Overview
Glyphosate is a broad-spectrum herbicide used to eliminate weeds in both industrial farming and domestic gardening. Introduced in the 1970s by Monsanto under the brand name RoundUp, glyphosate is widely used by farmers of soy, corn and cotton and attributed with higher yields and easier crop management.

Recently, however, studies have been released raising doubts about the safety of the herbicide. Gauzier et al., 2009 conclude that glyphosate based herbicides are toxic and endocrine disruptors in human cell lines. An Argentinian team led by Carrasco et al., 2010 conclude that prenatal glyphosate exposure can lead to birth defects in amphibian embryos. Numerous other studies have been published: Vousel et al., 1995; Savitz et al., 1997; Barua et al., 2001; Houriet et al., 2005; Dallegre et al., 2007; Oliveira et al., 2007; Cavalcante et al., 2008.

The potential toxicity of glyphosate is of special interest in Argentina, where 95% of the soy grown is sprayed with glyphosate. Hospitals in the cities of Cordoba and Resistencia, both in soy growing regions, have noted a sharp rise in birth defects. Local municipalities and news agencies allege that the chemical is directly responsible for these birth defects. The purpose of this analysis is to identify areas in Argentina where potential exposure to glyphosate is highest. This will allow policy makers to determine which areas are most critical to consider for public health and safety.

Methodology
This analysis relies on geospatial analysis of risk factors that may contribute to glyphosate exposure. Summarily, three broad categories of potential risk factors were examined:

1) Soy Production Figures: Because over 95% of the soy grown in Argentina is genetically-modified for use with glyphosate, these figures present a reliable proxy for spraying of the herbicide.

2) Small Holder Farmers: Based on interviews with industry experts at Monsanto and Soyatech, farmers face high levels of primary-level exposure risk, due to constant and direct contact with the chemicals.

3) Socioeconomic Indicators: Factors such as level of wealth, literacy, access to plumbing and population density also affect the level of risk.

Analysis
Soy Production: Using crop production figures as a proxy for chemical level exposure is not unique. Kettle et al., 1997 use corn production data as a proxy for triazine exposure in Kentucky. Nuckols et al. 2004, similarly provides guidance for using crop data on epidemiological surveys. Soy production figures were obtained at Sistema Integrado de Informacion Agropecuaria (SIIA), a statistical division of Argentina’s Ministry of Agriculture. These data were imported into GIS, creating a map of areas of soy harvested, in accordance with the department level in 2010. This was also combined with Land Cover data from Argentina’s Geographic Agency (SIG-250) to arrive at a more fine-grained assessment of where soy is grown. Lastly, the maps were converted to a kernel-density raster and given a risk score based on intensity of soy production.

Small Holder Farmers: Calculations for determining the presence of smallholders throughout Argentina were performed using 2001 Rural Infrastructure data from the SIG-250 dataset. This dataset consisted of 29,215 discrete points labeled by farm type. Points with labels representing small farms (Chacra, Finca) were filtered and then used to create a kernel-density raster map. Scores were then given, with higher scores associated with areas possessing a higher density of these small farm infrastructures.

The SIG-250 dataset also provided information on watercourses and elevation. While many exposure assessments use these data as representative risk factors, I chose not to. Elevation data in soy growing regions is incredibly consistent, so factoring this into the final risk assessment would not have had a meaningful impact. Additionally, the case for heightened toxic exposure risk due to waterways is quite weak. Current literature suggests that rivers tend to diffuse - more than spread toxins - so the argument for this epidemiological pathway is somewhat suspect.

Socioeconomic Indicators: Lastly, 2010 data provided by the Instituto Nacional de Estadisticas y Censos (INDEC), was used to assess general department level risk. Of the possible census indicators, I chose population density, literacy rate, and access to tap water. Population density is typically used in epidemiological surveys, simply because there is a greater chance for health ailments in larger populations. Literacy rate is used as a proxy for wealth in some studies, but also of importance in relation to glyphosate: farmers who are illiterate will be unable to read warning labels or directions on proper use of the chemical. They are also more likely to be undereducated, increasing potential risks. Finally, access to piped water is crucial in the context of glyphosate. Households without access to water infrastructure are more likely to use well water, or exterior sources of water that may be contaminated with toxins.

Conclusions
The results of this analysis may come as a surprise to some areas in Argentina that at highest risk of glyphosate exposure are not in the regions where soy is most heavily grown. Though the Pampas “breadbasket” of the nation has the most acres under cultivation, the center north of the country, in provinces such as Santiago del Estero, Chaco, Tucuman and Salta face greater risks. Specifically, the departments of Burruyacu, Nuevo del Julio (Chaco) and General Belgrano (Chaco) fall entirely in the high risk zone. The reasons for this have to do with the greater concentration of smallholder farmers and poorer economic conditions which may lead to lower safety and sustainability standards. However, it is important to point out that other ways for combining production data, economic data and farm data exist, and different methods may have varied results.

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