

Article

Spatial Modeling of Child Malnutrition and Farming Methods in Rural Sub-Saharan Africa

Brent Lloyd ¹ ¹ Nez Perce Tribe, Land Services Department, Lapwai, ID 83540, United States; brentl@nezperce.org

Abstract: Food security in rural sub-Saharan Africa is dependent on crop yields grown on subsistence rainfed farms. Yields for rain-fed farms in Africa are often affected by the high variability in precipitation during the growing season. Low crop yields in many communities in developing regions affect the physical and mental growth of children by reducing their caloric intake. Water harvesting farms provide a way to capture water for agricultural purposes and increase crop yield. This study aimed to determine whether the prevalence of water harvesting farm techniques is spatially correlated with malnutrition. Multilevel regression models at the within-household and geographic levels were used to evaluate the correlation between water harvesting farms and stunting, a measurement of malnutrition, among children aged 1 to 5 years. The results suggest that the use of water harvesting farm methods is correlated with stunting and offers the potential to reduce malnutrition in rural subsistence farming communities in Africa.

Keywords: spatial analysis; malnutrition; multilevel regression; water harvesting farms; demographic health surveys; rural health; developing countries; health demand; stunting

1. Introduction

The ability of a country to achieve economic growth, structural transformation, and poverty reduction relies on stable production of agricultural crop yields (Barrett et al., 2017; Enongene, 2024). Communities in developing countries of sub-Saharan Africa (SSA) struggle, in some years, to be food secure throughout the year because of low crop yields. Food security was defined by the World Food Summit in 1996 as “when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.” The Food and Agriculture Organization (FAO) defined four pillars of food security in 2006: food availability, food access, utilization, and stability (Alexandratos & Bruinsma, 2006). The stability of crop yields has been highly variable in many areas of SSA over the past 40 years and is projected to be so in the future because of factors such as drought, flooding, pests, population growth, and economic instability (Alimagham et al., 2024; Noort et al., 2022; Rojas et al., 2011). Low crop yields restrict the daily caloric intake of individuals and increase local food market prices (Grace et al., 2014). Food insecurity due to low crop yields in many communities in developing regions affects the physical and mental health and well-being of families (Nanama & Frongillo, 2012). High variability in climate, compounded with other problems, such as low soil fertility and crop diseases, can cause low per capita food production (Chakraborty & Newton, 2011; Richard et al., 2022). This is the result of the breakdown of conventional practices, and policymakers have given low priority to farming communities (Feder & Savastano, 2017; Sanchez, 1987). Crop yields provide an important economic measurement of food security (Godfray et al., 2010), while malnutrition in children provides an important anthropometric measurement of food security (FAO, 2014).

Child malnutrition is prevalent in many developing SSA countries (de Sherbinin, 2011; Godfray & Garnett, 2014; Grace et al., 2012). Malnutrition lacks adequate energy, protein, and micronutrients to meet the basic requirements of body maintenance, growth, and development (FAO, 2014). Malnutrition affects all groups of people; however, infants and children are more vulnerable because of their higher nutritional requirements for growth and development (Blössner & de Onis, 2005; Morales et al., 2023). Malnutrition in children is routinely measured as wasting or stunting. Wasting is < -2 standard deviations for weight-for-age, and stunting is < -2 standard deviations for height-for-age. Stunting is commonly used as an indicator of malnourishment because wasting can vary throughout the year depending on food availability, whereas stunting outcomes occur as a result of chronic exposure to inadequate calories or nutritional inputs



Citation: Lloyd, B. (2025). Spatial Modeling of Child Malnutrition and Farming Methods in Rural Sub-Saharan Africa. *Agricultural & Rural Studies*, 3(2), 13.
<https://doi.org/10.59978/ar03020012>

Received: 1 April 2025
Revised: 29 April 2025
Accepted: 7 May 2025
Published: 10 June 2025



Copyright: © 2025 by the author. Licensee SCC Press, Kowloon, Hong Kong S.A.R., China. This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\) license](https://creativecommons.org/licenses/by/4.0/).

(Frongillo, 2022). Stunting in children has been associated with behavioral problems, cognitive deficits, and an increased risk of hypertension and cardiovascular diseases (Black et al., 2013). As of 2012, approximately 165 million children under 5 years of age worldwide were considered stunted (de Onis et al., 2012).

Multiple studies have been conducted using demographic and health survey (DHS) data to monitor malnutrition in children in SSA (e.g., Beni et al., 2024; Grace et al., 2012). Many developing countries outside SSA have seen a decrease in malnutrition and an increase in agricultural production in the past 40 years, but overall, countries in SSA have seen a much lower agriculture production rate compared to other developing countries in the world; in addition, the malnutrition rate in some SSA countries has increased (Kanamori & Pullum, 2013).

Production from small farm plots is important for the food security of people in areas of low population density in SSA. Villagers rely primarily on what they produce. Low crop yields have caused malnutrition in many parts of SSA (i.e., stunted growth, impaired mental development, and impeded physical growth; Slingerland et al., 2006). The intake of nutrients from crop yields in rural areas of SSA has been shown to positively affect health outcomes (Beyene, 2023; Reij et al., 2009; Slingerland et al., 2006).

The farming techniques used in SSA affect crop yields (Barbier et al., 2009; Lloyd & Dennison, 2018; Sidibé, 2005). Conventional farming practices in SSA usually consist of farmers plowing or hoeing fields without modifying the landscape. Conventional agricultural farming can lead to soil leeching of nutrients and a low water-holding capacity. Water harvesting systems may be defined as “methods of collecting and concentrating various forms of runoff (rooftop, runoff, overland flow, stream flow, etc.) from various sources (precipitation, dew, etc.) and for various purposes” (Reij et al., 1988, p. 4). The adoption of water harvesting techniques, such as macrocatchments, helps to maintain soil erosion by slowing the rate of water flow. Water harvesting can be practiced within, around, and outside areas used for farming (Reij et al., 2009). Water harvesting farms help maintain nutrients and organic matter in the soil and increase the water productivity of farms.

While the literature has focused on the relationship between children’s health and other variables, such as climate (Dos Santos & Henry, 2008; Grace et al., 2012), socio-economics (Balk et al., 2005; Pérez-Mesa et al., 2022), and geophysical variables (de Sherbinin, 2011), no study has evaluated farming techniques applied to children’s health. This analysis examines the relationship between stunted growth and local farming practices in rural Burkina Faso. The research questions for this study are as follows: 1) What areas in Burkina Faso have high concentrations of water harvesting farms? 2) Does the concentration of water harvesting farms within the DHS cluster areas correlate with child stunting in Burkina Faso? 3) Does the proportion of farms within each DHS cluster area correlate with child stunting in Burkina Faso? 4) What land uses besides farms can be correlated with stunting? 5) How do water harvesting farm practices spatially relate to stunting in Burkina Faso? A unique contribution of this analysis is the use of land-use data in combination with household- and community-level DHS data, using a multilevel regression model. The significance of this study is that it provides an understanding of whether investment in water harvesting farms may contribute to the overall health of children and overall communities. In addition, this study provides insights into the determinants of health within-household along with geographic factors related to the stunting of children.

