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ORIGINAL ARTICLE

Impact of desertification and land degradation on Colombian children

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Abstract

Objectives Desertification affected more than 24% of Colombia's land mass in 2012. The study aims to establish the singular impact of desertification on under-five mortality in Colombia.

Methods Descriptive statistics and multivariate logit regressions are applied to the population of live births and under-five deaths in Colombia 2008–2011.

Results Children have a higher probability to die in rural communities and among mothers with low education who also have inferior health insurance. Controlling for those, desertification below about 50% of the land, lowers child mortality and increases it after that percentage. The impact of extraction of hydrocarbons is 12.45, metals 5.73 and others 4.91 times higher in municipalities with more than 50% of desertification territory. Rural areas with high desertification have 2.25 times higher risk of mortality due to malnutrition.

Conclusions In the short term, when mines have less or no effect on desertification, living conditions may improve and reduce child mortality. In the long term, however, as desertification intensifies affecting the ecosystem, child mortality increases. More research is needed, and policy formulated accordingly.

Keywords Desertification · Land degradation · Desert · Child mortality · Poverty · Food security · Colombia

Introduction

The United Nations Convention to Combat Desertification (UNCCD) defines desertification as the degradation of land occurring in arid, semiarid and dry subhumid areas, known as drylands. Desertification is caused primarily by climatic variations and human activities (Reynolds 2001). The UNCCD defined the drylands ecosystems by the annual average range of the ratio P/PET (P = precipitation; PET = evapotranspiration) between 0.05 and 0.65. Accordingly, drylands in the world are about 40% of the land (Koohafkan and Stewart 2008).

The convention clarifies that desertification is the consequence of ecosystems' vulnerability due to over-exploitation and inappropriate use of the land. It does not refer to the expansion of existing deserts. Furthermore, true deserts have a P/PET ratio of less than 0.05; therefore, unless they receive an additional water supply, deserts are not part of arid areas (FAO 2011; Koohafkan and Stewart 2008).

There are four types of drought in drylands: (1) meteorological, (2) agriculture, (3) hydrological and (4) socioeconomic. When the last occurs, the loss of water affects the population adversely (Koohafkan and Stewart 2008; NDMC—National Drought Mitigation Center 2012). This effect may follow the other type of drought since they strongly affect the people's food security and their nutritional status (Stanke et al. 2013).

Colombia is "mega-diverse." It comprises a wide range of environments and ecosystems. Despite its geographical location in the tropics, non-sustainable activities combined with topographical conditions have resulted in land degradation, which accelerates the desertification of Colombia. In fact, according to the Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), 24% or 274,020 km^2 of continental land in Colombia are susceptible to desertification in 2012 (Sánchez et al. 2012).

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The state administrative division of Colombia includes 33 departments further divided into 1122 municipalities (localities) (DANE and Gobierno de Colombia 2017). The most severe level of desertification in Colombia (Etter et al. 2008) is in the department of La Guajira, which has 75% of its area desertified, the departments of Magdalena, Sucre and Cordoba have between 50 and 75% levels of desertification (IDEAM et al. 2007). The fast land degradation processes particularly in these departments, considering the water-rich context and legacy, extraordinarily affect biodiversity and hydrological cycles and, as a result, vulnerability, poverty, food security and violence [Global Environment Facility (GEF), United Nations Convention to Combat Desertification (UNCCD) 2006]. Deteriorating water and fertile land supplies adversely affect the quantity and quality of safe water and food supply, from both agricultural and animal sources. The population in the affected areas has traditionally been already exposed to multidimensional poverty, female adult literacy decrease, with a high infant mortality rate (IMR), in the range of 25–20, before considering decreasing food supplies and childhood mortality increases (Jaramillo-Mejia 2016; Jaramillo-Mejía et al. 2013; UNDP 2009). In 2005 the "Plan de Acción Nacional de Lucha Contra la Desertificación y la Sequía en Colombia"—PAN—was the last detailed study and plan about desertification in Colombia. The PAN proposed to strengthen the knowledge about the operation, structure and management of dryland ecosystems (Ministerio de Ambiente, Vivienda y Desarrollo Territorial 2005). The IDEAM is still developing a project, which was expected to be ready in 2015.

The objective of this study is to establish the association of desertification with child mortality in Colombia, while accounting for the association of socioeconomic conditions and access to medical care.

Methods

Desertification is hypothesized to contribute to a slowdown and even a reversal in Colombia's effort to reduce its IMR in the affected areas by counter-acting the efforts to alleviate poverty and reach out with medical services. Infant mortality, especially in the postneonatal period, is hypothesized to increase because of the lower quality of breastfeeding, induced early weaning and increased risk of infection, which results from higher numbers of animal deaths, polluted water and increasing problems with managing human waste (Koohafkan and Stewart 2008).

