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The joint distribution of wasting, stunting and underweight among children in Somalia

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Abstract

Objective: Wasting, stunting and underweight are different indicators of childhood nutritional status. Empirical evidence suggests that they co-occur at the individual child level; however their ecological association is uncertain. Understanding shared and non-shared determinants may inform interventions. We aimed to assess the correlation between wasting, stunting and underweight, and investigate their shared determinants among children under the age of five years in Somalia.

Setting: Cross-sectional nutritional assessments surveys using structured interviews were conducted among communities in Somalia each year from 2007 to 2010. A two-stage cluster sampling methodology was used to select children aged 6-59 months from households across three livelihood zones (pastoral, agro-pastoral, and riverine).

Participants: A total of 73,778 children between the age of 6-59 months from 1,066 clusters in Somalia.

Results: Raw pairwise child level correlations of nutrition status were 0.32, 0.71 and 0.66 between wasting and stunting; stunting and underweight; and wasting and underweight respectively. Access to protein and vegetation cover, a proxy of rainfall or drought, were strong predictors of wasting and stunting. Age, gender, illness, access to carbohydrates and temperature were predictors of all three indicators. Posterior spatial effects were highest for underweight, followed by stunting, and lowest for wasting. Spatially, the posterior correlations in prevalence ranged from 0.36 to 0.64, 0.12 to 0.92 and 0.22 to 0.74 for stunting and wasting; stunting and underweight; wasting and underweight respectively.

Conclusion: The determinants of wasting and stunting are largely shared. Although nutrition response in Somalia has traditionally focused on the wasting, integrated programming and interventions can be directed at the common risk factors.

Strength and Limitation: The consistency and timeliness of FSNAU survey data provides an opportunity to analyze the trends of malnutrition in Somalia. The use of individual level data has improved the estimates in our analysis as it accounted for the variability between children ensuing more accurate estimates than using of aggregated data. However the effect of conflict on malnutrition was not controlled in this study because the information was not captured during the FSNAU surveys. Further research should include conflict, and longitudinal studies should be undertaken to provide a better understanding of the relationship between wasting and stunting.

Introduction

Malnutrition is one of the major causes of childhood deaths in developing countries[1]. Globally, in 2011, one in four children (26%, 165 million) were stunted, one in six (16%, 101 million) were underweight, and one in twelve (8%, 52 million) were wasted. More than 90% undernourished people live in developing countries[2]. In Somalia, 35% (2.85 million) of the population were estimated to be affected by food security crisis in 2011. In central-south zone, the prevalence of acute malnutrition was estimated to be at least 30%[3].

There are a number of measurements of nutritional status including biomarkers, body composition analysis, and simply anthropometry[4 5]. Wasting (low weight-for-length/height) and stunting (low height-for-age) and are the most commonly used indicators for individual assessment, designing programs and assessing impact[6-8]. Wasting and stunting are normally presented as distinct nutritional problems, contributing separately to mortality and disease[9]. Studies emphasize the evaluation of long-term consequences of stunting for adult health and human capital while wasting has been interpreted as a predictor of short-term mortality[10]. Strategies are usually targeted at a single indicator[11].

Studies in the developed countries have shown that wasting and stunting may be independent of each other when compared to a standard population[12]. This is because growth potential of healthy young children is largely similar across ethnic groups and within regions in developing countries[8]. If linear growth falters due to infection or poor diet, catch-up growth might be attained once the infection is eliminated or the diet improves. However in resource-poor settings, where dietary intake may be consistently inadequate and there exists high rates of infectious diseases, the process of catch-up growth may never be possible and this result to high level of stunting[12 13]. In this context, wasting might precede linear growth retardation and therefore it is possible that wasting may influence linear growth[14] however, currently this is uncertain.

A third indicator of malnutrition, underweight defined as low weight for age combines information on linear growth and bulk[11]. The use of underweight has been criticized because it is influenced by both the height and weight making it difficult to interpret in current conceptual frameworks that focus on wasting and stunting[15]. In general terms, the worldwide variation of low weight-for-age and its age distribution are similar to those of low height-for-age[15]. This means that over the long term, the prevalence of underweight largely describes linear growth faltering in young children[16].

Due to prolonged drought and famine and conflict in Somalia, the rates of malnutrition persistently remain at “critical” levels and have been cited as the highest in the world[17 18]. The distribution of malnutrition varies across regions mainly influenced by climatic conditions[19]. In addition, malnutrition rates in a region are influenced by the nutrition status of the neighboring regions. In Somalia, for example, conflict and drought lead to frequent displacement of vulnerable people into safer regions[17]. Thus, stunting and underweight may be affected by the cumulative effect of intermittent rates of wasting. The UNICEF conceptual framework has been used to define the causal factors of indicators of malnutrition[20]. However, the framework is not translated to integrated policy and programming for common intervention[6 9]. Understanding the common drivers and extent of coexistence of the indicators in space would help formulate common and effective programs for intervention.

