Nutrition CRSP Research Briefing Paper No. 10 December 2012

Measuring the Links Between Agriculture and Child Health in Nepal

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Nutrition CRSP Research Briefing Paper No. 10

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Acknowledgments

This work was made possible in part through support provided by the Bureau of Economic Growth, Agriculture and Trade, US Agency for International Development through the Global Nutrition Collaborative Research Support Program (Grant AID-OAA-10-00005). The opinions expressed herein are solely those of the authors and do not represent the opinions of the sponsors. Any mistakes are solely those of the authors. This paper is a DRAFT containing preliminary findings. It is intended for comments and discussion only, and findings are subject to change. Please do not quote at this time. Direct correspondence to: shivelyg@purdue.edu.

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Abstract/Executive Summary

We combine three distinct datasets to study the connections between agriculture and child health in Nepal. Demographic and Health Survey (DHS) data from 2006 are merged on the basis of common GIS data points with satellite remote sensed Normalized Difference Vegetation Index (NDVI) composites. Using these data we explore the association between the NDVI, a monthly proxy for agricultural production, and nutrition outcomes in children under age 5. We also employ nationally representative data from the 2003-2004 Nepal Living Standards Survey (NLSS) to assess connections between district-level agricultural characteristics and subsequent child growth outcomes. Findings quantify the importance of agriculture to child nutrition and demonstrate the potential value of satellite remote sensing variables such as the NDVI both for understanding observed patterns of nutrition risk and for early warning of household food insecurity.

Keywords: agriculture, DHS, food security, Nepal, nutrition, stunting, wasting

Part 1: Introduction

Nepal faces numerous development challenges, among them chronic and widespread food insecurity and adult and child malnutrition. As a result of rapid population growth, agricultural stagnation and reductions in food aid, the threat of a serious food crisis in Nepal is substantial.[1] The majority of districts in Nepal were estimated to be food insecure in 2007, and 13districts reported annual per capita cereal production below 150 kg/person. In addition, 14 other districts had per capita cereal production between 150 kg/person and 180 kg/person, a level that is significantly below the national average and below that considered the minimum requirement for sufficiency (FAO/WFP, 2007). According to data from the 2006 Nepal Demographic and Health Survey, half of all Nepalese children under age 5 have a low height-for-age or suffer from stunting as a consequence of chronic malnourishment. Approximately 40% are underweight

More optimistically, Nepal has made substantial progress toward meeting health targets, as identified in the country's 10th 5-year planning period. These include reducing child and maternal mortality (World Bank, 2010). FAO data indicate that both the number and the proportion of undernourished people in Nepal peaked in 1998, and data from the 2006 Nepal Demographic and Health Survey (DHS) show a marked decline from previous years in the percentage of children with stunted growth and a modest decline in the percentage of children who are underweight. Despite these gains, however, the Millennium Development Goal to reduce the proportion of underweight children by 50% before 2015 remains elusive.

In many locations, the most relevant ongoing problem related to malnutrition is simple lack of food. Data from the 2004 Nepal Living Standards Survey show that nearly half of household income in Nepal comes from directly from agricultural production. The poorest and second poorest quintiles (based on consumption) derive 62% and 58% of their income, on average, from farming activities (Floyd et al., 2003). This high reliance on agriculture is exacerbated by very low purchasing power and high market prices in remote locations. When these areas face food deficits they rarely see an influx of private supplies (FAO/WFP, 2007). Moreover, deficits tend not to be filled by national or international agencies because of extremely high transportation costs. These features suggest that in many locations, local agricultural conditions will be the primary determinants of local nutrition risks. Paradoxically, however, the correlation between agricultural productivity and nutritional outcome is not clear. For example, Table 1 summarizes patterns of child growth and agricultural yields in Nepal at the district level. A substantial number of districts fall along an expected gradient, with above average nutrition outcomes corresponding to above average yields, and below average nutrition outcomes lining up with below average yields. However, the off-diagonal cells in the table are not empty, suggesting that some districts performing relatively well from an agricultural perspective nevertheless exhibit poor nutritional performance, and vice-versa.

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[1] In decreasing order of deficit these districts are Kathmandu, Humla, Lalitpur, Bajura, Achham, Dolakha, Bhaktapur, Mahottari, Kalikot, Baitadi, Bajhang, Dolpa and Rautahat.

Nepal's agricultural system is characterized by small, rain-fed farms producing wheat, millet, maize and barley, augmented with gardens with vegetables and pulses. Rice is cultivated in flood-irrigated fields sensitive to interannual variations in temperature and precipitation. Few improved crop varieties are used, and very little fertilizer is imported (stats), leaving agriculture highly sensitive to interannual variability of growing conditions. Nepal experiences a substantial east to west gradient of moisture conditions, and north to south altitude changes, both of which impact on overall productivity potential for agriculture. Since the level of adoption of advanced agricultural technologies is low, and fairly even across the country, we use satellite data to explore the impact of climatological and interannual growing conditions on agricultural production. These differences in production have a direct impact on nutrition outcomes given the thinness of markets, low purchasing power of smallholders, and the relative isolation of most of Nepal's population.

In recognition of these basic stylized features of the nutrition landscape in Nepal, in this paper we combine three distinct datasets in an attempt to better understand the connections between agriculture and child health outcomes in Nepal. The first set of data we use comes from the 2006 Nepal Demographic and Health Survey (DHS). The DHS data are nationally representative and provide the most comprehensive assessment of nutrition outcomes available for Nepal. The 2006 sample includes 10,793 women and 4,397 men between the ages of 15 and 59, and includes anthropometric measurements for 5,464 children below age 5. The growth indicators of these children constitute our primary subject of interest.

Onto the DHS database we merge a second set of data derived from the 2003-2004 Nepal Living Standards Survey (NLSS), a nationally-representative household survey conducted by Nepal's Central Bureau of Statistics (CBS). The integrated household questionnaire addresses multiple topics including food consumption and production, household expenditures, farm and off-farm income, labor, and other welfare measures at both the household and individual levels. The 2003-2004 NLSS includes 3,912 completed household questionnaires. We summarize the NLSS data at the district level and combine it with the DHS dataset according to district, type of residence (urban or rural), sex of the household head, and relative farm size. Finally, we utilize data sourced from satellite remote sensing.

The Normalized Difference Vegetation Index (NDVI) is derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) Climate Modeling Grid (CMG) at a 5 km spatial resolution (Justice et al. 1998). We use these data as a proxy for continuous and comparable information on the effect of weather on production, and the effect of overall environmental productivity on nutrition outcomes. NDVI has been shown by three decades of research to be an excellent proxy for rainfall and yield in semi-arid rain fed agro-ecosystems in the developing world (see, e.g. Rasmussen 1998; Goetz et al. 1999; Genovese et al. 2001; Rojas 2007; Lloyd et al. 2011). We match NDVI data to children in the DHS survey on the basis of common GIS data points. This allows us to use the merged data to explore the association between contemporaneous and lagged monthly vegetation index data and child nutrition outcomes.[2] Our approach,

[2] Here we focus attention on stunting and wasting among children under age 5. In ongoing work we

combining observed characteristics of agriculture (obtained from NLSS data) and factors we can see from space (such as weather, length of growing season, interseasonal and interannual variability in rainfall as reflected in NDVI) demonstrates the role agriculture plays in determining patterns of child growth. We also demonstrate the potential usefulness of satellite remote sensing variables such as the NDVI both for understanding observed patterns of nutrition risk and for providing early warning prediction of household food insecurity.