2. Methods

Land-use data were collected around DHS cluster locations to identify the types of farming techniques and other land-use classifications that are correlated with stunting. A 1.6 x 1.6 km square was overlaid on high-resolution imagery from Google Earth for three random farming communities within 5 km of each DHS cluster location. The size of the overlaid square and number of points were chosen based on the average area around the villages used for agricultural purposes. The majority of farming communities in Burkina Faso consist of fewer than 200 people (WorldPop, n.d.), with agricultural farms spread around the center of the community at an average 0.8 km in each direction. Within each randomly positioned square, 50 randomly selected points were used for land-use identification. The land use underlying each point was classified into one of ten land-use types (Table 1). Land use was assigned to points if images with pan-sharpened spatial resolution less than or equal to 1 m were available within four years of 2010. Land-use data in this study were compared to a land cover classification image produced by GlobeLand30-2010 (GLC30). GLC30 has a multispectral 30 m resolution image with 10 classified land cover types for most of the Earth’s surface, with an overall accuracy of 80.33% (Office for Outer Space Affairs UN-SPIDER Knowledge Portal, 2016).

Table 1. Image interpretation description of land use types; Adapted from [Anderson et al., 1976](#).

Land-use Type	Description
Conventional farm	Distinctive areas of geometric shape and pattern (usually square or round) that have been cultivated for the production of food and fiber
Water harvesting farm	Same description as conventional farms including the use natural or man-made barriers to collect or store water for the use of crops
Road	Linear features interconnected with each other and bare of vegetation
Urban	Built-up land comprised of areas of intensive use with structures
Water	Areas or linear features within a land mass covered with water
Rangeland	Area where natural vegetation is predominantly grasses, grass-like plants, forbs, or shrubs
Forestland	Area of land having a tree-crown area density of 10% or more
Barren land	Area of land limited to less than one-third vegetation or another land cover (usually an area of thin soil, sand, or rocks)
Intermittent stream	Ephemeral riverbed that contains water only during times of heavy rain

2.1. Study Area

Burkina Faso lies within the Sahel region of Africa on the fringe of the Sahara Desert. The terrain is mostly flat, with dissected plains and plateaus. The elevation of the country ranges from 200 to 750 m. Approximately 70% of Burkinabes live in rural areas ([World Bank, 2015](#)). More than 90% of the workforce is employed in agriculture and is dominated by small-scale farms of less than 5 ha ([FAO, 2014](#)). The main crops grown in the region are millet, sorghum, and cotton. Most farmers practice dryland farming to grow crops during the monsoon season.

2.2. DHS Data

In 2010, the DHS collected over 17,000 household surveys, including information on the health of children, clustered into 540 spatially referenced locations within Burkina Faso (Figure 1). The spatially referenced DHS cluster locations are randomly shifted 0–2 km in urban areas, 0–5 km in rural areas, with 1% of rural cluster locations displaced 0–10 km, to protect the privacy of respondents ([DHS, n.d.](#)). Stunted growth collected for this study was obtained from each of the DHS survey cluster locations, and land-use data were collected in proximity to each DHS survey cluster location. The displacement of the cluster points was restricted within each provincial boundary.

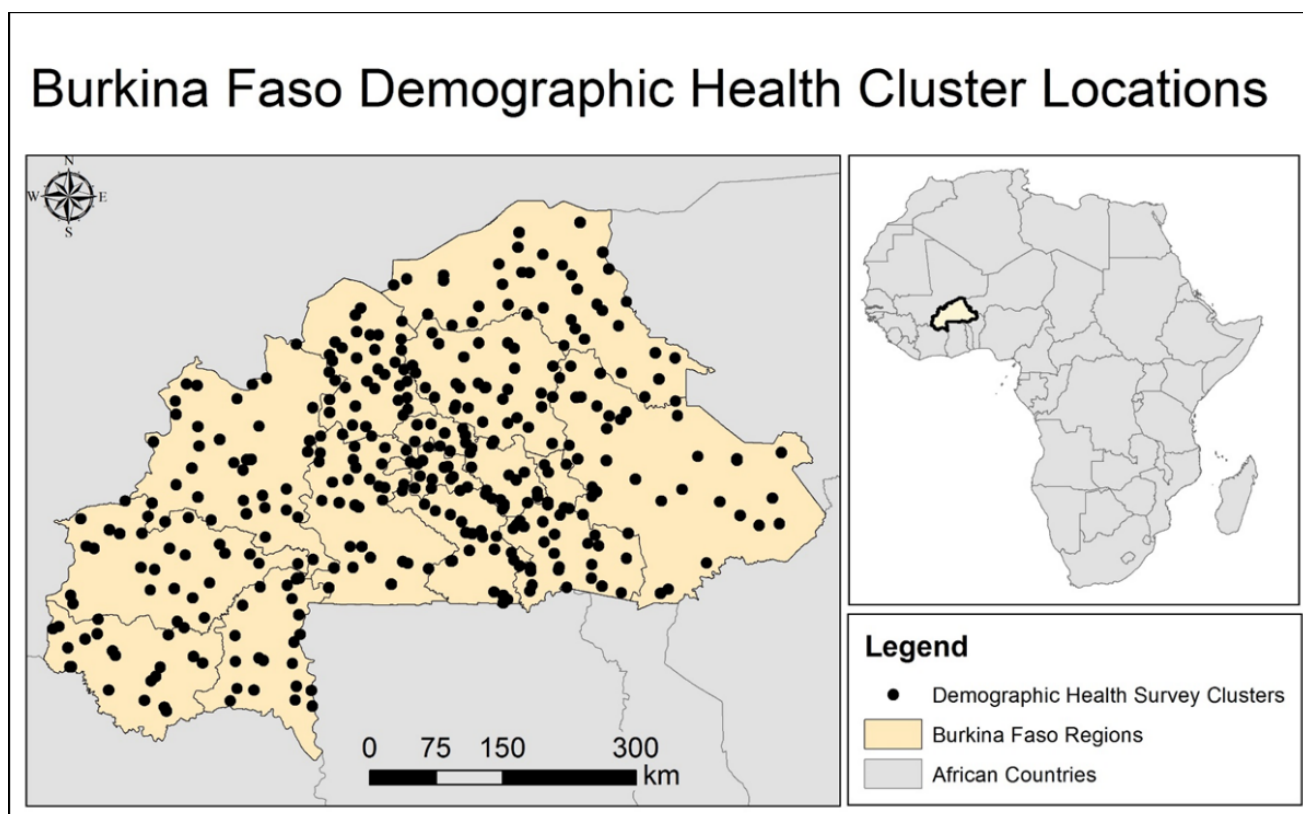


Figure 1. Rural DHS cluster locations within Burkina Faso.

The DHS surveys provide measures of children's anthropometric health and well-being, including indicators of malnutrition. Burkina Faso is among the countries in SSA that suffer from the highest malnutrition rates. In 2011, the National Nutritional Survey estimated that 35% of Burkinabé children under 5 are affected by stunted growth (United Nations International Children's Fund [UNICEF], 2013).