The focus of this study is La Guajira the Department (state) most affected by desertification. The problem concentrates in the region of "*Alta Guajira,*" where municipalities like Manaure and Uribia have an IMR twice as much La Guajira's average. According to the 2010 National Survey About Demographic and Health, the national average rate of chronic malnutrition is 13%, while the same rate for la Guajira is 28% (Profamilia 2011). It is noteworthy that these municipalities are geographically located in the tropical desert biome which exhibits an annual rainfall lower than 500 mm (IDEAM et al. 2007; IGAC 2008). This situation has brought the decrease of land productivity and land capacity, as well as the reduction of the water supply (CORPOGUAJIRA 2012).

Specifically, the study is based on the entire population of individual records of live births and deaths of under five years old in Colombia provided by the Departamento Administrativo Nacional de Estadística (DANE), for the period of 2008–2010. These data or unit of analysis combined with the fixed effect for each record: percentage of desertification in the municipality of birth or death (2005). The data include mothers' and infants' demographics, socioeconomic characteristics and basic cause of death.

The study uses multivariate methods, notably odds ratio (OR) analysis, to establish the association of desertification, a fixed community effect, while accounting for the association of this mortality with socioeconomic conditions, and availability of medical coverage, by the inferior subsidized health insurance vis-a-vis the superior contributory insurance (Jaramillo-Mejía 2016).

Data show that the municipalities are affected by high desertification and drought problems, including total municipality area. These data were drawn from the *Plan de Acción Nacional: Lucha contra la desertificación y sequía* of the Colombian Ministry of Environment and Sustainable Development (Ministerio de Ambiente, Vivienda y Desarrollo Territorial 2005). Desertification is classified by four levels: low, medium, high and very high, and percent of the area that is subject to desertification (km^2), based on the classification of desertification levels used by IDEAM. Municipalities with high and very high desertification were taken if that level of desertification was registered in more than 60% of its geographical territory, and grouped as a new variable "high desertification" (IDEAM 2010).

Additionally, geographical information about the location of the tropical desert biome—which corresponds mostly to the department of La Guajira—is drawn from the Instituto Geográfico Agustín Codazzi (IGAC) (IGAC 2008).

Based on the classification of desertification levels used by IDEAM—low, medium, high and very high—municipalities with high and very high desertification were taken if that level of desertification was registered in more than 50% of this geographical territory, grouped them as a new variable "high desertification."

Membership in the Contributory Regime measures the access to medical service. Members of the Contributory

Regime are expected to have access to service more readily. Additionally, mothers with higher level of schooling are hypothesized to have orderly and compliant prenatal care that reduces the risk of infant mortality; thus, the socioeconomic variable of the mother's level of schooling is also included.

The data are subject to both descriptive and multivariable analysis. The descriptive analysis aims to identify the relative importance of land desertification in infant mortality rate (IMR), when the baby died before 1 year old, especially the postneonatal rate (PNR), baby who died from 28 days until below 365 days, and additionally, the childhood mortality rate (CMR), when the baby died between one (1) to under five (5) years old. The rates were calculated for 1000 live births for each year.

Now, by estimating the singular hypothesized effects of relevant variables on the probability of death during postneonatal period, the multivariable analysis employs a logit regression whereby the dependent variable is whether (= 1) or not (= 0), a child died in a household. The independent control variables are the individual records of a child who died in the rural area, had a mother with high education, and who was affiliated to the subsidized regime, the percentage of desertification and the square of the total percentage of desertification by municipality. Thereby, municipalities with high desertification can be possibly identified as a situation that requires policy focus.

In addition, we use on the basis on preliminary estimates: "percentage of area desertification" and the square of this variable to allow for a nonlinear singular association of desertification. That is, for each household we indicate the level of desertification it is subject to in the area of their residence.

The numerical estimates rather than an odds ratios analysis permit no to demonstrate the actual estimated impact of desertification on a child's probability to die.

Results

Descriptive analysis

There is a statistically significant difference in the IMR, postneonatal mortality rate (PMR) and CMR for the period 2008–2010 between the desert municipalities and the rest of the country. These rates are marked by types of desertification, particularly for the people living in the rural areas (relative risk (RR):1.48; 95% confidence interval (95% CI):1.28–1.70). During every year of the period studied, the PMR doubles the rate for the desert municipalities.

It is evident that the impact of the desert on all types of mortality is stronger on weaker populations: the rural, the low educated mother and those with relatively limited medical insurance (Table 1).