Part 2: Malnutrition and Food Security in Nepal

Undernutrition is a nationwide problem in Nepal, but disparities across socioeconomic groups and ecological regions are masked when looking at national aggregates. As an example, 54% of children under age 5 were found to be underweight in the lowest income quintile, compared with 24% in the highest quintile (MOHP, 2007). In terms of regions, 53% of children from the Mid-West region were found to be underweight in 2006, in comparison to 37% of children from the Eastern region. Looking at the sub-regional level, child mortality ranges from a low of 4% in the Central Hill sub-region to 18% in the Western, Mid-West and Far-Western Mountain sub-regions (Hollema and Bishokarma, 2009). Large income disparities persist across ecological zones, urban and rural locations, and along gender, ethnicity and caste lines. Although recent declines in consumption poverty have been accompanied by substantial reductions in child poverty, 11% of children in the 2006 DHS data fall more than three standard deviations below the international reference population for weight-for-age, an indicator of severe malnutrition. Rural children are disproportionately affected by malnutrition relative to their urban cohorts, with 51% vs. 36% stunted, and 41% vs. 23% underweight (Hobbs, 2009). Shively et al. (2011) provide a comprehensive review of the evidence regarding malnutrition and health in Nepal, including research showing that a key contributor to chronic undernutrition in Nepal is low weight at the time of birth. More than a third of Nepalese children suffer from low birth weight (LBW), which originates with poor maternal nutrition.

Detailed malnutrition maps developed and published in 2006 by the Nepal Central Bureau of Statistics, the World Food Programme and the World Bank illustrate a high degree of overlap among wasting and underweight indicators. In contrast, stunting is far more prevalent in Mountain sub-regions. The maps underscore the considerable geographic diversity among nutrition indicators in Nepal. The highest incidences of stunting and underweight occur in the Mountain and Hill areas of the Far- and Mid-West development regions. In these areas, 60% of children show signs of stunting and 50% register as underweight. These outcomes can be attributed largely to the limited availability of food and high underlying rates of poverty in these areas. Overall, households in the most vulnerable areas have few viable coping strategies. Markets tend to function poorly, alternative sources of income and livelihood are rare and temporary or permanent migration is difficult. The message, therefore, is that households in areas prone to drought and low agricultural performance must internalize

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examine additional nutritional indicators including child mortality, anemia incidence, and mother's BMI.

a significant proportion of external shocks through reduced consumption and subsequent degradation of nutrition and health.

From the perspective of food production, overall performance in Nepal is disappointing and agricultural productivity remains low by South Asian standards. A 2004 report by the Ministry of Agriculture (MoA) indicated that the main staple food crops in Nepal (wheat, maize, rice, and potato) were produced at only 50% of the maximum attainable yield. Cereal yields are estimated to be roughly 2 tons per hectare. The primary reasons put forward for low productivity are a heavy reliance on rain-fed production (roughly two-thirds of agricultural production is rain fed) and subsistence orientation. The MoA reported that the sources of low yields were low investment in irrigation, infrastructure, fertilizers, rural credit and rural power, as well as a lack of research into improving agriculture and very little coordination among government departments (Shrestha et al., 2008). As a result of these failures, the annual growth rate of agriculture remains quite low (below 3%). Not surprisingly, observers have pointed to increasing agricultural production, marketing and trade as pathways to reduce malnutrition in Nepal, with a specific focus on boosting agricultural activity in the remote areas of the Hill and Mountain regions. Seasonal food shortages are quite common in many parts of Nepal, a pattern that is driven by sharp monsoonal influences in production, poor post-harvest storage and handling, and weak transport infrastructure and market integration (Sonogo, 2008). A crop calendar for Nepal's main cereal crops is presented in Table 2. This indicates strong temporal correlations of harvests within agroecological zones, but substantial negative covariance of production across agroecological zones.

In 2007, the FAO and World Food Programme engaged in a nationwide assessment to better understand the causes of chronic and transitory food insecurity in Nepal. The metrics used in that assessment included harvest indicators for year 2007 winter cereal crops, a measure of food availability, market access assessments, and national, sub-national and household-level indicators of food utilization. The report highlights the importance of agricultural modernization in reducing food insecurity. In the Terai, where reliable irrigation exists, three annual rice or maize crops can be grown and harvested. Irrigation in the Hills allows for two crops of rice (summer and spring), but areas in the Hills that must rely on rainwater as a source of irrigation–largely those at higher elevations–grow primarily a single crop of maize. Rice yields in Nepal have gradually increased since the early 1990s, although the realized growth rate has been much lower than those of neighboring countries.

Between 1990 and 2005, Nepal's rice yield increased by 13%. This compares with growth over the same period of 20% in India, 37% in Pakistan and 47% in Bangladesh. Based on average yields over the period 2001 to 2005, Nepal's rice yields were 7% below Pakistan's, 8% below India's, and 22% below Bangladesh's. Yields are highest in the Terai, making this the dominant rice-producing region of Nepal. Nevertheless, average rice yield in the Terai substantially lags those of Nepal's neighbors. In the case of maize, a comprehensive study conducted by CIMMYT concluded that, as of 2001, there had been very few improvements in yields over the previous 30 years. The authors attribute this to the expansion of maize into less suitable agroecological zones, declining soil fertility and slow adoption of improved management practices (Paudyal et al., 2001). The same authors also underscore the problems of seasonal and interannual variability in yields.

Part 3: Data and Methods

3.1 Satellite remote sensing data

Earth scientists use satellite remote sensors to measure and map the density of green vegetation on Earth. The data collected using remote sensing methods have been used to monitor major fluctuations in vegetation and understand how those fluctuations affect the environment. The data are also used by programs such as the Famine Early Warning Systems Network (FEWS NET), which helps food security analysts determine and predict household risk of food insecurity, and provides decision makers timely and rigorous early warning and vulnerability information on emerging and evolving food security issues.

The satellite data used in this analysis are maximum value Normalized Difference Vegetation Index (NDVI) composites (Holben, 1986) from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) launched in 2000 (Justice et al. 1998). The dataset is global and has a native spatial resolution of 250m, aggregated to 0.05 degrees in this analysis (Huete 2002). MODIS data have been shown to be well-correlated with vegetation data from other sensors (Brown et al. 2006, Fensholt 2004), and have been extensively validated across many ecosystems across the world (Morisette et al. 2004, Fensholt et al. 2006).

The MODIS sensor collects images of the Earth's surface and measures the wavelengths and intensity of visible and near-infrared light reflected by the land surface back up into space, capturing the activity of chlorophyll in a given area at a given time. Figure 1 illustrates a typical "snapshot" of these data for Nepal. These observations are expressed in a vegetation index to maximize the metric's sensitivity to concentrations of actively photosynthesizing green leaf vegetation around the globe and reduce the impact of sources of contamination of the signal such as clouds, air pollution, and soil color. NDVI provides a direct estimate of vegetation health and a means of monitoring changes in vegetation over time, because when plants are not healthy their photosynthesizing activity shuts down and the NDVI value plummets. The possible range of values is between -1 and 1, but the typical range is between about 0.1 (for a not very green area) to 0.6 (for a very green area). Negative NDVI values are typical for snow, water or ice covered surfaces. NDVI values are routinely multiplied by 1,000 to remove rounding errors. We follow this convention in our analysis.