Data collected by the DHS aids in explaining where major problems of malnutrition occur, as it relates to the measurement of children's height and weight (Nanama & Frongillo, 2012). The survey data cover information about health, lifestyle, personal information, and the surrounding environment for each applicant; 4,870 households with children under five were surveyed throughout Burkina Faso. Seventy-six percent (3,696) of the surveys were conducted in rural areas. One of the objectives of the DHS survey data is to collect information on the growth of children under five. Physical measurements based on height and weight were compared with the World Health Organization (WHO) global database on child growth and malnutrition (WHO & UNICEF, 2009). The physical measurements of children under 5 were collected and recorded at DHS cluster locations; however, it should be noted that it is unknown how long each of the children lived in a certain location. Several studies using DHS data have been conducted in Burkina Faso to monitor malnutrition and its effects on individuals and households (Beiersmann et al., 2007; Grace et al., 2017; Maxwell, 1996; Wuehler et al., 2011). Malnutrition affects all regions of Burkina Faso (Institut National de la Statistique et de la Démographie & ICF International, 2012). Some explanations for the high rate of malnutrition as related to farming within the country include low soil fertility, variable precipitation, unsustainable farming management strategies, and low-quality seeds (Ikazaki et al., 2011; Miller & Welch, 2013).

2.3. Land-Use Data

Land-use data were collected around DHS cluster locations to identify what types of farming techniques and other land-use classifications are correlated to stunting. A 1.6 x 1.6 km square was overlaid on high-resolution imagery from Google Earth for three random farming communities within 5 km of each DHS cluster location. The size of the overlaid square and the number of points were chosen based upon the average area around villages used for agricultural purposes. The majority of farming communities in Burkina Faso consist of less than 200 people (WorldPop, n.d.), with agricultural farms spread around the center of the community on average 0.8 km in each direction. Within each randomly positioned square, 50 randomly selected points were used for land-use identification. Land use underlying each point was classified into one of ten land-use types

(Table 1). Land use was assigned to points if images with pan-sharpened spatial resolution less than or equal to 1 m were available within 4 years of 2010. Land-use data in this study were compared to a land cover classification image produced by GlobeLand30-2010 (GLC30). GLC30 has a multispectral 30 m resolution image with 10 classified land cover types for most of the surface of the earth, with an assessed overall accuracy of 80.33% (Office for Outer Space Affairs UN-SPIDER Knowledge Portal, 2016).

2.4. Multilevel Regression Modeling

A multilevel regression model was created to test whether the stunting of children at the within-household level was highly impacted by water harvesting farming. Multilevel modeling analyzes the data in a hierarchical structure, allowing for residual components at each level in the structure. The dependent variable in this study is the height-for-age Z-scores (HAZ) of children between 1 and 5 years old. HAZ is a standard measurement for chronic childhood malnutrition (Frongillo & Nanama, 2006; Grace et al., 2012). The child growth standards provided by the WHO were used to calculate Z-scores for child stunting (WHO & UNICEF, 2009). The independent variables selected for this study have been used in other studies to assess malnutrition in children (Grace et al., 2012; Balk et al., 2005; de Sherbinin, 2011). The model uses two hierarchical levels categorized as within-household and geographic (Table 2). Within-household determinants include children’s age, child’s size at birth, child’s sex, mother’s age, mother’s height, mother’s education, number of small children, child body mass index, floor material, mosquito nets, approved water sources, and scooters or motorcycles. The within-household variables were retrieved from the 2010 DHS data (DHS, n.d.). Geographic determinants include soil type, population density, province, percentage of water harvesting farms, and percentage of total farm area. The soil type data have a resolution of 100 km and were collected by the Joint Research Centre- European Soil Data Centre in 2013 (JRC-ESDAC, 2013). The population density data have a resolution of 30 seconds and were created by the Center for International Earth Science Information Network (CIESIN) for the year 2000 (CIESIN, 2016).

Table 2. List of variables and a description of how each variable is categorized for each child respondent under 5.

Determinants	
Within-household	Geographic
1. Child Age	13. Soil Type
2. Child Size at Birth	14. Population Density
3. Child Sex	15. Province
4. Mother’s Age	16. Water Harvesting Farms %
5. Mother’s Height	17. Total Farm Area
6. Mother’s Education	
7. Small Children	
8. Floor Material	
9. BMI	
10. Mosquito Bed Net(s)	
11. Approved Water Source	
12. Scooter/Motorcycle	

The multilevel regression accounts for associations among observations within levels to make efficient and valid inferences. The multilevel model equation is as follows (Bafumi & Gelman, 2006):

$$y_i = \alpha_{s[i]} + \beta x_i + \epsilon_i \tag{1}$$

where $s[i]$ is the group’s containing unit i

$$\alpha_j = \alpha_0 + \eta_s \tag{2}$$

Equation (1) shows where y_i is the score of a variable on the dependent variable and is being predicted by modeling varying intercepts α_s and a predictor x_i . The error in the model is denoted by ϵ_i . Equation (2) displays the hierarchal level equation that estimates the mean of the varying intercepts α_0 and the hierarchal level error η_s . The method of using a multilevel structure regression model over other regression models has proven to be a more reliable model estimate between

response and independent variables when data could be nested at different geographic scales (Curtis & Rees Jones, 1998). Multicollinearity was assessed between each variable.

2.5. Moran's I Index

In addition to multilevel analysis, an ordinary least squares (OLS) regression model using spatial filtering regression with eigenvectors analyzed how farm types are spatially correlated with stunting. Regression models using spatial data may contain spatially autocorrelated residuals causing a misspecification error. Moran's I methodology tests for global spatial autocorrelation and corrects for misspecification errors (Moran, 1950). Moran's I was used in this study to measure farm land-use and water harvesting farms clustering in Burkina Faso and is based on the cross-products of the deviations from the mean and is calculated for n observations on a variable x at locations i , and j as:

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\sum_i (X_i - \bar{X})^2} \quad (3)$$

where \bar{x} the mean of the x variable and w_{ij} are the elements of the weight matrix. Moran's I uses eigenvectors with OLS regression accounting for spatial autocorrelation during the statistical modeling of the spatial data using an inverse distance spatial relationship (Griffith, 2000). Moran's I is similar to a correlation coefficient varying from -1 to 1 . Values toward 1 indicate clustering while values toward -1 indicate dispersion.

2.6. Geographic Weighted Regression

Geographic weighted regression (GWR) is a relatively new local statistical technique that analyzes spatial relationships between a dependent variable and one or more independent variables (Fotheringham et al., 2002). The GWR is a local regression model used to examine spatial heterogeneity across a study area. The GWR equation is based on the OLS regression by constructing an equation for every location in the dataset and is as follows (Charlton & Fotheringham, 2009):

$$y_i(u) = \beta_{0i}(u) + \beta_{1i}(u)x_{1i} + \beta_{2i}(u)x_{2i} \dots \beta_{mi}(u)x_{mi} \quad (4)$$

where y_i is the dependent variable, and u is an observation at a specific location, while x is an independent variable. The notation $\beta_{0i}(u)$ is a parameter that describes a relationship around a location (u) and is specific to that location. The parameters set for this analysis included using a fixed kernel type and an AIC bandwidth. The output of running a GWR provides a table delineating where and how much variation is present between the dependent and independent variable(s) at each location.

2.7. Interpolation

The distribution of water harvesting farms and stunting in Burkina Faso were mapped using a process called empirical Bayesian kriging (EBK). EBK is a common geostatistical interpolation algorithm for scattered point data and has been used in multiple DHS data studies (Gemperli et al., 2004; Gosoni et al., 2010; 2012). The EBK method uses an intrinsic random function accounting for the error introduced by estimating the underlying semivariogram model (Krivoruchko, 2012). The parameters chosen for the EBK model include using a k-Bessel semivariogram model with a maximum search neighborhood parameter of 10. The parameters provide a way to identify local trends from the inserted DHS data while providing prediction surfaces from the interpolated values. The stunted growth survey data collected at each clustered location were averaged at each of the 540 geolocated point locations. Water harvesting farm data were collected at three farming communities around each DHS clustered location and averaged. Due to the nature and distribution of the cluster points, EBK was a suitable method for deriving an interpolated surface of the study area. The random shift in the geolocated DHS cluster areas should have little effect on predicting cell values as the offset is minimal and the interpolation method accounts for multiple surrounding values.

