOCIO-ECONOMIC SURVEY QUESTIONNAIRE ........... 112
TABLES

Table 1.1 Sustainability criteria ................................................................. 17
Table 2.1 Indicators used at the farm household level ........................................ 39
Table 2.2 Indicators used at the plot level ....................................................... 40
Table 2.3 Indicators used at the watershed level .............................................. 40
Table 2.4 Indicators used at the developmental level ...................................... 41
Table 2.5 Average yield per ha⁻¹ (in tons) showing the stability level of individual crops and fruit/trees -from mixed-farms ....................................... 44
Table 2.6 Relative monthly production information (percentage income) showing the time dispersion/concentration (n = 65). * Parameters: V, SD, CV, and X ...... 45
Table 2.7 The main risk factors (proportion per number of farmers interviewed and locational distribution) .......................................................... 46
Table 2.8 Descriptive statistics related to cultural diversity ............................... 47
Table 2.9 Community satisfaction with ADRA's projects ................................ 49
Table 2.10 Index computation: attributes and factors ...................................... 50
Table 2.11 Differences in soil quality attributes between cassava-based and maize-based plots (the unit of measurement is listed in the degraded factors, below) ........... 60
Table 2.12 Paired samples t-test in soil quality for cassava- and maize-based plots .... 61
Table 2.13 Tests of between-subjects effects: degraded plot tests of between-subjects effects (percrop denotes percentage of crop on a plot) .............................. 62
Table 2.14 Comparing indicators from degraded and less degraded plots in the study area (currency: euros; fertiliser and pesticide applications: kg ha⁻¹) ............... 65
Table 2.15 Human health risk: univariate statistics for the research area ............. 68
Table 2.16 Information derived from cross-validation of the model to show how well the model predicts the unknown values when arriving at the map shown in Figure 4.8 .... 69
Table 2.17 Economic indicators at the farm household level in Euros .................. 71
Table 2.18 Prediction error for threshold income probability ............................ 72
Table 2.19 Prediction error for threshold labour income probability ................... 72
Table 2.20 Moran's I index for the spread of development projects, i.e., roads/paths, schools, and hospitals are shown here as partially dispersed because of the distribution of these features ................................................................. 74
Table 2.21a, b Technical efficiency and the production frontier .......................... 75
Table 2.22 Prediction error for surface stability map ........................................... 76
Table 2.23 Ranking of cultural diversity based on household response to ADRA’s activities .................................................................................. 81
Table 2.24 Summary of criteria weight change effects on sensitivity, i.e., the first and last five sustainable ranking households ............................................ 85
FIGURES

Figure 1.1 Sustainability dimensions: scheme of the agriculture-based poverty alleviation programme showing the intersection of three conceptual standards of Sustainability (adopted from: Sustainable Development Portal). ............................................... 16
Figure 1.2 Conceptual model for solving geospatial problems .................................................. 19
Figure 1.3 Plot of a theoretical variogram base on a Gaussian model with nugget = 2, sill = 10, and range of influence = 8 .................................................................................. 27
Figure 2.1 The study area: Ga West ......................................................................................... 29
Figure 2.2 Paper map of Ga West (source of data: Geological Survey of Ghana)................. 32
Figure 2.3 Snapshot satellite image of Ga West (source of data: Landsat Geocover) ......... 33
Figure 2.4 DEM image of Ga West: digital elevation model (source of data: East-View Cartographic) .................................................................................................... 34
Figure 2.6 Aquatic species and the pollution level (Modification from schoolweb) ..... 37
Figure 2.7 Average farm efficiency percentage adjustment (average TE = 0.6)................. 42
Figure 2.8 Ranking of the 11 influential factors after the study area’s Technical Efficiency and Productivity evaluation ................................................................. 43
Figure 2.9 An example of how the SSI visual map and calculations are derived from the datasets using the 16 sustainability attributes/factors .............................................. 51
Figure 2.10 Locations of plots (maize and cassava plots are shown separately). Pest and disease pressure affected plots shaded with grey. .................................................. 54
Figure 2.11 Degraded plots were mainly clustered around rivers and watersheds with a higher crop income ............................................................................................... 57
Figure 3.2 Estimated marginal means of degraded plot in relation to crop percentage on plot .................................................................................................................. 62
Figure 3.3 Pie chart showing the pest/disease effects of different types of mixed farming ......................................................................................................................... 63
Figure 3.4 Profile plot for crop percentage effect on trees ....................................................... 63
Figure 3.5 Chart demonstrating how plot suitability matches fruit tree yield and an eventual increase in total farm income (total farm inc). This plot includes both cassava- and maize-based plots, so the slope is not highly positive......................... 65
Figure 3.6 Distribution of tree income and degraded plots in the study area ....................... 66
Figure 3.7 Distribution of gross margin and degraded plots in the study area ..................... 67
Figure 3.8 Ordinary kriging map of human health risks in the study area ............................ 68
Figure 3.9 Raster layer showing the distance to rivers ............................................................ 70
Figure 3.10 Water quality/distance to river .......................................................................... 70
Figure 3.11 Indicator kriging: probability of income >4936.45 Euros ................................. 71
Figure 3.12 Indicator kriging: probability of a day’s wage >0.75 Euros ............................... 72
Figure 3.13 Density surface map showing areas of higher church density (perceived church influence). Kernel density bandwidth 1.33, N = 43 ............................................ 73
Figure 3.14 Gaussian kernel ................................................................................................. 74
Figure 3.15 Erosion assistance projects were mainly located at comparatively low elevations in the research area ............................................................................. 75
Figure 3.16 Map illustrating the efficiency level in different plots with the research area ......................................................................................................................... 76
Figure 3.17 Sustainable stability surface map ........................................................................ 77
Figure 3.18 Prediction map of organic matter content to illustrate the nitrogen level and its effect on the soil ...................................................................................... 78
Figure 3.19 Pollution map estimating the level of pollution and how stable or strained ecosystem affected the aquatic life. A type species indicates the level of pollution in a river in the research area. ................................................................. 79

Figure 3.20 A raster layer showing the risk level at different locations in the research area. ...................................................................................................................................... 82

Figure 3.21 Spatial Sustainability Index .................................................................................. 83

Figure 3.22 Sustainable Poverty Alleviation Map (SPAM) .................................................. 84

Figure 3.23a. Sensitivity map: +10 ecological, -10 social-economic-developmental criteria weights ........................................................................................................................................ 85

Figure 3.23b. Sensitivity map: +10 social-economic-developmental, -10 ecological criteria weights ........................................................................................................................................ 85
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADRA</td>
<td>Adventist Development and Relief Agency</td>
</tr>
<tr>
<td>AMISE</td>
<td>Asymptotic mean integrated squared error</td>
</tr>
<tr>
<td>APM</td>
<td>Area production model</td>
</tr>
<tr>
<td>BIFAD</td>
<td>Board of International Food and Agriculture Development</td>
</tr>
<tr>
<td>CCAI</td>
<td>Collaborative Community Agroforestry Initiatives</td>
</tr>
<tr>
<td>CCFI</td>
<td>Collaborative Community Forest Initiative</td>
</tr>
<tr>
<td>CGIAR</td>
<td>Consultative Group on International Agriculture Research</td>
</tr>
<tr>
<td>CIDAR</td>
<td>Centre for International Development and Reconciliation</td>
</tr>
<tr>
<td>CIS</td>
<td>Cardinal Index of sustainability</td>
</tr>
<tr>
<td>CSR</td>
<td>Complete spatial randomness</td>
</tr>
<tr>
<td>CSS</td>
<td>Community Social Services</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital elevation model</td>
</tr>
<tr>
<td>DHS</td>
<td>Demographic and Health Surveys</td>
</tr>
<tr>
<td>D + C</td>
<td>Development and Cooperation</td>
</tr>
<tr>
<td>Ed</td>
<td>Euclidian distance</td>
</tr>
<tr>
<td>EDA</td>
<td>Exploratory data analysis</td>
</tr>
<tr>
<td>EPAG</td>
<td>Environmental Protection Agency of Ghana</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>ERDAS</td>
<td>Earth Research Data Analysis System</td>
</tr>
<tr>
<td>ESDA</td>
<td>Exploratory spatial data analysis</td>
</tr>
<tr>
<td>ESRI</td>
<td>Environmental System research Institute</td>
</tr>
<tr>
<td>ESTDA</td>
<td>Exploratory spatiotemporal data analysis</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organisation</td>
</tr>
<tr>
<td>FIDA</td>
<td>Finnish International Development Agency</td>
</tr>
<tr>
<td>FNCSDF</td>
<td>Finnish National Commission for Sustainable Development</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross domestic product</td>
</tr>
<tr>
<td>GIRT</td>
<td>Geographical Information Response Team</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information System</td>
</tr>
<tr>
<td>GNA</td>
<td>Ghana News Agency</td>
</tr>
<tr>
<td>GNG</td>
<td>Ghana National Grid</td>
</tr>
<tr>
<td>GO</td>
<td>Governmental organisation</td>
</tr>
<tr>
<td>GPS</td>
<td>Global positioning systems</td>
</tr>
<tr>
<td>GRID</td>
<td>Arendal United Nations Environment Programme Information collaborating centre</td>
</tr>
<tr>
<td>GSS</td>
<td>Ghana Statistical Service</td>
</tr>
<tr>
<td>GTZ (GMBH)</td>
<td>Deutsche Gesellschaft für Technische Zusammenarbeit</td>
</tr>
<tr>
<td>GWC</td>
<td>Ghana Water Company</td>
</tr>
<tr>
<td>IDW</td>
<td>Inverse distance weight</td>
</tr>
<tr>
<td>IFAD</td>
<td>International Fund for Agriculture Development</td>
</tr>
<tr>
<td>Infor agrar</td>
<td>Agricultural information and documentation service for sustainable agriculture</td>
</tr>
<tr>
<td>KDE</td>
<td>Kernel density estimate</td>
</tr>
<tr>
<td>KVIP</td>
<td>Kumasi Ventilated Improvement Pit</td>
</tr>
<tr>
<td>LSM</td>
<td>Living Standards Measurement Study</td>
</tr>
<tr>
<td>LISA</td>
<td>Local indicators of spatial analysis</td>
</tr>
<tr>
<td>MMA</td>
<td>Massachusetts Municipal Association</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-governmental organisation</td>
</tr>
<tr>
<td>NORAD</td>
<td>Norwegian Agency for International Development</td>
</tr>
<tr>
<td>NTU</td>
<td>Nephelometric turbidity units</td>
</tr>
<tr>
<td>OECD</td>
<td>Organization for Economic Co-operation and Development</td>
</tr>
<tr>
<td>pH</td>
<td>Power/potential of hydrogen</td>
</tr>
<tr>
<td>ppm</td>
<td>Part per million</td>
</tr>
<tr>
<td>RTC</td>
<td>Relative time concentration</td>
</tr>
<tr>
<td>RTD</td>
<td>Relative time dispersion</td>
</tr>
<tr>
<td>SADA</td>
<td>Spatial analysis and decision assistance</td>
</tr>
<tr>
<td>SA</td>
<td>Sensitivity analysis</td>
</tr>
<tr>
<td>SPAM</td>
<td>Sustainable Poverty Alleviation Map</td>
</tr>
<tr>
<td>SSI</td>
<td>Spatial Sustainability Index</td>
</tr>
<tr>
<td>TIN</td>
<td>Triangulated Irregular Network</td>
</tr>
<tr>
<td>UNRISD</td>
<td>United Nations Research Institute of Sustainable Development</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nation Development Program</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Programme</td>
</tr>
<tr>
<td>USAID</td>
<td>United States of America International Development</td>
</tr>
<tr>
<td>UTM</td>
<td>Universal Transverse Mercator</td>
</tr>
<tr>
<td>WB</td>
<td>World Bank</td>
</tr>
<tr>
<td>WBR</td>
<td>World Bank Report</td>
</tr>
<tr>
<td>WDR</td>
<td>World Development Report</td>
</tr>
<tr>
<td>WED</td>
<td>World Environmental Day</td>
</tr>
<tr>
<td>WGS</td>
<td>World Geodetic System</td>
</tr>
</tbody>
</table>
1. INTRODUCTION AND BACKGROUND

1.1 Agriculture and Sustainable Development

In recent decades, the pursuit of poverty alleviation in developing countries has shifted dramatically towards development assistance, by seeking ways to accommodate, encourage, and support agricultural practices with economic and social development. This is based on the obvious assumption that agricultural development is an essential element of a successful strategy for alleviating mass poverty. The prevailing logic is that agriculture is a source of food and also because agriculture and rural off-farm activities are major sources of income for the rural poor (Broca, 2002; FAO, 2002). The pitfall of this assumption and practice is that agricultural practices can upset the balance of ecosystems and exhaust the land, and because the soil nutrients required to grow crops are consumed by those trying to eke out a living by farming activities. Unfortunately, the poorest in society eventually bear the brunt of these adverse environmental impacts (Oxfam, 2009). The effect leads to a vicious circle of environmental degradation and poverty.

Recognition of this problem has led to many declarations and resolutions related to sustainable development by the international community, starting with the Brundtland Commission (WCED, 1987). Thus, the alleviation of poverty, especially where it is based on agriculture, should consider the capacity of natural systems as well as the social and economic challenges facing humanity. Several governmental organisations (GOs) and non-governmental organisations (NGOs) that use agriculture as a tool for poverty alleviation have adopted sustainable development as a cardinal development agenda (OECD, 2001). This area is now prominent in poverty alleviation projects in many developing countries, especially in Sub-Saharan Africa where the reserves of good land continue to dwindle and the amount of tropical land continues to be degraded by the disruption of land and forest ecosystems, both at alarming rates (FAO, 1995).

In recent years, many inputs have been made by various development agencies, GOs and other NGOs, including, ADRA, AGRID, CGIAR, CIDA, EU, FAO, FIDA, ICRAF, JÖB/BMZ, NORAD, OECD, Oxfam, UNEP/GRID-Arendal, USAID, and WB. These agencies use agriculture as a means of enhancing socio-economic development and environmental welfare. However, despite these noble objectives and the positive contributions made by researchers, policies, and practices towards these goals, there is little consensus regarding appropriate performance measurements to quantify agriculture-based poverty alleviation considering environmental welfare (Scott, 2003). Clearly, the attainment of the goals of such projects needs to be evaluated, as with any other goal attainment system. According to Sabine Muller (1999), a form of measurement of the system is required if the concept of agriculture-related sustainable development is to be used as an underlying component of human interventions in the environment and ecosystems. Completing such an evaluation will make an agriculture-based poverty alleviation programme a feasible operational concept when offering guidance on sustainable development initiatives. Evaluation is also important after a set time period to assess the process, content, and results of a strategy so as to correct its weaknesses and identify improvements (FNCSD, 2009). This research study was directed towards this task by using geospatial techniques and methods. However, it is broadly a multidisciplinary approach for measuring diverse interacting parameters.
related to environmental conditions and human activities. Eventually, the aim is to address how the development goals of an agriculture-based poverty alleviation programme can be measured "to support informed and evidence-based decision-making" (Messerli et al., 2009). This study was conducted with and applied to the ADRA’s (Adventist Development and Relief Agency) programme in the Ga West district of the Greater Accra Region in Ghana.

1.1.1 The Role of Agriculture in Poverty Alleviation

Agriculture is used globally and locally as a multi-functional tool (EU Commission, 2000). It is no longer limited to solely producing food and fibres, but instead it has socio-economic and environmental dimensions that could be enhanced to alleviate poverty. The present study broadly adopts the definition of poverty given by the OECD Development Action Committee’s Guidelines on Poverty Reduction (OECD, 2001):

"Poverty encompasses different dimensions of deprivation that relate to human capabilities, including consumption and food security, health, education, rights, voice, security, shelter, dignity, decent work and environmental well-being."

Poverty and hunger are the major problems confronting the vast majority of developing countries and we can safely say that its consequences are the socio-economic and environmental problems engulfing those countries. This was eloquently summed up by Smith (1776): "No society can surely be flourishing and happy, of which the far greater part of the members are poor and miserable." Poverty and hunger make people more susceptible to conflicts, environmental degradation, illiteracy, marginalisation and social tension.

Agriculture, in its broadest sense, has been instrumental in solving the poverty problems listed above, especially in the poorest countries where the economies have yet to be diversified and where the great majority of people rely on agriculture for their livelihoods. It has long been demonstrated that agriculture can contribute three to four times more to poverty reduction than any other sector (IFAD, 2006). Cross-country econometric estimates indicate that the overall GDP growth originating in agriculture is, on average, at least twice as effective in benefiting the poorest half of a country's population as growth generated in non-agricultural sectors (WBR, 2008). Clearly, many countries with relatively high agricultural growth rates have seen substantial reductions in poverty.

Furthermore, a study on agricultural productivity and poverty alleviation produced a few years ago in a Development Policy Review showed that growth in agriculture benefits the poor more than growth in any other sector and yield increases of just 1% reduce the proportion of people living on less than $1 per day by 0.6–1.2% (Wadsworth, 2008). China's sudden growth in agriculture was initially responsible for a rapid decline in rural poverty from 53% in 1981 to 8% in 2001. Agriculture was also the key to India's slower, but still substantial, long-term decline in poverty. More recently, Ghana has been Africa's breaking story with a 24% reduction in rural poverty over 15 years, partly because of recent strong agricultural performance (WDR, 2008). In addition, agriculture remains one of the easiest ways to relate to the environment (MMA, 1999). Societal development efforts may be enhanced by using agriculture to bring together a community for its common good. Under many circumstances, agricultural growth in developing countries is a necessary condition for rural non-farm growth and rural development in general (Infor agrar, 2007).
Based on the above trend, a consensus is gradually growing around a view that the increase in agriculture and its productivity are essential for achieving sustainable growth and a significant reduction in poverty in developing countries (Prasada et al., 2004). However, using agriculture for poverty reduction and for solving pressing social problems may be problematic for environmental protection. Many of the major environmental problems are linked closely to land use, such as desertification and the loss of biodiversity (Flores et al., 2008).

1.1.2 Agriculture-based Poverty Alleviation Programme as Sustainable development

Working towards an agriculture-based poverty alleviation programme requires balancing several goals spread over three developmental dimensions, i.e., economic, social, and environmental.

![Figure 1.1 Sustainability dimensions: scheme of the agriculture-based poverty alleviation programme showing the intersection of three conceptual standards of Sustainability (adopted from: Sustainable Development Portal).](image)

However, none of these developmental dimensions can successfully be achieved in isolation because they are inherently intertwined in the context of poverty alleviation. The farm is considered to be the basic unit of sustainability assessment and it has increased in popularity in recent years, which has proved useful for policy-makers because this is the focal unit of most public policies (Reig-Martinez et al., 2011). Agriculture-based poverty alleviation programmes can be addressed within a broad conceptual framework of sustainable development. The main concept involves using available biophysical and human resources to achieve an economically viable yield/income infrastructure that will be environmentally sustainable and equitably distributed across a society (Figure 1.1).

Like any sustainable development, using agriculture to alleviate poverty requires balancing the three dimensions shown in Figure 1.1. These three dimensions of sustainability are used in many approaches when analysing poverty alleviation and sustainable development (Segnestram et al., 2000, Van der Werf and Petit, 2002).
This view assumes that sustainable development uses a decision-making framework that takes into account the biophysical environment as well as human society and its economy. The logic assumes that sustainable development is anchored by principles, policies, and practices that guide personal and collective behaviour related to food security, which is based on the life-sustaining processes of the earth and its natural resources, the provision of jobs, incomes, wealth, and social amenities resulting from economic and developmental activities (Broca, 2002). This objective can be achieved in a number of ways, so sustainable development is not linked to any particular technological, agricultural, or developmental practices, nor is it the exclusive domain of any particular agricultural technology (Arthur, 1995).

### Table 1.1 Sustainability criteria

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rules of Resource Management</td>
<td>Natural resources are to be managed so that its stock does not decline over time. Ecological restrictions should be respected.</td>
</tr>
<tr>
<td>Satisfaction of basic needs</td>
<td>The appraisal of development may be considered by its contribution to the satisfaction of basic needs of the society.</td>
</tr>
<tr>
<td>Efficiency and productivity</td>
<td>Efficiency is a measure of how well (efficient) the transformation of inputs into a set of outputs (productivity) based on a given set of technology and economic factors.</td>
</tr>
<tr>
<td>Resilience</td>
<td>Resilience as applied to integrated systems of people and the natural environment is the degree to which the system is capable of self-organisation, retain the same function and structure even after a change, and capacity to learn and adopt.</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>The convention of biodiversity calls upon parties to conserve and sustainably use biological diversity. Healthy human environment depends entirely on biodiversity.</td>
</tr>
<tr>
<td>Stability</td>
<td>The concept of balancing nature as demanded by sustainable development implies that the system will maintain integrity under any sort of perturbation: the system will return to the position of equilibrium when disturbed.</td>
</tr>
<tr>
<td>Equity</td>
<td>Distribution of resources, and also of production results among humans, considering issues such as gender, race, religion, age, should be done fairly to sustain development.</td>
</tr>
<tr>
<td>Profitability</td>
<td>In many cases, profit motivation is the main reason for environmental degradation, but profit is very important for the future and for the realisation and implementation of sustainable development. Financial profit may be unreliable in sustainable development if it is acquired at the expense of the environment.</td>
</tr>
<tr>
<td>Culture diversity</td>
<td>The promoting of local access and control over resources, enhancing autonomy, indigenous knowledge, and respecting the cultural diversity of rural communities is important for sustainable development. Cultural diversity is as necessary for mankind as biodiversity is for nature.</td>
</tr>
<tr>
<td>Risk</td>
<td>The balancing act for a sustainable development is to devise a decision-making policy to ascertain the health and socially acceptable level of risk so that they do not exceed derived benefits.</td>
</tr>
<tr>
<td>Time dispersion</td>
<td>The time dispersion of income and food production is an important part of farming performance and sustainable development as a whole.</td>
</tr>
</tbody>
</table>

However, depending on the dimensionality of the analysis or the evaluated variables, the general concepts of sustainable development use a series of common sustainability criteria accepted by many authors (Aigner et al., 1977; Conway, 1987; McConnell and Dillon- (FAO), 1997; TOB, 2000). The expanded version of these criteria (Table 1.1) shows the multifaceted character of sustainable development, although they can be
analysed holistically to arrive at a sustainability index for particular units of analysis. Agriculture-based poverty alleviation programmes have the same characteristics as sustainable development and the practical challenge is to identify an analytical framework within which various aspects can be examined, compared, and integrated.

1.2 Objectives

The main objective of the study was to develop appropriate geospatial techniques and methods using other known impact assessment parameters (FAO, 1997, Muller, 1999), to assess an agriculture-based poverty alleviation program. The study generated a framework that could integrate agro-ecological, socio-economic, and developmental information to allow the evaluation of various levels of the agriculture-based poverty alleviation programme and its impacts. The intention was to adopt extremely divergent parameters, including scientific quantitative data and normative settings that are mainly quantitative (Messeri et al., 2006). The ultimate goal was to use geospatial analysis to integrate social values and interrelated technological knowledge to develop agriculture-based poverty alleviation programme evaluation techniques. It was assumed that the technique would provide detailed knowledge and quantitative characterization of our living environment and the socio-economic settings that are required for prediction at local and global scales, both in time and space.