Figure 2 displays Nepal's monthly average NDVI values over the period February 2000 to December 2011. The graph displays the substantial interannual variability that Nepal experiences in vegetation cover and health.[3] Below, we use monthly NDVI values as key

[3] We might instead show a smaller area to illustrate inter-annual variability, since the current figure is averaged over the entire country, resulting in low variability. We could average only 9 or 25 pixels around a specific location (say, Kathamandu) to show variability.

independent variables in the analysis. As an example, Figure 3 displays the distribution of average NDVI values for the month of September, based on data from 2000-2011. Figure 3 overlays separate probability density charts for each agroecological zone and illustrates that peak vegetation indices for the Mountain and Hill zones are, on average, somewhat “greener” than those of the Terai, but are also more variable. Figure 4 provides an alternative view of the same data in which monthly NDVI levels, averaged across all available years, are plotted across the calendar, again by agroecological zone. In all zones, NDVI levels tend to peak in the August-October period, which broadly coincides with the growing season for most of the major crops identified in the cropping calendar (see Table 2). Recorded NDVI levels are generally higher in the Hills and Mountains than in the Terai. Such patterns are intensified when one compares early-season and late-season averages, as we do in Figure 5. During the March to May period, peak NDVI levels are lower across all zones, but they are also more greatly separated. In part this is because there tends to be more variability in vegetation greenness across regions due to altitude and the timing and extent of monsoon arrival. These differences are agriculturally important, which is why we include them below in our regression analysis.

3.2 DHS anthropometry data

Nutritional status and a range of individual- and household-specific characteristics used in the analysis are drawn from the Demographic and Health Survey for Nepal. We use the 2006 data, which were collected from a nationally-representative probability sample selected using a stratified two-stage cluster design. Characteristics of the sample include data covering anemia and anemia testing, anthropometry, birth registration, causes of death, early childhood education, HIV knowledge and testing, micronutrient intakes, vitamin A supplementation, and maternal mortality. Figure 6 presents the observed distributions of height-for-age z-scores (left panel) and weight-for-height z-scores (right panel), by agroecological zone. In all zones, the probability mass of the Nepal DHS z-score distribution is shifted substantially left compared with that of a healthy population.

Both the satellite remote sensing data and the DHS data include geolocation information, which provide the ability to connect the former to the latter. During DHS data collection, hand-held GPS units were used to collect GPS coordinates for the center of the populated area being surveyed (in this case the centroids of 254 sample clusters). In order to ensure that respondent confidentiality would be maintained, the GPS coordinates were randomly displaced. The random displacement is applied so that rural points contain a minimum of 0 and a maximum of 5 kilometers of positional error. Urban points contain a minimum of 0 and a maximum of 2 kilometers of error. A further 1% of the rural sample points are randomly offset a minimum of 0 and a maximum of 10 kilometers. These introduced errors are substantially lower than the spatial resolution of the satellite remotely sensed data discussed below. The monthly average NDVI data were added to the DHS dataset such that each DHS observation has a corresponding complete set of cluster-level NDVI values which correspond to monthly averages between February 2000 and December 2006. To add additional spatial and temporal relevance to our observed NDVI data, we index observed NDVI values using observed details regarding an individual child’s date and location of birth and the crop-specific growing season relevant to main staple in the location of residence. So, for example, below we refer to NDVI values in the "year of birth" and the "year prior to birth." These are defined as the average NDVI values observed during the months of the agricultural calendar most relevant for the main agricultural crop grown in the district of residence for the year in which the child was born, and the year prior to the child's birth. In this way we tie NDVI values to the time and location that are likely to be most nutritionally relevant to each child.

3.3 NLSS data

The 2003-2004 Nepal Living Standards Survey (NLSS) provides a comprehensive description of socioeconomic characteristics of rural and urban households. Data are nationally representative and consist of observations for 3,912 households and 5,234 children under age 5. Collection followed the methodology of the World Bank's Living Standard Measurement Survey using a two-stage stratified random sampling technique. Available variables relate to agriculture, income and expenditures, loans, and access to facilities and market infrastructure. Within each district (n=75), variables of interest were summarized for eight unique categories/levels. These were: (i) location of residence (urban or rural); (ii) sex of the head of household (male or female); and (iii) size of owned agricultural land (large or small, according to whether the reported farm size was above or below the survey median). For each unique district-location-sex-size combination we computed the observed mean, median, standard deviation, minimum, and maximum value for a set of key NLSS variables. These statistics describe agricultural conditions and performance for the agricultural growing season of 2003-2004, and were therefore observed approximately 48 months *prior* to the DHS survey.

3.4 Empirical strategy

Table 3 reports summary statistics for the main variables used in the analysis. These are organized into three main blocks: (1) information about the child and the household obtained from the 2006 DHS survey; (2) information about agricultural characteristics in the district of residence obtained from the 2004 NLSS survey; and (3) remotely sensed vegetation data from the cluster-relevant monthly MODIS observations. To measure the association between child growth indicators and child, family, district and vegetation variables, we use a series of multiple regression models in which the height-for-age z-score (HAZ) and the weight-for-height z-score (WHZ) serve as dependent variables. Given that errors in the measurement of individual child HAZ and WHZ are likely to be correlated, to improve the efficiency of our regression estimates we employ a Seemingly Unrelated Regression (SUR) approach and use 1,000 bootstrap replications to obtain robust standard errors for our parameter estimates.

Part 4: Results and Discussion

Regression results are presented in Tables 4 (HAZ) and 5 (WHZ). We report results from three models. Model A includes DHS variables only, corresponding to children, their mothers and specific characteristics of their households. Model B adds to Model A set of NLSS variables that summarize key features of district-level agricultural performance, matched to DHS households based on headship, farm size and urban/rural status. Model C adds to Model B indicators from the remotely-sensed data matched based on GIS clusters. In the case of the stunting regression we use the late-season cluster average NDVI value for the months of August, September and October in the year of the child's birth. We include this lagged variable for HAZ in recognition that HAZ measures cumulative effects of malnutrition and with the expectation that nutritional deficits that occur early in the child's growth will likely be expressed in subsequent stature. For WHZ, a short-term measure of wasting, we use the late season cluster average NDVI value for the months of August, September and October in the year prior to the DHS survey, in the expectation that short-term nutritional deficits will be most sensitive to growing conditions during the previous growing period. When including these NDVI variables, we also include all other monthly NDVI variables for 2005, to control for seasonal variation in agriculture-nutrition outcomes.[4]

4.1 Stunting

Regression results for height-for-age z-scores (Table 4) are consistent across our models and robust to inclusion of district (Model B) and remotely-sensed (Model C) variables. We find significantly higher levels of stunting in the hills compared with the mountains or Terai, and a positive correlation between stunting and altitude. Not surprisingly, given that HAZ is a measure of cumulative response to undernutrition, we find a strong negative correlation between HAZ and child age, with each year reducing the HAZ by approximately 0.27 points. To some degree, very young children may be protected by breastfeeding, but as children begin to rely on other food sources for the bulk of their calories, the effects of food scarcity intensify. Controlling for other factors, we see no difference in average rates of stunting between boys and girls. We find evidence that children from female-headed households exhibit slightly greater rates of stunting than those from male-headed households. In addition, three variables corresponding to mothers show a statistically strong and consistent relationship to stunting. Children from younger mothers are more stunted and stunting falls with mother's education and BMI. We find no correlation between access to safe water and HAZ, but an index of household wealth has a positive and statistically strong relationship with HAZ. Controlling for overall wealth, however, we find no additional impact from land or livestock holdings.