When analyzing mortality rates in the desert areas of La Guajira, there is a statistically significant higher risk increase in the rural area, low education and low medical coverage of the subsidized regime, for childhood mortality rates compared to the rest of the municipalities of the department (Table 2).

The IMR and PMR between the territories with desertification and non-desertification are similar; moreover, both mortality rates do not show significant differences by desertification levels; on the contrary, non-desertification municipalities register higher values in both mortality rates, even in relation to municipalities with high desertification in all risk factors.

The results of the logit regression are reported in Table 3. It confirms and reinforces the descriptive analysis. The findings suggest that the association with mortality of the mothers living in a rural area, having low education and being a member of the subsidized regime, have all singular association on measuring mortality.

Based on the estimated numerical desertification coefficients, we calculated that impact of a ten (10) percentage points increases in desertification on the mortality probabilities, which we translated into death rates per 1000 births (1% change in probability = 10 deaths per 1000).

The results are presented in Table 3 and illustrated in Fig. 1.

That is, for example, an increase in the level of desertification from 10 to 20% will reduce postneonatal mortality by 1.54 per 1000 and total infant mortality by 2.88. As can be seen, the impact of desertification is nonlinear. Initially, it reduces mortality, and eventually, it increases off.

As hypothesized, the percentage of area affected by desertification has an association with infant mortality by the logit estimates. Interestingly, the results suggest that relatively low percentages of desertification have a negative effect on infant mortality; in contrast, if the percentage is greater than 55%, the effect becomes positive, and its magnitude increases as the area affected by desertification raises. In postneonatal mortality, the percentage is greater than 47%; the effect becomes positive. Nominally speaking, living in a municipality affected by desertification would increase IMR by $(-\text{b4}*1000 + \text{b5}*1000(X))$ deaths per 1000 live births, where X stands for the percentage of area affected by desertification (Fig. 1).

As hypothesized, we find a direct and significant partial correlation between the different types of extraction materials and the condition of desertification in the municipalities of Colombia (Table 4). The effect of extraction of hydrocarbons is 12.45, metals 5.73 and others 4.91 times higher in the municipalities with more 50% of

Table 1 Infant mortality rate and postneonatal mortality rate by socioeconomic conditions and desertification level, Colombia 2008–2010

Type of mortality rate	Socioeconomic variables	Type of desertification				Deserts
		High	Very high	Others	No desert	Biodesert
Infant mortality rate (per 1000 live births)	Rural	14.88	14.41	14.34	17.15	23.02
	Non-rural	12.61	13.08	11.78	12.59	15.01
	Low education	11.76	10.92	11.22	12.32	14.62
	High education	7.73	7.56	7.74	8.11	8.55
	Subsidized	14.89	14.94	14.33	15.92	20.39
	Contributive	9.84	10.03	9.55	9.59	9.56
Postneonatal mortality rate (per 1000 live births)	Rural	6.26	6.09	6.13	7.90	10.90
	Non-rural	4.75	4.97	4.05	4.56	4.79
	Low education	4.79	4.61	4.50	5.25	5.46
	High education	2.33	2.44	2.35	2.34	2.17
	Subsidized	6.07	6.06	5.56	6.63	7.77
	Contributive	3.07	3.26	2.94	2.94	2.61

Table 2 Infant mortality rate by deserts of la Guajira municipalities of Uribia, Maicao and Manaure, Colombia, 2008–2010

Socioeconomic variables	Type of mortality rate		
	Postneonatal mortality rate	Infant mortality rate	Child mortality rate
Rural	11.67	22.77	9.41
Non-rural	5.93	15.40	4.17
Low education	6.47	14.39	SD
High education	0.61	3.96	SD
Subsidized	8.83	18.52	5.86
Contributive	3.55	8.12	3.55

Table 3 Logit regression coefficients; infant and postneonatal mortality as dependent variable, Colombia, 2008–2010

	Variable	Coef.	[95% CI]	SE
Infant mortality (n = 1,969,125)	Rural	0.07453***	(0.03915 to 0.10992)	0.01805
Depend variable = infant deaths				
	High education	− 0.33300***	(− 0.36539 to − 0.30061)	0.01653
	Subsidized regime	0.13564***	(0.10218 to 0.16911)	0.01708
	Percentage of desertification	− 0.00451***	(− 0.00613 to − 0.00290)	0.00082
	Percentage of desertification[2]	0.00004***	(0.00002 to 0.00006)	< 0.00001
Postneonatal mortality (n = 1,957,106)	Rural	0.17706***	(0.12195 to 0.23218)	0.02812
Depend variable = postneonatal deaths				
	High education	− 0.56047***	(− 0.61613 to − 0.50482)	0.02840
	Subsidized regime	0.31828***	(0.26062 to 0.37594)	0.02942
	Percentage of desertification	− 0.00267**	(− 0.00530 to − 0.00005)	0.00134
	Percentage of desertification[2]	0.00003**	(< 0.00001 to 0.00006)	0.00001

[2] denotes squared

*Statistically significant p value < 0.05; **statistically significant p value < 0.01; ***statistically significant p value < 0.001

the desertification territory. The result corresponds to the scenario of desertification and exploitation of hydrocarbons in the department of La Guajira where the highest mortality and desertification rates in the country are concentrated. The construction materials did not show effect.