Specifically, the systematic procedure adopted here involves exploring and understanding the patterns, relationships, and situations based on spatiotemporal data within the research area. From this, eight specific hypotheses (Sections 3.4 to 3.4.8) were defined and individually tested to determine the potential impact (sustainability) of the programme at various geographical scales. These hypotheses were also a strong contributory factor when selecting appropriate analytical methods and tools from those readily available in the GIS regime. The sustainability of the agriculture-based poverty alleviation programme was tested in the case study area based on the outputs of the hypotheses.

The focus was on an investigation of spatial patterns and relationships to guide a broader understanding of spatial patterns and processes within the research area. It was envisaged that the outcome would yield empirical information, poverty maps, and a SSI related to the environmental, socio-economic, and developmental impact. Additionally, this helped to demonstrate the operationalisation of sustainable development. The methodology was tested with ADRA’s programme of poverty alleviation in the study area. The results could provide informed knowledge and understanding to guide decision-makers towards possible areas that require further intervention with development activities, or to provide effective management and environmental protection.

Well-defined and iterative stages of the geospatial problem-solving process were followed to achieve these objectives (Figure 1.2). The stages involved: problem formulation, breaking the problem down, exploratory analysis, hypothesis formulation, performing the analysis, verifying the model results, final reporting, and providing suggestions for further intervention.
Figure 1.2 Conceptual model for solving geospatial problems

The need for a more iterative approach (Haining, 2003) partly reflects the adoption of a scientific analytical task as well as normative settings within a much broader context. This recognises the method of most analytical tasks, such as assessing ADRA's agriculture-based poverty alleviation programme, which exist within a much broader context of analytical methodologies.

1.3 Conceptual Framework

1.3.1 Outline of the Systems Approach to Evaluation

The focus of evaluation is mainly an assessment of the contributions and relationship between various factors affected by a given development outcome. Therefore, an appropriate analytical framework for the identification and description of the spatial patterns of different factors leads us to produce models that help us to understand the processes giving rise to certain outcomes. The phenomenon of poverty has multiple dimensions and is not simply limited to economic aspects (Epprecht et al., 2009). Poverty alleviation is not only about solving a given set of existing problems at particular scales, but is instead concerned with the dynamic capacity of entire socio-economic-ecological systems to keep pace with emerging new problems and crises, as well as maximising the systematic problem-solving capacity. The systems approach is widely considered by most authors as appropriate for understanding the complex factors associated with agricultural programmes intended to alleviate poverty (Conway, 1983; Maples, 2005). Interactions between man and nature are complex matters and they require a holistic systems approach for their investigation and analysis (Ohlsson, 2009). In this framework, different concepts and techniques are merged into a systems approach for evaluating the consequences and potentials of alternative aspects of a sustainability programme. This is less concerned with a specific farming or development strategy and more related to a systems-oriented approach for understanding complex ecological, social, and environmental interactions in poor communities.
In their new approach to quantifying Landscape Mosaics Development in Laos (Lao PDR), Messerli et al. (2009) re-emphasised the importance of “collaboration between scientists and decision-makers” (Kates et al., 2001) when measuring poverty programmes. Understanding a system involves understanding all the social, economic, environmental, and developmental actors connected with the unit under study.

The basic concept used to describe any system that integrates ecological and societal systems is that of ecosystems (Sayer, 2005). Agriculture-based poverty alleviation impact assessments require an understanding of ecosystems. Thus, agroecosystems are managed to ensure a continuous agricultural output that satisfies the changing needs of current and future populations (BIFAD, 1988; Young, 1989; CGIAR, 1990; Girt, 1990; FAO, 1991; Ruttan, 1991). Agroecosystems are defined here as "regionally defined entities, managed for the purpose of producing food, fibre and other agricultural products." This explicitly includes human beings (as decision-makers, producers, and consumers) as essential elements, which means that this includes socio-economic and public health, as well as environmental, dimensions (Walterner-Toews, 1993).

An agroecosystem is defined for a given domain, pattern and process. Different agroecosystems are interrelated and a disruption in any subset could have an impact at the same or different hierarchical levels. Thus, agriculture-based poverty alleviation in a region is not simply evaluated by examining the sustainability of its different subsystems. It is important to identify a sustainability criterion for the region (domain) itself. A sustainable socio-economic system must also consider its impact on other systems in the region. Communities generate a web of interactions among the environment, the economy, and the society.

1.3.2 Criteria and Indicators used for Project Evaluation

Using sustainability as the development goal of agriculture-based poverty alleviation programmes implies that programmes have to be analysed in terms of the relationships among their implicit economic, environmental, and social objectives. This emphasises the multiple-dimensional nature of any programme that requires a form of multi-criteria decision-making approach (Messerli et al., 2009.). Sustainability requires the integration of multi-dimensional indicators with links among the economy, environment, and society. Indicators perform many functions and they can be used as an important tool for providing the requisite information for multi-criteria decision-making. The United Nations Conferences on the Environment and Development (1992–2007) continue to highlight the important role indicators play in helping to make informed decisions concerning sustainable development. The importance of the indicator approach in sustainability discussions is also reflected by the numerous efforts of international organisations and countries to define indicator sets suitable for specific respective purposes (Muller, 1999).

Indicators aggregate and simplify diverse information into a useful and more advantageous form. This means that a sustainability indicator is a value or a quality that captures the status or condition of a given process or phenomenon related to sustainable development (Adriaanse, 1993). Indicators can measure and calibrate progress towards sustainable development goals. Well-defined sustainability indicators can be a useful tool when making sustainability more operational because they highlight which factors are the most important and why, as well as showing how they interact (Adiku, 2001). It should be emphasised that no universal indicators exist and that the selection of indicators is, to a large extent, determined by the purpose of the indicator set. They are very flexible instrument because they can be defined with different degrees of precision.
and they can be aggregated to suit the objectives of the analysis and available databases (Bates, 1989). However, the following principles must be observed when selecting indicators to produce a useful tool for evaluation and decision-making.

- The selection of indicators should be based on a conceptual framework.
- Objectivity and transparency must be applied.
- Significant aspects specific to the system need to be considered.

Selecting appropriate indicators and their measurement is paramount in the process of evaluation although not sufficient on its own. Indicators will only work when they can be referenced against a target (Woodley et al., 2000). Defining reference values is one of the most critical points in any discussion of an indicator’s eventual application. To evaluate and use indicators, it is often highly informative to compare the status and trends measured by the indicators against a reference state. Any evaluation in a given situation and its comparison with different alternatives is highly dependent on the type of reference values selected.

Without a baseline, it is hard to objectively assess the magnitude of changes, understand whether the magnitude of a change is important, or determine if amelioration efforts have been successful (National Research Council, 2003). Reference values have many names such as benchmarks, standards, trends, thresholds, desired future conditions, norms, tendencies, and average values of similar systems. Evaluating any system needs a reference value, including geospatial analysis.

1.3.3 Geospatial Analysis of Poverty

Considerable research effort has been devoted to spatial analysis and poverty, which has led to the subject's continuous evolution in recent years. Spatial analysis is utilised by a number of policy and research applications, ranging from the anti-poverty programmes that are the concern of this study, to assessing the determinants of poverty, food insecurity, and food aid. Location and geographical effects assume a growing importance in the analysis of poverty and its related areas. Spatial or geospatial analysis provides a distinct global perspective and a unique lens for examining the events, patterns, and processes that operate on or near the surface of our planet (Smith et al., 2008). Spatial relationships may exist between agricultural growth and rural poverty for two reasons. First, the existence of spatial poverty traps in developing countries emphasises that decisions taken by one agent in a given location may influence the decisions taken by their neighbours (Ravallion and Jalan, 1996; Janlan and Ravallion, 2002) and secondly, location-specific factors can potentially affect the outcome of agriculture growth within the context of dimensions of poverty. Understandably, geospatial analysis involves identifying how, why, and what happens where, and it makes use of geographical information that links features and phenomena on the earth’s surface to their respective locations. Therefore, spatial analysis provides invaluable tools for addressing the central questions (how, why, and what happens where) related to poverty issues. This is an active research area and many projects are in continuing development (Davis, 2003). Like any area of research, the available literature on spatial analysis of poverty reflects different methodological approaches and applications that depend on the philosophical beliefs and the domain of knowledge of individual researchers.

A recent review (Hyman et al., 2006) shows that extensive spatial analysis research work conducted in the late 1990s in the international agricultural research community
applied various spatial analysis approaches to poverty and food security assessment. Case studies from six countries (Mexico, Ecuador, Kenya, Malawi, Bangladesh, Sri Lanka, and Vietnam) were presented in the review to illustrate the use of different spatial analysis procedures for mapping the poor and the causes of their deprivation (UNEP/GRID-Arendal, 2006). The Small Area Estimation (SAE)\(^1\) procedure was adopted in all of these studies. GIS-based measures were used to calculate travelling time to markets and facilities, and the review demonstrated the importance of accessibility and distance as explanatory factors in poverty and food security outcomes. The review also treated location as a variable in a statistical analysis, when evaluating the importance of spatial relationships and proximity to welfare and environmental factors.

Another group of researchers (Bellon et al., 2005) used SAE methods and spatial analysis to study the benefits of agricultural research to poor farmers in Mexico. Using spatial analysis, the group generated high-resolution poverty maps and they combined them with geo-referenced biophysical data relevant to maize-based agriculture in Mexico. They then applied classification and cluster analysis to synthesise biophysical data relevant to crop performance with rural poverty data. The results illustrated the concentration of rural poverty in particular regions and under particular circumstances. Therefore, formal maize germplasm improvement trials were largely outside the core areas of rural poverty and there was little evidence for direct spill-over of improved germplasm.

Epprecht et al. (2008) explored the spatial distribution of poverty and inequality in Laos (Lao PDR) to generate information for use by policy-makers and development practitioners. Their study also adopted the increasingly popular SAE method to examine the geographic determinants of poverty by spatial regression analysis. Poverty maps generated by the study identified the broad spatial patterns of poverty and additional details such as the standard errors of the poverty estimates, as well as urban and rural poverty rates for each study area. The explanatory variables were topography, soil, climate, and market accessibility. Both the local and the global spatial regression models adopted in the study demonstrated that the spatial patterns of poverty depended on various geographic factors.

Despite continuous advances, the vast majority of spatial analysis research related to poverty has been limited to local determinants of poverty or ranking particular areas based on different poverty indicators. There has been minimal research into the contributions of various human actions and the environment in spatial analysis poverty studies. The living environment is a major factor affecting human evolution and socio-economic development (Matejicek, 2010). Therefore, more efforts and indicators are needed to further explore human actions within space and time that affect the environment and poverty. This is especially important when spatial analysis is used to measure programmes intended to alleviate poverty. The determinants of actor changes in locations and other variables could affect poverty. Spatial analysis of poverty is not just about the location, economy, and environment. To understand the many aspects of poverty, interactions among socio-economic, environmental, and geographical variables

\(^1\) Small area estimation (SAE) is any of several statistical techniques involving the estimation of parameters for a small sub-population. This method is generally used when a sub-population of interest is included in a larger survey.
should be treated as a system. This may be better achieved by adopting a technique based on the overall spatial arrangement of the area concerned, rather than just the distance between the measured points and the predicted location.

The use of SAE in most spatial analysis studies of poverty mainly involves econometric models and livelihood system analysis. The prevalent use of econometric models and livelihood-system analysis in poverty mapping is mainly because economic measurements are the focus of most debates addressed by poverty spatial analysis and poverty measurement. Given the multidimensionality of locations and other livelihood properties, the measures of location used in traditional studies may be regarded as relatively crude proxies (Stasl et al., 2002). Spatial analysis of poverty is a multidisciplinary research field and its measurement should involve a multifaceted approach that can serve to evaluate social, economic, agricultural, emergency, environmental, and anti-poverty programmes.

Spatial analysis mainly involves manipulating spatial data into different forms and extracting additional meaning as a result (Bailey, 1995). Most applications of spatial analysis to poverty mapping are restricted to analyses that are purely deterministic. However, this does not mean that the application of other forms of analytical functionality is not equally important (e.g., network analysis, routing, location/allocation modelling, site selection, projection, or cartographic algebra), although such forms of analysis are insufficient on their own for comprehensive poverty mapping.

1.3.4 Poverty Mapping and Interpolation

Poverty mapping is increasingly an important instrument for investigating and reporting socio-economic and environmental issues, where it provides a spatial representation of poverty assessments. It is a method for visualising the spatial dimension of poverty. The assessment of information during poverty mapping comes from a variety of sources and it can be presented at various levels from the local to the global (Henninger, 1998; Deichmann, 1999; Davis, 2002). Poverty mapping facilitates the comparison of various indicators of poverty data derived from other assessments. Well-documented poverty mapping can quickly and easily provide information on the spatial distribution of poverty, which can then facilitate the targeting of interventions or development projects. If effectively applied, poverty mapping can be an effective mechanism for identifying the poor. It can also reveal the outcome of a programme and whether further intervention is needed.

Two main distinctions should be made in poverty mapping, i.e., the spatial summarisation of data and the spatial analysis of the data. The former refers to basic mapping functions for the selective retrieval of poverty information within defined areas of interest and the compilation, tabulation, or mapping of various basic summary statistics for that information. The latter is more concerned with the investigation of patterns in poverty data, particularly when seeking possible relationships between patterns, attributes, or features within the study region, and when modelling such relationships for the purpose of understanding, predicting, reporting, and/or implementation.

A variety of methods are proposed for poverty mapping, but there is no accepted standard methodology (Henninger and Snel, 2002; Davis, 2002). Nonetheless, the choice of method is crucial. Poverty mapping is influenced by the selection of a specific conceptual approach for defining poverty and by the choice of a specific poverty
indicator. The data collection method can determine the resolution of a poverty map and the type of analysis that can be conducted. Thus, poverty mapping is essentially a tool. Its functionality should be considered in terms of its intended use, the research and policy questions addressed, and the hypotheses tested (Davis, 2002).

Poverty mapping can be a useful method for producing maps, but it also a method of influencing policy decision-making processes. It can lead to serious misinterpretations of causal relationships between different variables that can result in misrepresentations. However, the use of appropriate geospatial techniques and other parameters should minimise misrepresentations and misinterpretations.

Spatial analysis has been applied to poverty mapping by organisations ranging from (GOs) to (NGO) (Henninger, 1998; Snel and Henninger, 2002). Spatial patterns and processes in poverty are very important during the decision-making and implementation stages of developmental activities. The importance of poverty reduction to the world development agenda has elicited great interest in spatial analysis, poverty, and food security (Hyman, 2005). It is undoubtedly of vital importance to poverty mapping because it can combine the best variables for visual interpretation, which is difficult for conventional models, especially when the variables are, by definition, spatially distributed. Spatial analysis poverty mapping methods can incorporate environmental information, which is important because standardised household surveys such as the LSMS and DHS² rarely collect these types of data (i.e., environmental data).

Spatial analysis to poverty mapping in the context of this study is defined as the spatial analysis of agriculture-based poverty alleviation programmes, in visual and sustainability terms. Thus, it is the mapping of programme outcomes using spatial analysis with sustainability indicators. Like most sustainable programme measurements, indicators are the focal point when representing and analysing socio-economic and environmental well-being in poverty, as related to agriculture.

Spatial determinants are important for understanding the distribution of assets that are fundamental for alleviating poverty and combating food insecurity. These include the following: human capital such as health, education, and technological advancement; social capital such as the ability to co-operate and social networks; developmental capital such as water, roads, and electricity; and environmental or biophysical capital such as sound agricultural practices and sustainable development.

The effective mapping of any ecologically and socio-economically complex system, such as the Agro-ecology Poverty Alleviation System, requires an understanding of the relationships among its many components. The first step for understanding these components is to identify patterns and relationships. An important aspect of these patterns and relationships is the spatial distribution of components with respect to each other and the variable conditions across space and time that these components occupy. The spatial arrangement of objects and processes has a vital role in understanding or investigating phenomena. All phenomena of environmental, developmental, and ecological interest have spatial locations that can be designated using geographic coordinates and other characteristics, such as measured attributes. Data have fairly precise spatial, temporal, and other property labels (attributes) associated with them.

² LSMS – Living Standards Measurement Study is mainly used with household data to measure quality of life as the basis for policy decision-making. DHS – Demographic and Health Surveys are designed for the study of health and population trends in developing countries.
Therefore, analysing these components requires information on object attributes and their associated geographical locations. Attributes and objects can be readily depicted, and the human eye can quickly discern patterns and anomalies in a well-designed map (Goodchild, 1992).

Classifying the techniques used for spatial analysis in poverty mapping is difficult because it involves different fields of research and different fundamental approaches can be applied. It can also take many forms. The selection of the appropriate methods for use with spatial data may be determined by the research objective, the measurement types, and the sampling design of the data (ibid).

The development of a collection of core statistical procedures for spatial analysis has made it possible to create poverty maps from "relatively complex, finely structured, and large spatial databases using a wide range of methods" (Longsel, 1999). Spatial statistics can be applied to measure spatial information, by identifying characteristic spatial distributions and quantifying geographical patterns. This consists of three main components (Cressie, 1999): (I) point pattern analysis: pertaining to the location of "events" of interest; (II) lattice data: spatial data indexed over a lattice of points; and (III) geostatistics: a spatial process indexed over a continuous space. Much of fundamental spatial statistics is concerned with the description and exploitation of spatial datasets (EDA), or in the context of spatial and spatio-temporal analysis, i.e., ESDA and ESTDA, respectively (Fortin et al., 2002). Such methods are by no means exclusively statistical in nature and some special forms of data mapping (i.e., visualisation) are of considerable importance for ESDA.

The advent of global and local spatial statistics, such as G statistics (Getis Ord, 1992), Geary's C (Geary, 1954), LISA (Anselin, 1995), Moran I (1948), and geostatistics, made it easier to detect the spatial patterns (spatial associations and spatial autocorrelations) in data (Bao, 1999).

Combining the cartographic visualisation of objects, events, and attributes with statistical tools provides valuable insights when determining areas of concern, patterns, and relationships. Cluster analysis is one of many exploratory data analysis techniques and statistical methods have been implemented and widely used in spatial analysis. This method of classification places objects in groups based on shared characteristics, which helps to identify spatial patterns, relationships and trends. Amaze of concepts, techniques, and algorithms are associated with cluster analysis. According to Bailey and Garell (1995), all clustering techniques begin in the same manner. Thus, each method begins with the calculation of a \((n \times n)\) matrix, \(D\), of dissimilarities between every pair of observation. Cluster analysis gives an understanding of feature distributions, degree of clustering, or dispersion across the study area, and it facilitates the tracking of changing patterns over time.

Cluster hunting refers to a family of techniques that involve computationally intensive search procedures for point and zone-based cluster identifications. This search method is aimed at identifying clusters based on spatial arrangements of incidents combined with basic information on the background population. A search of clusters (areas of unexpectedly high incidence) exhaustively examines all possible locations on a fine grid covering the study area. Identifying clustering in spatial and spatio-temporal databases does not provide a detailed picture of the nature and pattern of clustering. It is therefore helpful in most cases to apply hot spot (and cold spot) identification techniques to gain an understanding of dataset distributions, degree of clustering, or dispersion across the
study area, and tracking changing patterns over time. The tool calculates the Getis-Ord Gi* statistic for each feature in a dataset. This method determines (z-score results) whether high values or low values tend to cluster in a study area. A statistically significant hot spot must have a high value and it must also be surrounded by other features with high values. Thus, higher statistically significant positive z-scores indicate more intense clustering of the higher values (hot spots). Low statistically significant negative z-scores indicate more intense clustering of low values (cold spots). A hot spot analysis requires the following considerations: (I) the analysis field; (II) appropriate conceptualisation of the spatial relationship; and (III) the hypothesis tested (de Smith, 2008).

Other procedures for identifying spatial patterns- can also provide informative (exploratory) tools for cluster analysis such as (KDE) Kernel Density Estimate (point patter analysis), Ripley's K (or L) Function (Multi-Distance Spatial Clustering), and Moran's I (the extent to which features are clustered, dispersed, or random).

The use of geostatistical methods is not common in poverty mapping spatial analysis, but it is increasingly used in the environmental modelling of continuous demographic indicators and even economic indicators. Geostatistical methods begin with a recognition that the spatial variation of any continuous attribute is often too irregular to be modelled using a simple, smooth mathematical function. Instead, the variation can be better described using a stochastic surface (Burrough and McDonnell, 2000). The primary tool in geostatistical analysis is a variogram that displays the variances within groups of observations, which are plotted as a function of the distances between observations. This method determines whether data exhibit spatial dependencies, i.e., measurements at points that are close together are more similar than those that are further apart. The variogram consists of an experimental variogram calculated from the data and a variogram model, or theoretical variogram, which is fitted to the data. This is defined as follows:

\[ 2\gamma(h) = E \{(Z(u) - Z(u+h))^2\} \]

where

- \(2\gamma(h)\) represents the variogram at \(h\)
- \(h\) represents the distance = \(u_i - u_j\) (lag)
- \(u\) (location vector) represents all possible locations
- \(Z\) represents the data
- \(E\) represents mean.

The variogram is a graph where a change in variance can be observed with a change in distance between sample pairs. The following three main parameters are estimated from the experimental variogram to fit the theoretical variogram (Figure 1.2): nugget effect \(c_0\), the spatial range \(a\), and the sill \(c_1\). The nugget is an intercept at the origin, which is greater than zero. The nugget effect is used to account for the measurement error, observed variability, or noise. The range of the variogram provides clear information about the size of the search window that should be used. The distance \(h\) indicates whether pairs of sites are too distant to be significantly correlated, i.e., too distant to make any contribution. Beyond the range of influence, the distance between sampling locations does not affect the spatial structure of the data and the variogram values level off, forming a sill.
Determining the optimal weights for interpolation makes the variogram an essential step during interpolation (Burrough and McDonnell, 2000). The modelling is very important for interpolation and it should be conducted with care. Selecting and fitting variograms is more of an art than a science (McArthur, 1987). Variograms may be used to select an appropriate variogram depending on the type of spatial variation present in an area of study; a model can be fitted to the experimental variogram. A number of models are used in practice. ArcGIS, like other GIS software packages, has interactive guideline routines for variogram-fitting with various models.

Figure 1.3 Plot of a theoretical variogram base on a Gaussian model with nugget = 2, sill = 10, and range of influence = 8

Kriging uses information from the variogram to identify an optimal set of weights that can be used to estimate a surface at unsampled locations. Kriging is a group of geostatistical techniques that relies on the notion of autocorrelation\(^3\). It is based on a spatial interpolation technique, which is essentially a weighted moving average technique that uses the spatial parameters (spatial range, nugget, and sill) estimated from the experimental variogram. Kriging aims to estimate the value of a random variable, \(z\), at one or more unsampled points or over larger blocks, using more or less sparse sample data. For example, \(z(s_1), z(s_2), \ldots, z(s_N)\), at \(s_1, s_2, \ldots, s_N\). The surrounding measured values are weighted to derive a prediction for an unmeasured location. The generally known formula for this type of interpolation is formed as a weighted sum of the data: Where \(\lambda_i\) is an unknown weight for the measured values at the \(i\)th location, \(s_i\) is the prediction location, and \(N\) is the number of measured values.