Five variables characterizing district-level agricultural outcomes (in 2004, approximately 18 to 24 months prior to the HAZ measurements) are included in Models B and C. These are jointly significant in the HAZ regressions. Levels of individual significance vary across models. The correlation between district-level yields and HAZ is systematically weak. Somewhat surprisingly, in districts with higher rates of agricultural intensification—measured here by the variables for average rates of fertilization and irrigation—we find lower HAZ, on average. One possible explanation might be that districts with greater rates of agricultural intensification have greater commercial orientation, and are therefore more highly focused on production of cash crops than food crops. The results from Model B provide two pieces of information that contradict this view to some extent, since in that model greater use of improved seeds is positively correlated with HAZ and a higher ratio of agricultural sales to production is also associated with higher HAZ. However, the finding from our preferred specification, Model C supports the conjecture that greater agricultural intensification is positively correlated with

[4] We do this because DHS surveys tend to be conducted over a period of 6-9 months, introducing variability across months as the harvest comes in. See for example Hillbruner and Egan (2008) and Becquey, et al. (2012).

stunting. A number of possible explanations exist, including choice of crop, greater cash expenditures on inputs, increased labor demand on household members.

Past studies have suggested that contemporaneous NDVI may not have a consistent association with stunting (Curtis & Hossain 1998). For example, Johnson and Brown (2012) find mixed results between NDVI and HAZ for Benin and Mali. However, our results point to a positive correlation between HAZ and our NDVI variable, which in this case measures the average index in the August to October period corresponding to the year of the child's birth. In this way, the NDVI variable points to the potential importance remotely-sensed information in generating improved understanding of future nutritional risk.

4.2 Wasting

Patterns in the WHZ regressions (Table 5) are somewhat similar to those of the HAZ regressions. We find consistently lower levels of wasting among urban children and those at higher elevations. Older children are less likely to be wasted. Mother's BMI and the household's level of livestock wealth are also positively correlated with WHZ. On average, children in Brahmin households and larger households have lower WHZ scores, perhaps reflecting dietary restrictions and preferences among the former and competition for food among the latter. Overall, district level agricultural variables are strongly correlated with WHZ, with patterns that differ somewhat from the HAZ regressions. We find a positive correlation between average rates of fertilizer use in the district and average WHZ, but a negative correlation with irrigation and use of improved seed. The district agricultural sales ratio is positively correlated with WHZ. In the WHZ regression our included measure of NDVI is the average level for August-September-October in the year prior to the WHZ measurement. This is significantly associated with a reduction in wasting, a pattern consistent those reported by Johnson and Brown (2012) for Mali.

The positive bivariate (unconditional) relationships between NDVI variables and child growth indicators are displayed graphically in Figures 7-9. Figure 7 plots HAZ against cluster average NDVI in August to October of a child's birth year (left panel) and the year prior to birth (right panel) for the Mountain zone. Figure 8 provides a similar plot for the Terai. In general, we find a somewhat stronger relationship between NDVI and z-score among children in the Mountain zone, with an approximate 1 standard deviation improvement in z-score associated with an observed full-range increase in NDVI. Figure 9 pools data for all zones, and illustrates that the overall relationship between NDVI and HAZ is similar regardless of whether one focuses on the August to October period or harvest period specific to the major crops grown in the area, and is also broadly similar regardless of whether one focuses on the year or birth or the year prior to birth, which likely underscores the critical importance of mother's nutrition prior-to, during, and immediately following gestation.

Part 5: Conclusions

In this paper we combined three distinct datasets to study the connections between agriculture and child health in Nepal. Growth measurements from 5,234 children under age 5 were obtained from the 2006 Nepal Demographic and Health Survey (DHS). We also employed nationally representative data from the 2003-2004 Nepal Living Standards Survey (NLSS) to measure district-level agricultural characteristics. On the basis of common GIS data points we combined the DHS data with satellite remote sensed Normalized Difference Vegetation Index (NDVI) composites. Using these data as a proxy for growing conditions, we were able to control for intra-annual variability in agricultural activity and explore the association between the NDVI, a monthly proxy for agricultural production, and nutrition outcomes in children. This approach extends the analysis of child growth by accounting for underlying features of agricultural production (due to temperature and precipitation) and district-level differences in agricultural characteristics and performance.

We find strong statistical evidence in support of the conjecture that, controlling for a range of factors specific to children, their mothers and their households, NDVI in the year of a child's birth is correlated with subsequent levels of stunting, and that NDVI measured in the year previous to child measurement is correlated with subsequent levels of wasting. We also find that in districts with higher rates of agricultural intensification—measured by matching variables for average rates of fertilization, irrigation, and use of improved seed—we find lower HAZ and WHZ, on average. These results are somewhat mixed and at times contradicted by accompanying evidence that a higher ratio of agricultural sales to agricultural production is correlated with more favorable nutrition outcomes. One possible explanation might be that districts with greater rates of agricultural intensification have greater commercial orientation, and are therefore more highly focused on production of cash crops than food crops. Only when sales ratios are high do children benefit from this orientation. A number of explanations for the patterns exist, including the possibility that the choice of crop matters, that greater cash expenditures on inputs places a nutritional drag on households, or that increased labor demands alter time allocation by household members that might have deleterious nutritional impacts. Such relationships have been suggested previously in the literature and warrant additional attention and analysis.

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Table 1: District-level comparison of child z-scores and agricultural performance

	District average height-for-age z-score	
Average yield	Below average	Above average
Below average	34	21
Above average	5	15

	District average weight-for-height z-score	
Average yield	Below average	Above average
Below average	17	38
Above average	14	6

Source: For yields, NLSS (2004); for z-scores, NDHS (2006)

Table 2: Crop calendar for main cereal crops cultivated in Nepal (Source: FAO, 2007)

Crop	Ecological Zones	Irrigation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Season
Paddy	Hills	Partially					TP	TP			H	H			Summer
		Year-round			TP	TP			H	H					Spring
	Terai	Rainfed						TP	TP		H	H	H		Summer
		Year-round			TP	TP			H	H	H				Spring
									TP	TP			H	H	Late summer*
Maize	Mountains	Irr./Rainfed			P	P				H	H	H			Summer
	Hills	Rainfed			P	P				H	H				Summer
		Irrigated		P	P			H	H						Spring
	Terai	Rainfed				P	P			H	H				Summer
		Year-round		P	P			H	H						Spring
				H	H							P	P		Winter
Millet	Mountains	Rainfed				P	P					H	H		Summer
	Hills	Rainfed						P	P			H	H		Summer
Wheat	Mountains	Rainfed					H	H					P	P	Winter
	Hills	Rainfed			H	H	H					P	P	P	Winter
	Terai	Rainfed**			H	H						P	P		Winter
Barley	Mountains	Rainfed				H	H						P	P	Winter
	Hills	Rainfed			H	H						P	P	P	Winter

P= Planting; TP= Trans-Planting; H= Harvesting.
* Recent option adopted by some farmers in the Eastern region, allowing two paddy crops a year.
** Supplemental irrigation is practiced in the east.