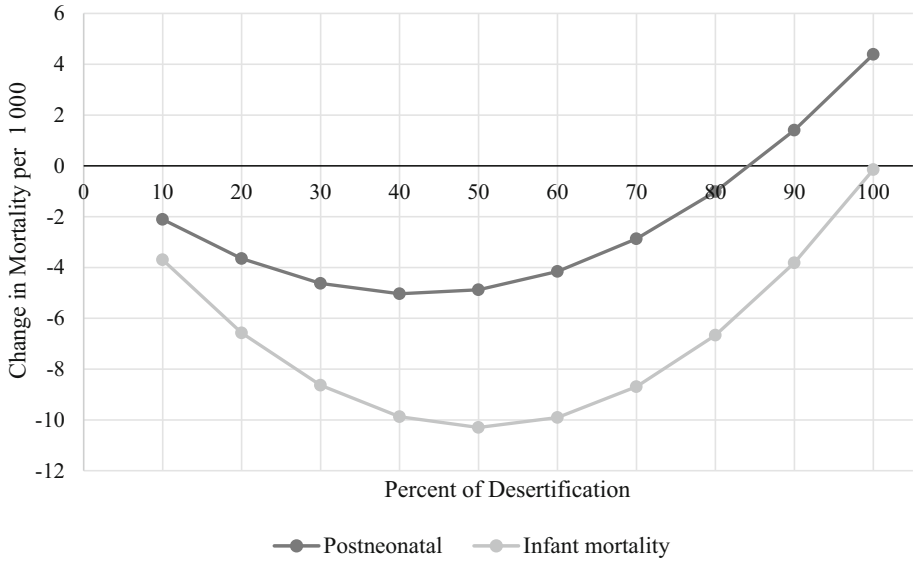

Fig. 1 Total effect of desertification on mortality, Colombia, 2008–2010

Table 4 Odds ratio; high desertification as dependent variable, Colombia 2008–2010

High desertification[a]	Odds ratio	(95% CI)	SE
Hydrocarbons	12.45***	(11.48–13.50)	0.5158
Construction materials	1.04	(0.96–1.13)	0.0451
Metals	5.73***	(5.27–6.235)	0.2446
Other mines	4.91***	(4.30–5.60)	0.3306

*Statistically significant p value < 0.05; **statistically significant p value < 0.01; ***statistically significant p value < 0.001

[a]Level of desertification high and very high up to 50% of the area certificated

Food insecurity and desertification

Given that the mining activities monopolize the scarce water available in the municipalities with high desertification and a desert, a great threat to food security is generated in these municipalities. The impact has multiple pathways: an increase in shortages safe drinking water and a reduction of land productivity in growing produce and rising cattle. All are detrimental to maternal nutrition and breastfeeding, as well as child food security and quality of available foods.

When the risk (odds ratio) of malnutrition mortality was calculated in the population $1 \geq$ year < 5 years of age in the rural areas with "very high" level of desertification, and with a proportion of the area $> 50\%$ of desertification was found twice the risk of mortality due to malnutrition (OR: 2.25, $p < 0.001$).

This same analysis was carried out for the municipalities of the department of La Guajira, where 81 child deaths were recorded due to malnutrition in the 2008–2010 period, with a higher risk of CMR and PMR in the municipalities with high levels of desertification, compared with the rest of the municipalities of the department. The results are the same lent with somewhat lower statistical significance (Table 5).

Discussion

The nonlinear impact of desertification may follow the nature of the causal process. It is plausible that as polluting industry moves in, the population benefits from employment, rising benefits from employment, rising incomes and better access to medical care. However, in the longer term, the ecological effects of high levels of desertification become dominant, reversing the short-term gains of rising incomes and access to care.

The impact of desertification is pronounced in rural disadvantaged communities. The drylands are populated mostly by peasant and indigenous, who depend on subsistence agriculture based on water. Worrisome fact is that based on the future scenarios of climatic change in Colombia, areas with desertification are part of regions where a reduction of precipitation is expected, besides the rise of temperature up to four Celsius degrees (Instituto de Hidrología, Meteorología y Estudios Ambientales—IDEAM—2010).