In kriging, the weight \(\lambda\) depends on the distance between the measurement points and the predicted location, and on the overall spatial arrangement of the area concerned. Two distinctive tasks are required for kriging prediction: (1) estimate the spatial autocorrelation of the data to create variograms and covariance functions; (2) predict the unknown values. The reliability of kriging is directly proportional to the reliability of the variogram model. Appropriate variogram selection is critical if a kriging method is

\(^3\) Auto-correlation: places close to each other tend to have similar values (i.e. their properties are positively related), whereas ones that are farther apart differ more on average.
to succeed. Kriging is a generic term that covers a range of least-squares methods of spatial prediction (Webster and Oliver, 2002). Various types of kriging are applicable to spatial analysis. Simple kriging assumes that the mean is constant throughout the region. By contrast, ordinary kriging allows the mean to vary in different parts of the region simply by using the sample point that needs to be predicted. Ordinary kriging is preferable in most environmental science applications, because of the assumption of second-order stationarity. However, it is often too restrictive for most data. The range of outcome variations with different kriging methods has led to another method of kriging, known as indicator kriging, which is now very popular. Indicator kriging is widely used because of its ability to handle almost any type of distribution and also because it can accommodate soft qualitative information to improve predictions. This type of kriging is very useful for researchers who are not interested in the best estimate of \( z(x_0) \), but only in the probability that the value of the attribute in question exceeds a certain threshold (Burrough and McDonnell, 2000). Indicator kriging is basically the same as ordinary kriging, but it is based on a non-linear form of ordinary kriging where the basic data is transformed from a continuous scale to a binary scale.

Clearly, kriging meets the aim of finding better ways to estimate interpolation weights and of providing information about errors (Chappel and Oliver, 1997). Combining other parameters with geospatial techniques for spatial analysis in poverty mapping could be of immense help in reducing the problems of overestimation and underestimation because of the strength of its (geostatistics) predictive power.
2. MATERIALS AND METHODS

2.1 Study Area

One of the most important factors when determining a research study area is considering the research objectives, questions, and core variables that are being studied. The Ga West district of the Greater Accra Region, Ghana was selected for this study.

![Study Area Map]

**Figure 2.1 The study area: Ga West**

The study area possessed all the important attributes required to determine the effectiveness of using spatial analysis and GIS for holistically measuring the key variables and addressing the questions that were pertinent to this project evaluation. The Ga West district is one of the six main agro-ecological zones in Ghana. The development activities occurring in the Ga West district were also representative of poverty alleviation programmes in Ghana and other developing countries. The farming system in the area had broadly similar resource bases, enterprise patterns, household livelihoods and constraints, development strategies, and interventions as most other poverty alleviation programmes.

Ga West was the second largest of the six municipal districts in the Greater Accra Region before it was divided into two districts, Ga East and Ga West (Ghana-district, 2008). It occupies a land area of approximately 710.2 km². There are approximately 1,028 communities and 300 farm communities with a total population of 426,439 (Statistical Service, 2006).

The district lies within the Coastal Savannah Zone of the six agro-ecological zones (Sudan Savannah, Guinea Savannah, Transition, Semi-deciduous forest, Deciduous Forest, Rainforest Coastal Savannah) and it is located between the latitudes 5°48’ North and 5°29’ North, and longitudes 0°8’ West and 0°30’ West. The district is relatively dry and humid because it lies within the Coastal Equatorial climate zone. Records from the Ghana Meteorological Department (Meteo-Ghana 2007) indicate that the temperature ranges from 20–30 °C, with an annual rainfall ranging from 635 mm along the coast to...
1,140 mm in the northern region. The vegetation is mainly coastal shrubs and grassland, which is interspersed with thickets. There are some patches of rainforest in the northeastern part of the district.

The land area of Ga West district consists of gentle slopes interspersed with plains in most regions, which generally undulates at < 76 masl. The slopes are mainly formed upon clay soils of the Dahomey gneiss, with alluvial areas surrounding the coastal lagoons that are generally flat (Dwomo and Kyei, 1998). The main soil type is related to the vegetation belt. The soils are mainly pale and sandy with brushy quartzite occurring on the surface in most areas. These soils are rich in sandstone and limestone, which makes the area a good source of materials for the construction industry. Red earth usually develops in old and thoroughly weathered parent materials (Ghana-district, 2006). The soils are typically loamy in texture near the surface, with more clay at greater depths. Soils are porous and well drained, providing ample moisture storage at depth for deep-rooting plants (Lal, 1995). The main rivers are the Densu, Nsakyi, Opinti, and Ponpon. The largest of the four is the Densu, which drains from the Eastern Region of Ghana through the western portions of the district to Weija where it enters the sea. It is the main source of water for over half the population of the Accra Metropolis (GSS, 2006). Other water bodies, mainly tributaries of the Densu, include the Adaiao, Doblo, Ntafafa, and Ponpon Rivers. Agriculture directly or indirectly supports about 55% of the economically active population in the district through various farming activities (IFAD, 2006). According to the Ghana Statistical Service (GSS, 2008), about 95% of the farmers have small-holdings. Approximately 70% of the population living in rural areas depend on agriculture and agriculture-related activities for their livelihood (Ghana-district, 2007). Land suitable for agricultural production is in demand by the estate development sector for the construction of physical structures, or for sand winning and stone quarrying. Land areas used for production are small and over-exploited without any meaningful soil conservation or improvement practices. Direct ownership of the land is in the hands of clans or family heads. Anyone in a lineage could inherit from their parents/grandparents. Land can also be owned by direct purchase or lease. According to the year 2000 census, the average household size in the district was 5.2 persons (GSS 2005). Plots of cultivated farm land are on average 2 ha with crops and fruit trees grown on the same farm plot. ADRA-assisted farms range in size from 1 ha to 4.5 ha (ADRA, 2006). Irrigation was non-existent in the study area. Farming was labour-intensive and visible signs of erosion are found in farming areas and communities. The watershed area was mostly affected by intensive farming with many farmers cultivating very close to the river banks. There was high pressure from pests and diseases so pesticide application was very common, typically about 20 times per crop per season (FAO, 2006). Chemical fertilisers were applied at a higher rate. Organic fertiliser was not common in the study area.

Ga West is one of the poorest districts in Ghana. The percentage of the population living below the poverty line (1500.40 Cedis a day\(^4\)) in Accra was 25%, while in Ga West the proportion was around 57% (IFDA, 2008), although both areas lie in the same region. Lack of access to social amenities and infrastructure is common in the district. The illiteracy rate is higher than the national average of 26% (Ghana-District 2006). ADRA's developmental initiative is intended to enhance the general well-being of the population in the study area. A total of 65 farm households, representing 43 farm

\(^4\) Equivalent to 0.86 Euros (average exchange rate: (Bank of Ghana, 2008)
communities in the study area, were selected for the study. Initially, 86 farm plots were selected but the final number dropped to 65, representing one farm plot per household or owner.

2.2 Description of Case Study Project

Since its inception in 1984 as an independent humanitarian organisation, the Adventist Development and Relief Agency (ADRA) operated under the auspices of the Adventist Church, has concentrated its activities on agriculture, the development of social infrastructure, health, and relief services in more than one 150 countries. It committed to sustainable, cost-effective, environmentally friendly, and appropriate development (ADRA, P1480, 1995). The agency (ADRA) is funded mostly by the Adventist Church, various agencies including the UN, USAID, CIDA, FIDA, SIDA, NORAD, DANIDA, and a number of GOs. ADRA has been granted General Consultative Status by the United Nations and is one of 14 agencies selected as part of the Global Food Education programme (ADRA, 2001).

ADRA's poverty alleviation programme in Ga West is similar to many programmes in other parts of the world because it is focused on the agency's commitment to combining ecological, socio-economic, and developmental interactions. The programme's goals are as follow: to enhance community access to adequate food to meet their dietary need for a healthy and productive life; to achieve an environmentally sustainable increase in agricultural production in existing schemes for the local market; to increase sector-led export production and investment; to increase the overall economic well-being of the poor, encourage developmental activities, and provide access to clean water and other social amenities.

The agency believes that the best solution for increasing food production without the expense of environmental degradation in Ga West is to prevent inappropriate land use practices and to provide and secure livelihood support for the poorest in the society (ADRA, 1999). ADRA's approach to this solution falls into two broad categories: 1. Community Social Services (CSS); and 2. Collaborative Community Agroforestry Initiatives (CCAI) (ADRA, 1999).

CSS is one of the most important activities used by ADRA to assist and bring together rural people for infrastructural provision through agriculture. This involves collaborating with the local communities and the authorities to provide building materials and other services for the construction of schools, hospitals, wells, farm footpaths, roads, and erosion prevention projects. These projects provide an enabling environment for the acquisition of knowledge and the development of skills that will eventually enhance the productivity of farmers and ensure sustainable food security and development (ADRA, 2006).

CCAI is part of ADRA's commitment to livelihood enhancement and ecologically responsible initiatives, where the promotion of indigenous farming knowledge and technical assistance are very important. Farmers are helped to pragmatically integrate fruit trees and woodlots with crops to meet their economic needs, ensure food security, and improve their livelihoods in general. ADRA provides poor farmers and poor consumers with assistance in farmland preparation, seedlings and nurseries, and investment in the market infrastructure. Financial, material, and technical assistance is given to farm households to upgrade the overall capacity of farmers to meet demanding
standards. More than 2,000 farm households benefit from ADRA’s programme in the Ga West district of the Greater Accra Region in Ghana (ADRA 2007).

2.3 Data Collection Methods and Analysis

2.3.1 GIS Data

The systematic collection of different, appropriate data types over space and time was conducted to allow the use of GIS as a tool in the study. This involved acquiring, capturing, verifying, and structuring processes. The geographical primitives collected were in the form of entities and data models. Much of the debate over the complexity of measuring agriculture-based poverty alleviation programmes is attributable to a lack of capacity in measuring techniques for collecting, storing, and retrieving data, as well as effectively handling the large datasets needed for manipulation, checking, and displaying. Our data collection procedure was directed to building a Geodatabase with adequate capabilities and a richer context to avoid any of the usual problems.

2.3.1.1 Blueprint Map Used

A paper map with a scale of 1:50,000 was acquired from the Survey Department of Ghana, Accra. This was a hand-drawn map showing most of the necessary features and their locational points of interest that the satellite images could not capture or that were not visible on the satellite images, but were digitised to suit our needs. It also had gridlines with tick marks placed on each side of the map, making it easier to adapt it with the Ghana National Grid (GNG) and for fixing the coordinates on the map.

Figure 2.2 Paper map of Ga West (source of data: Geological Survey of Ghana)
To make the paper map GIS-ready, it was scanned to generate high-resolution images for subsequent use in our GIS environment. Images were input into ArcGIS for further processing. The Ghana National Grid and the tick mark labels on each side of the paper map were used to make calculations to determine the map coordinates and convert them to GNG coordinates in decimal degrees from degrees/minutes (Appendix 2).

Using decimal degrees for longitude and latitude is considered the best option because it greatly facilitates the import of results into a GIS regime or other mapping applications (Fisher, 1995). The derived $x$ and $y$ coordinates for longitude and latitude were then exported to ArcGIS in table form to align the coordinates with the scanned map. UTM projection and datum WGS 1984 were used in UTM zone 30N.

The scanned paper map was rectified with the satellite image to yield a permanent transformation for continuous use. The root mean square of the rectification was approximately zero, but care was taken to ensure that the raster dataset matched the map coordinates of the target data.

The rectification made it feasible to undertake a step-by-step vectorisation of all the requisite vector features (polygons, points, and lines). This was achieved using our paper map and the GPS data (if the features were not captured in satellite images), while the same satellite images (where possible) used as base maps. Each feature class was captured independently according to its topological elements and map representation, before being registered to UTM zone 30N and WGS84 ellipsoid.

2.3.1.2. Satellite Imagery

Satellite images were acquired from US Landsat Geocover (2000, 2002) medium resolution data, before their conversion to fit the needs of the study using various techniques. To use the satellite images in conjunction with the existing spatial data, they were geo-referenced to the same coordinate system with the geo-reference tools in ArcGIS. This approach allowed the raster datasets to be viewed, queried, and analysed, then incorporated into the Geodatabase.

![Figure 2.3 Snapshot satellite image of Ga West (source of data: Landsat Geocover).](image-url)
Different image techniques from ArcGIS, IDRISI, and ERDAS were used to render, highlight, and enhance the vectors and surface data required for feature drawings and visualisation. The acquired images were also used as a visual backdrop to check the geographic data of the study area.

The spatial resolution of the Landsat satellite image had a low per-pixel value, which made it suboptimal for very small areas. However, the data and images required for the study were mainly used for planning, reconnaissance, and base maps, so we considered that the Landsat Geocover (acquisition date: 04.02.2002) was adequate. The Landsat data were ortho-rectified, so they could be used for the geo-rectification of maps and images. Each satellite passed over the study area once a year and consideration was given to acquiring more than two images from different years to produce cloud-free images during critical periods.

2.3.1.3 Digital Elevation Model

In conjunction with the satellite images and the paper map, a high-quality 90-m DEM.SRTM3, version2 Digital Elevation Model (DEM) was also acquired from East-View Cartographic (16.4.2008). Using data from different suppliers can cause compatibility problems (Burrough and McDonnell, 2002), but the two different images were used for different purposes and they could be aligned to the same coordinate system so any problems were likely to be minimal.

![Figure 2.4 DEM image of Ga West: digital elevation model (source of data: East-View Cartographic)](image)

DEM data could be displayed over the study area in a landform using the GIS capabilities to derive important features such as block diagrams, orthophotos, surface elevation variations, hydrological data, vegetation, and routes. Overall, the DEM provided important inputs for the exploration and analysis of various continuous fields.

2.3.1.4 GIS Database Structure

The Geodatabase construction was based on a data capture process in the form of tables, geometrically correct raster data, and topologically and geometrically correct vectors. Data were tabulated as feature classes, raster classes, and tables. These three primary datasets, which reflected the research objectives, were used as the main method for
organising and accessing information in ArcGIS. The attribute tables contained all the captured indicator values and they were initially recorded in Microsoft Access as an INFO table with all the attribute properties. This made it easier to build a relational database with the tables, which fitted the systems approach schema. It also facilitated simultaneous interaction with related attributes and information for their specific use, editing, and analysis in other GIS environments. Thus, a logical grouping of data was organised to determine the broad classification of functions, data, and topological associations, and their relationships.

Levels of analysis were connected by a "Community" table, thereby maintaining the systems approach schema that was required for sustainability measurement. It also provided the Geodatabase with the flexibility to relate feature classes or tables allowing analysis in other GIS environments. Subtypes, such as the types of crop, tree, or fruit, were also created for the lightweight classification of features (or objects) within a feature class. With these groupings and relationships, various entities used as indicators were classified based on their spatial representations and they were matched to the Geodatabase elements.

Figure 2.5 Feature classes and links developed using Microsoft Access

Once the verified, edited, and tailored raster and vector datasets, and attribute data, were in place, the attributes and spatial data were linked together using identifiers that were common to the records in both datasets. The identifiers were automatically generated using built-in database functions. The linkage process provided an opportunity to re-verify and check the quality of the spatial and attribute data. Linkages were also checked to ensure they were correct.
After producing and accepting the database for the purposes of the study, different geospatial analytical techniques and tools were utilised to test selected hypotheses based on data exploration. This facilitated the identification of dataset relationships that contributed to achieving the objectives of this study. The datasets were analysed and quantified to extract sustainability criteria for the agriculture-based poverty alleviation program. The poverty map and special sustainability index were then generated. Throughout these steps, the immediate task was to analyse the localisation of events and use geographical information to link various features and phenomena within the study area to their respective locations.

2.4 Planning of Sampling and Measurements

The total number of ADRA-programme supported farms in the 300 farm communities within the study area was 830. Farms and field plots were selected using a modified stratified random sampling scheme. The selected farms covered the entire geographic area and different environmental and landscape conditions (as described in section 2.1). A total of 400 individual points in 65 farm plots were located at random within selected blocks and used to collect soil samples. Of these, 65 observations were taken from the larger set of 400 soil samples to cover both the 0–20 cm and 20–40 cm soil zones. Each "data point refers to a support of 20 × 20 m within the study area, from which bulked samples were collected using the modified stratified random sampling protocol. This sample procedure was repeated in the dry and rainy seasons where all sample collections and tests were performed within 3 weeks. Forty surface water samples were collected following a regular transect sampling protocol, while 65 ground water samples were collected by random sampling. Visible field observations were also used to estimate surface water pollution levels in addition to the stated sample protocol. A water quality index protocol (fivecreeks.org) was used to measure the ground and surface water quality (Appendix 1). This was based on turbidity, temperature, pH, conductivity, phosphate, and nitrate levels of the water samples, and observations.

When assessing the water pollution level, we also sought the indigenous interpretations of water pollution level. The indigenous method of grading water pollution is based on a survey of specific aquatic life present, i.e., species indicators of the river pollution level. Figure 2.5 shows the different species recorded and the respective pollution levels. This data collection scheme was also supported by the Environmental Network "Schoolweb scheme."

Erosion could not be measured directly at the plot and watershed levels, because labour-intensive and long-term measurements would be required. Therefore, visible erosion field observations and the depth of the topsoil served as proxy indicators. These variables were recorded using coarsely graded scales in the field. Fertiliser and pesticide run-off were also not measured directly. Quantity of pesticides applied served as a proxy indicator for pesticide run-off. Twenty fruit samples were collected to measure the pesticides residues as an estimate of pest and disease pressure, and the vulnerability to pests and diseases.
Figure 2.6 Aquatic species and the pollution level (Modification from schoolweb)

Socio-economic and ground development indicators were derived mainly from field surveys that captured various views and responses collected from all the stakeholders. An active collaboration with community elders and chiefs in the research area helped familiarise us with local customs and beliefs before the field work commenced. Direct observations were also made at project sites and archival records were consulted. A recording tabulation sheet of farm household-financial activities was assigned to each farm household under study. To reduce the measurement error of questionnaires, they were tested before the actual survey. The questionnaires were structured but were based on open-ended method. This enabled respondents to give their general reactions to questions or encourage clarifying their interest attitude or interest related to a specific question. (e.g. Appendix 4). Much emphasis was also given to the systematic monitoring of the collection and recording of the requisite data for the tables. Sixty-five households participated in the social-economic study. This was also based on stratified random sampling with non-overlapping subgroups (i.e., age, gender, socioeconomic status, religion, tribe, and educational achievement). Monitoring of developmental activities in the farming communities was based in nine communities that represented all the development projects. Selection of these nine communities was based on population, size, infrastructure development, terrain, and the nature of human settlements in the communities located at random within the research area, using regularly laid out block strata. Emphasis was placed on active participation and the involvement of farmers, extension officers, and authorities.

A biannual extensive survey was conducted in all active areas within the research area (between March, 2002 and June, 2007). When conducting the field research, the indicators and their measurement had to be adjusted to make the study feasible in the research area, given the time frame, financial limitations, available resources and information, and changes were made provided that they did not compromise the accuracy of measurements.

A GPS receiver and the topographical map sheet with a scale of 1:50,000 were used to locate features, sample points, or supports, and their related behaviours with adequate precision. The coordinate readings were collected and recorded in a table containing
records with their attributes. Data collection was supported by three Masters-level students from the University of Science and Technology, Kumasi, Ghana. Farmers, ADRA staff members, community leaders, and settlers were fully involved at every stage of data collection. In some cases, approval was sought from the appropriate stakeholders before embarking on the survey. Farms were not entered without prior permission from the farmer concerned. To reduce the level of subjectivity, the data collection team worked together and activities or areas were occasionally rotated, depending on individual specialties.

2.5 Standards Used and Measurement Practices

Different sources were used for the reference values (Appendix 4). Most values were derived from the Ghana Government Statistical Services Department. Various acceptability thresholds set by notable international organisations were also used, e.g., limits for pesticide residues in crops, acceptable limits of chemical levels in water/soil, income, and yield levels.

Analysing soil degradation over a long period would have been the best way of determining whether the programme had altered the soil in the study area. Alternatively, unaltered soil of the same type under natural vegetation cover could have been analysed in comparable agro-ecological conditions, or soil could have been tested from plots in the same study area that lacked ADRA's support. It was not feasible to adopt the first approach, because the study area did not have natural vegetation. The second option was also problematic, because it was difficult to extract information from such plots. Due to these constraints, it was necessary to compare soil quality indicators for cassava-based soil samples with those taken from maize-based farms, which were all within ADRA's jurisdiction. A standard reference value was adopted that used the same scale of comparison for both farm-based indicators. A comparison of the two crop-based (cassava and maize) indicators may also provide decision-makers with the best crop/tree combination when assessing the optimum economic and environmental benefits.

2.6 Indicators at Different Geographical Scales

The indicators and criteria shown in Tables 2.1–2.4 were built around the four levels of analysis (development, farm household, plot, and watershed) and they formed a key component of the measurable objectives. They provide a focus for the spectrum of methods adopted by the research study. These indicators were also the basis of all the different objects and attributes constituting the datasets (materials). By combining the descriptive and process approach to geospatial analysis, different techniques were formulated to help understand the structures and relationships, and identify and possible causes and effects in ADRA's poverty alleviation programme in Ga West. The purpose here was not merely to identify patterns and relationships, but also to formulate hypotheses for the construction of models to provide some understanding of their causes and effects with respect to the programme's impact and its sustainability level. In some cases, understanding the process led to further investigation or the derivation of

---

5 The descriptive approach includes the identification of structures and relationships. The process approach requires a clearer understanding of causes and effects (de Smith et al., 2008).
additional data from input datasets, which was followed by more modelling and testing, before definitive conclusions could be reached about the events and processes under study.

The ground truth data collection was based on indicators assigned to four different aggregation levels or scales (i.e., plot, farm household, watershed, and developmental), within which they were classified as environmental/biophysical, economic, and social indicators. The criteria of sustainable agriculture based on the different concepts discussed in Section 1.3, were also specified, i.e., productivity and efficiency, resilience, rules of resource management, biodiversity, satisfaction of basic needs, cultural diversity, risk, time dispersion, stability, and profitability. The adoption of accepted sustainability criteria (UNRISD; FAO; Conway, 1987; Muller 1999) guided the generation of indicators that eventually provided a solid basis for index measurement. Four different indicator matrices were created for the purposes of the study using the named aggregate levels and the specified criteria for sustainable agriculture. The breakdown of the adopted criteria into variables provided the indicators used in the study.

No single indicator can capture the complexities of an agriculture-based poverty alleviation programme. Some indicators may be manifested at more than one level, whereas others are only related to one level. For example, erosion could be measured at the watershed, plot, and even developmental level, whereas soil quality parameters are specific to the plot level. Farm household level and plot level have pest and disease pressures as well as management practices that are related to both levels.

Surface water refers to the watershed level, whereas groundwater analysis is carried out at the plot level, developmental level, and watershed level. Economic aspects are related to all levels. Social aspects relate to farm household and developmental levels or externalities that may spread across both levels.