Note that the ecological zones do not fully reflect existing cropping patterns and the cropping calendar represents the most common practices within each zone. For instance, the lower parts of the Hills have similar cropping options as the adjacent Terai.

Note that for paddy, maize and millet, the crop calendar is earlier in the Eastern region by approximately one month as compared to Far- and Mid-Western regions. Therefore, for the Eastern region the earlier dates presented in the crop calendar can be utilized while for the Far- and Mid-Western regions, the later dates are accurate. Wheat and barley are not affected.

Table 3: Descriptive statistics for the sample

Variable	Mean	Std. Dev.	Min.	Max.
DHS variables (n=5,234)				
Height for Age z-score	-1.96	1.34	-5.96	4.59
Weight for Height z-score	-0.84	1.06	-4.94	4.07
Urban (%)	22.4	41.7	0.0	1.0
Mountain (%)	15.0	35.7	0.0	1.0
Hills (%)	39.1	48.8	0.0	1.0
Altitude (masl)	826.7	740.9	51.0	3,189
Child age (years)	2.0	1.4	0.0	4.0
Sex (% female)	49.4	50.00	1.0	2.0
Mother's age (years)	27.0	6.1	15.0	49
Mother's education (% primary)	63.9	87.9	0.0	3.0
Mother's BMI (index)	20.3	2.6	14.0	33.9
Female head (%)	21.0	40.7	0.0	1.0
Household size (# of members)	6.8	3.2	2.0	30.0
Safe water (%)	72.0	44.9	0.0	1.0
Household wealth (index)	-21.7	82.9	-102.6	393.2
Brahmin (%)	11.4	31.8	0.0	1.0
Livestock units (weighted #)	2.3	2.3	0.0	20.8
Agricultural land (hectares)	0.46	0.82	0.0	23.7
NLSS variables (n=75)				
District average yield (kg/ha)	3,340	1,168	870	8,600
Per cent of farms using fertilizer (%)	61.4	32.4	0.0	100.0
Per cent of farms using improved seed (%)	23.6	25.8	0.0	100.0
Per cent of farms using irrigation (%)	64.9	28.0	0.0	100.0
Average ratio of sales to production (%)	9.9	10.2	0.0	80.0
MODIS variables (n=254)				
Avg. NDVI in Aug-Sep-Oct, year of birth	698.4	70.9	22.0	854.3
Avg. NDVI in Aug-Sep-Oct, 2005	709.5	70.4	121.3	852.7

Table 4: Regression results for height-for-age z-score (stunting)

	Model A	Model B	Model C
constant	-2.260***	-2.208***	-2.430***
	(0.034)	(0.215)	(0.016)
urban/rural (0/1)	0.041	0.033	0.027
	(0.044)	(0.022)	(0.068)
mountain zone (0/1)	0.113	0.059	-0.037
	(0.073)	(0.031)	(0.060)
hill zone (0/1)	0.098***	0.104***	0.117***
	(0.023)	(0.019)	(0.013)
altitude (1000 masl)	-0.253***	-0.266***	-0.290***
	(0.014)	(0.013)	(0.009)
child's age (yrs)	-0.272***	-0.272***	-0.269***
	(0.021)	(0.004)	(0.005)
sex of child (1=F)	-0.017	-0.011	-0.014
	(0.023)	(0.007)	(0.012)
mother's age (yrs)	-0.006	-0.006*	-0.006***
	(0.005)	(0.003)	(0.002)
mother’s education	0.223***	0.216***	0.204***
	(0.056)	(0.008)	(0.018)
mother’s BMI	0.054***	0.056***	0.055***
	(0.007)	(0.012)	(0.001)
female-headed household	-0.064*	-0.102***	-0.082*
	(0.032)	(0.023)	(0.033)
household size (#)	-0.005	-0.007*	-0.008
	(0.007)	(0.003)	(0.008)
safe water source (0/1)	0.049	0.053	0.045
	(0.073)	(0.029)	(0.056)
wealth index	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)
brahmin (0/1)	-0.094***	-0.106	-0.105
	(0.025)	(0.077)	(0.115)
livestock (tlu)	0.010	0.010	0.012
	(0.009)	(0.020)	(0.011)
farm size (ha)	-0.006	-0.032***	-0.020
	(0.023)	(0.009)	(0.015)
average crop yield		-0.038	-0.032
		(0.024)	(0.036)
% using fertilizer		-0.103***	-0.040*
		(0.011)	(0.017)
% using irrigation		-0.153***	-0.148***
		(0.004)	(0.008)
% using improved seed		0.225***	0.204
		(0.042)	(0.111)
sales/producton		0.283***	0.151
		(0.047)	(0.099)
ndvi: aug-sep-oct, birth year			1.600***
			(0.290)
N	5234	5234	5234
R^2	0.189	0.193	0.203

Note: HAZ and WHZ estimated jointly as SUR. Regressions also contained monthly NDVI controls for 2005. Standard errors, based on 1000 bootstrap replications, presented in parentheses. *** Significantly different from zero at the 1%, ** 5%, and *10% level.*

Table 5: Regression results for weight-for-height z-score (wasting)

	Model A	Model B	Model C
constant	-3.067***	-3.061***	-3.252***
	(0.042)	(0.034)	(0.070)
urban/rural	0.120***	0.134*	0.157*
	(0.028)	(0.067)	(0.066)
mountain zone	0.139	0.158***	0.102
	(0.149)	(0.012)	(0.055)
hill zone	0.128	0.125***	0.103
	(0.087)	(0.007)	(0.117)
altitude (1000 masl)	0.105	0.132***	0.154***
	(0.072)	(0.007)	(0.037)
child's age	0.077***	0.076***	0.077***
	(0.011)	(0.004)	(0.004)
sex of child	-0.014***	-0.013	-0.013
	(0.002)	(0.073)	(0.057)
mother's age	-0.003	-0.002	-0.003***
	(0.001)	(0.002)	(0.000)
mother’s education	0.036*	0.038***	0.028
	(0.018)	(0.000)	(0.041)
mother’s BMI	0.100***	0.099***	0.097***
	(0.000)	(0.006)	(0.007)
female-headed household	0.025	0.035	0.040
	(0.031)	(0.047)	(0.050)
household size (#)	-0.014**	-0.015***	-0.014***
	(0.005)	(0.003)	(0.001)
safe water	-0.004	-0.009	-0.012***
	(0.042)	(0.018)	(0.001)
wealth index	0.001***	0.001	0.001
	(0.000)	(0.000)	(0.000)
Brahmin	-0.204***	-0.199**	-0.203***
	(0.051)	(0.070)	(0.053)
livestock units	0.013	0.014	0.012***
	(0.010)	(0.009)	(0.003)
farm size (ha)	0.014***	0.006	0.006
	(0.001)	(0.018)	(0.014)
avg crop yield		-0.005	-0.005
		(0.012)	(0.023)
% fertilizer use		0.094***	0.116***
		(0.016)	(0.021)
% irrigated		-0.058***	-0.076
		(0.011)	(0.060)
% improved seed		-0.138***	-0.108***
		(0.009)	(0.023)
sales/producton		0.574*	0.589***
		(0.234)	(0.170)
ndvi: aug-sep-oct 2005			0.422***
			(0.007)
N	5234	5234	5234
R^2	0.122	0.125	0.128