3. Results

Over 50,000 land-use sample points were collected from farming communities around DHS cluster locations in Burkina Faso. Table 3 displays the average and standard deviation of the percentage of land-use for each land-use type. Conventional farms and rangeland comprised the majority of land-use types around farming communities, consisting of 75% of total land usage while

water harvesting farms averaged 12.6% of land usage. Roads, urban areas, water areas, forestland, barren land, and intermittent stream combine for a minority portion of land-usage sample data at 12.4%

Table 3. Descriptive statistics of land use types for farming communities in Burkina Faso.

Land-use Types	Average Percentage of Land Use	Standard Deviation Percentage of Land Use
Water	1.0%	2.2%
Forestland	1.0%	3.8%
Barren land	1.6%	4.9%
Intermittent Stream	2.0%	2.9%
Road	2.8%	3.2%
Urban	4.0%	6.6%
Water Harvesting Farms	12.6%	13.4%
Rangeland	33.2%	18.2%
Conventional Farms	41.8%	19.3%

Results from Moran’s I test show areas of clustering, as shown in Figure 2a for the total farm area and Figure 2b for water harvesting farms. Areas of high-high clustering indicate the concentration of total farm area per land-use. There was significant clustering of the percentage of total farm area per land use in Burkina Faso, with a Moran’s index of 0.97 and a Z-score of 81.97. The concentration of the percentage of the total farm area is prevalent in the central areas of the country near the capital of Ouagadougou, but there are other regions throughout the country with high clustering. Areas of low-low clustering are areas where there is little farming. Most water harvesting farms are located in the north-central part of the country. Water harvesting averages, where high-high clustering occurred, averaged 62% of the land usage. The majority of areas with low-low clustering had no water harvesting farms. The spatial analysis of the clustering of water harvesting farms had a Moran’s index of 0.96 and a Z-score of 80.51, indicating significant clustering of water harvesting farms in the country.

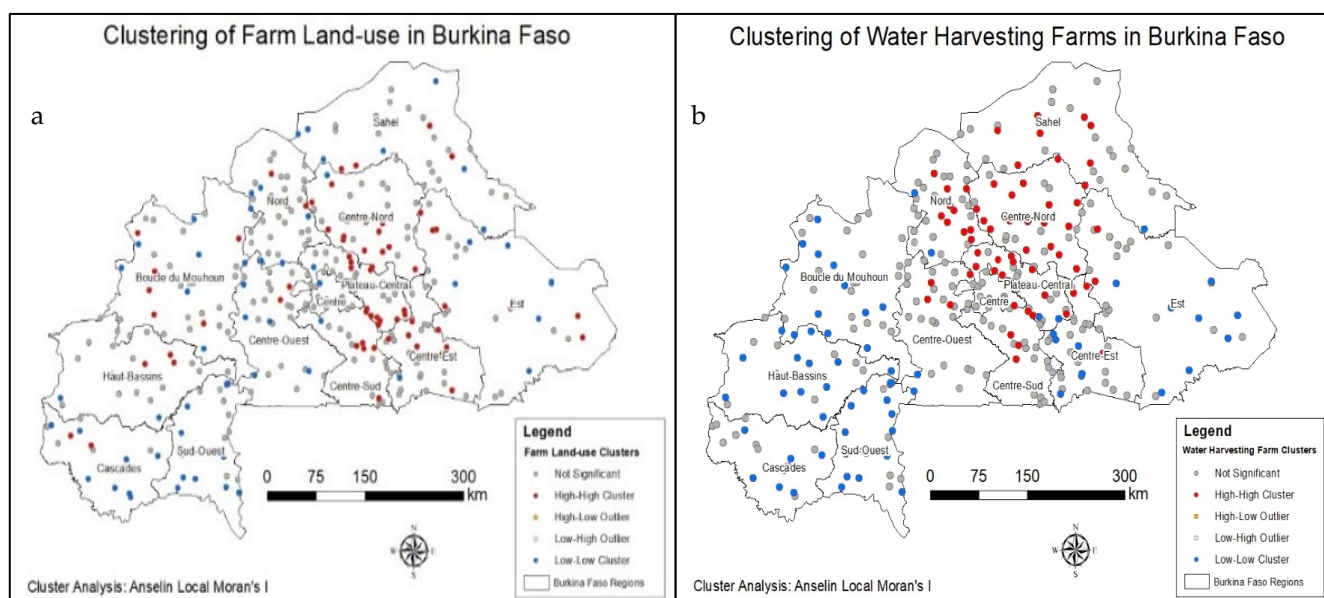


Figure 2. The concentration of percentage of total farm area (a) and percentage of water harvesting farms (b) in Burkina Faso using Moran’s index.

The results in Table 4 show the significant factors for each hierarchal level related to stunting. Within-household variables in this analysis are similar to those seen in other studies modeling malnutrition in SSA (de Sherbinin, 2011; Grace et al., 2012; Henry & Dos Santos, 2013; Sandler & Sun, 2024). The mother’s influence is an important factor in the health of their children. Mother’s height, education, and maternal age were all negatively correlated with the stunting of their children.

Table 4. Significant variables related to stunting at the within-household and geographic hierarchal levels.

Dependent Variable: Stunting				
Significant Values	p < 0.001	0.001 < p < 0.01	0.01 < p < 0.05	0.05 < p < 0.1
Within-household Variables	Mother’s Height (–)	Population Density (–)	Natural Floor Material (+)	Maternal Age (–)
	Mother’s Education: Secondary (–)		Mother’s Education: Primary (–) Sex – Male (+)	
Geographic Variables	Comoé Province (+)	Ioba Province (+)	Bazèga Province (+)	Banwa Province (+)
	Water Harvesting Farms (–)	Kadiogo Province (+)	Kompienga Province (+)	Boulkiemdé Province (+)
			Kouritenga Province (+)	Gourma Province (+)
			Kourwéogo Province (+)	Houet Province (+)
			Léraba Province (+)	Koulpélogo (+)
			Poni Province (+)	Zoundwéogo (+)
			Tapoa Province (+)	Roads (–)
			Tuy Province (+)	
			Ziro Province (+)	

The geographic variables in this study included soil types, population density, provinces, the percentage of water harvesting farmland, and the percentage of total farm area. Only the percentage of water harvesting farms and certain provinces indicated a correlation with malnutrition rates based on the DHS 2010 Survey. Provinces that positively correlated with stunting in this analysis include Ganzourgou, Kadiogo, Banwa, Kompienga, Tapoa, Poni, Tuy, Gourm, and Bazega; these provinces are distributed throughout central and southern areas of Burkina Faso.

The distribution of land designated for farming based on sample data is significantly clustered. The average percentage of the land used for the total farming area was 60.6%, with areas of high clustering averaging 78%. There is no significant correlation between total farmland and stunting in Burkina Faso in this study. Besides water harvesting farms, the only other land-use type that showed correlation were roads, which were negatively correlated with stunting ($p < 0.05$).