Table 2.1 Indicators used at the farm household level

<table>
<thead>
<tr>
<th>Sustainability criteria</th>
<th>Environmental/biophysical indicators</th>
<th>Economic indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>Depth of top soil</td>
<td>Gross (Marginal per ha)</td>
</tr>
<tr>
<td></td>
<td>Exchangeable aluminium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nutrient availability (kg/ha)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water retention capacity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yield (kg/ha)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil pH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil structure index</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% of organic matter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visible erosion</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>Planted trees as % of nurseries</td>
<td></td>
</tr>
<tr>
<td>Resilience</td>
<td>Pesticide application in g. active ingredients according to toxicity</td>
<td>Cost of plant protection per ha</td>
</tr>
<tr>
<td>Rules for resource management</td>
<td>Potential fertiliser leaching (kg/ha)</td>
<td>Plant protection cost as percentage of total production costs</td>
</tr>
<tr>
<td></td>
<td>Residues treatment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Application of soil conservation measures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other practices</td>
<td></td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Microbiological diversity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of earthworms per soil unit</td>
<td></td>
</tr>
</tbody>
</table>
### Table 2.2 Indicators used at the plot level

<table>
<thead>
<tr>
<th>Sustainability criteria</th>
<th>Environmental/biophysical indicators</th>
<th>Economic indicators</th>
<th>Social indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>Average soil quality per firm</td>
<td>Farm income per man-day total labour input</td>
<td>Farm income per capita</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Income per day of family labour</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>Production costs per unit (kg crops/trees)</td>
<td></td>
<td>Farm household income</td>
</tr>
<tr>
<td>Resilience</td>
<td>Area with crops/trees as % of total area planted</td>
<td>Income of crops/trees as % of total farm income</td>
<td>Education level of the farmers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Farmers provisions for health and old age</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Area with low input crops as % of total area planted Bushes, hedges as % of farm area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfaction of basic needs</td>
<td></td>
<td>Health impairment due to pesticides application</td>
<td>Ratio of farm household income to minimum income</td>
</tr>
</tbody>
</table>

### Table 2.3 Indicators used at the watershed level

<table>
<thead>
<tr>
<th>Sustainability criteria</th>
<th>Environmental/biophysical indicators</th>
<th>Economic indicators</th>
<th>Social indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>Average yield per ha n the watershed compared with the national average</td>
<td>Land rent</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>% of forest land in the watershed</td>
<td>Salary of farm workers</td>
<td></td>
</tr>
<tr>
<td>Resilience</td>
<td>Forest area as % of total area Area with annual crops as % of total area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Area with erosion features as % of total Ratio of land use capacity to current land use Water quality of the watershed area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rules of resource management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfaction of basic needs</td>
<td></td>
<td>Number of cases of intoxication by pesticides Income per capita compared with National average %of crops with pesticide residues</td>
<td></td>
</tr>
</tbody>
</table>
In some cases, the stipulated sustainable criteria could not be measured directly. Thus, it was necessary to use proxy indicators when making measurements. They may not have a directly quantifiable relationship with the phenomena being studied or described, but the derived end-result may not make any difference. It is important to note here that care was taken to make ensure that the accuracy of proxy measurements is closely related to that of the focal phenomenon. However, some of the cells in Tables 3.1–3.4 were left empty, because no appropriate indicator could be defined in a specific case. The boxes for productivity and technical efficiency contain strongly related indicators. For example, yield per ha or per nutrient input are productivity indicators, but comparing them with the maximum attainable yield under given conditions can also describe technical efficiency. Generally, the link between productivity and efficiency was so close that the two were combined as one criterion during the measurement of sustainability criteria.

2.7 Quantitative Assessment of Sustainability and Poverty

The 11 properties of sustainability and poverty identified in the different scales were analysed and quantified to determine the degree to which the programme under study met an accepted sustainability level.
2.7.1 Technical Efficiency and Productivity

The Frontier Production Function concept (Farrel, 1957; FAO, 1994) was combined with spatial analysis to assess the Technical Efficiency and Productivity (TEP) of the programme.

The output levels of the best farmers applying the same inputs within the study area were set as the Production Frontier (i.e., the maximum level of technical efficiency). A simple statistical summary determined the efficiency coefficients around the production frontier for cassava- and maize-based farms (Table 3.12a and b).

The plots were ranked against the production frontier to detect the inefficient plots (i.e., farmers that fell far below the best plots when applying the same inputs within the study area). Figure 3.8 shows the proportion of farmers in each efficiency level.

Spatial analysis and standard statistical tools were used to analyse and understand the possible factors contributing to the different levels of technical efficiency, and determine the critical issues affecting individual farmers below the production frontier (i.e., those considered less technically efficient).

Figure 2.7 Average farm efficiency percentage adjustment (average TE = 0.6)

The range of impact was expressed relative to the average level of technical efficiency, which was ranked from the most to the least influential. The range of values for each factor was defined as follows.

1. Zone of farm: less than or greater than 50 m from a river
2. Production: yield ha$^{-1}$

$^6$TEP here can be defined as the ability of a farmer as a decision-making unit to produce maximum output given a set of inputs and technology.
3. Farm-type: cassava/mangoes, cassava/woodlots, cassava/cashew, cassava/citrus, maize/mangoes, maize/woodlots, maize/cashew, or maize/citrus
4. Land type: own land, family land, sand harvesting and quarry area, rental land, close to urbanisation area
5. Experience: production experience ranging from less than five to over five years
6. Market availability: yes or no
7. Level of education: literate or illiterate
8. Technical assistance: yes or no
9. Number of farms: 1–3
10. Producer: present on the farm less than three weeks or greater than weeks every month
11. Gender: male or female

**Figure 2.8 Ranking of the 11 influential factors after the study area’s Technical Efficiency and Productivity evaluation**

Several variables were binary rather than scaled values, so a simple model was constructed using a flow diagram of technical efficiency. This model was used to estimate the level and range of each influential factor, before applying this model to the spatial patterns of all plots. Each factor's range of influence was depicted (Figure 3.16) in absolute and relative terms for the spatial distribution of levels of efficiency on sample plots in the study area.

2.7.2 Stability

Stability was measured using the ArcGis temporal time-series analysis tool and expressed as the coefficient of variation (CV) to analyse the magnitude of yearly yield
variations among crops and locations based on our survey and records available. An annual time-series set of observations was produced for maize (MZ) and cassava (CA), with their respective yields from fruit/tree mixed farms, i.e., maize/mango (MZMA), maize/cashew (MZCE), maize/citrus (MZCT), maize/woodlot (MZWO), cassava/mango (CAMA), cassava/cashew (CACE), cassava/citrus (CACT), cassava/woodlot (CAWO). The yield ha\(^{-1}\) from plots in the study area during the 12 years from 1995–2006 indicated the stability of a particular farm. Table 3.5 shows the stability levels with individual crops and on mixed farms.

The coefficient of variation (CV) was used as a stability measure for expressing the magnitude of yearly yield variations among crops and locations. It was calculated as follows:

\[
CV = \frac{100 \times \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n(n-1)}}}{\bar{X}}
\]

The CV relates the standard deviation, denoted as SD, or positive square root of the variance (V) of a sample of observations, for a variable X as a percentage of the sample's mean value (where n is the number of observations, X\(_i\) is the ith observation, and \(\sum\) denotes the sum of the following values for \(i\) from 1 to n).

Table 2.5 Average yield per ha\(^{-1}\) (in tons) showing the stability level of individual crops and fruit/trees -from mixed-farms

<table>
<thead>
<tr>
<th>YEAR</th>
<th>MZMA</th>
<th>MA</th>
<th>MZCE</th>
<th>MA</th>
<th>MZCT</th>
<th>CA</th>
<th>MZWO</th>
<th>MA</th>
<th>CAMA</th>
<th>MA</th>
<th>CACE</th>
<th>MA</th>
<th>CACT</th>
<th>MA</th>
<th>CAWO</th>
<th>MA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>1.5</td>
<td>4.6</td>
<td>3.6</td>
<td>321</td>
<td>1.9</td>
<td>6.3</td>
<td>2.1</td>
<td>100</td>
<td>14.5</td>
<td>3.6</td>
<td>12.2</td>
<td>562</td>
<td>10.5</td>
<td>5.6</td>
<td>14.3</td>
<td>700</td>
</tr>
<tr>
<td>1996</td>
<td>2.5</td>
<td>6.7</td>
<td>2.3</td>
<td>934</td>
<td>2.0</td>
<td>6.5</td>
<td>2.3</td>
<td>619</td>
<td>14.2</td>
<td>5.3</td>
<td>14.4</td>
<td>590</td>
<td>10.6</td>
<td>5.9</td>
<td>13.6</td>
<td>705</td>
</tr>
<tr>
<td>1997</td>
<td>1.3</td>
<td>3.3</td>
<td>2.5</td>
<td>921</td>
<td>2.1</td>
<td>6.5</td>
<td>2.0</td>
<td>914</td>
<td>14.2</td>
<td>6.4</td>
<td>14.3</td>
<td>806</td>
<td>13.5</td>
<td>6.4</td>
<td>14.5</td>
<td>707</td>
</tr>
<tr>
<td>1998</td>
<td>2.0</td>
<td>7.7</td>
<td>2.9</td>
<td>616</td>
<td>2.1</td>
<td>6.7</td>
<td>2.1</td>
<td>912</td>
<td>14.6</td>
<td>6.5</td>
<td>13.3</td>
<td>809</td>
<td>14.5</td>
<td>6.7</td>
<td>14.5</td>
<td>714</td>
</tr>
<tr>
<td>1999</td>
<td>2.3</td>
<td>7.2</td>
<td>1.7</td>
<td>716</td>
<td>2.2</td>
<td>6.9</td>
<td>2.2</td>
<td>916</td>
<td>14.2</td>
<td>6.9</td>
<td>14.3</td>
<td>516</td>
<td>8.5</td>
<td>7.9</td>
<td>13.4</td>
<td>712</td>
</tr>
<tr>
<td>2000</td>
<td>1.7</td>
<td>4.3</td>
<td>1.3</td>
<td>118</td>
<td>2.3</td>
<td>7.4</td>
<td>2.0</td>
<td>723</td>
<td>11.2</td>
<td>6.5</td>
<td>14.4</td>
<td>890</td>
<td>12.5</td>
<td>5.6</td>
<td>10.6</td>
<td>714</td>
</tr>
<tr>
<td>2001</td>
<td>2.4</td>
<td>7.9</td>
<td>2.1</td>
<td>637</td>
<td>2.4</td>
<td>7.5</td>
<td>2.2</td>
<td>809</td>
<td>10.3</td>
<td>6.9</td>
<td>12.3</td>
<td>917</td>
<td>14.4</td>
<td>7.8</td>
<td>7.8</td>
<td>700</td>
</tr>
<tr>
<td>2002</td>
<td>1.5</td>
<td>4.6</td>
<td>1.9</td>
<td>412</td>
<td>2.5</td>
<td>7.8</td>
<td>2.3</td>
<td>908</td>
<td>6.4</td>
<td>6.3</td>
<td>10.0</td>
<td>745</td>
<td>9.6</td>
<td>7.0</td>
<td>9.6</td>
<td>780</td>
</tr>
<tr>
<td>2003</td>
<td>2.1</td>
<td>6.0</td>
<td>2.3</td>
<td>476</td>
<td>1.9</td>
<td>7.1</td>
<td>2.1</td>
<td>500</td>
<td>7.3</td>
<td>4.5</td>
<td>8.2</td>
<td>634</td>
<td>7.6</td>
<td>6.7</td>
<td>13.7</td>
<td>705</td>
</tr>
<tr>
<td>2004</td>
<td>1.6</td>
<td>4.5</td>
<td>1.5</td>
<td>342</td>
<td>2.1</td>
<td>7.7</td>
<td>1.9</td>
<td>912</td>
<td>5.2</td>
<td>3.2</td>
<td>8.1</td>
<td>321</td>
<td>8.4</td>
<td>5.6</td>
<td>6.9</td>
<td>500</td>
</tr>
<tr>
<td>2005</td>
<td>2.8</td>
<td>7.1</td>
<td>1.1</td>
<td>397</td>
<td>2.4</td>
<td>7.8</td>
<td>2.5</td>
<td>913</td>
<td>4.1</td>
<td>3.3</td>
<td>6.0</td>
<td>567</td>
<td>6.5</td>
<td>5.1</td>
<td>9.6</td>
<td>600</td>
</tr>
<tr>
<td>2006</td>
<td>1.9</td>
<td>3.9</td>
<td>2.3</td>
<td>746</td>
<td>1.9</td>
<td>7.8</td>
<td>2.5</td>
<td>100</td>
<td>3.6</td>
<td>4.5</td>
<td>5.4</td>
<td>346</td>
<td>7.5</td>
<td>3.0</td>
<td>7.9</td>
<td>607</td>
</tr>
<tr>
<td>Mean</td>
<td>1.97</td>
<td>4.68</td>
<td>1.89</td>
<td>601.7</td>
<td>2.1</td>
<td>7.2</td>
<td>2.16</td>
<td>703.59</td>
<td>9.93</td>
<td>5.17</td>
<td>10.94</td>
<td>64.5</td>
<td>10.20</td>
<td>5.86</td>
<td>11.28</td>
<td>672.25</td>
</tr>
<tr>
<td>Std</td>
<td>0.90</td>
<td>1.40</td>
<td>0.32</td>
<td>227.9</td>
<td>1.50</td>
<td>0.90</td>
<td>0.17</td>
<td>140.60</td>
<td>4.42</td>
<td>1.42</td>
<td>3.74</td>
<td>192.98</td>
<td>3.06</td>
<td>1.61</td>
<td>2.86</td>
<td>116.18</td>
</tr>
</tbody>
</table>

A graphical representation of the time-series yield for crops and fruit/trees from mixed farms in various locations could be generated from the outcome data, to show the stability levels of individual plots and crop/tree during a 12-month interval.

2.7.3 Biodiversity Variables

The complexity of life makes it difficult to measure biodiversity, so an assessment method appropriate for this study that indicated how the programme contributed to biological diversity was developed based on proxy indicators (aquatic species richness), and pesticide application rates. It was assumed that the excessive application of pesticides limits the survival and recovery of an ecosystem. Thus, plots with little or no
pesticide applications would facilitate species survival and retain the same controls on function and structure.

In the context of this study, biodiversity was measured according to Whittaker’s (1972) three terms for measuring biodiversity over spatial scales, i.e., alpha, beta, and gamma diversity. The IDRISI-Land Modeller for Ecological Sustainability was used and the main focus was on utilising alpha diversity to express the total number of each type of aquatic species in different locations throughout the study area. The richness of individual species in a location illustrated the degree of disturbance or pollution level. Thus, the relationship between species richness and the variable pesticide applications in different locations was analysed to determine the impact of pesticide application or farming techniques and biodiversity in the research area.

The percentage of natural vegetation covering the study area as reviewed by the satellite images manipulation was also assessed as a refuge for flora and fauna.

2.7.4 Seasonal Variation of Variables

Time dispersion/concentration was analysed relative to separate crops or trees found in whole farm activities or systems. In this case, each crop or tree was treated as an independent variable.

Table 2.6 Relative monthly production information (percentage income) showing the time dispersion/concentration (n = 65). * Parameters: V, SD, CV, and X

<table>
<thead>
<tr>
<th>MONTH</th>
<th>MAIZE</th>
<th>CASSAVA</th>
<th>MANGO</th>
<th>CITRUS</th>
<th>CASHEW</th>
<th>WOOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>February</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>March</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>April</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>May</td>
<td>5</td>
<td>0</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>June</td>
<td>10</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>July</td>
<td>15</td>
<td>20</td>
<td>0</td>
<td>30</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>August</td>
<td>20</td>
<td>5</td>
<td>0</td>
<td>25</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>September</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>October</td>
<td>20</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>November</td>
<td>15</td>
<td>25</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>December</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

*STATISTIC

<table>
<thead>
<tr>
<th></th>
<th>8.33</th>
<th>8.33</th>
<th>8.33</th>
<th>8.33</th>
<th>8.33</th>
<th>8.33</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>60.61</td>
<td>69.70</td>
<td>196.97</td>
<td>119.65</td>
<td>233.35</td>
<td>251.52</td>
</tr>
<tr>
<td>SD</td>
<td>7.78</td>
<td>8.35</td>
<td>14.03</td>
<td>10.94</td>
<td>15.28</td>
<td>15.86</td>
</tr>
<tr>
<td>CV</td>
<td>93.42</td>
<td>100.18</td>
<td>168.42</td>
<td>131.29</td>
<td>183.30</td>
<td>190.31</td>
</tr>
<tr>
<td>RTC</td>
<td>0.49</td>
<td>0.52</td>
<td>0.82</td>
<td>0.68</td>
<td>0.96</td>
<td>1.00</td>
</tr>
<tr>
<td>RTD</td>
<td>0.51</td>
<td>0.48</td>
<td>0.18</td>
<td>0.32</td>
<td>0.40</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Alpha diversity refers to the species diversity within a particular area or ecosystem. Beta examines the change in species diversity between ecosystems. Gamma diversity measures the overall diversity in the different ecosystems within a region (Hunter, 2002).
Income was measured on a monthly basis. We compared and validated the official records from ADRA and the survey questionnaire. The relative time concentration (RTC) of a concentrated crop or tree was obtained by calculating the ratio of its CV to the CV of a perfectly concentrated crop/tree. Here, a perfectly concentrated crop/tree had a CV of 190 per cent (i.e., the highest CV in Table 3.6). A completely time concentration crop/tree had a RTC index of 1.

Based on the RTC, the RTD (relative time dispersion) could be obtained. Each farm was given an index of one (1), so the relative farm time dispersion (RTD) was measured as one minus its relative concentration, i.e., $RTD = 1 - RTC$. Based on the above expression, a perfectly time-dispersed crop or tree would have an RTC index of zero, and an RTD value of 1. A spatial pattern could be created from the RTD and RTC by overlaying the attributes and the thematic derived with the query functions.

2.7.5 Risk Factors in Farming

Risk assessment was conducted by studying all the possible risk factors observed in the study area. Based on the empirical results, the biggest threat to a farmer in the research area was the risk of losing farmland through various routes (Table 3.7). The study of risk factors in the study area showed that more than 70% of farmers felt more at risk of losing their farmland than any other risk factor. Financial and marketing risk factors constituted a very minimal risk to most farm households. Less than 10% of the factors can be regarded as financial or marketing risks. It should be emphasised here that human health risk was treated separately.

<table>
<thead>
<tr>
<th>MAIN RISK FACTORS</th>
<th>PERCENTAGE OF FARMERS AT RISK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lost of family land</td>
<td>30</td>
</tr>
<tr>
<td>Lost of land to commercial-farmers</td>
<td>20</td>
</tr>
<tr>
<td>Poor land management</td>
<td>6</td>
</tr>
<tr>
<td>Near Urbanskeds lands</td>
<td>30</td>
</tr>
<tr>
<td>Near sand-winning and quarry area</td>
<td>10</td>
</tr>
<tr>
<td>Financial risk</td>
<td>2.5</td>
</tr>
<tr>
<td>Marketing risk</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Thus, the risk of a farmer losing their farmland and their potential to engage in farming activities could be used as a proxy indicator for farm risk factor measurement. Based on the empirical results, the loss of family lands was mainly through the sale of the land to commercial farmers, sand-harvesters, or urban/estate developers by a family member(s).

Therefore, loss of family land was classified as loss of land to commercial farmers. Of all these factors, proximity was a deciding factor determining the high risk of a farmer losing their farmland, i.e., the closeness of a farm to these indicators. Therefore each dataset was given a weight depending on the percentage influence. A higher percentage indicated greater influence of a risk factor in a particular dataset in the overall risk level.
model. The strength of a risk factor on a farm was manifested in the spatial analysis distance model.

2.7.6 Cultural Diversity Variables

In the context of this study, cultural diversity was assessed with three indicators: adoption and acceptance of appropriate technology, the effect of the programme on the indigenous culture, and the interaction between the farmers and ADRA, (from interviews). The acceptance of appropriate technology was further broken down to: prefers traditional farming, benefits from farm education/technology, and understanding farm technology. The non-parametric test for several independent samples was used to compare two or more groups of cases for one variable. The variables provided a fair idea of the level of cultural diversity in relation to the programme in the research area. The asymptotic significance shown in Table 3.8 indicates the approximate probability of obtaining a chi-square statistic as extreme as 28,354 with repeated samples, if the frequency of acceptance was only different at random.

Table 2.8 Descriptive statistics related to cultural diversity

<table>
<thead>
<tr>
<th>CULTURAL DIVERSITY INDICATORS</th>
<th>VALUES</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand farming technology</td>
<td>0</td>
<td>64</td>
</tr>
<tr>
<td>Good interactions</td>
<td>28</td>
<td>36</td>
</tr>
<tr>
<td>Affects culture</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td>Prefer traditional farming</td>
<td>22</td>
<td>43</td>
</tr>
<tr>
<td>Benefitting from farm education</td>
<td>11</td>
<td>53</td>
</tr>
</tbody>
</table>

Table 2.8 shows that the only possible outcomes for each variable were 0 for "no" and 1 for "yes". Therefore, the mean measured the proportion of farmers who confirmed a cultural diversity variable, which also indicated the level of effect the programme had on the people and their culture. In other words, it measured how well cultural diversity was being preserved.

2.7.7 Profitability

A comprehensive gross margin analysis compared relative profitability across different crop/tree farms in the research area. Higher gross margins for a farm type reflected greater profitability when converting production into farm income. Larger gross margins are generally considered ideal for most farmers. However, computing margins without including all the farm products from a mixed farm did not give a true picture of the profitability of individual farm types.

Computation of the gross margin per period (annual) for a given farm type was expressed as the ratio of gross profit to the cost of production in the form of a percentage, as follows:

\[ \text{GMP} = 100 \left( \frac{(P_y Y) - V_c}{P_y Y} \right) \]

where GMP is the Gross margin percentage for a given farm type for a given production period, Py is the farm gate price of a given crop or fruit/woodlot, Y is the quantity of a crop or fruit/tree per hectare for a given period, and Vc is the total production cost of a particular farm type for a given production period. The cost of production was based on any cost that was directly linked to the production of the farm products on a particular farm type. It should be emphasised that the yield value of a farm type serves as the farm revenue for a given period. Yield sales would not be feasible in this study because
farmers tend to use a portion of their farm products for household and family consumption according the interview and records.

2.7.8 Resilience Factors

Three different aspects of resilience were analysed to assess its maintenance in the agriculture-based poverty alleviation system, i.e., ecological, economical, and social resilience. The level of ecological resilience was measured based on the rate of over-application of fertiliser (> $181 \, \text{kg ha}^{-1} \, \text{NPK}$) and pesticide (> $0.01 \, \text{mg kg}^{-1} \, \text{active ingredient on crops}$), as well as the proximity of the farm to rivers (> $50 \, \text{m}$). Economic resilience was based on the over-reliance of farmers on a particular crop or tree in the research area (measured as tree/crop percentage). Social resilience was measured as the ability of farm households to rebuild after a disturbance or any disruption to the system, i.e., land was a factor of social tension that could disrupt farming activities leading to family land disputes. With all these measurements, information derived from the analysis at different scales in Section 4 guided the outcome.

2.7.9 Rules of Resource Management

The rules of resource management were measured according to the intensity of land use, which was linked to decreasing the quality of fertiliser and the over-application of pesticides. It was assumed that the continuous over-application of fertiliser (> $181 \, \text{kg ha}^{-1}$) was correlated with a farmer's erratic response to the decreased quality of fertiliser. Extra nitrate could cause deficiencies in fertiliser availability leaving a soil depleted of other nutrients (degraded). Both variables were observed during the over-production of cassava (based on tree crop percentages) and the adoption of a pest-prone mixed farm on some plots. Thus, a decision was made to compare areas applying high levels of active ingredients to crops and degraded plots (Table 3.1) with the cost of production on farms in the research area. The intensity of land use might possibly increase the cost of production relative to plot size. The ArcGis kriging tool was used to predict the organic matter content. The map produced was verified by checking the concentration level of nitrate in surface water and groundwater.