Note: HAZ and WHZ estimated jointly as SUR. Regressions also contained monthly NDVI controls for 2005. Standard errors, based on 1000 bootstrap replications, presented in parentheses. *** Significantly different from zero at the 1%, ** 5%, and *10% level.*

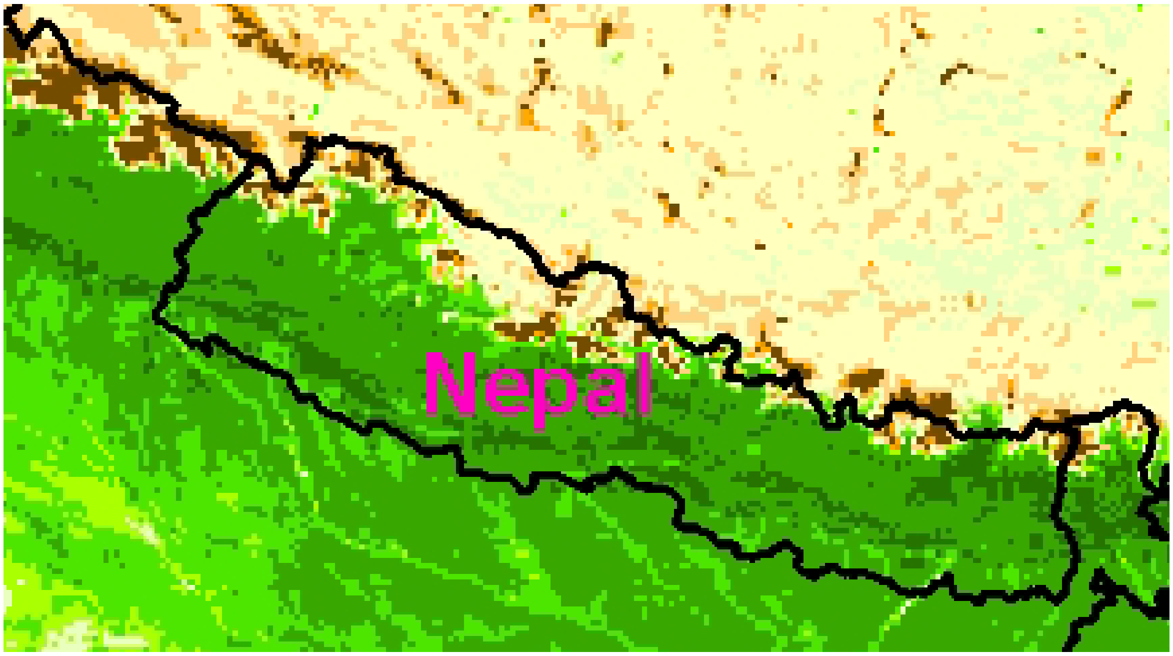

Figure 1: Map of Nepal indicating NDVI values, October 2005.

Dark green indicates dense vegetation; brown is non-vegetated or bare ground.