Figures 3a and 3b display an interpolated distribution of water harvesting farms and stunting in Burkina Faso. The highest concentration of water harvesting farms is in the central and north-central parts of Burkina Faso, with total land use over 44.8%. Child stunting is also clustered in Burkina Faso but varies throughout the country. The highest areas of stunting occur away from the center of the country with pockets of low stunting scattered throughout the country.

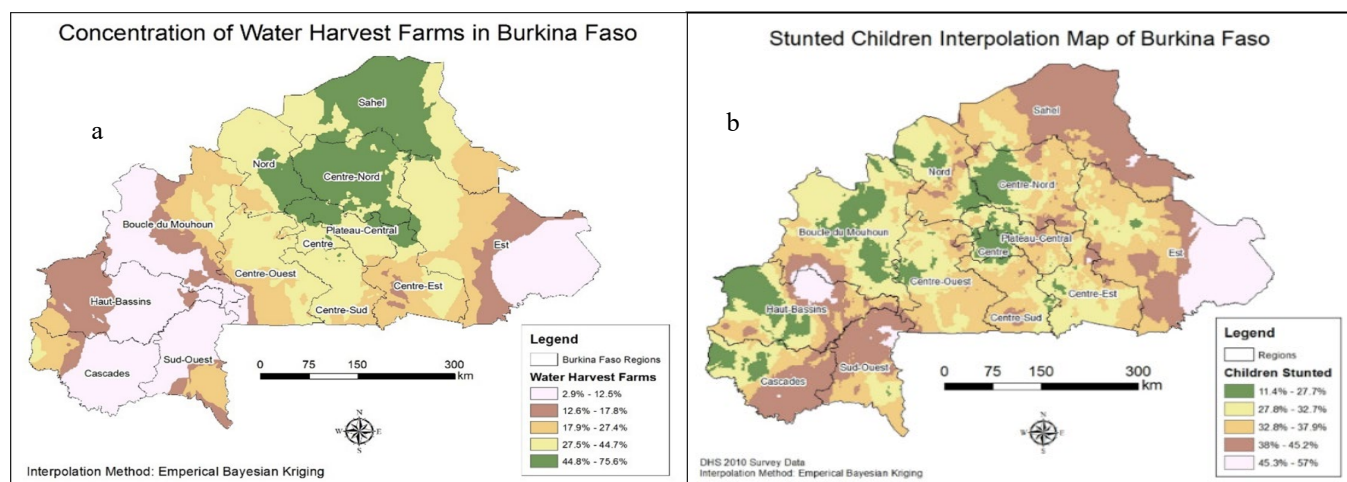


Figure 3. Interpolation of water harvesting farms based upon collections of land cover data around DHS survey locations (a) and Interpolation of stunted children data based upon DHS 2010 Survey data cluster locations (b).

GWR analysis was performed at each DHS survey cluster point to explain the local variance. Figure 4 displays the GWR map of the standard regression of water harvesting farms to stunting.

The standard regression residuals provide information for understanding where water harvesting farms, the locally weighted regression coefficient to stunting, move away from their global values. Standard regression areas close to zero were predicted to indicate a strong relationship between water harvesting and stunting. Areas with a higher standard regression away from zero will have a weaker correlation between water harvesting farms and stunting. Areas with a high standard regression imply that other key explanatory variables are missing from this spatial model to explain spatial variance. Areas in red (high standard regression) are relatively low in stunting and have a high percentage of land-use appropriated for water harvesting farms. Areas in blue (low standard regression) were high in stunting and low in water harvesting farms.

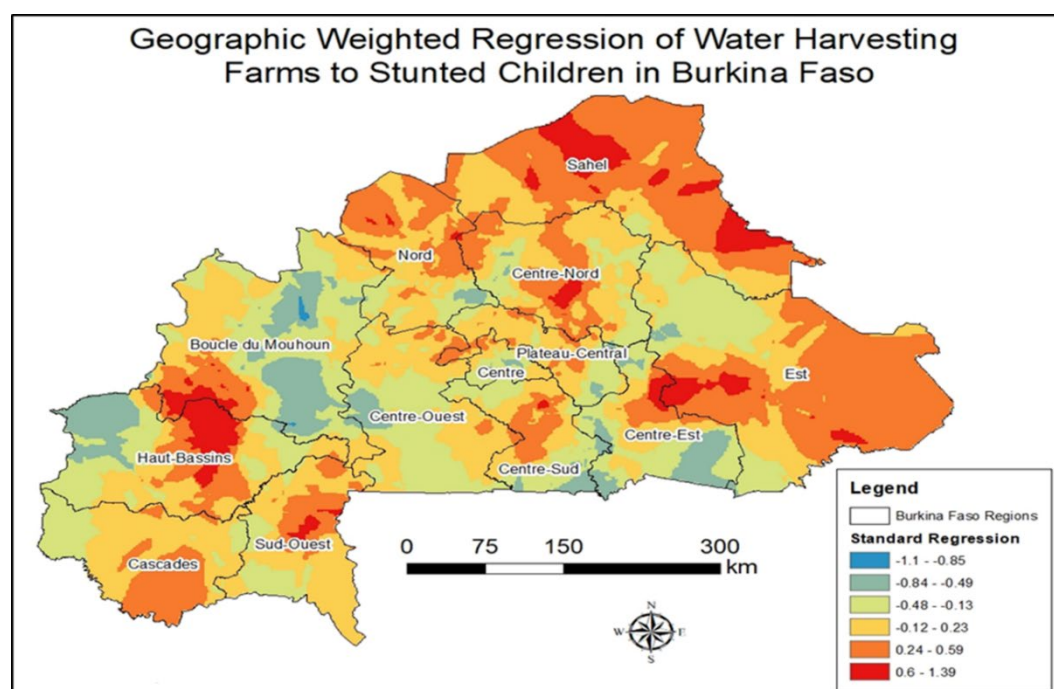


Figure 4. Displays the GWR interpolation map of the percentage of stunting from DHS 2010 surveys and data collected on water harvesting farms per land use in farming communities around the survey locations.

4. Discussion

The production of crops from small farm plots is critical to the food security of people in areas with low population density in SSA. Low investments in land improvement and fertilizer use have caused long-term deterioration in soil fertility and crop productivity, affecting the nutritional requirements for productive crops to be met (Dimkpa et al., 2023). As the population increases and more arable land is being used for farming, water harvesting farms can be an important investment for rural households that rely on farming. Water harvesting farms provide a sustainable solution to produce higher crop yields by replenishing fertility and water productivity for agricultural use, with little management costs for small-scale farmers. DHS cluster locations where communities invest in water harvesting farming techniques correlate with lower rates of stunting. The ability of an area to invest in land rehabilitation using water harvesting techniques can aid the health of households by increasing nutrients in the soil, providing stable production in seasons with high climate variability. Households that do invest in water harvesting farming techniques come from government or non-government organizations projects or from farmers that understand soil conservation strategies, have resources, and the money to implement water harvesting techniques (Bunclark, 2015).

Correlations between within-household factors and stunting in this analysis were similar to those found in other studies modeling malnutrition in SSA (Bain et al., 2013; Grace et al., 2012; Sandler & Sun, 2024). Mothers' influence is an important factor in the health of their children. The mother's height, education, and maternal age were all important within-household variables that were negatively correlated with the stunting of their children. This study, along with other studies, reflects the importance of mothers' well-being in raising healthy children.