The finding supports the "Current State and Trends" MA Ecosystem report by which the land degradation of the drylands reduces the natural rate of the ecosystem service provision, for instance, water and biological productivity, that have a direct effect over drylands' habitants (Hassan et al. 2005). We do not have other evidence of the specific effects on mortality. A Brazilian study shows that infant

Table 5 Death due to risk of malnutrition in rural areas of high desertification and the Guajira Desert, Colombia, 2008–2010

	> 28 days to < 5 years		1 year to < 5 years	
	Odds ratio	(95% CI)	Odds ratio	(95% CI)
High desert[a] (rural)	1.67***	(1.16–2.37)	2.25***	(1.28–3.84)
Deserts (Guajira)	1.59**	(1.03–2.47)	2.06**	(1.07–4.01)

*Statistically significant p value < 0.05; **statistically significant p value < 0.01; ***statistically significant p value < 0.001

[a]Level of desertification high and very high up to 50% of the area desertificated

mortality is higher in dry areas than in other areas (Sena et al. 2014).

Desertification regarding the social well-being of drylands habitants, the Millennium Ecosystem Assessment board says: "At the broadest level of generalization, it's clear that infant mortality rates are higher within drylands and that most of the world's population and GDP is located within cultivated system." It is also important to say that it is clarified that generalization does not imply causality. In other words, the fact that there is a high IMR in a particular ecosystem does not mean that the ecosystem itself is the explanation of the rate. Nonetheless, it can be said that based on the results discussed drylands are populated by communities with low levels of well-being, then they are potentially vulnerable to ecosystem services loses (Hassan et al. 2005), and this vulnerability exacerbates elements such as a high IMR.

It should be highlighted that social and economic consequences of desertification have been recognized for several years. For example, in 2005 the Minister of Environment stated that cattle breeding, being one of the major economic activities of drylands, had been weakened by the crescent ecological deterioration (Ministerio de Ambiente, Vivienda y Desarrollo Territorial 2005). Now, in the past few months the effect of desertification processes has become even more visible: economic loses, food insecurity, water scarcity and others, like in other development countries (Delbiso et al. 2017).

Among the municipalities with a percentage higher than 51% of desertification, the effect of mining extraction on the different levels of desertification seems to be influencing the mortality rate in the population under 5 years of age, linked to both as socioeconomic, but mainly in food insecurity. The specific case of food insecurity in La Guajira is associated with desertification, water shortages in the desert territory and the high level of multidimensional poverty in territories with high mining extraction. The greater risk of mortality due to malnutrition in children between one (1) year and children under five (5) years old (CMR) accounts for the relationship between food insecurity and desertification in these territories. In this age group the vulnerability is greater when not having the exclusive breastfeeding of the mother that the infant had during the first year of its life. However, a set of risk factors interact in this association, which require a specific analysis to separate the effects of each phenomenon. On the one hand, the high level of multidimensional poverty that combines social determinants directly affects the health of these populations. On the other hand, it is necessary to highlight that for this period 2008–2010, 98% of mining is mainly illegal, which means higher environmental impacts on the scarce water sources, and the productive capacity of the soil is reduced and therefore the basis of food production.

Finally, it must be recognized that the challenges of drylands increase with mining and agricultural activities that demand more water (Sternberg and Edwards 2017). Given the increase in mining exploitation in these areas, there is a lack of stimulation for the cultivation of the land and its protection, and the social capital of the communities is reduced given the increase in the population that migrates to participate in this economy, which reduces the mechanisms protection and care of vulnerable groups as a child population.

This study presents the association between mining exploitation in areas of high desertification and higher risk of postneonatal mortality. In this regard, it is necessary to study the impact of the transfer of both public and private subsidies associated with mining royalties.

Therefore, it is essential to develop policies that not only observe the impact of climatic change, but also the one it has on the productivity and habitability of the drylands.

In conclusion, in the short term, when mines move in with little effect on desertification, living conditions may improve and reduce child mortality. In the long term, however, as desertification intensifies affect the ecosystem, child mortality increases. More research is needed, and policy formulated accordingly.

Compliance with ethical standards

Conflict of interest The authors declare that they do not have conflict of interest.

Ethical statement The data used in this paper were not collected from human subjects, so it did not require ethical approval. The availability of data was based on an agreement between Departamento Administrativo Nacional de Estadística (DANE) and Universidad Icesi, and it did not include any identification of people; thus, it remains anonymous.

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