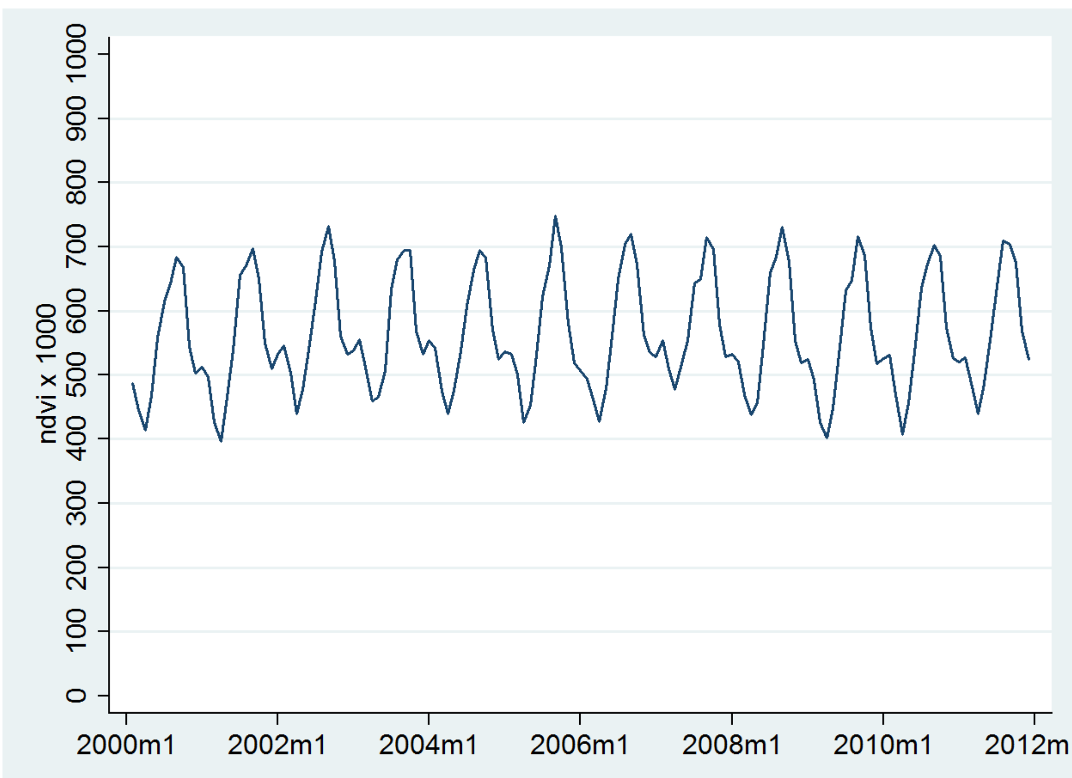

Figure 2: Average monthly NDVI values for Nepal, 2000-2011

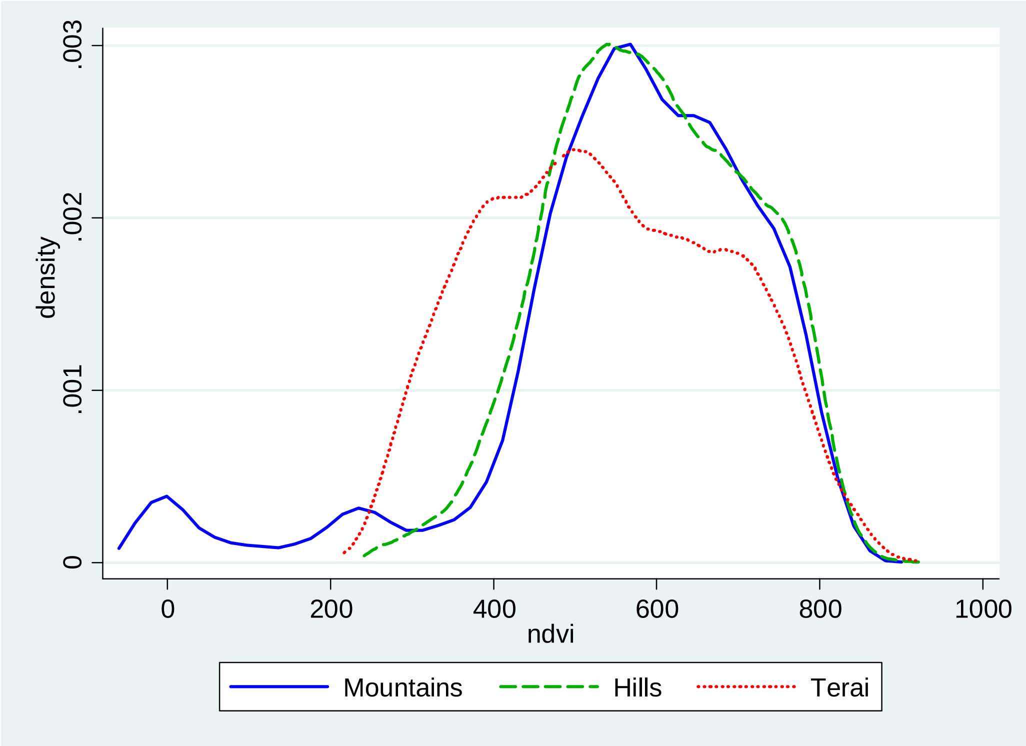

Figure 3: Distribution of average NDVI values for month of September, by agroecological zone

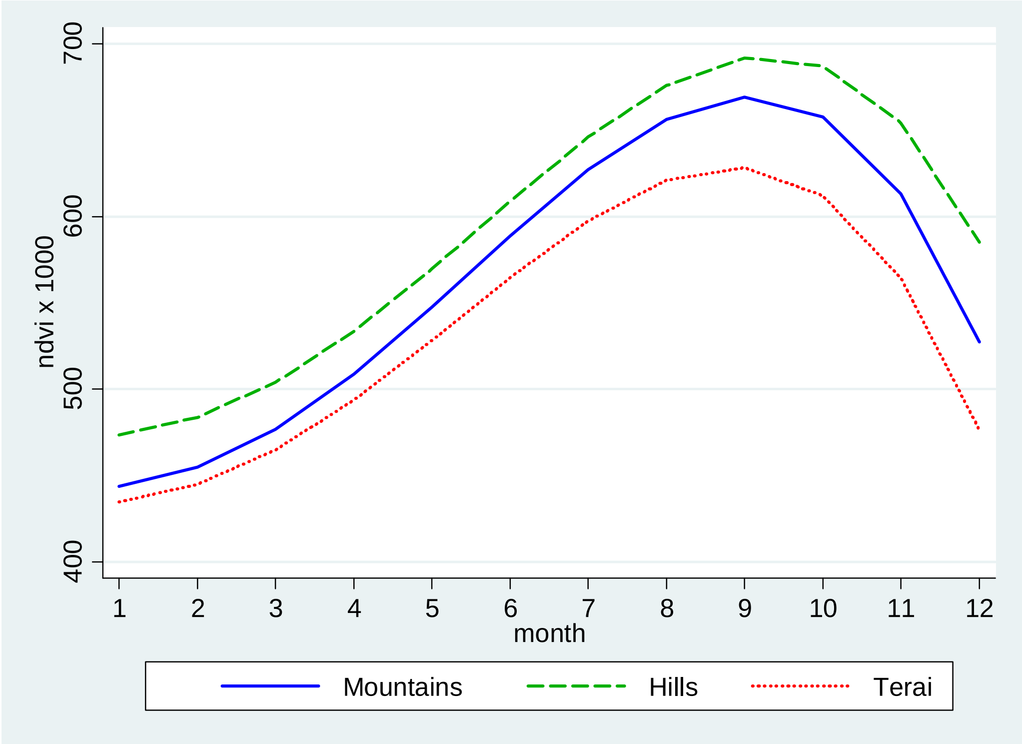

Figure 4: Plot of average monthly NDVI levels across all years, by agroecological zone

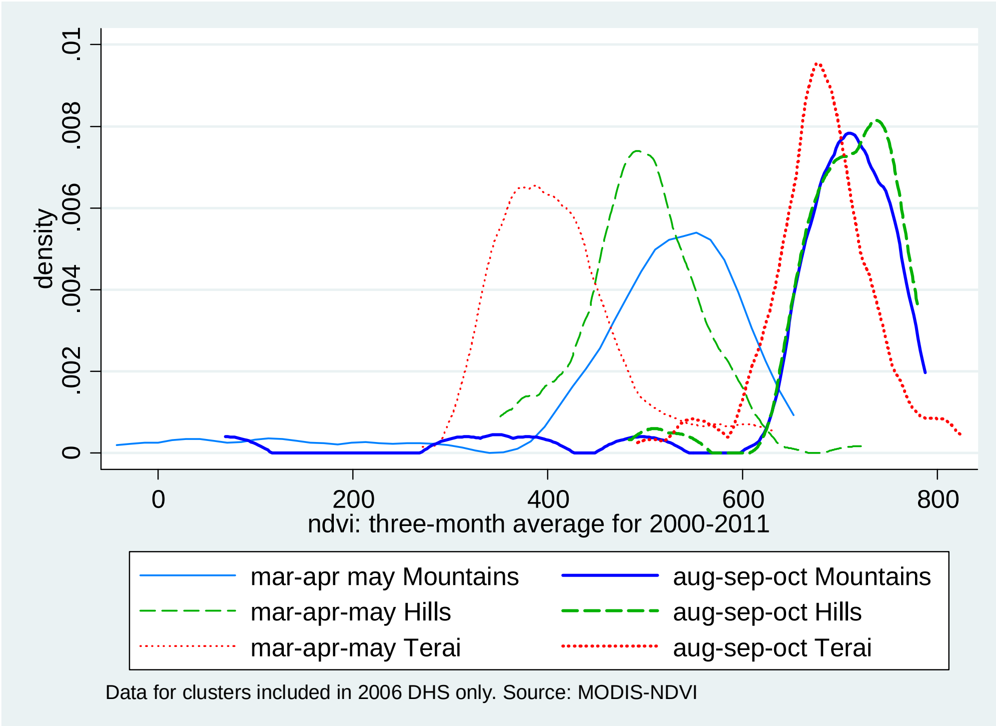

Figure 5: Early-season and late-season average NDVI levels, by agroecological zone

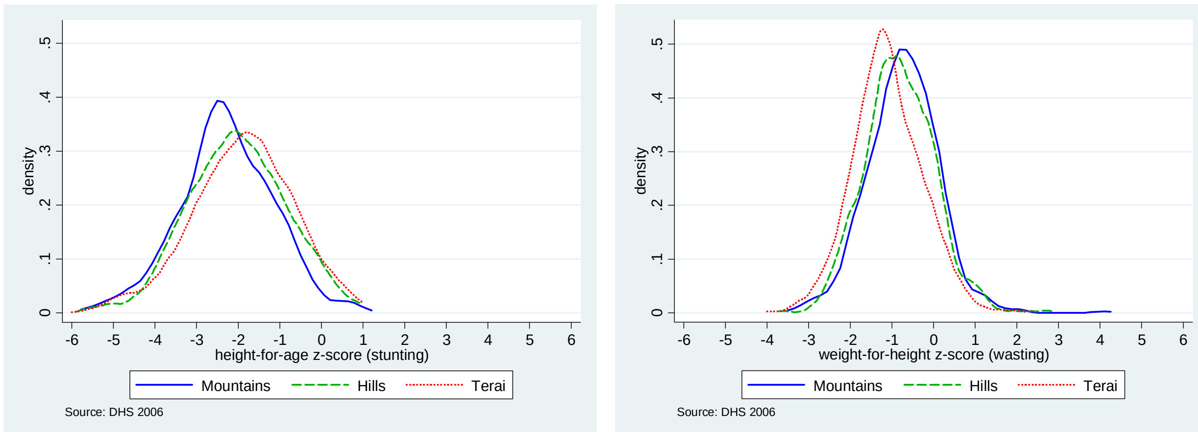

Figure 6: Distribution of height-for-age (left panel) and weight-for-height (right panel) in 2006, by agroecological zone (from left to right, means = -2.27, -2.02, -1.89, -1.11, -0.82, -0.73)