2.7.10 Satisfaction of Basic Needs

The contribution of ADRA to basic needs was observed visually. However, further analysis was conducted to ascertain the level of the community satisfaction with the projects and to measure the sustainability of the assistance and social amenities. Thus, the positive influence of the projects on the daily life of communities was captured based on the views (interviews and interactions) of the beneficiaries. The dataset was produced by interviewing and interacting with a range of the population in settlement areas. The contribution of health facilities, provisions, assistance to schools, water, sanitation, barns, economic empowerment, and marketing facilities was reported as the community member's satisfaction measures. The values "satisfied" and "not satisfied" were used, denoted by 1 and 0 respectively. These values were statistically tested to compare their distributions and determine how they were associated with the beneficiaries.
Table 2.9 Community satisfaction with ADRA's projects

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Health facilities</td>
<td>8</td>
</tr>
<tr>
<td>Assistance for schools</td>
<td>16</td>
</tr>
<tr>
<td>Provision for drinking water (wells)</td>
<td>10</td>
</tr>
<tr>
<td>Sanitation improvement</td>
<td>24</td>
</tr>
<tr>
<td>Storage facilities</td>
<td>9</td>
</tr>
<tr>
<td>Economic empowerment</td>
<td>12</td>
</tr>
<tr>
<td>Marketing facilities</td>
<td>6</td>
</tr>
<tr>
<td>Footpath</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 2.9 summarised the number of reports of "satisfied" (1) or "not satisfied" (0) with each basic societal need provided by ADRA. This provides fair idea of how communities viewed ADRA's provision of social amenities and other related basic needs.

2.7.11 Spatial Distribution of Equity

The spatial pattern of ADRA's developmental activities based records and visible inspection was used to assess equity associated with the programme. Moran I (Table 3.11) was used to analyse the spread and dispersal of the projects. Datasets for male and female, and church and non-church members derived from this study were also used to test whether there was an equitable distribution of assistance and projects.

2.8 Sustainable Poverty Alleviation Map (SPAM) and Spatial Sustainability Index (SSI)

To assess the application of sustainability in the agriculture-based poverty alleviation programme, the empirical analysis was finalised with the creation of a Sustainability Poverty Alleviation Map (SPAM) and a Spatial Sustainability Index (SSI). This was conducted using the functionality of ArcMap and geospatial analysis.

A total of 16 attributes/factors were derived from the hypothesis and the analysis criteria combined. Eight of these attributes represented socio-economic and developmental factors, while the other represented environmental aspects of sustainability. Social, economic, and developmental factors were combined because of positive links between them and the overlapping derived benefits for target groups, e.g., the average number of farmers benefiting from ADRA's social assistance, including the infrastructure to enhance their farm production. It should be emphasised that, as with any multi-criteria analysis, the selection and weighting of attributes was a subjective measure. Therefore, the decision to combine environmental and socio-economic developmental attributes in equal numbers means a form of weighting was applied to both groups, i.e., a weight of 50%. The weighting method adopted here was a departure from regular GIS, which normally reclassifies weight values in the inputs onto a common evaluation scale of suitability, preference, risk, or some similar unifying scale. However, the current study considered that all datasets were equally important when assessing the most sustainable
farm households. The datasets used here included all the data from the various levels of analysis (developmental, farm household, plot, and watershed levels). Derived datasets were created from these existing datasets to acquire new information required for the analysis.

For the purpose of comparison, the relative distance of the actual values of attributes from their target values was treated as a common unit. Each of the 16 indicators/factors was reclassified to give values that were ranked from 10 (more sustainable) to 1 (less sustainable), with values in between.

Table 2.10 Index computation: attributes and factors

<table>
<thead>
<tr>
<th>Ecological Attributes</th>
<th>Social-Economic-Developmental Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Area with trees as % of cultivated plot</td>
<td>1. Crop income as % of farm revenue</td>
</tr>
<tr>
<td>2. Area with low-input crop/tree as % of total cultivated plot</td>
<td>2. Farm-labour-income per month compare to national average</td>
</tr>
<tr>
<td>3. Average value of factor “structure”</td>
<td>3. Mean efficiency of farm production</td>
</tr>
<tr>
<td>4. Average value of factor “acidic”</td>
<td>4. Average gross margin per ha</td>
</tr>
<tr>
<td>5. Areas with fertilizer exceeding the required level</td>
<td>5. Farmer access to social/farm-assistance from ADRA</td>
</tr>
<tr>
<td>6. Plot-river distance (distance less than 50m or more)</td>
<td>6. Percentage involved in decision-making and implementation processes</td>
</tr>
<tr>
<td>7. Average water quality</td>
<td>7. Average risk factor</td>
</tr>
<tr>
<td>8. Average production of cassava per ha</td>
<td>8. Education factor</td>
</tr>
</tbody>
</table>

Thus, the total maximum indicator/factor value that a farmhouse could achieve was 160.

The reference values used in the index assessment were those applied in the analysis of attributes at the various levels of analysis and the 11 sustainable criteria, previously listed. Thus, a sustainable farm was one where all indicators reached the respective reference values. Given a value of SSI =1 and the datasets derived from spatial analysis, the aggregated index of a farm was derived using the following equation:

\[ \text{SAL} = \frac{(\text{RV} \times \text{X} \times \text{W})}{(\sum \text{X} \times \text{W})} \]

where

\( \text{SAL} \) = sustainable attribute value
\( \sum \text{X} \) = total number of attributes/indicators
\( \text{W} \) = weight
\( \text{RV} \) = reference value
\( \text{X} \) = attribute/indicator

Using this equation, every attribute/indicator was valued at 0.0625, making the aggregate value 1 (i.e., 16 \( \times \) 0.0625). Therefore, a farm was sustainable if its aggregate value for the 16 attributes equalled 1 (SSI):
\[
\sum_{i=1}^{N} SSI_i = 1
\]

Using the derived datasets, an output map (SPAM) showing each farm household's sustainability level was generated using the geoprocessing modelling technique (Figure 2.9). The aim was to increase work-flow efficiency because the geoprocessing modelling technique can easily alter input data or other parameter values during model re-execution and produce different results with different sustainable attribute/factors or criteria weight changes.

Three main subjective elements were considered when interpreting the results, i.e., the selection of the 16 indicators/attributes, the definition of target values, and a justification for the weightings used. Based on the systems analysis approach, which makes the function of every component important when achieving a coherent whole, and because no common explicit weights have yet been used, the implicit weighting gave the same weight to each indicator, i.e., the percentage influence of every sustainability indicator was the same. Therefore, all datasets (attributes/indicators) were equally important, so they were simply combined for visual and quantitative interpretations. Applying equal weights in the SSI and SPAM modelling was acceptable in this study because a recognised weighting system based on relative importance has yet to be developed, applied, or accepted for the assessment of agriculture-based poverty alleviation programmes.

The question of weighting is crucial and difficult in any multi-criteria evaluation (Boulanger, 2008), and has become a very controversial issue. Methods can vary depending on the main decision investigated and the evaluation rules. A wide range of geospatial-based techniques exists for the development of weights used in multi-criteria evaluation, but there is always a rational justification for uncertainties in criteria weighing. Most of these techniques (SA-ANOVA: Archer et al., 1997; AHP-GIS: Marinoni, 2004; MCDA: Acera, 2008; GIS-MCDM: Chen et al. 2009) incorporate geospatial analysis with the well-known Analytical Hierarchy Process (AHP) (Saaty, 1977; 1980). AHP is a mathematical method for evaluating complex multi-dimensional phenomena based on decomposition, comparative judgement, and a synthesis of priorities. AHP was first introduced into GIS applications by Roao et al. (1991). Saaty (1980), claimed that AHP was the best method for minimising the impact of inconsistencies in criteria weighting ratios, but there is a concern that criteria weightings...
should be meaningful in the sense that they properly reflect the unit under study. Thus, it is important to understand how criteria are broken down into variables/attributes or target/reference values, and the analytical or modelling procedures that are used to measure the indicators concerned. The current study emphasises the level of precision and accuracy at spatial and temporal scales. Most criteria weighting techniques are based on the premise that one criterion cannot be considered as more important than another. However, in the case of agriculture-based poverty alleviation programme assessment, the use of weightings is limited because current scientific knowledge alone cannot justify any weighting structure applied to different sectors (Boulanger, 2008).

2.10 Sensitivity Analysis of Attribute/Indicator Weights

The sensitivity analysis (SA) used in this study aimed to explore the dependency of the SPAM and SSI outcome on indicator weights. It also provided a potential mechanism to examine weight sensitivity by flexibly altering the ranges of indicator weightings. The sensitivity of weightings was analysed by adopting the same geoprocessing model work-flow and dataset used in the original SPAM and SSI. However, instead of applying the same criteria weightings to each dimension (ecological, socio-economic, and developmental), the weights were altered in the range of ± 10%. For example, instead of assigning 50% to each dimension and 0.0625 to each attribute/indicator in the original computation, we assigned 60% and 40% or 0.375 and 0.0250 to each dimension and indicator in turn, respectively. Simulation runs for each scenario and criterion generated new SPAMs and SSIs that were used to compare the changes in spatial pattern and SSI with different weightings. As with the original computation, the aggregate index value of the most sustainable farm household/plot was 1.

2.11 Interpolation of Regional Data

Different geostatistical methods of interpolation (Section 1.2.3) were tested using sufficient data from the survey to ensure that suitable predictions were achieved for some values of the continuous attributes (e.g., those related to soil and water) at unvisited points.

\[
\hat{Z}(x') = \begin{pmatrix} \lambda_1 \\ \vdots \\ \lambda_n \end{pmatrix} \cdot \begin{pmatrix} Z(x_1) \\ \vdots \\ Z(x_n) \end{pmatrix}
\]

Measured points of samples attributes required for modelling were used to produce continuous estimates or surfaces. Block diagrams were also derived from the DEM to show the landform of the study area. The aim was to use these for subsequent exploratory studies and overlay analysis, as well as for quantitative modelling in poverty mapping. Depending on the underlying spatial structure of the data, geostatistical methods from GIS interpolation functionalities were used to optimise the interpolation.
2.12 Development of the Analysis and Assumptions\(^8\) at Specific Scales

2.12.1 Crop Production Practices in the Research Area were Assumed to Lead to Soil Degradation.

Further analysis required the identification of degraded plots in the study area using GIS overlay analysis. The aim was to identify the locations of degraded plots based on soil samples taken from the study area on the map. The new map of degraded plots was used as a pivot in the analysis to develop an overlay map with other feature classes for visual analysis and interpretation, as well as to examine the utility of the different attributes and their explanatory power. However, there was some doubt as to whether several of these attributes could be represented using a common factor to reduce the number of indicators in further analysis. This process led to the elimination of some variables, thereby reducing the dimensionality of the input dataset. Two statistical factors describing soil degradation were extracted using the following factors:

\[
\text{Degradation} = f (\text{soil structural index (O, T, E), acidity (S, Al)})
\]

where

- **O** = organic matter content (%: 0–40 cm)
- **T** = depth of topsoil (cm)
- **E** = erosion (visible)
- **S** = soil pH
- **AL** = Al content.

The relationship between soil quality indicators and the percentage of crop on a plot was statistically tested (GLM: Table 3.1 and Figure 3.1) and a spatial query function was applied as the hypothesis. A significant relationship between degraded plots and crop percentage was detected. Note that the GLM is a statistical linear model that may be written as: \(Y = XB + U\), where \(Y\) is a matrix with a series of measurements, \(X\) is a matrix that might be a design matrix, \(B\) is a matrix containing parameters that are usually to be estimated, and \(U\) is a matrix containing errors or noise.

A degraded plot as described in this study, means any soil with an acidity level less than 5.0 and with a structure of less than 6.5 (acidity < 5.0 and structure < 6.5). This function was used to build a Structured Query Language (SQL) query with the "SELECT" function in ArcGis. The spatial query functions provided information about individual features and their interactions with other feature attribute values, as well as their locations, which revealed how the attribute values were distributed. The expected derived map and results showed the locations of degraded land with the type and percentage of crop, as well as the size of the plot (i.e., the degraded plot and its spatial relationship with these variables).

2.12.2 Production Techniques Favour Development of Specific Pests and Diseases, Which is Assumed to Lead to Increased Pesticide Input with Negative Environmental Consequences

The main datasets used for testing this hypothesis were field sample plots, soil quality information, and crop data. Pest and disease pressure could be measured using two

\(^8\) Assumption as depict here refers to as working assumption or arguments put forward for verification.
indicators. The first was the attribute crop effect, describing the pest and disease pressure that possibly resulted from a particular type of mixed farming on a cultivated plot (Figure 3.4), while the second was a proxy indicator, pesticide application. Pesticide application was an attribute that described the reaction of farmers, i.e., farmers had to apply more pesticides when there was a high pest and disease pressure. Thus, the outcome of this hypothesis was based on these factors.

Buffer function techniques were used on the plots in the study area to create a new layer (crop effect) from the tree plot. The goal was to use overlay analysis to combine the characteristics of the features plots, trees, and crops, as an input to intersect the layer crop effect.

The output identified locations in the study area with high levels of pest and disease pressure. These locations were overlaid with the feature type of mixed farm to indicate the spatial distribution of mixed farms and their level of pest and disease pressure.

Figure 2.10 Locations of plots (maize and cassava plots are shown separately). Pest and disease pressure affected plots shaded with grey.

The toxicity levels detected on the plots were also related to the mixed farms to assess the relationship between toxicity and pest and disease pressure in different locations.
Analysis of variance for within-subject effects was used to analyse the significance of the different effects.

2.12.3 Soil Erosion and Production Techniques Affect River Water Quality

The main datasets used were rivers, plots, watershed borders, and soil quality data. In the topography of the area’s watershed, large-scale developments were associated with a lot of land clearing and grading, which was also considered to determine the magnitude of other influences apart from farming activities.

The parameters for the water quality index factor were derived from the attributes turbidity, temperature, pH, conductivity, pollution level, phosphate, and nitrate (Appendix 1). It was assumed that these parameters would affect water quality when eroded soil from farm plots, construction sites, and other anthropogenic developments was carried into rivers. To determine the effect of farming activities on water quality in the study area, erosion rates measured on the plots and the distances between plots and rivers were matched. Distance from each plot point was calculated to the nearest river polyline within the search radius (NEAR procedure of ArcGIS). The "Near distance" tool computes the distance from each point to the nearest assigned feature, based on the principle of the Euclidean shortest distance, i.e., the distance of a point \( p(x_p, y_p) \) to a line \( l \) on an \( x-y \) plane. The results of this analysis were recorded in the attribute table. A surface feature was then created (interpolated) from the nearest distance field to provide a raster classification of the near-river influence.

To better understand this interaction, the erosion feature is classified into three categories: less eroded, moderately eroded, and severely eroded. The classification was clearly specified on the map based on the level of erosion in each plot indicated by the erosion level attribute. A statistical test of the near-river water quality effect was used to evaluate the significance of this factor.

2.12.4 The Environmental Impact of Current Land Use has a Negative Effect on Human Health in Society

The main datasets used were: community, settlement and farm locations, field sample plots, rivers, and crop data. The risk-based contaminant areas attribute was used as a proxy indicator for measuring poisoning through exposure to surface soil sediment, groundwater, and surface water.

The nitrate and phosphate levels in the ground and surface water in communities within the study area were used as a measure of health risk-based contaminants. We used surface water as the primary measurement, because there was an inter-measure correlation between groundwater and surface water. These variables exhibited co-linearity, indicating that they were linked. The interpolation computational method of ordinary kriging was fitted using a spherical module based on the type of variogram found in the study area.

\[ Z(s) = \mu + \varepsilon(s) \]

The spherical module was as follows:

\[
\tilde{\gamma}(h) = \begin{cases} 
C_0 + C_1 \left( 1.5 \frac{h}{\alpha} - 0.5 \left( \frac{h}{\alpha} \right)^3 \right) & \text{if } |h| \leq \alpha \\
C_0 + C_1 & \text{if } |h| > 0 
\end{cases}
\]
where:
\[ h = \text{lag} \]
\[ C_o = \text{nugget} \]
\[ C_o + C_1 = \text{sill} \]
\[ a = \text{range}. \]

A risk-based contaminant surface map was created from point support samples in the study area.

Overlaying this map (risk prediction map) with the plot of the study area produced a new map that identified the human health risk-based areas of concern (i.e., locations with a higher risk of contaminants), which were located mainly in areas with high concentrations of farm plots or with intense farm activities.

The general human health risk indices used by the Environmental Protection Agency of Ghana (EPA) were applied for the spatial point risk calculations by the modification (site-specific parameters) of Spatial Analysis Decision Analysis (SADA)\(^9\) for human health risk analysis, as follows.

\[
\text{Nonrad intake in } h = C_{wn} VF EF ED CF_2 BW AT
\]

where
\[ C_{wn} = \text{non-radionuclide chemical concentration} \]
\[ VF = \text{volatilisation factor (L m}^{-3}) \]
\[ EF = \text{exposure frequency (days/years)} \]
\[ ED = \text{exposure duration (years)} \]
\[ CF_2 = \text{conversion factor (days/h)} \]
\[ BW = \text{body weight (kg)} \]
\[ AT = \text{averaging time (years)}. \]

2.12.5 Production Costs Increase Due to the Additional Quantities of Chemicals and Labour Input Required to Compensate for the Negative Effects of Current Land Use, while Yields Tend to Decline. Both Effects will Reduce Farm Income.

The main datasets used for this measurement were as follows: plot at study area, degraded plot, river at study area, income, and soil quality. Exploring these datasets indicated that the average crop production in the degraded plots was unexpectedly high.

---

\(^9\) SADA is a program that incorporates tools from environmental assessment fields into an effective problem solving environment. These tools include integrated modules for geospatial analysis, geostatistical analysis, human health risk assessment, ecological risk assessment, and decision analysis. SADA has a strong emphasis on the spatial distribution of contaminant data, which makes it suitable for looking at data with a spatial context.
Exploration of the dataset indicated a high crop income level on the intersect scale with degraded plots, which was mainly closer to rivers. Tree income also had a very high level relationship with the degraded plot intersect. Further spatial analysis showed that production costs in these locations were comparatively high, which would lead to a lower total farm income (crop and tree income) in the long-term.

Figure 2.11 Degraded plots were mainly clustered around rivers and watersheds with a higher crop income

Thus, it was necessary to re-examine the significance of these locations to farmers and investigate why crop production tended to be so high on degraded plots. The hot spot and cluster analysis tool (Ripley's k-function) was used to identify clusters of features with values that are similar in terms of magnitude and heterogeneity:

\[ L(d) = \sqrt{\frac{A \sum_{i=1}^{N} \sum_{j=1}^{N} k(i,j)}{\pi N (N - 1)}} \]
2.12.6 The Production and Economic Well-being of Communities Can be Increased with Various Incentives

The farm household, owner, income, plot, and community datasets were used in this analysis. Two hypotheses were identified when measuring or ascertaining the impact of ADRA's incentives on farm yields and the socio-economic enhancement of farmers in communities: 1) quantify ADRA's overall incentives per farmer; and 2) compare the average farm income per hectare of farmers operating as part of ADRA's programme with a reference value, (i.e., the national average farm and labour income in agroforestry systems excluding cocoa, coffee, and shea-butter). However, the available records provided no meaningful measures of the incentives provided, so it was assumed that ADRA's incentive was equal for all (i.e., all farmers enjoyed equal assistance).

Using the reference values as thresholds, the original data was transformed to a binary scale by indicator kriging, i.e., 1 if income > = Tj, and 0 otherwise or vice-versa. This probability kriging assumed the following model:

\[ I(s) = I(Z(s) > c_t) = \mu_1 + \varepsilon_1(s) \]
\[ Z(s) = \mu_2 + \varepsilon_2(s) \]

where \( \mu_1 \) and \( \mu_2 \) are unknown constants and \( I(s) \) is a binary variable created by using a threshold indicator, \( I(Z(s) > c_t) \), with two types of random errors, \( \varepsilon_1(s) \) and \( \varepsilon_2(s) \).

A probability map showing the relationship between the income of an ADRA-assisted farmer or their casual labourers and the national average farmer was derived from this kriging process.

2.12.7 There was an Even Distribution of Development Projects Across the Communities

The main datasets used to tests how development projects were distributed in the research area were: development, community, and households. Data made available by ADRA showed an even project provision, but the perception of many farm household members was that there had been discrimination in this regard. Thus, it was necessary to establish the validity of these claims and counter-claims. The Moran 1 function in ArcGis was used to verify the distribution of ADRA's development project in the study area:

\[ I = \frac{N}{s_2} \sum \sum W_{ij} Z_i Z_j / \sum Z_i^2 \]

where \( Z_i \) is the deviation of the variable of interest with respect to the mean, \( W_{ij} \) is the matrix of weights which in some cases is equivalent to a binary matrix with ones in position \( i, j \) when observation \( i \) is a neighbour of observation \( j \), but zero otherwise.

2.12.8 The Degree of Freedom in Decision-making Processes was Low in Farm Households

This hypothesis used the following datasets: farm household, owner, and developmental. It was found that farmers had regular meetings with ADRA to deliberate on issues of concern related to their farming activities and development projects.
However, over 55% of farmers and community leaders claimed to have been left out of the decision-making processes and that they were only consulted during the implementation stages. The survey also suggested that 40% of farmers felt that some of the ADRA extension officers were closer to Adventist Church members than non-Adventist Church members. According to the farmers, the attitude of the officers sometimes gave an unfair advantage in decision-making, skewing decisions more favourably towards Adventist Church members in the study area.

The truth of these perceptions was difficult to prove based only on interviews with the communities. However, the present study tried to analyse how widespread the perceptions were by measuring the density of the Adventist church member population and its concentration in the research area. Church population (church members) for each community settlement area and community population (population of a farm community) were used as indicators to measure the scale of influence that the church might have on the community and its development. It was assumed that a high church population density in a community would increase the rate of influence.

The ArcGis Kernel density (KD) procedure was applied to the dataset \( x_1, x_2, \ldots, x_n \sim f \), which contained independent and identically distributed samples of a random variable. The KD (kernel density) approximation of its probability density function is:

\[
\hat{f}(x) = \frac{1}{n} \sum_{i=1}^{n} K\left( \frac{x - x(i)}{h} \right)
\]

where \( K \) is a kernel, and \( h \) is a smoothing parameter known as the bandwidth. To minimise AMISE (asymptotic mean integrated square error), an optimal bandwidth was derived using the automatic format in the R program.

The procedure computed the density of church members in each associated community settlement area to generate a continuous surface map distribution of the measured quantities at each point. Higher church member density indicated the possibility of influence by church members and would be apparent on a continuous density map. A plot of a KD estimate provided a graphical summary of the shape of the data.
3. RESULTS

3.1 Analysis of Poverty at different Scales

3.1.1 Hierarchy of GIS Analysis

The core objective of any evaluation technique based on GIS and spatial analysis is to present an empirical set of results derived from data collection (plot), economic (household), environmental (ecology), and community (geographical administrative) levels of analysis that demonstrate the tangible outputs of any measurable contributions (negative or positive). This study conducted analyses at the plot, farm household, watershed, and developmental levels.

The empirical results presented in this section are based on indicators at each level of analysis. The 11 sustainability criteria used by the agriculture-based poverty alleviation programme were as follows: efficiency and productivity, resilience, biodiversity, rules of resource management, satisfaction of basic needs, stability, equity, profitability, cultural diversity, risk, and time dispersion. These criteria were used in the measurement of the programme's sustainability, and they were used to produce a poverty map and an index. The ultimate objective was to present the results of the study in the form of commentaries (discussions), maps, tables, and statistics.