In addition to water harvest farms being a significant geographic determinant of stunting, the distance of stunted children from major roads was negatively correlated. Another study found a significant relationship between transportation infrastructure and crop production (Dorosh et al., 2010). Road density is a major factor in cash income from agricultural sales (Briceño-Garmendia

& Domínguez, 2011). The proximity to roads also helps decrease travel time to healthcare facilities, which has been shown to be an important indicator of children's health (Rutherford et al., 2010).

Local, national, and international agencies began to successfully implement water harvesting techniques in the 1980s in the north-central region of Burkina Faso. These projects have helped subsistence farmers achieve more stable crop production. Agencies and local farmers who have invested in such techniques have been, on average, able to produce higher crop yields (Barbier et al., 2009; Lloyd & Dennison, 2018). Examining the spatial distribution of water harvesting farms to stunting helps to better understand regional variations in the GWR model.

This study provides a unique perspective in accounting not only for information related to a child's immediate care but also for a spatial, environmental, and agricultural perspective in relation to the stunting of children. Understanding spatial components is crucial for providing aid to those who have less access to nutritious food and clean water. In the case of stunting, practicing water harvesting methods for farmers who rely on what they produce can influence a child's health.

There are many areas in the GWR model where there is varying standard regression, implying that other key variables are needed to explain spatial variance. Key variables such as those related to the mother in this study and in other studies can have an impact on some of these areas. Some areas with high spatial variance may also have been influenced by variables that were not used in this study. Local areas can also have factors that affect malnutrition that are not prevalent in other communities. An influencing variable that could affect the growth of children in a local area could be prolonged illness from malaria, which could reduce their nutrition and growth over time.

Future research on farming practices in relation to health in developing countries can help local government agencies and other stakeholders determine how to meet future food security requirements. This includes knowing the best methods to grow crops where there is high variability in climate. This study was conducted in a small area of SSA; further investigation is needed to understand how water harvesting techniques affect the health of people in other areas of SSA where rainfed crops dominate. Long-term studies of farming practices and health within Burkina Faso would allow for a more in-depth exploration of the interactions between the different factors affecting crop yields and stunting in this region.

5. Conclusion

Food security will continue to be a major issue in developing countries because of climate variability, population growth, and economic instability. This study examined the concentration of water harvesting farms and their spatial correlation with stunting in Burkina Faso. This study found that mothers' height, education, and age strongly influenced stunting within households, similar to other studies. Water harvesting farms were significantly clustered in Burkina Faso and spatially correlated with stunting in certain areas of Burkina Faso. Water harvesting farms were correlated with stunting; however, the amount of land use dedicated to farming in farming communities did not correlate with stunting, indicating that investment in soil and water conservation techniques is important to the livelihood of people in rural areas of Burkina Faso. These findings indicate that simply adding more farmland or expanding it to more marginal land may not improve stunting. However, this research suggests that investing in existing agricultural land to develop water conservation techniques could lead to reductions in stunting. Google Earth's high-resolution historical imagery provides a cost-effective way to sample land use, especially in remote parts of the world, and Google Earth data for other regions can be used to examine land-use variables correlated with global malnutrition.

CRedit Author Statement: This is a single author paper and the author was solely responsible for the content, including the concept, design, analysis, writing, and revision of the manuscript.

Data Availability Statement: Data available in a publicly accessible repository. <https://dhsprogram.com/data/>

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

Acknowledgments: Not applicable.

References

- Alexandratos, N., & Bruinsma, J. (2006). *World agriculture: Towards 2030/2050: The 2012 revisions*. Food and Agriculture Organization. <http://www.fao.org/3/a-ap106e.pdf>
- Alimagham, S., van Loon, M. P., Ramirez-Villegas, J., Adjei-Nsiah, S., Bajjukya, F., Bala, A., Chikowo, R., Silva, J. V., Soulé, A. M., Taulya, G., Tenorio, F. A., Tesfaye, K., & van Ittersum, M. K. (2024). Climate change impact and adaptation of rainfed cereal crops in sub-Saharan Africa. *European Journal of Agronomy*, 155, 127137. <https://doi.org/10.1016/j.eja.2024.127137>