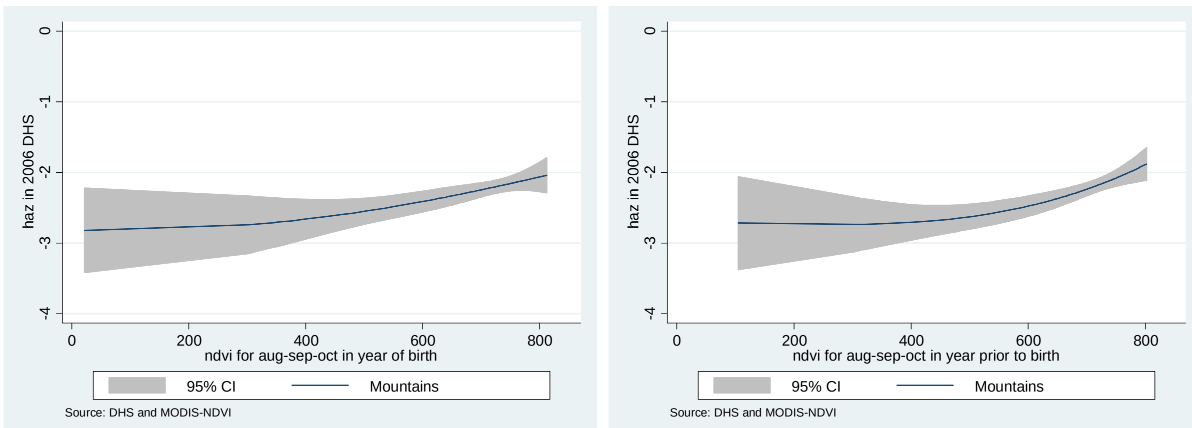

Figure 7: Plots of height-for-age in 2006 against cluster average NDVI for district in Aug-Oct of birth year (left panel) and year prior to birth (right panel), Mountain zone

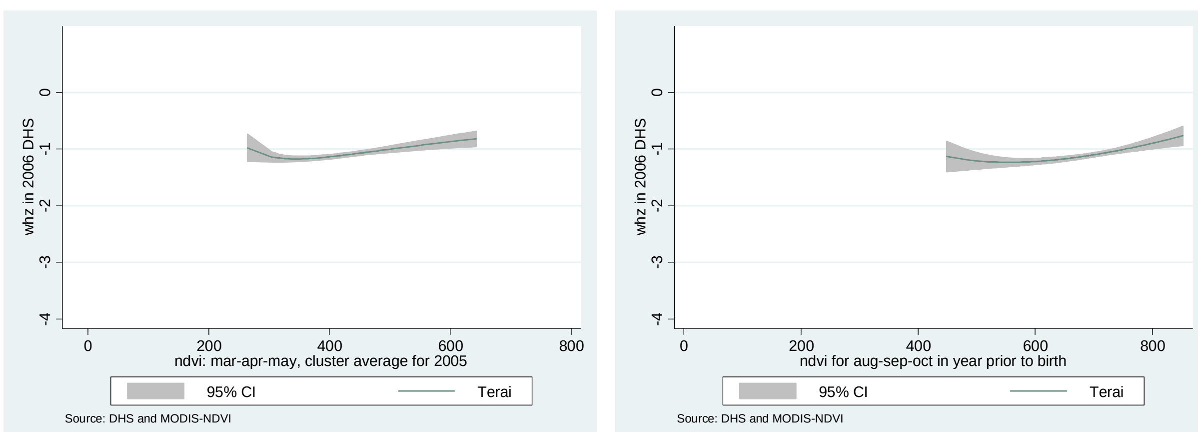

Figure 8: Plots of weight-for-height in 2006 against cluster average NDVI for district in Aug-Oct of 2005 (left panel) and year prior to birth (right panel), Terai zone

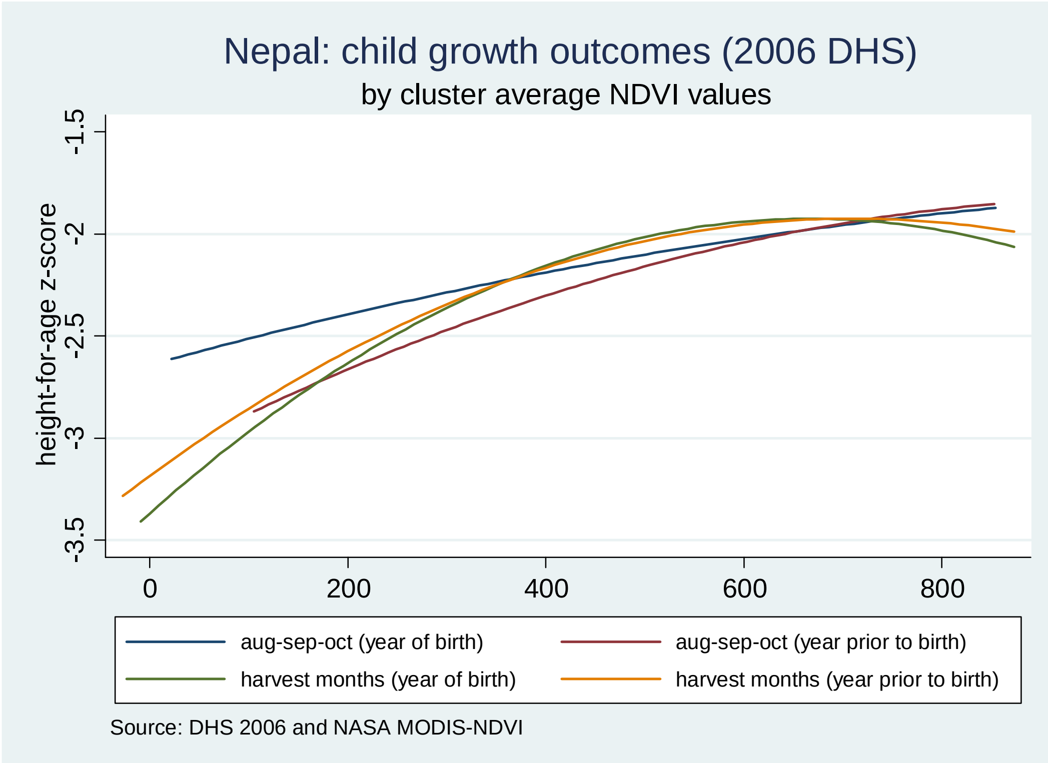

Figure 9: Height-for-age Z-score in 2006 against cluster average NDVI values for selected periods in year of birth and year prior to birth, all zones