3.1.2 Plot Level Analysis

3.1.2.1 Crop Production and Soil Degradation

It was assumed the crop production practices found in the research area would lead to detrimental changes in soil quality. This hypothesis was tested using field sample plots, soil quality information, and crop data. A comparison of soil quality indicators from cassava-based plots and maize-based plots (Table 3.1) showed there was a significant difference between all the related supports derived from these two crop-based plots. This was also confirmed by a paired samples $t$-test (Table 3.2) that compared soil quality in these two different crop-based plots.

Table 3.1 Differences in soil quality attributes between cassava-based and maize-based plots (the unit of measurement is listed in the degraded factors, below)

<table>
<thead>
<tr>
<th>Soil Quality Attributes</th>
<th>Cassava (Mean)</th>
<th>Maize (Mean)</th>
<th>Differences (Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exchangeable aluminium</td>
<td>0.399</td>
<td>0.201</td>
<td>0.197</td>
</tr>
<tr>
<td>Depth of topsoil</td>
<td>37.574</td>
<td>43.063</td>
<td>-5.489</td>
</tr>
<tr>
<td>Organic matter (%) (0-20cm)</td>
<td>3.038</td>
<td>6.043</td>
<td>-3.005</td>
</tr>
<tr>
<td>Organic matter (%) (0-40cm)</td>
<td>2.813</td>
<td>5.245</td>
<td>-2.432</td>
</tr>
<tr>
<td>Soil pH</td>
<td>5.431</td>
<td>6.101</td>
<td>-0.676</td>
</tr>
<tr>
<td>Structure index (0-20cm)</td>
<td>7.137</td>
<td>11.304</td>
<td>-4.167</td>
</tr>
<tr>
<td>Structure Index (0-40cm)</td>
<td>5.998</td>
<td>9.543</td>
<td>-3.545</td>
</tr>
<tr>
<td>Visible erosion</td>
<td>2.759</td>
<td>1.932</td>
<td>0.836</td>
</tr>
</tbody>
</table>

This comparison revealed that support analysis of maize-based plots gave significantly
better values in terms of soil quality. The identification of these differences provides an important springboard for investigating the possible causes of the degradation that mainly affected cassava-based plots.

Table 3.2 Paired samples t-test in soil quality for cassava- and maize-based plots

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>t</th>
<th>df</th>
<th>sig (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.284</td>
<td>2.218</td>
<td>0.784</td>
<td>Lower[−4.139] Upper[−0.429]</td>
<td>−2.912</td>
<td>7.000</td>
<td>0.0230</td>
</tr>
</tbody>
</table>

Thus, the main component of crop production on a mixed farm promoted the loss of soil fertility. This was most obvious on the cassava-based plots (Tables 3.1 and 3.2). Spatial query functions, which provide information about individual features and their interactions with other features, and their locations, also indicated how the attribute values were distributed. The spatial pattern indicated on the map (Figure 3.1) suggests a relationship between the percentage of crop on a plot and the degraded plot factor, confirming the significant effect of crop production and soil degradation in the study area.

Figure 3.1 Degraded plots and proportions of crop production
Table 3.3 Tests of between-subjects effects: degraded plot tests of between-subjects effects (percrop denotes percentage of crop on a plot)

<table>
<thead>
<tr>
<th>Square</th>
<th>Type 3 Sum</th>
<th>df</th>
<th>Mean</th>
<th>F</th>
<th>P</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected model</td>
<td>38.498(b)</td>
<td>20</td>
<td>1.95</td>
<td>4.944</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Intercept</td>
<td>1247.007</td>
<td>1</td>
<td>1247.00</td>
<td>3202.817</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Size</td>
<td>0.245</td>
<td>2</td>
<td>0.122</td>
<td>0.314</td>
<td>0.732</td>
<td>0.097</td>
</tr>
<tr>
<td>Percrop</td>
<td>19.443</td>
<td>8</td>
<td>2.430</td>
<td>6.242</td>
<td>0.000</td>
<td>0.999</td>
</tr>
<tr>
<td>Size*Percrop</td>
<td>1.388</td>
<td>10</td>
<td>0.139</td>
<td>0.356</td>
<td>0.959</td>
<td>0.162</td>
</tr>
<tr>
<td>Error</td>
<td>16.743</td>
<td>43</td>
<td>0.389</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2228.739</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>55.241</td>
<td>63</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.2 Estimated marginal means of degraded plot in relation to crop percentage on plot

The significance of the interaction between crop percentage and degraded plot analysed in Table 3.3 shows the effects that contribute most to the model. Thus, the percentage of crop production had a significant effect on soil fertility ($p < 0.001$). The profile plot (Figure 3.2) shows the estimated decrease in soil quality as the crop percentage increases. However, the plot size did not significantly contribute to the model ($p = 0.732$).

Spatial analysis of the related datasets and the GLM confirmed that crop production (over-production of crops, especially cassava) practices used in the research area led to soil degradation.
3.1.2.2 Pesticides and Environmental Impact

It was assumed that production techniques favoured the development of pests and diseases, which led to an increased pesticide input with negative environmental consequences. The test of this hypothesis detected locations in the study area with higher pest and disease pressures that were associated with mixed farming. Thus, plots containing different combinations of maize and fruit/trees favoured the development of specific pests and diseases in the study area. Overall, maize-based plots grown with mangoes and cashews had the highest level of pest and disease pressure, as shown in Figure 3.3.

Figure 3.3 Pie chart showing the pest/disease effects of different types of mixed farming

The relatively high level of pesticide application in these locations confirmed the pest and disease pressure, and the reaction of farmers in the study area. The average pesticide input in terms of active ingredients was comparatively high in the study area (Table 3.4). The consequences of these treatments were the greater negative environmental impacts detected in this category.

Figure 3.4 Profile plot for crop percentage effect on trees
On average, the toxicity level was relatively high in maize-based plots (3/5) and lower on cassava-based plots (2/5). The percentage of crop factor also contributed to pest and disease pressure, as shown in Figure 3.4. Table 4.4 shows that each term was statistically significant ($p < 0.05$). The partial eta-squared values (Table 3.4) indicated that some amount of variation was accounted for by each model term.

Table 3.4 Tests of between-subjects effects

<table>
<thead>
<tr>
<th>Source</th>
<th>Type3 Sum of Square</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>P</th>
<th>Partial Eta</th>
<th>Noncent. Parameter</th>
<th>Observed Power(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected</td>
<td>38.976(b)</td>
<td>9</td>
<td>4.331</td>
<td>5.736</td>
<td>0.000</td>
<td>0.489</td>
<td>51.639</td>
<td>1.000</td>
</tr>
<tr>
<td>Intercept</td>
<td>219.078</td>
<td>1</td>
<td>219.078</td>
<td>290.253</td>
<td>0.000</td>
<td>0.843</td>
<td>290.243</td>
<td>1.000</td>
</tr>
<tr>
<td>Crop</td>
<td>11.624</td>
<td>1</td>
<td>11.624</td>
<td>15.400</td>
<td>0.000</td>
<td>0.222</td>
<td>15.400</td>
<td>0.971</td>
</tr>
<tr>
<td>Percrop</td>
<td>37.086</td>
<td>8</td>
<td>4.636</td>
<td>6.142</td>
<td>0.000</td>
<td>0.476</td>
<td>49.134</td>
<td>0.999</td>
</tr>
<tr>
<td>Error</td>
<td>40.758</td>
<td>54</td>
<td>0.755</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>445.500</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected</td>
<td>79.734</td>
<td>63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a)Computed using alpha = 0.05, (b) R Squared = 0.489 (Adjusted Squared = 0.404)

Visual and statistical analyses demonstrated that production techniques based on mixed farming tended to increase the pest and disease pressure on crops and trees. This also led to over-application of pesticides, which had negative environmental consequences.

3.1.3 Farm Household Level Analysis

3.1.3.1 Farm Production Cost and Income

It was assumed that production costs would increase because of the additional quantities of chemicals and labour that would be required to compensate for the negative effects of current land use practices, whereas yield would tend to decline. Both effects would reduce farm income.

A visual inspection revealed that locations with comparatively higher production costs and higher crop yields (especially cassava) were mainly clustered around river or watershed areas (Figure 3.2).
Table 3.5 Comparing indicators from degraded and less degraded plots in the study area (currency: euros; fertiliser and pesticide applications: kg ha$^{-1}$)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Less Degraded Plots (Mean)</th>
<th>Degraded Plots (Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop Income</td>
<td>710.29</td>
<td>2116.20</td>
</tr>
<tr>
<td>Tree Income</td>
<td>11716.17</td>
<td>3064.51</td>
</tr>
<tr>
<td>Production Cost</td>
<td>600.00</td>
<td>1100.00</td>
</tr>
<tr>
<td>Farm Labour Cost</td>
<td>250.00</td>
<td>400.00</td>
</tr>
<tr>
<td>Fertilizer Application</td>
<td>425.15</td>
<td>876.22</td>
</tr>
<tr>
<td>Pesticides Application</td>
<td>33.00</td>
<td>97.45</td>
</tr>
</tbody>
</table>

The non-spatial statistics function in ArcGIS was used to analyse the related socio-economic attributes of farm labour, pesticides, and fertiliser applications, which showed a definite increase in these attributes in the degraded plot areas.

There was a higher average crop income on degraded plots, and further analysis showed that the average farm labour, pesticides, and fertiliser applications were also higher in these degraded plots. This outcome may be related to factors such as very intense land use and decreased quality of fertilisers. Thus, farming in the research area is labour intensive, because more intensive soil preparation leads to high labour costs. The decrease in fertiliser quality factor could also be interpreted as a reduction in the efficiency of fertiliser application as a result of soil degradation. The decrease in soil quality also reduced overall yields and income in the long-term, as indicated by the factors structural index and acidity (Section 3.2).

It was found that plots in these locations had a lower woodlot or fruit tree production, which affected farm incomes. Thus, the general average level of soil suitability affected the overall average total farm income (Figure 3.5).

Figure 3.5 Chart demonstrating how plot suitability matches fruit tree yield and an eventual increase in total farm income (total farm inc). This plot includes both cassava- and maize-based plots, so the slope is not highly positive.
Because the overall total farm income and tree income were lower in degraded plots in the study area, the gross margin and degraded plots were intersected to verify the observed production factors (Figure 3.7). The outcome indicated a lower gross margin in degraded plots.

This outcome may also be linked to crop production, because higher crop income was mainly located on degraded plots. This also indicates that a number of farmers placed a higher premium on immediate gains rather than long-term profit.

Figure 3.6 Distribution of tree income and degraded plots in the study area

Thus, looking at short-term increases in crop income often fails to tell the entire story. Increased crop yields are desirable, but an increase does not always mean that the profit margin of the farmer is improving. The farmer’s production costs may have increased, thereby lowering profits.
Empirical results indicated that production costs led to an overall decrease in farm income, despite a higher crop yield in the affected plots. The additional costs of chemicals and labour inputs was a result of improper land use practices, which led to a lower total farm income or lower gross margin. This reflected lower efficiency and lower profitability.

3.1.3.2 Environmental Impact of Current Land Use

It was assumed that the environmental impact of current land use practices would have a negative external effect on human health in society. However, the number of incidents of occupational pesticide or fertiliser poisoning among farmers in the study area was relatively small. A check with farmers and clinics in the study area found that less than 1% of farmers had experienced occupational pesticide or fertiliser poisoning.

The risk-based contaminant surface map (Figure 3.8) created from the data points identified human health risk-based areas of concern (i.e., locations with higher risk-based contaminants) that were mainly located in areas with a high concentration of farm plots or farm activities. This was also confirmed by the detection of 25 human health risks in some areas, based on the SADA analysis (Table 3.6).
3.1.3.2 Environmental Impact of Current Land Use

It was assumed that the environmental impact of current land use practices would have a negative external effect on human health in society. However, the number of incidents of occupational pesticide or fertiliser poisoning among farmers in the study area was relatively small. A check with farmers and clinics in the study area found that less than 1% of farmers had experienced occupational pesticide or fertiliser poisoning.

The risk-based contaminant surface map (Figure 3.8) created from the data points identified human health risk-based areas of concern (i.e., locations with higher risk-based contaminants) that were mainly located in areas with a high concentration of farm plots or farm activities. This was also confirmed by the detection of 25 human health risks in some areas, based on the SADA analysis (Table 3.6).

Table 3.6 Human health risk: univariate statistics for the research area

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Detects</th>
<th>N</th>
<th>Mean</th>
<th>Coeff’t</th>
<th>Interq.</th>
<th>Min</th>
<th>Max</th>
<th>UCL95(S’t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CN22</td>
<td>25</td>
<td>65</td>
<td>2.543</td>
<td>0.316</td>
<td>1.5</td>
<td>0.7</td>
<td>4.1</td>
<td>2.673</td>
</tr>
</tbody>
</table>

The SADA risk assessment module calculated the risk of adverse health impacts on a population exposed to toxic chemicals in groundwater and surface water, which was also applicable to soils and sediments.

![Figure 3.8 Ordinary kriging map of human health risks in the study area](image)

In both cases, the areas of health risk concern were mainly located in downstream areas with a high concentration of farms.
Table 3.7 Information derived from cross-validation of the model to show how well the model predicts the unknown values when arriving at the map shown in Figure 4.8

<table>
<thead>
<tr>
<th>Prediction Error Parameters</th>
<th>Sample: 65 of 65</th>
<th>Error Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td></td>
<td>0.0018</td>
</tr>
<tr>
<td>Root-Mean-square</td>
<td></td>
<td>0.0559</td>
</tr>
<tr>
<td>Average Standard Error</td>
<td></td>
<td>0.0825</td>
</tr>
<tr>
<td>Mean Standardised</td>
<td></td>
<td>0.0679</td>
</tr>
<tr>
<td>Root-Mean-Square Standardised</td>
<td></td>
<td>1.0060</td>
</tr>
</tbody>
</table>

Other factors such as domestic and industrial waste discharge could be part of this risk, but there was a correlation between water quality and the concentration of farms suggesting that farming activities were a major contributory factor to human health risks in the research area and its surroundings. To strengthen this argument, available records show that Ghana Water Company (GWC), which supplies potable water to about 2.8 million people in Accra, spends more than 300,000 Euros each year on chemicals for water treatment (Ghana Water Company, 2008). It should be emphasised that the main catchment area of the water supply dam falls within the study area. Another health risk factor was the pesticide residues found in crops and fruits. Three out of 20 samples were found to contain residues and some surpassed the levels permitted for human consumption (0.01 mg kg$^{-1}$).

It is difficult to make a general conclusion because of the relatively small number of farmers experiencing farm-related poisoning and the small sample of crops/fruits screened for pesticides residues. However, the fact that pesticides residues were found and that some samples exceeded the permitted levels, as well as the detection of contaminants and human health-risk locations, supports the hypothesis of negative external effects on society, i.e., the consumers of products and water in the research area.

3.1.3 Watershed Level Analysis

It was assumed that soil erosion and production techniques would affect the water quality of the rivers. An overlay map of the erosion level with the raster distance to rivers layer supported the initial (Section 2.12) that plots closer to rivers would be eroded the most.

The empirical results showed that the quality of water in the study area was affected by the agricultural land use practices. A visual analysis of the map (Figure 3.9) found that the most severely eroded plots were mainly found closer to rivers.
Figure 3.9 Raster layer showing the distance to rivers

Figure 3.10 Water quality/distance to river

Figure 3.10 also shows that water quality was a function of the distance from the plot to the river. There was a significant correlation between water quality and proximity to rivers (two-tailed $t$-test; $p < 0.01$), which confirmed the assumption that agricultural land use contributed to the contamination of rivers with nitrate, phosphorus, pesticides residues, and sediments (Villegas, 1995). Factors contributing to the contamination of rivers in the study area also affected the ecosystem in the research area. The total benefit of the water supply to people is a function of both its quantity and quality, and the ecosystem plays a key role in quality (Egoh et al., 2008).

This analysis confirmed that the water quality in the research area was affected by contaminants as a consequence of agricultural land use practices and erosion.
3.1.4 Developmental Level Analysis

3.1.4.1 The Production and Economic Well-being of Communities was Assumed to Increase Due to Various Incentives Provided by the Project

The yield performance (income) and labour income (farm labour income) of farmers/labourers in the study area was compared with the national average, using probabilistic kriging maps (Figures 3.11 and 3.12) to display continuous data in the range 0–1. This provided insights into how the probability of exceeding income thresholds varies at different income levels. The location of a farm household was associated with its probability range. The resulting maps indicate the probability that a farm household or labourer in a location exceeded the national average (Table 3.8).

Table 3.8 Economic indicators at the farm household level in Euros

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Farm Income (Annual)</th>
<th>Farm Income Total Labour</th>
<th>(Friday)</th>
<th>Farm Income (Monthly) Farmer/labourer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>12 888</td>
<td>10</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>22 380</td>
<td>22</td>
<td>286</td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>6 100</td>
<td>6</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Standard deviation</td>
<td>2 660</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>18</td>
<td>20</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Reference value</td>
<td>4 936</td>
<td>4</td>
<td>36</td>
<td></td>
</tr>
</tbody>
</table>

1) Total weekly labour wages payable on Fridays (average wage for a hired labourer)
2) Total monthly income for a farmer or a hired labourer

Overall, the ADRA-assisted farm households and their associated labourers had higher incomes than the average national farmer.

Figure 3.11 Indicator kriging: probability of income >4936.45 Euros
The official and unofficial average daily/monthly labour income was also higher. The maps show the probability that farmers and their labourers exceeded the stated thresholds.

Table 3.9 Prediction error for threshold income probability

<table>
<thead>
<tr>
<th>Prediction Error Parameters</th>
<th>Sample: 65 of 65 Error Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.0132</td>
</tr>
<tr>
<td>Root-Mean-square</td>
<td>0.379</td>
</tr>
<tr>
<td>Average Standard Error</td>
<td>0.306</td>
</tr>
<tr>
<td>Mean Standardized</td>
<td>0.0400</td>
</tr>
<tr>
<td>Root-Mean-Square Standardized</td>
<td>1.263</td>
</tr>
</tbody>
</table>

The predicted map in Figure 3.11 clearly shows that the majority of farm households in ADRA’s programme had a farm income that exceeded the national average.

Figure 3.12 Indicator kriging: probability of a day’s wage >0.75 Euros

Figures 3.11 and 3.12, and Table 3.8 confirmed that farmers and labourers in most locations exceeded the average farmer/labourer income in Ghana, supporting the hypothesis.
Table 3.10 Prediction error for threshold labour income probability

<table>
<thead>
<tr>
<th>Prediction Error Parameters</th>
<th>Sample: 65 of 65 Error Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.0211</td>
</tr>
<tr>
<td>Root-Mean-square</td>
<td>0.269</td>
</tr>
<tr>
<td>Average Standard Error</td>
<td>0.309</td>
</tr>
<tr>
<td>Mean Standardised</td>
<td>0.0213</td>
</tr>
<tr>
<td>Root-Mean-Square Standardised</td>
<td>1.097</td>
</tr>
</tbody>
</table>

These results may be sufficient to support the claim that ADRA’s provision of incentives and assistance to farmers in the research area has enhanced their economic well-being. According to ADRA, a larger proportion of farmers selected for the programme fell below the national average income (ADRA Executive Summary, 2000).

3.1.4.2 The Degree of Freedom Enjoyed by Farm Households when Making Decisions was Assumed to be Low

There was a strong perception that community decision-making was skewed in favour of Adventist Church members, which was confirmed empirically by data collected from the communities. More than 55% of farmers and community leaders claimed to have been left out of decision-making processes, and they claimed they were only consulted during the implementation stages. It was claimed that the relationship among ADRA staff and Adventist Church members was more cordial than that among other community members, thereby giving them an unfair advantage in decision-making processes affecting projects and farming activities in the research area.

Figure 3.13 Density surface map showing areas of higher church density (perceived church influence). Kernel density bandwidth 1.33, N = 43.
The derived density surface map shows the concentration of Adventist Church relative to the general population, indicating the possible scale of the church members' influence in the research area.

Figure 3.14 Gaussian kernel

Figure 3.13 shows that a higher population density of church members (and possibly a greater influence on decisions) was confined to a few locations within the research area. This was also confirmed by the kernel density chart shown in Figure 3.14. Thus, if church members had more influence in decision-making processes it would not be widespread in the study area, because it was apparent that the church member population was not high enough to affect overall decision-making processes.

Based on these results, the hypothesis was rejected despite strong opinions of interviewees; because the density of church members (Figure 3.13) was too low to allow the church to influence decision-making processes.3.1.4.3 Projects were Assumed to be Evenly Distributed Across Communities.

Table 3.11 Moran’s I index for the spread of development projects, i.e., roads/paths, schools, and hospitals are shown here as partially dispersed because of the distribution of these features

<table>
<thead>
<tr>
<th>Project</th>
<th>MORAN’S I IND</th>
<th>Z Value</th>
<th>Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well</td>
<td>-0.74</td>
<td>-3.09</td>
<td>Dispersed</td>
</tr>
<tr>
<td>Barn</td>
<td>-0.81</td>
<td>-4.68</td>
<td>Dispersed</td>
</tr>
<tr>
<td>KVIP</td>
<td>0.64</td>
<td>-2.65</td>
<td>Dispersed</td>
</tr>
<tr>
<td>Road/Path</td>
<td>0.04</td>
<td>0.12</td>
<td>Partially dispersed</td>
</tr>
<tr>
<td>Hospital</td>
<td>0.22</td>
<td>0.39</td>
<td>Partially dispersed</td>
</tr>
<tr>
<td>Schools</td>
<td>0.38</td>
<td>0.59</td>
<td>Partially dispersed</td>
</tr>
<tr>
<td>Erosion</td>
<td>1.06</td>
<td>2.76</td>
<td>Clustered</td>
</tr>
</tbody>
</table>

Moran's I index showed that the erosion assistance project as the only project that was clustered. Thus, this factor was analysed independently to understand the contributory factors. Based on the landform derived from the DEM, the erosion assistance feature was used as an overlay to verify the information obtained from ADRA, i.e., that most erosion assistance projects were sited at areas of higher elevation.
The spatial pattern of ADRA’s development projects in the study area was analysed independently, showing only the clustering of erosion assistance projects (Table 3.15).

Figure 3.15 Erosion assistance projects were mainly located at comparatively low elevations in the research area

Development projects in the study area were generally evenly distributed (Moran's I, Table 3.11). Clusters were attributable to the fact that areas had need of erosion assistance 3.2 Analysis of the Variables in the Sustainability Model.

3.2.1 Efficiency and Productivity

Farms that were considered to be less technically efficient and that had low productivity fell below the production frontier (Section 2.7.1).

The statistical summary shown in Table 3.12a indicates that the efficiency coefficients of cassava-based and maize-based plots varied between 42% and 90% of the production frontier. Figure 3.12b also shows that the top 25% of farms had technical efficiency levels >0.70, which was considered to be a relatively high level of efficiency. By contrast, the technical efficiency level of the bottom 25% was <0.58. Approximately 50% of farms had technical efficiency levels of 0.67–0.90. Thus, significant differences among farms were attributable to the influences shown in Figure 4.16.

Table 3.12a, b Technical efficiency and the production frontier

<table>
<thead>
<tr>
<th>Efficiency Level</th>
<th>Cassava</th>
<th>Maize</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean efficiency</td>
<td>0.67</td>
<td>0.78</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.42</td>
<td>0.45</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.89</td>
<td>0.90</td>
</tr>
</tbody>
</table>

The greatest influence on efficiency was farm type (cassava-based or maize-based farm) with values ranging from 55% to 70%. The absolute range of change with farm types was 17, (i.e., farm type had a maximum range of 17 and the greatest impact on technical efficiency. The type of farm and its location also had a great impact on technical efficiency. Together, these factors produced a 32% range.
Figure 3.16 confirms the initial finding that most of the low efficiency farms were either located very close to rivers (mostly cassava-based farms) or they were maize-based/mango mixed farms. The first five factors shown in Figure 3.16 were clearly related to production practices and they had the greatest impact on technical efficiency. Marketing was also an influential factor. As was noted earlier in Section 3.2.1, the number of farms variable appeared to have no significant influence.