- Anderson, J. R., Hardy, E. E., Roach, J. T., & Witmer, R. E. (1976). *A land use and land cover classification system for use with remote sensor data*. U. S. Geological Survey. <https://doi.org/10.3133/pp964>
- Barbier, B., Yacouba, H., Karambiri, H., Zoromé, M., & Somé, B. (2009). Human vulnerability to climate variability in the Sahel: Farmers' adaptation strategies in northern Burkina Faso. *Environmental Management*, 43, 790–803. <https://doi.org/10.1007/s00267-008-9237-9>
- Beiersmann, C., Sanou, A., Wladarsch, E., De Allegri, M., Kouyaté, B., & Müller, O. (2007). Malaria in rural Burkina Faso: Local illness concepts, patterns of traditional treatment and influence on health-seeking behaviour. *Malaria Journal*, 6, 106. <https://doi.org/10.1186/1475-2875-6-106>
- Bafumi, J., & Gelman, A. (2006). Fitting multilevel models when predictors and group effects correlate. SSRN. <https://doi.org/10.2139/ssrn.1010095>
- Bain, L. E., Awah, P. K., Geraldine, N., Kindong, N. P., Sigal, Y., Bernard, N., & Tanjeko, A. T. (2013). Malnutrition in sub-Saharan Africa: Burden, causes and prospects. *Pan African Medical Journal*, 15, 120. <https://doi.org/10.11604/pamj.2013.15.120.2535>
- Balk, D., Storeygard, A., Levy, M., Gaskell, J., Sharma, M., & Flor, R. (2005). Child hunger in the developing world: An analysis of environmental and social correlates. *Food Policy*, 30(5–6), 584–611. <https://doi.org/10.1016/j.foodpol.2005.10.007>
- Barrett, C. B., Christian, P., & Shiferaw, B. A. (2017). The structural transformation of African agriculture and rural spaces: Introduction to a special section. *Agricultural Economics*, 48(S1), 5–10. <https://doi.org/10.1111/agec.12382>
- Beni, R., Ramroop, S., & Habyarimana, F. (2024). Analyzing childhood (0-59 months) malnutrition determinants in five West African Countries of Gabon, Gambia, Liberia, Mauritania, and Nigeria using survey logistic regression-insights from DHS data. *Archives of Public Health*, 82, 147. <https://doi.org/10.1186/s13690-024-01374-6>
- Beyene, S. D. (2023). The impact of food insecurity on health outcomes: Empirical evidence from sub-Saharan African countries. *BMC Public Health*, 23, 338. <https://doi.org/10.1186/s12889-023-15244-3>
- Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., de Onis, M., Ezzati, M., Grantham-McGregor, S., Katz, J., Martorell, R., & Uauy, R. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet*, 382(9890), 427–451. [https://doi.org/10.1016/S0140-6736\(13\)60937-X](https://doi.org/10.1016/S0140-6736(13)60937-X)
- Blössner, M., & de Onis, M. (2005). *Malnutrition: Quantifying the health impact at national and local levels*. WHO Nutrition for Health and Development. <https://iris.who.int/bitstream/handle/10665/43120/9?sequence=1>
- Briceño-Garmendia, C., & Domínguez-Torres, C. (2011). *Burkina Faso's infrastructure. A continental perspective*. World Bank Group. <https://doi.org/10.1596/1813-9450-5818>
- Bunclark, L. A. (2015). Water harvesting for crop production: Exploring adoption and use in Burkina Faso from a livelihood's perspectives [Doctoral thesis, Newcastle University]. Duraspace. <http://hdl.handle.net/10443/3126>
- Center for International Earth Science Information Network. (2025, April 10). *SEDAC data catalog* [Data catalog]. Columbia Climate School. <https://ciesin.columbia.edu/content/data>
- Chakraborty, S., & Newton, A. C. (2011). Climate change, plant diseases and food security: An overview. *Plant Pathology*, 60(1), 2–14. <https://doi.org/10.1111/j.1365-3059.2010.02411.x>
- Charlton, M., & Fotheringham, A. S. (2009). *Geographically weighted regression: White paper*. National Centre for Geocomputation. https://www.geos.ed.ac.uk/~gisteac/fspat/gwr/gwr_arcgis/GWR_WhitePaper.pdf
- Curtis, S., & Rees Jones, I. (1998). Is there a place for geography in the analysis of health inequality? *Sociology of Health & Illness*, 20(5), 645–672. <https://doi.org/10.1111/1467-9566.00123>
- Demograph & Health Surveys. (n.d.). *DHS Methodology*. Retrieved December 12, 2017, from <http://dhsprogram.com/What-We-Do/Survey-Types/DHS-Methodology.cfm>
- de Onis, M., Brown, D., Blössner, M., & Borghi, E. (2012). *Levels & trends in child malnutrition: UNICEF–WHO–The World Bank Joint Child Malnutrition Estimates*. United Nations Children's Fund, World Health Organization, & World Bank. https://cdn.who.int/media/docs/default-source/child-growth/jme-brochure2012.pdf?sfvrsn=ca20d895_2
- de Sherbinin, A. (2011). The biophysical and geographical correlates of child malnutrition in Africa. *Population, Space and Place*, 17(1), 27–46. <https://doi.org/10.1002/psp.599>
- Dimkpa, C., Adzawla, W., Pandey, R., Atakora, W. K., Kouame, A. K., Jemo, M., & Bindraban, P. S. (2023). Fertilizers for food and nutrition security in sub-Saharan Africa: An overview of soil health implications. *Frontiers in Soil Science*, 3. <https://doi.org/10.3389/fsoil.2023.1123931>
- Dorosh, P., Wang, H.-G., You, L., & Schmidt, E. (2010). *Crop production and road connectivity in sub-Saharan Africa: A spatial analysis*. The World Bank Africa Region Sustainable Development Division. <http://documents.worldbank.org/curated/en/319731468006253963/pdf/WPS5835.pdf>
- Dos Santos, S., & Henry, S. (2008). Rainfall variation as a factor in child survival in rural Burkina Faso: The benefit of an event-history analysis. *Population, Space and Place*, 14(1), 1–20. <https://doi.org/10.1002/psp.470>
- Enongene, B. E. (2024). Structural transformation and poverty alleviation in Sub-Saharan Africa countries: Sectoral value-added analysis. *Journal of Business and Socio-economic Development*, 4(4), 326–339. <https://doi.org/10.1108/JBSED-12-2022-0128>
- Feder, G., & Savastano, S. (2017). Modern agricultural technology adoption in sub-Saharan Africa: A four-country analysis. In P. Pingali, & G. Feder (Eds.), *Agriculture and rural development in a globalizing world* (pp. 11–25). Routledge. <https://doi.org/10.4324/9781315314051-2>
- Food and Agriculture Organization. (2014). *Food and agriculture policy decision analysis country fact sheet on food and agriculture policy trends: Burkina Faso*. <http://www.fao.org/3/i3760e/i3760e.pdf>
- Fotheringham, A. S., Brunsdon, C., & Charlton, M. (2002). *Geographically weighted regression: The analysis of spatially varying relationships*. John Wiley & Sons. https://www.researchgate.net/publication/27246972_Geographically_Weighted_Regression_The_Analysis_of_Spatially_Varying_Relationships
- Frongillo, E. A. (2022). Validity and cross-context equivalence of experience-based measures of food insecurity. *Global Food Security*, 32, 100599. <https://doi.org/10.1016/j.gfs.2021.100599>
- Frongillo, E. A., & Nanama, S. (2006). Development and validation of an experience-based measure of household food insecurity within and across seasons in northern Burkina Faso. *The Journal of Nutrition*, 136(5), 1409S–1419S. <https://doi.org/10.1093/jn/136.5.1409S>