3.2.2 Resilience

As noted in Section 3.3.1, a high proportion of cassava was grown on most plots located closer to rivers, which led to a strong economic dependency on this crop by farmers in the research area. It was found that over-cultivation of crops, especially cassava, makes plots susceptible to greater soil loss and the soil becomes less capable of self-organisation. In the long-term, depleted soil affected the yield of fruit trees and woodlots, which subsequently impacted farm income (section 3.1). Thus, the income of farmers became more unstable, while farmland became less resilient. Figure 3.1 shows the differences in soil quality in maize-based and cassava-based plots.

Figure 3.3 shows that maize/mango mixed farms were more prone to pests and farmers reacted with the over-application of pesticides. Ecological resilience was reduced, which was indicated by the water quality and the aquatic life in the research area. Social resilience was measured as the ability of farm households to rebuild after any disturbance or disruption to the system. Table 2.7 shows that family land disputes were the main social disturbances or disruptions associated with land as a factor in production. This presents a resilience challenge to a significant number of farmers. Land acquisition is difficult for farmers or people who want to enter farming in the Greater Accra Region, because of the general pressure for land in the area. Over 70% of farmers are faced with the risk of losing their plots because of land acquisitions, family members, and big commercial farmers.

3.2.3 Stability

Table 3.7 shows the results of the ArcGIS temporal time-series analysis and the
coefficients of variation (CV) annual reviews for crops, trees, and types of mixed farm in the study area over the 12-year study period. Figure 3.17 illustrates the stability level and the type of mixed farm for each plot. Each type of farm was given a unique number between 1 and 8, indicating its location. The stability level was classified from 1 (lowest) to 10 (highest).

There was strong variation in most cassava-based plots, which confirmed the results shown in Table 2.5. The maize/citrus mixed farm was the most stable system.

Table 3.13 Prediction error for surface stability map

<table>
<thead>
<tr>
<th>Prediction Error Parameters</th>
<th>Sample: 65 of 65</th>
<th>Error Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td></td>
<td>0.673</td>
</tr>
<tr>
<td>Root-Mean-square</td>
<td></td>
<td>15.10</td>
</tr>
<tr>
<td>Average Standard Error</td>
<td></td>
<td>37.81</td>
</tr>
<tr>
<td>Mean Standardised</td>
<td></td>
<td>0.321</td>
</tr>
<tr>
<td>Root-Mean-Square Standardised</td>
<td></td>
<td>1.249</td>
</tr>
</tbody>
</table>

Figure 3.17 Sustainable stability surface map
This does not mean that the most stable system or farming activity is the best. An unstable system with a long-term high relative profit may be preferable to a stable system, depending on other factors such as production cost. However, a stable system will generally be preferable to an unstable system in terms of sustainability.

3.2.4 Rules of Resource Management

The factors intensity of land use and decreases quality of fertiliser indicated how resources were mismanaged or wasted on many plots in the research area (Section 2.7.9). The intensity of land use meant that higher labour costs increased the cost of production, thereby reducing the farm income. It was found that 65% of farmers applied more fertiliser than was required by the crops \((400 \text{ kg ha}^{-1})\). This waste of resources increased the production costs, and it also meant that the active ingredients in organic and minerals fertilisers leached into (or loaded) waters and wells (Section 3.1.2 & 3.1.3). Apart from the decreased soil fertility, pest pressure was also evident on farms (De Groote et al., 2010). Watershed area farming activities were conducted far closer to river banks than the recommended distance (50 m). This study found that there was an increase in the concentration of nitrate in downstream waters during the rainy and dry seasons (> 45 ppm nitrate). The total average nitrogen in the soil was > 25 ppm (i.e., >10 ppm nitrate and >15 ppm ammonium).

![Figure 3.18 Prediction map of organic matter content to illustrate the nitrogen level and its effect on the soil](image)

This was also confirmed by the average soil organic matter content (%) in the research area, which was less than 4%, as shown on the surface prediction map (Figure 3.18). A high concentration of phosphate was found in the lower soil section \((1.730 \pm 0.01 \text{ mg L}^{-1})\) and upper sections \((1.04 \pm 0.01 \text{ mg L}^{-1})\). The recommended value is 0.03 mg L\(^{-1}\). Excessive fertilisation and erosion, especially in watershed areas, may be a strong contributory factor to the poor water quality found in the rivers in the area. As already stated in the results (Section 3.1.3), the proximity of rivers had an impact on water quality in the study area.
3.2.5 Biodiversity

Two proxy indicators (aquatic species richness and pesticide application) were used for measuring biodiversity in the study area. Aquatic species richness was used as one reference, while pesticide over-application was measured because it was a human activity that contributed to the rate of biological diversity (biodiversity) loss, threatening the stability of the affected ecosystems.

A large proportion of plots located in the research area (65%) were heavily polluted by pesticides (Table 3.4 and Figure 3.18). Pesticide over-application affected ecological functions and structure. Observations during the dry seasons from 2002–2007 showed that approximately 70% of rivers in the study area contained many species of fish, especially those with less polluted water, as well as water lice and bloodworms. These findings are illustrated in the pollution map shown in Figure 3.19. The map also shows that most aquatic species were present in downstream rivers, indicating that the rivers could support many coarse species of fish. The alpha and beta diversity measures of the aquatic species (Figure 3.10) indicated the level of biodiversity at different spatial scales in the research area.

![Pollution map estimating the level of pollution and how stable or strained ecosystem affected the aquatic life. A type species indicates the level of pollution in a river in the research area.](image)

Apart from the protected area around the Weija dam, less than 1% of the study area was covered with natural vegetation that could support or provide refuge for flora and fauna.
Lower biodiversity results in weaker resilience and stability in the system.

3.2.6 Contributing to the Satisfaction of Basic Needs

Provision of social amenities is one of ADRA's cardinal aims for alleviating poverty in its operational areas. Ground water wells are provided to all the farming communities served by ADRA. This provides potable water, which communities lacked before the development program was initiated. ADRA's assistance to schools and educational financial support to individual farmers has increased the school-going population by 28% over the past 5 years (ADRA, 2007). Based on the interviews conducted, 80% of households considered ADRA's project to be the most convenient source of educational support and schools. Based on the records gathered from households, 60% of pupils/students in the research area received their educational finance via farm household farming activities. Storage facilities (barns) were also provided to all farming communities by ADRA. The efficient and effective use of these barns reduced post-harvest losses, thereby ensuring food availability throughout most of the year. Average farm labour incomes in the study area exceeded the national average (Section 3.1.4.1). The same also applied to the per capita income, which was substantially higher than the basic needs income and the national average per capita income. Seventy-five percent of the farm households had per capita income above the national average. Less than 10% of the farms had a farm income below the basic needs income. About 80% of the footpaths used by pupils to travel from villages to schools were covered with trees (fruit trees and woodlots) after ADRA's initiatives. These footpaths provided shade for pupils who would otherwise have walked to and from school in the hot sun.

As shown in Table 3.11, most of the programme's beneficiaries were generally happy with ADRA's provision of basic needs in the research area. The outcomes information gathered from farm households clearly showed that positive marks were given to the providers, as is found with most developmental assistance programmes in the developing world (Fowler, 1997).

3.2.7 Equity

As discussed earlier, ADRA's developmental activities were assumed to be evenly and fairly distributed. ADRA's rural infrastructure programme clearly tends to favour farming communities. This study found that erosion assistance projects were the only developmental projects that were not evenly distributed in the research area (Section 3.1.4.3). This was clearly determined by spatial constraints. In terms of gender equity, it was found that 65% of the people in the farm households were male (ADRA, 2007). This reinforces the perception that men are the heads of the family. Superficially, this might suggest that males are more favoured by ADRA's poverty alleviation programme.

3.2.8 Profitability

A comprehensive gross margin analysis compared the relative profitability of crop/tree farms in the research area indicating that maize/woodlots performed best of all the farming options. This was also highlighted in Section 3.2.2 & 4.2.2. The overall average farm gross margin in the research area was 54%, whereas maize/woodlot mixed farming had an average gross margin of 68%. The worst performing was maize/mango mixed farming with 45%, which reflected the analysis presented in the hypothesis. The complete and detailed results provided in Section 3.6 show that the actual per hectare farm income excluding the direct cost of production, including all farm management
and production expenses. Overall, the studies confirmed that farm households in the research area were more profitable than the national average (Figures 3.11 and 3.12).

3.2.9 Cultural Diversity

If ADRA is to work effectively with the communities, there is a need to understand the human cultures that shape communities. This can be achieved via a unifying dialogue based on indicators that help maintain the cultural diversity in the area of operations.

Further statistical analyses ranking the cultural diversity data reported in Section 2.7.6 can be found in Table 3.14. This ranking shows the benefits of farming education as the most important variable preserving their cultural diversity (3.54, mean ranking). In contrast, farmers/households reported highly negative or mixed reactions on to ADRA’s activities that affected their cultural diversity, i.e., understanding technology, interaction, and their preference for traditional farming.

Table 3.14 Ranking of cultural diversity based on household response to ADRA’s activities

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding Farming Technology</td>
<td>2.88</td>
</tr>
<tr>
<td>Interaction</td>
<td>2.99</td>
</tr>
<tr>
<td>Culture Practices</td>
<td>3.15</td>
</tr>
<tr>
<td>Traditional Farming</td>
<td>2.45</td>
</tr>
<tr>
<td>Benefitting from Education</td>
<td>3.54</td>
</tr>
</tbody>
</table>

Based on a questionnaire, approximately 45% of the farmers interviewed had no adequate technical explanations for their problems, nor were they aware of the range of opportunities available for improving their farming conditions. However, 83% claimed to have had the chance to participate and learn the new or shifting farming techniques offered by ADRA. The same number believed that the participatory technique proved very useful in their daily farming activities. The interaction between farmers and ADRA extension workers was cordial according to 67% of the farmers in the study area. Thus, ADRA facilitated the articulation of the farmers' position, thereby building a consensus in the programme implementations.

The main cultural practice that formed a bone of contention was the empowerment of women through ADRA's activities in the research area. Approximately 75% of the men in the study area had some reservations about the empowerment of women through ADRA's assistance. This accounted for the high ranking of the response that ADRA affected cultural practices (3.15, mean ranking). Men still held on to their old beliefs that they should be favoured in the disbursement of funding, positions, and other assistance as the traditional family heads, hence they believe that any assistance to the household should be channelled through them.

3.2.10 Risk

Based on empirical results, the biggest threat to farmers in the research area was the risk of losing their farmland. More than 70% of farmers felt more at risk of losing their farmland than any other risk factor.
Figure 3.20 A raster layer showing the risk level at different locations in the research area

Financial and marketing risk factors constitute a minimal risk to most farm households. Less than 10% of the factors were related to financial or marketing risk. Thus, the risk of a farmer losing his/her farmland, and for that matter their farming activities, could be used as a proxy indicator for farm risk factor measurement. Based on the empirical results, the loss of family lands mainly occurred through the sale of the land to commercial farmers by a family member or members. Thus, loss of family land was classified as loss of land to commercial farmers. Of all the risk factors (table 2.7), proximity was the deciding factor (i.e., the closeness of a farm to these indicators) governing the risk of a farmer losing their farmland. Therefore, each dataset was given a weight according to the percent influence. A higher percentage indicated the greater influence of a particular dataset or risk factor on the overall risk level model. The strength of a risk factor on a farm was manifested in the spatial analysis distance model.

Figure 3.20 shows that a large proportion of farmland in the research area was at risk of losing its farm activities, where extremely at risk was the top level. Only the south-western and the north-eastern parts of the research area were at low risk, which were mainly farmer-owned farms.

3.2.11 Time Dispersal/Concentration

According to the analysis, a perfectly time-dispersed crop or tree would have a CV of zero, an RTC index of zero, and an RTD value of unity (1). Table 2.6 shows that the income from maize farms was the most dispersed farming activity (0.51), while mango farms production is the least concentrated farming activity (0.18). Overall, crop production was more dispersed than fruit/tree production in the research area. This was predictable because crop production in most of the research area enjoyed more than two farming seasons per year. Woodlots harvesting was conducted mostly during the lean
season (January–May), making it more time-concentrated. Farmers sold more woodlots around this time of the year to meet their financial needs when other farm income was inadequate.

3.3 Sustainability Map and Index

To meet the sustainability requirements of the agriculture-based poverty alleviation programme, the empirical analysis was finalised by calculating a Spatial Sustainability Index (SSI). The SSI could help to alleviate the difficulties of comparing farm systems in terms of sustainability, when information is available only in the form of individual attributes in space and time.

The farm with the highest SSI achieved a score of 0.9 (OID.44 at location; X: 788390, Y: 632860). The lowest recorded index was 0.16 (OID.31, at location; X: 784390, Y: 639070). On average, the farm households in the study area achieved SSI scores of 0.52. Only 25% of farms in the study area had SSIs that were less than or equal to 0.5. However, 50% achieved scores in excess of 0.7. Only 12.5% of farm households achieved scores between 0.7 and 0.9, and these can be regarded as near sustainable or comparatively sustainable according to the attributes/indicators defined in this study.

Figure 3.21 Spatial Sustainability Index

The farm with the highest SSI achieved a score of 0.9 (OID.44 at location; X: 788390, Y: 632860). The lowest recorded index was 0.16 (OID.31, at location; X: 784390, Y: 639070). On average, the farm households in the study area achieved SSI scores of 0.52. Only 25% of farms in the study area had SSIs that were less than or equal to 0.5. However, 50% achieved scores in excess of 0.7. Only 12.5% of farm households achieved scores between 0.7 and 0.9, and these can be regarded as near sustainable or comparatively sustainable according to the attributes/indicators defined in this study. Figure 4.21 provides a graphical interpretation of the outcome map, showing that the potentially less sustainable areas were located mainly in watershed areas. These less sustainable plots or households were mainly associated with variables such as proximity to a river, crop over-production, particular types of mixed farms, strong perceptions of ADRA's activities, risk of losing farmland, and human health risk.
These indicators cut across all the sustainability dimensions, but they were generally related to the ecological dimension. This may indicate that ecological problems were prevalent in most locations in the research area. It also shows the extent of the spatial and quantitative influences of individual indicators. It might also reflect the potential sensitivity of the numerical weighting structure used in the study, which could in turn affect the index calculations and the outcome of the sustainability map SSI.

The sensitivity analysis (section 2.10) identified a very remarkable trend (Figure 3.23a&b, and Table 3.15), i.e., altering the criteria weights in both dimensions showed that ecological criteria were the most sensitive to weight variations, and they led to significant sustainability ranking modifications.
Table 3.15 Summary of criteria weight change effects on sensitivity, i.e., the first and last five sustainable ranking households

<table>
<thead>
<tr>
<th>HouseholdID</th>
<th>Original SSI</th>
<th>Percentage change of criteria</th>
<th>weight and SSI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ecology = 50%</td>
<td>Ecology = +10%</td>
<td>Ecology = -10%</td>
</tr>
<tr>
<td></td>
<td>Socio-econ-dev* = 50%</td>
<td>Socio-econ-dev* = -10%</td>
<td>Socio-econ-dev* = +10%</td>
</tr>
<tr>
<td>44</td>
<td>0.91</td>
<td>0.86</td>
<td>0.92</td>
</tr>
<tr>
<td>27</td>
<td>0.82</td>
<td>0.74</td>
<td>0.83</td>
</tr>
<tr>
<td>38</td>
<td>0.73</td>
<td>0.68</td>
<td>0.73</td>
</tr>
<tr>
<td>48</td>
<td>0.60</td>
<td>0.59</td>
<td>0.61</td>
</tr>
<tr>
<td>18</td>
<td>0.55</td>
<td>0.55</td>
<td>0.57</td>
</tr>
<tr>
<td>52</td>
<td>0.49</td>
<td>0.46</td>
<td>0.49</td>
</tr>
<tr>
<td>20</td>
<td>0.41</td>
<td>0.39</td>
<td>0.42</td>
</tr>
<tr>
<td>12</td>
<td>0.35</td>
<td>0.27</td>
<td>0.35</td>
</tr>
<tr>
<td>6</td>
<td>0.21</td>
<td>0.18</td>
<td>0.22</td>
</tr>
<tr>
<td>31</td>
<td>0.16</td>
<td>0.13</td>
<td>0.17</td>
</tr>
</tbody>
</table>

*Socio. Economic and Developmental

Figure 3.23a. Sensitivity map: +10 ecological, -10 social-economic-developmental criteria weights

Figure 3.23b. Sensitivity map: +10 social-economic-developmental, -10 ecological criteria weights

Figure 3.23a shows that a sensitivity map with a 10% ecological weight increase
produced more locational variations and differences in classifications compared with Figure 3.23b (10% social-economic-developmental weight increase). Increasing the ecological factor weight by 10% meant that the number of less-sustainable households increased from 25% to 55%. Apart from few extreme SSI changes with ±10% social-economic-developmental criteria weight changes, the figures remained stable in most locations. Although the two sustainable criteria sensitivity maps produced a significant cell change among locations, the increase or decrease of pixels/cells in most locations was never more than one sustainability level away from the initial ranking. Changes in the ecological dimension criteria led to higher sensitivity in watersheds and lower SSI locations, but the degree of sensitivity was higher in the classification rank range of 0.53–0.65, and in locations with higher farm risk variables linked to social-economic-developmental dimensions. Overall, the greatest sensitivity to indicator weights appeared to be in locations closer to rivers or watershed areas, and locations where there was a risk of farmers losing their farm plots (through sand harvesting), with both weight variations. This also shows the strong influence of ecological indicator weights on the sensitivity level, because any impact on watershed and sand harvesting affects the ecology more than the other dimensions measured.

The sensitivity analysis (SA) and weight variation confirmed the initial outcome of the study and the reliability of the model adopted, but it did not provide any insights into the process of breaking down the criteria into indicators, or the measurement of suitable indicators that could serve as a solid basis for agricultural-based poverty alleviation programme assessment. Thus, this method did not solve the usual problem of multiple legitimate values from stakeholders. The SA was only important for the validation and calibration of numerical and spatial models, where it checked the robustness of the final outcomes against criteria weight changes.
4. DISCUSSION

This study has presented an alternative approach to assessing and operationalising an agriculture-based poverty alleviation programme, sustainable development, and building a dynamic poverty map. It combined the descriptive and process approach to geospatial analysis and techniques to formulate and understand the structures and relationships that identified possible causes and effects of ADRA's poverty alleviation programme in Ga West. Geospatial capabilities were used for data collection, and continue through data input, storage, manipulation, output, and interpretation of the results. In a departure from the common approach where a single routine measurement (i.e. either deterministic or stochastic) is adopted (Ofori, 1991; Muller, 1999; Praneetvatakul, et al. 2001; Messerli, et al. 2009; Mainardi, 2011), the study combined the two routine measurements relying on geotemporal and geospatial events/dataset between and within plots, farm households, watershed and development levels. Sustainable parameters played a critical role, but patterns/trends and relationships in time and space formed the basis of the analytic and modelling technique used. Using sustainability as a development goal of agriculture-based poverty alleviation programmes implies that programmes have to be analysed in terms of the relationships among their implicit economic, environmental, and social objectives (Maertnes et al., 2006; La Rose, 2009).

The approached revealed that livelihood improvement through agriculture requires a system-balancing act; it involves biophysical environment and socioeconomic factors, which are inter-related. Factors were therefore treated in relationship to each other. Understandably, this study involves interactions among ADRA and its clients, (farm households, farming communities, community leaders, etc.), the ecosystem and the communities, all connected to the developmental activities. Such interaction among humans, biophysical environment, and developmental features are too noisy to be modelled narrowly by deterministic or a stochastic technique alone, which is too restrictive. Multi-faceted issues demand multi-faceted solutions. To assess and understand these complex interactions, the study adopted an analytical regime that could identifying how, why, and what happens where, and makes use of geographical information that links features and phenomena at the study area to their respective locations and relationships.

In general the study not only confirms Krishna's (2003) assertion that, "poverty does not get reduced because growth occurs, or the climate changes, or some structural factors ebbs or grows in some way... poverty get reduced when more households and individuals do the things and take the pathways that lead out of poverty, and fewer individuals take the other pathways that lead into poverty," but it also showed that the poor or vulnerable communities can increase the incidence of poverty by adopting unsustainable practices. The effects of geographical characteristics are widely acknowledged (Stifel, 2008), but this study has demonstrated that more effort and inputs are needed to further explore the span of human actions within space and time that affect poverty in its totality. This could only be achieved by creating a framework that links all the sustainable dimensions and criteria with the levels of analysis to locations and time.

One of the main characteristics of the approach consists of various interpolation techniques (e.g. kriging, kernel), which capitalized on the spatial correlation between observations to predict attribute values at unsampled locations using information related to one or several attributes. The intention was to create a framework of stochastic and
deterministic models, which accurately represented real world phenomena and processes in plot, watershed, household and developmental indicators. The stochastic simulation allowed a generation of several models and images of the spatial distribution of indicator values, all of which are consistent with the information available. Conversely, the deterministic simulation helped in dealing with decidable questions and issues which are mostly human-centred. I applied this framework to explore, predict and validate the processes of human actions in space and time that affect the programme under study. In some cases the study constructed stochastic models out of deterministic models that allow the possibilities of model error. An example is the interpolation (kriging) from the results of time-series analysis to simulate sustainable stability level for each farm household. This model provided useful results related to the possible causes and effects of sustainable instability. Visualised demonstration of stability level in each location was depicted on a map, which could easily be understood by stakeholders.

In summary, this study identified significant progress in the well-being of individuals, households, communities, and their environment, but many challenges remain that need to be met if ADRA's and NGO's goal of alleviating poverty through agriculture is to be sustained in Ga West. Only 12.5% households could achieve ‘near-sustainable’ level. The majority of the problems related to sustainability identified in this research area were based on environmental indicators, which apparently stemmed from economic factors. Nonetheless, they were also evident in the social indicators and perceptions. There is no universal solution or panacea for sustainable transitions of human-environmental systems (Ostrom, 2007; GPN, 2009), but a good assessment technique that uses multiple complementary measures could assist development partners to adopt innovative intervention strategies. The geospatial technique adopted for this study was able to locate with optimum accuracy areas with lower sustainable level and the processes that led to unsustainable. Consequently, decision-makers could initiate appropriate intervention strategies at specific targeted locations.

Developmental problems are invariably perceived as pre-existing conditions that need to be alleviated (Khalid, 2003). Therefore, the failure of policies and programmes intended to alleviate these problems leads to calls for possible interventions. Various integrative approaches could be adopted as a method for intervention, depending on the locations and the problems involved.

The major approaches for intervention are: (I) advisory and voluntary approaches, (e.g., the adoption of environmentally appropriate practices reliant on provisions, encouragement, and persuasion); (II) economic approaches (e.g., relying on the fact that farmers tend to be responsive to changes in the relative profitability of different products and the cost of production techniques); (III) regulatory approaches based on setting standards (UNRISD, 1994; Muller, 1999).