- Gemperli, A., Vounatsou, P., Kleinschmidt, I., Bagayoko, M., Lengeler, C., & Smith, T. (2004). Spatial patterns of infant mortality in Mali: The effect of malaria endemicity. *American Journal of Epidemiology*, *159*(1), 64–72. <https://doi.org/10.1093/aje/kwh001>
- Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. (2010). Food security: The challenge of feeding 9 billion people. *Science*, *327*(5967), 812–818. <https://www.science.org/doi/10.1126/science.1185383>
- Godfray, H. C. J., & Garnett, T. (2014). Food security and sustainable intensification. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1639), 20120273. <https://doi.org/10.1098/rstb.2012.0273>
- Gosoni, L., Veta, A. M., & Vounatsou, P. (2010). Bayesian geostatistical modeling of malaria indicator survey data in Angola. *PLoS One*, *5*(3), e9322. <https://doi.org/10.1371/journal.pone.0009322>
- Gosoni, L., Msengwa, A., Lengeler, C., & Vounatsou, P. (2012). Spatially explicit burden estimates of malaria in Tanzania: Bayesian geostatistical modeling of the malaria indicator survey data. *PLoS One*, *7*(5), e23966. <https://doi.org/10.1371/journal.pone.0023966>
- Grace, K., Davenport, F., Funk, C., & Lerner, A. M. (2012). Child malnutrition and climate in sub-Saharan Africa: An analysis of recent trends in Kenya. *Applied Geography*, *35*(1–2), 405–413. <https://doi.org/10.1016/j.apgeog.2012.06.017>
- Grace, K., Frederick, L., Brown, M. E., Boukerrou, L., & Lloyd, B. (2017). Investigating important interactions between water and food security for child health in Burkina Faso. *Population and Environment*, *39*, 26–46. <https://link.springer.com/article/10.1007/s11111-017-0270-6>
- Grace, K., Husak, G., & Bogle, S. (2014). Estimating agricultural production in marginal and food insecure areas in Kenya using very high resolution remotely sensed imagery. *Applied Geography*, *55*, 257–265. <https://doi.org/10.1016/j.apgeog.2014.08.014>
- Griffith, D. A. (2000). A linear regression solution to the spatial autocorrelation problem. *Journal of Geographical Systems*, *2*, 141–156. <https://link.springer.com/article/10.1007/PL00011451>
- Henry, S. J. F., & Dos Santos, S. (2013). Rainfall variations and child mortality in the Sahel: Results from a comparative event history analysis in Burkina Faso and Mali. *Population and Environment*, *34*, 431–459. <https://doi.org/10.1007/s11111-012-0174-4>
- Ikazaki, K., Shinjo, H., Tanaka, U., Tobita, S., Funakawa, S., & Kosaki, T. (2011). “Fallow Band System,” a land management practice for controlling desertification and improving crop production in the Sahel, West Africa. 1. Effectiveness in desertification control and soil fertility improvement. *Soil Science and Plant Nutrition*, *57*(4), 573–586. <https://doi.org/10.1080/00380768.2011.593155>
- Institut National de la Statistique et de la Démographie & ICF International. (2012). *Enquête démographique et de santé et à indicateurs multiples du Burkina Faso 2010* [Burkina Faso Demographic and Health Survey 2010]. <https://www.dhsprogram.com/pubs/pdf/FR256/FR256.pdf>
- Joint Research Centre-European Soil Data Centre. (2013). European Soil Database Derived data [Data set]. <https://esdac.jrc.ec.europa.eu/content/european-soil-database-derived-data#tabs-0-description=0>
- Kanamori, M. J., & Pullum, T. (2013). *Indicators of child deprivation in sub-Saharan Africa: Levels and trends from the demographic and health surveys*. United States Agency for International Development. <https://www.dhsprogram.com/pubs/pdf/CR32/CR32.pdf>
- Krivoruchko, K. (2012). *Empirical Bayesian kriging*. ESRI. <https://www.esri.com/news/arcuser/1012/empirical-byesian-kriging.html>
- Lloyd, B. J., & Dennison, P. E. (2018). Evaluating the response of conventional and water harvesting farms to environmental variables using remote sensing. *Agriculture, Ecosystems & Environment*, *262*, 11–17. <https://doi.org/10.1016/j.agee.2018.04.009>
- Maxwell, D. G. (1996). Measuring food insecurity: The frequency and severity of “coping strategies.” *Food Policy*, *21*(3), 291–303. [https://doi.org/10.1016/0306-9192\(96\)00005-X](https://doi.org/10.1016/0306-9192(96)00005-X)
- Miller, D. D., & Welch, R. M. (2013). Food system strategies for preventing micronutrient malnutrition. *Food Policy*, *42*, 115–128. <https://doi.org/10.1016/j.foodpol.2013.06.008>
- Morales, F., Montserrat-de la Paz, S., Leon, M. J., & Rivero-Pino, F. (2023). Effects of malnutrition on the immune system and infection and the role of nutritional strategies regarding improvements in children’s health status: A literature review. *Nutrients*, *16*(1), 1. <https://doi.org/10.3390/nu16010001>
- Moran, P. A. P. (1950). A test for the serial independence of residuals. *Biometrika*, *37*(1–2), 178–181. <https://doi.org/10.1093/biomet/37.1-2.178>
- Nanama, S., & Frongillo, E. A. (2012). Altered social cohesion and adverse psychological experiences with chronic food insecurity in the non-market economy and complex households of Burkina Faso. *Social Science & Medicine*, *74*(3), 444–451. <https://doi.org/10.1016/j.socscimed.2011.11.009>
- Noort, M. W. J., Renzetti, S., Linderhof, V., du Rand, G. E., Marx-Pienaar, N. J. M. M., de Kock, H. L., Magano, N., & Taylor, J. R. N. (2022). Towards sustainable shifts to healthy diets and food security in sub-Saharan Africa with climate-resilient crops in bread-type products: A food system analysis. *Foods*, *11*(2), 135. <https://doi.org/10.3390/foods11020135>
- Office for Outer Space Affairs UN-SPIDER Knowledge Portal. (2016). *Land Cover Map (GlobeLand 30 - NGCC)*. United Nations. Retrieved July 26, 2016, from <http://www.un-spider.org/links-and-resources/data-sources/land-cover-map-globeland-30-ngcc>
- Pérez-Mesa, D., Marrero, G. A., & Darias-Curvo, S. (2022). Child health inequality in Sub-Saharan Africa. *Economics & Human Biology*, *47*, 101176. <https://doi.org/10.1016/j.ehb.2022.101176>
- Reij, C., Mulder, P., & Begemann, L. (1988). *Water harvesting for plant production*. World Bank Group.
- Reij, C., Tappan, G., & Smale, M. (2009). *Agroenvironmental transformation in the Sahel: Another kind of “Green Revolution”*. International Food Policy Research Institute. <https://www.researchgate.net/publication/239807425>
- Richard, B., Qi, A., & Fitt, B. D. L. (2022). Control of crop diseases through Integrated Crop Management to deliver climate-smart farming systems for low-and high-input crop production. *Plant Pathology*, *71*(1), 187–206. <https://doi.org/10.1111/ppa.13493>
- Rojas, O., Vrieling, A., & Rembold, F. (2011). Assessing drought probability for agricultural areas in Africa with coarse resolution remote sensing imagery. *Remote Sensing of Environment*, *115*(2), 343–352. <https://doi.org/10.1016/j.rse.2010.09.006>
- Rutherford, M. E., Mulholland, K., & Hill, P. C. (2010). How access to health care relates to under-five mortality in sub-Saharan Africa: Systematic review. *Tropical Medicine & International Health*, *15*(5), 508–519. <https://doi.org/10.1111/j.1365-3156.2010.02497.x>

- Sanchez, P. A. (1987). Soil productivity and sustainability in agroforestry systems. In H. A. Steppeler, & P. K. R. Nair (Eds.), *Agroforestry: A decade of development* (pp. 205–223). International Council for Research in Agroforestry. https://www.doc-developpement-durable.org/file/Culture/Fertilisation-des-Terres-et-des-Sols/agroforetrie/Agroforestry_a_decade_of_development.pdf#page=214
- Sandler, A., & Sun, L. (2024). The socio-environmental determinants of childhood malnutrition: A spatial and hierarchical analysis. *Nutrients*, 16(13), 2014. <https://doi.org/10.3390/nu16132014>
- Sidibé, A. (2005). Farm-level adoption of soil and water conservation techniques in northern Burkina Faso. *Agricultural Water Management*, 71(3), 211–224. <https://doi.org/10.1016/j.agwat.2004.09.002>
- Slingerland, M. A., Traore, K., Kayodé, A. P. P. & Mitchikpe, C. E. S. (2006). Fighting Fe deficiency malnutrition in West Africa: An interdisciplinary programme on a food chain approach. *NJAS: Wageningen Journal of Life Sciences*, 53(3–4), 253–279. [https://doi.org/10.1016/S1573-5214\(06\)80009-6](https://doi.org/10.1016/S1573-5214(06)80009-6)
- United Nations International Children’s Fund. (2013). Improving child nutrition: The achievable imperative for global progress [Data set]. <https://data.unicef.org/resources/improving-child-nutrition-the-achievable-imperative-for-global-progress/>
- World Health Organization & United Nations International Children’s Fund. (2009). *WHO child growth standards and the identification of severe acute malnutrition in infants and children: A joint statement*. <https://www.who.int/publications/i/item/9789241598163>
- World Bank. (2015). *Data: Burkina Faso*. Retrieved July 24, 2017, from <http://data.worldbank.org/country/burkina-faso>
- WorldPop. (n.d.). *WorldPop open population repository*. <https://wopr.worldpop.org/?BFA/>
- Wuehler, S. E., Hess, S. Y. & Brown, K. H. (2011). Accelerating improvement in nutritional and health status of young children in the Sahel region of sub-Saharan Africa: Review of international guidelines on infant and young child feeding and nutrition. *Maternal & Child Nutrition*, 7(s1), 6–34. <https://doi.org/10.1111/j.1740-8709.2010.00306.x>

Disclaimer: The views, statements, and data presented in *Agricultural & Rural Studies (A&R)* reflect solely the perspectives of the individual authors and contributors, and do not represent the official positions of SCC Press and/or the editorial team. SCC Press and/or the editorial team assume no liability for any harm, injury, or damage to persons or property arising from the ideas, methodologies, instructions, or products referenced herein.