4.1 Critical Appraisal of the Approach Adopted

The lack of an accepted metric or generally accepted procedure for evaluating agriculture-based poverty alleviation programmes and the growing need for spatial analysis and poverty mapping in sustainable development in general, prompted this research study to develop an appropriate conceptual and methodological approach. This study combined different models, techniques, concepts, and tools, so there is the need for a critical appraisal of the approach adopted in the study and its applicability when
evaluating agriculture-based poverty alleviation programmes.

4.1.1 Conceptual Framework and Research Process

The use of sustainable development to conceptualise agriculture-based poverty alleviation programmes serves as a useful starting point. However, the operationalisation of sustainable development is always a difficult and complex task, so the discussion and identification of different elements of sustainable development as recommended by FAO (1997), and Muller (1999), were highlighted. It was apparent that a simple definition of sustainable development or agriculture-based poverty alleviation would not be enough to evaluate the programme. Thus, specific criteria were developed that facilitated an informed understanding when selecting indicators, based on a spatial exploration of the research area. Indicators were defined according to criteria of sustainability, but also to reflect the specific location and events in the research area selected. The criteria and indicators of sustainable development allowed the formulation of hypotheses, and the recognition of potential cause-effect relationships related to possible impacts of the programme.

As with any evaluation method, the definition of reference values was crucial for the study. A slight change in the reference values could alter the outcome of the research. Their utility critically hinges on the rationale used for selecting these values. When no objective values are available, a second-best solution has to be found (Harrell, 1999; Muller, 1999). Thus, areas under different crops (i.e. maize or cassava) were considered as a reference sample. The limitation of this approach needs to be emphasised. For example, the impacts of degradation may be underestimated if land under maize is not completely free from degradation. However, the empirical results indicated the utility of the approach because significant differences in soil quality were detected in different crop-based plots. If no reference values were available, the best available cases in the study area were used as a proxy for the true reference value (e.g. depth of the topsoil served as proxy indicators for erosion level).

4.2.2 Application of Geospatial Analysis

The use of geospatial analysis in measuring agriculture-based poverty alleviation is confronted with many issues, i.e. the definition of the objectives of the study, the construction of analytical operations that are to be used, the use of computers and tools for analysis, the known limitations and particularities of the analysis, and the presentation of analytical results. Apart from these inherent problems, care was taken to avoid common errors that often arise in spatial analysis such as the spatial mathematics and the particular methods used to present spatial data.

Given the vast range of geospatial analysis techniques and the associated modelling tools that have been developed over the past half century, only a few were selected for this study based on the study specific needs. Even the few methods selected only covered a limited depth, which suits the scope of the study. However, considering the interdisciplinary nature of the study, a comprehensive approach was adopted. The GIS software tools that were selected to facilitate geospatial analysis were also not the most exhaustive. Different software tool applications for the same model may arrive at the same outcomes with different visualizations. The models and forms of visualisation used in the study were selected to maintain uniformity. The combination of geospatial analysis with SA in this study was particularly helpful, because it simplified the analysis of the sensitivity of a criterion in different locations.
4.2.3 Application of Poverty Mapping

Like any subject, there is a wealth of methodologies for poverty mapping. Adopting a particular methodology requires suitable data sources, assumptions, and a combination of statistical (stochastic and deterministic) routines. Well-known and tested methods are used for poverty mapping that could help promote better awareness of poverty and its eventual alleviation. Prominent among these methods are the following: livelihood assets (Kristjanson et al., 2005; Erenstein et al., 2010); SAE (Henninger, 1998; Bellon et al., 2005; Farrow et al., 2005; Okwi et al., 2006; Epprecht et al., 2008; UNEP/GRID-Arendal, 2009); micro-level estimation of poverty (Elber and Lanjouw, 2003); spatial autocorrelation of the key variables of interest in rural poverty and agricultural growth (Palmer-Jones and Sen, 2004); remote-sensing data (Rogers et al., 2006; Elvidge et al., 2009); APM (Anon, 1999; Sandeval and Nilson, 2001); household level method (UNDP, 1998; Hentchel et al., 2000; Minot and Blalch, 2005); spatial price analysis (Moser et al., 2009); and spatial regression modelling (Mainardi, 2005). The main hallmarks of all these methods are as follows: the social-economic distribution of poverty; the importance of where one lives; geographical determinants of poverty; livelihood assets and poverty; and, alternative rankings of poverty using a chosen unit. In all these, process and relationship among the various dimensions of poverty is usually ignored in poverty mapping.

When environmental or ecosystem dimensions are considered, as in the livelihood asset-based approach (Egoh et al., 2008; Erenstein et al., 2010), the methods adopted do not take into account the spatial variations of environmental attributes, which are often too irregular to be modelled using a deterministic approach. The approach is most restrictive when stochastic techniques are applied in poverty mapping. It is mainly used for measuring the random distribution of food poverty (Farrow et al., 2005), or for describing poverty (Robinson et al., 2011). The relationship between the various dimensions of poverty and their contributions to the causes of poverty are mostly ignored. Therefore, there seems to be a need to move away from a static poverty mapping approach to a much more dynamic approach to reveal the underlying processes that produce the visible poverty landscapes (Robinson et al., 2011). Failure to understand and account for these processes could wrongly result in the proportion of areas or households classified as poor. Thereby overwhelming the ranking of geographical areas identified as poor, as well as the underlying processes that cause poverty. Statistical error and possible bias are fundamental issues in most poverty mapping (Davis, 2003). These can seriously affect decision-making and lead to the misallocation of resources. However, most practitioners remain unaware of these problems. Growing concerns about the link between poverty and local or regional ecosystems require that poverty mapping employs methods for integrating both statistical routines into its approach. Poverty mapping research needs to recognise that sustainable poverty alleviation-mapping is a multi-faceted subject involving complex developmental, social, economic, and environmental dimensions, which requires both stochastic and deterministic analytical routines. The study of poverty mapping needs to consider: the irregularity or noisy dynamics of some processes outside a biological system; the random nature of events; and, the individuality of a population in an environmental system.

The sustainable poverty mapping produced in the current study used spatial factors that were continuous in character and that helped to enhance or diminish the sustainability level of a farm household/plot, depending on the magnitude of a particular farm household's standing in a factor range. Every attribute/indicator carried the same weight.
in the sustainability system unit. Like the sustainability index, the values on the sustainability map were standardised to a range of zero (0) to one (1). Map and index formulation encompasses many subjective elements that begins with the following: the selection of indicators that are to be included in the map and index: the creation of datasets from existing data to generate new information; reclassification of each dataset to a common scale; the assignment of weights; and, the use of reference values. A change in the reference values and the assignment of weights can change the results.

4.2.4 Tracking Sustainability by Indexing and Mapping

Comparing different farm households and measuring their levels of sustainability is always difficult when information is available only in the form of desegregated indicators. Consequently, the SSI for each farm and the SPAM of the study area were computed and created. The use of SI (sustainable Index) as an assessment tool was not new, but the use of SSI and combining it with poverty mapping (in this case SPAM) was a new approach for guiding research and determining outcomes. The major advantage of this approach was that it provided a solution to the problem of estimations and predictions based on discrete and continuous measurement, which was needed to fully understand the causes and effects of the various dimension of poverty in space and time. It could also be interpreted visually to the understanding of stakeholders.

The sustainability index provided information on the degree of sustainability based on the aggregated index expressed using a range of values between zero (0) and one (1). The indices of individual farm households were independent, making it possible to include additional farm households without altering the results and the explanatory power. This facilitated the monitoring of differences in time and space, while at the same time avoiding the ecological fallacy (Blalock, 1964). This approach helped to enhance the efficiency of poverty alleviation interventions and reduce leakage to the non-poor (Bigman and Srinvasan, 2002).

The geoprocessing model work-flow facilitated the assessment procedure when testing the sensitivity of criteria weightings. The SA provided a very useful and important reliability test of the model, as well as generating quantitative and visualisation criteria weight sensitivity analyses of individual aggregate dimensions and geographic space. However, it did not necessarily assign a weight to every single criterion indicator independently of other dimensions. This was because each single indicator weight was assigned according to the weight assigned to the dimension (i.e., ecology and socio-economic-developmental) from which the indicator was derived. It would have been possible to conduct SA on the indicators weight independently from the dimension weights. However, conducting more SA would not necessarily improve the quality of the assessment method and the indicators used. It mainly demonstrated the relationship between criteria weights and performance scoring. The use of SA mainly served as a platform for checking the robustness of the final evaluation outcome against slight changes in the weights assigned to the criteria values.
5. CONCLUSION AND RECOMMENDATIONS

The conclusion and recommendation section was designed to reflect on the evaluation principles used in this study. Thus, the generic goal, as with most evaluation techniques, was to provide a conclusion that gave useful feedback.

This study has developed a versatile and systematic procedure of using Geospatial capabilities to assess agriculture-based poverty alleviation programmes. It was conceptualised in terms of sustainable development, which remains a challenging concept for researchers and development partners in general; because of the complexity of the interaction between humans and environmental factors and the difficulty to estimate and predict various issues. The major advantage of this approach was that it provided practical solution to the problem of estimations and predictions of inter-related variables, including both discrete and continuous measurement needed to fully understand the causes and effects of the various dimensions of poverty in space and time. This study demonstrated that, reliable and measurable indicators could be derived by developing a framework that links sustainable dimensions and criteria with the levels of analysis to locations and time. Locations, events, time, patterns and relationship were crucial in this procedure. I proposed the adoption of geoprocessing work-flow to facilitate the use of spatial factors in computing SSI and the SPAM. The capabilities of geoprocessing technique facilitated the validation of the outcome with SA. The creation of SSI and the SPAM allowed information to be easily visualised and understood by decision-makers and stakeholders to support informed and evidence-based decision-making.

Despite the identification of significant improvement in the livelihood of the targeted beneficiaries of ADRA’s present programme in the Ga West district in terms of infrastructural development, food-security, and poverty, less than a quarter of the household studied reached a ‘near-sustainable level; future productivity growth hinges on the preservation of natural resources.

The over-production of perceived short-term profitability crops such as cassava led to an increase in exploitative and non-sustainable rates of resource use. This also weakened or distorted the system leading to eventual lost of soil and water quality, which can adversely affect farm income and human-health in the long-term. Thus, over-reliance on cassava in most parts of the study area makes the yield/income less stable, and less resilient over the long-term. The logic of immediate survival discourages farmers from giving up regular short-term income for a greater continued future income. Both advisory and economic approaches seem to be the most promising interventions. However, further study is needed to identify alternative crops that will be suitable for the area concerned, considering their potential demand. More effort should also be made to highlight conservation measures that could maintain or improve productivity in the long-term, which must be linked to measures that improve productivity in the short-term.

The integration of pest management and a more rational or regulated use of pesticides would be helpful in curbing the over-use of pesticides and fertilisers. A monitoring task force could be formed in communities to monitor the supply of pesticides from sources other than ADRA, to avoid the erratic and reactive use of pesticides and fertiliser. Fertiliser product control measures need to be intensified. Less pest-infested mixed farms should also be assessed. Refuse collection and disposal was a major problem in the study area so communities should be encouraged to embark on more rigorous organic fertiliser programmes to reduce their over-reliance on mineral (inorganic) fertilisers.

ADRA is helping communities to reduce the process of soil erosion in the research area, but farmers need more education on appropriate farm management techniques. The study found that
farmers rarely perceived soil erosion as a pressing problem that could increase plant-stress, negative outcomes and loss of income. The results showed that plots along riverbanks had an impact on the quality of surface water. Thus, the monitoring of farm activities on riverbanks could minimise their impacts on natural ecosystems, where this must be conducted by qualified institutions. Frequent monitoring of the river water quality relative to different farming regimes should be performed. There needs to be a strict enforcement of environmental laws and regulations regarding riverbank farming activities. More regular public education is needed to educate communities on the adverse effects of their farming activities on water bodies, their health, and society as a whole.

The potential loss of farmland, as indicated in Section 3, requires the intervention of the Government of Ghana to safeguard farming activities and prevent possible land fragmentation in the Ga West district. The district falls within the Greater Accra Region and is close to the country’s capital, so only the intervention of the government can protect the communities from the on-going anthropogenic activities in the research area. The conversion of agricultural land to urban land use during the urbanization process has become a serious issue (Li and Yeh, 2000). Laws and regulations need to be enacted to make the area a protected buffer zone for these vulnerable farmers.

To dispel the perception that ADRA tends to favour Adventist farmers when it comes to the distribution of farm inputs, extension services to households, and general interaction with the communities, ADRA workers should be encouraged to foster close relationships with all farmers in and outside farm activities. Workers need to make concerted efforts to regularly visit non-Adventist farmers and their families as much as they visit Adventist households.

The SPAM and the SSI applied in the present research area described the sustainability of agriculture-based poverty alleviation programmes within the framework of the following assumptions, which were critical to the research outcome:

- the concept of sustainable development
- the essential elements of agriculture-based poverty alleviation programmes derived from this concept (sustainable development)
- the precise definition of locations and events within the research area
- the concept of poverty mapping
- the analysis of events in the research area and the elaboration of the hypothesis
- the selection of indicators at various levels of analysis
- the selection of attributes for the index and mapping
- the definition of weights and reference values.
- Sensibility analysis adopted to validate the outcome

The conclusions reached regarding the causes, effects, and sustainability of the agriculture-based poverty alleviation programme in the research area must be measured in the context of the assumptions described above. Making unequivocal assumptions is important when evaluating agriculture-based poverty alleviation programme, because any change in the assumptions can change the results. Thus, any replication of this research approach must be guided by the framework of these assumptions, especially in different conditions and locations.
BIBLIOGRAPHY

Adiku, S., Rose, C.W., (2001). Conceptual methodologies in agro-environmental systems. Faculty of Environmental Sciences, Griffith University, Nathan, Qld 4111, Australia. Department of Soil Science, University of Ghana, Legon, Accra, Ghana.


106


Stifel, D. Minten, B. Isolation and agricultural productivity Agricultural Economics Volume 39, Issue 1, July 2008, Pages 1-15


APPENDIX

Appendix 1. Water Quality Index Calculation based on Turbidity, Temperature, pH, Phosphate, and Nitrate

These charts were built using a step-by-step water quality index calculation tool from Fivecreek.org. Conductivity is not shown because it was derived from water temperature.

**Turbidity Quality Index**

Turbidity >100 jtu = 5 water quality index

**pH Quality Index**

pH unit < 2 or >12 = 0 water quality index

**Temperature Change Quality Index**

Temperature change was derived from the difference between upstream and downstream support. (Water temperature of 5 °C = 73 water quality index)

**Nitrate Quality Index**

Nitrate-Nitrogen > 100 ppm = 1 water quality index

**Phosphate Quality Index**

Total phosphate > 10ppm = 2 water quality index
Appendix 2. Spatial reference values table derived from the tick marks on the Paper map (Figure 2.2)

<table>
<thead>
<tr>
<th>id</th>
<th>x</th>
<th>y</th>
<th>xmin</th>
<th>xsec</th>
<th>ymin</th>
<th>ysec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.833333</td>
<td>0.5</td>
<td>5</td>
<td>50</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>5.833333</td>
<td>0.416667</td>
<td>5</td>
<td>50</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>5.833333</td>
<td>0.333333</td>
<td>5</td>
<td>50</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>5.75</td>
<td>0.5</td>
<td>5</td>
<td>45</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>5.75</td>
<td>0.416667</td>
<td>5</td>
<td>45</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>5.75</td>
<td>0.333333</td>
<td>5</td>
<td>45</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>5.666667</td>
<td>0.5</td>
<td>5</td>
<td>40</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>5.666667</td>
<td>0.416667</td>
<td>5</td>
<td>40</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>9</td>
<td>5.666667</td>
<td>0.333333</td>
<td>5</td>
<td>40</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>5.583333</td>
<td>0.5</td>
<td>5</td>
<td>35</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>5.583333</td>
<td>0.416667</td>
<td>5</td>
<td>35</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>12</td>
<td>5.583333</td>
<td>0.333333</td>
<td>5</td>
<td>35</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>13</td>
<td>5.5</td>
<td>0.5</td>
<td>5</td>
<td>30</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>14</td>
<td>5.5</td>
<td>0.416667</td>
<td>5</td>
<td>30</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>15</td>
<td>5.5</td>
<td>0.333333</td>
<td>5</td>
<td>30</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

Using the Ghana National Grid (GNG) and the tick marks labelled on each side of the paper map (Figure 2.2), a calculation was made using Excel to determine the map coordinates by converting them to GNG coordinates, i.e., degrees/minutes to decimal degrees.
### Appendix 3. Indicator-Reference Values

<table>
<thead>
<tr>
<th>Variables</th>
<th>Reference Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poverty Lines</td>
<td>0.86 Euro</td>
<td>IFDA</td>
</tr>
<tr>
<td>Average yield- Cassava (Ghana)</td>
<td>13.8MT/H</td>
<td>MoFA</td>
</tr>
<tr>
<td>Average yield- Maize (Ghana)</td>
<td>1.7 MT/H</td>
<td>MoFA</td>
</tr>
<tr>
<td>Average yield-Cashew (Ghana)</td>
<td>9.6MT/H</td>
<td>MoFA</td>
</tr>
<tr>
<td>Average yield-Mangoes (Ghana)</td>
<td>2.6MT/H</td>
<td>MoFA</td>
</tr>
<tr>
<td>Average yield-Citrus (Ghana)</td>
<td>30MT/H</td>
<td>MoFA</td>
</tr>
<tr>
<td>Fertilizer limit:</td>
<td></td>
<td>FAO</td>
</tr>
<tr>
<td>Nitrogen- 68kg/h</td>
<td></td>
<td>FAO</td>
</tr>
<tr>
<td>Potassium- 68kg/h</td>
<td></td>
<td>FAO</td>
</tr>
<tr>
<td>Pesticides limit:</td>
<td></td>
<td>EPA- Ghana</td>
</tr>
<tr>
<td>Active ingredients: Maximum</td>
<td></td>
<td>EPA- Ghana</td>
</tr>
<tr>
<td>Average Farm Income</td>
<td>4936.45 (Euro)</td>
<td>GSS-Ghana</td>
</tr>
<tr>
<td>Average Farm-labour dag wage</td>
<td>0.85 (Euro)</td>
<td>GSS-Ghana</td>
</tr>
<tr>
<td>Water quality- Wells:</td>
<td></td>
<td>WHO</td>
</tr>
<tr>
<td>pH</td>
<td>6.5-8.0</td>
<td>WHO</td>
</tr>
<tr>
<td>Nitrate-Nitrogen</td>
<td>10mg/l</td>
<td>WHO</td>
</tr>
<tr>
<td>Soil quality:</td>
<td></td>
<td>FAO-UNESCO</td>
</tr>
<tr>
<td>pH</td>
<td>5.4-8.2</td>
<td>FAO-UNESCO</td>
</tr>
<tr>
<td>Nitrate-Nitrogen</td>
<td>150kg/h</td>
<td>FAO-UNESCO</td>
</tr>
<tr>
<td>Water quality- Surface water:</td>
<td></td>
<td>EPA-Ghana</td>
</tr>
<tr>
<td>pH</td>
<td>6.5-8.2</td>
<td>EPA-Ghana</td>
</tr>
<tr>
<td>Nitrate-Nitrogen</td>
<td>90mg/l</td>
<td>EPA-Ghana</td>
</tr>
<tr>
<td>Nitrite</td>
<td>0.05mg/l</td>
<td>EPA-Ghana</td>
</tr>
<tr>
<td>Phosphate</td>
<td>0.03mg/l</td>
<td>EPA-Ghana</td>
</tr>
<tr>
<td>Gross Margin</td>
<td>50%</td>
<td>GSS-Ghana</td>
</tr>
<tr>
<td>Average farm wage (day)</td>
<td>0.75 Euros</td>
<td>GSS-Ghana</td>
</tr>
</tbody>
</table>
Appendix 4. Specimen of Socio-Economic Survey Questionnaire

1 of 2

FORM NO. B0007GA

STUDYING ADRA'S POVERTY ALLEVIATION PROGRAMME IN THE GA WEST DISTRICT OF GHANA

(BAFFOUR AWUAH)

FARM-HOUSEHOLD QUESTIONNAIRE


MARITAL STATUS: .................................. FAMILY SIZE: ..............

PLOT-ID: .................................... GPS-LOCATION: .............. FARM-SETTLEMENT-ID: ..............

FARM-SIZE: ........ FARM-TYPE: 1 2 3 4 5 6 7 8

SOURCE OF FARM-LAND: FAMILY ○ RENT ○ OWN ○

NUMBER OF FARMS: .............. NUMBER OF CHILDREN IN SCHOOL GOING AGE: ..............

EDUCATION: ILLITERATE ○ LITERATE ○ FAMILY SIZE: ........ SOCIAL STATUS: ..............

PERCENTAGE OF TREES TO CROPS: .............. QUANTITY OF FERTILISER PER HA.: ..............

AMOUNT SPENT ON PLANT PROTECTION: .............. WEEKS 5 PER MONTH ON FARMING: ..............

FARM PRODUCTION EXPERIENCE [YEARS]: 1 – 2 ○ 3 – 4 ○ 5 – 6 ○ MORE THAN 6 YEARS ○

BENEFIT FROM ADRA'S FARM EDUCATION: YES ○ NO ○

ACCEPT APPROPRIATE TECHNOLOGY: YES ○ NO ○

UNDERSTAND APPROPRIATE TECHNOLOGY: YES ○ NO ○

WEEKLY VISIT BY ADRA'S EXTENSION OFFICERS: 1 – 2 ○ 3 – 4 ○ MORE THAN 5 TIMES ○

THREE SPECIFIC PROGRAMME EFFECT ON THE INDEGENOUS CULTURE: 1. .............. 2. .............. 3. ..............

SATISFACTION OF DEVELOPMENTAL PROJECTS:

HEALTH FACILITIES: SATISFIED ○ NOT SATISFIED ○

SCHOOLS: SATISFIED ○ NOT SATISFIED ○

WELLS: SATISFIED ○ NOT SATISFIED ○

SANITATION: SATISFIED ○ NOT SATISFIED ○

STORAGE: SATISFIED ○ NOT SATISFIED ○

ECONOMIC EMPOWERMENT: SATISFIED ○ NOT SATISFIED ○
Appendix 4. Specimen of Socio-Economic Survey Questionnaire

FORM NR. B0007GA

STUDYING ADRA’S POVERTY ALLEVIATION PROGRAMME IN THE GA WEST DISTRICT OF GHANA

(BAFFOUR AWUAH)

FARM-HOUSEHOLD QUESTIONNAIRE

MARKETING:
Satisfied ☐ Not satisfied ☐

FOOTPATHS:
Satisfied ☐ Not satisfied ☐

EQUITABLE DISTRIBUTION OF DEVELOPMENT PROJECTS:
Satisfied ☐ Not satisfied ☐

FARM RISK FACTORS: LOST OF FARMLAND: Yes ☐ No ☐ IF YES THROUGH WHAT? URBANISATION ☐

COMMERCIAL FARMERS ☐ POOR LAND MANAGEMENT ☐ SAND-WINNING/QUARRY ☐

FINANCIAL RISK: Yes ☐ No ☐ MARKETING RISK: Yes ☐ No ☐

LEVEL OF PARTICIPATION IN DECISION MAKING: 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

HEALTH IMPAIRMENT THROUGH FARMING: NUMBER OF TIMES: ____________________________

NUMBER OF PESTICIDES INTOXICATIONS: ____________________________

YIELD PER HA: TREE: ____________________________ CROP: ____________________________

OTHER NON-FARMING INCOME: ____________________________

TOTAL COST OF PRODUCTION: ____________________________