In this study, we mapped the co-distribution between the rates of stunting, wasting and underweight among children under the age of five years in Somalia from 2007 to 2010 using Bayesian Geo-statistical modelling approach[21]. We used a shared-component model to fit common unobserved and unmeasured spatial risks to determine the areas that the indicators are strongly correlated and identify common risk factors.

Methods

Survey Data

The data used for this study were obtained from Food Security and Nutrition Unit (FSNAU). Our study focuses on survey data ranging from the year 2007 to 2010 [FSNAU 2007-2010]. Within this period, FSNAU in partnership with UNICEF conducted a bi-annual seasonal nutrition assessment surveys where they used standard methods, indicators and tools for data collection[22 23]. Detailed descriptions of the survey methods and data collection are described elsewhere[23]. We considered three outcome measurements describing the anthropometric indicators of malnutrition: low weight-for-height (wasting), low height-for-age (stunting), and low weight-for-age (underweight). These anthropometric measures were used to compute wasting, stunting and underweight among children under the age of five using WHO 2006 references[24]. A child was defined as wasted or stunted or underweight when he/she was below -2 Z scores[25].

Ethical approval

Ethical approval was provided through permission by the Ministry of Health Somalia, Transitional Federal Government of Somalia Republic, Ref: MOH/WC/XA/146./07, dated 02/02/07. Due to the extremely high illiteracy rate of the population, informed verbal consent was sought from all participating households and individuals. An additional 10% was added to the sample size to allow for drop out or refusal to participate.

Statistical methods

Our analysis used joint modelling for multiple conditions approach[26-28] to investigate the co-distribution of the three malnutrition indicators using the Integrated Nested Laplace Approximation (INLA) as implemented in R-INLA library to produce risk maps at 1 x 1 km spatial resolution[26 29]. This was done controlling for the main putative predictors of malnutrition. In this approach the relative risk of each condition is assumed to depend on a latent spatial component shared by three conditions in addition to a condition-specific component[26]. The shared component is considered to contribute to the overall risk scaled by additional unknown weights where a risk gradient is associated with the common field. We modeled three latent spatial components common to the three pairs of the conditions (wasting and stunting; stunting and underweight; wasting and underweight). These underlying interactions between the three indicators of malnutrition contribute to the levels, trends and patterns of malnutrition in children. Further, the marginal excursion probabilities based on the estimated posterior distribution of the shared component were simultaneously calculated using quintile correction (QC) method as implemented by Bolin and Lindgren 2012[30]. Areas where the shared component was above 0.5 and below 0.2 were determined using the excursion function in QC method and the parametric family of excursion sets[30]. Detailed description of the methods and output from the shared component model can be found in the supplementary information for this paper.

Results

A total of 73,778 children under the age of five years were examined from 1066 clusters and of which 15,735 (21%), 22,739 (31%) and 18,982 (26%) were wasted, stunted and underweight respectively. Fifty two percent of children were boys and the mean age of the children was 33 months. Other characteristics of the children measured during the surveys are shown in Table I. By livelihood zones, 42%, 27% and 16% of children were from areas of agro-pastoral, pastoral and riverine livelihoods respectively while 11% lived in internally displaced people (IDP) camps and 4% lived in urban areas.

Table I: Baseline characteristics of the study population (FSNAU 2007-2010)

Characteristic		Number					
Total number of children examined		73778					
Total number of clusters examined		1066					
Summary by livelihood		**Wasting; n=12802, (%)**		**Stunting; n=22063 (%)**		**Underweight; n=60333 (%)**	
Livelihood	Agro-pastoral	3580 (28)		7074 (32)		17546 (29)	
	Pastoral	4032 (31)		5043 (23)		17271 (29)	
	Riverine	2473 (19)		5547 (25)		12772 (21)	
	Urban areas	679 (5)		926 (4)		3270 (5)	
	Internally Displaced Persons	2038 (16)		3473 (16)		9473 (16)	
Child data		**Wasted; n = 12802 (17%)**	**Not wasted; n=60976 (83%)**	**Stunted; n =22063 (30%)**	**Not stunted ; n =51715 (70%)**	**Underweight; n = 60333 (82%)**	**Not underweight n=13445 (18)**
Vitamin A supplementation		7318 (57)	35042 (57)	12471 (57)	29889 (58)	34610 (57)	7750 (58)
Measles vaccination		6807 (53)	32436 (53)	11564 (52)	27679 (54)	32008 (53)	7234 (54)
Polio vaccination		10044 (78)	48869 (80)	17728 (80)	41185 (80)	48400 (80)	10514 (78)
Diarrhoea in the last 2 weeks		3050 (24)	11214 (18)	4983 (23)	9280 (18)	12192 (20)	2071 (15)
Acute Respiratory Infection		3089 (24)	12637 (21)	4938 (22)	10788 (21)	13213 (22)	2513 (19)
Febrile Illness in the last 2 weeks		3086 (24)	12514 (21)	4705 (21)	10896 (21)	12771 (21)	2830 (21)
Suspected measles in last 1 month		641 (5),	2612 (4)	995 (5)	2259 (4)	2692 (4)	562 (4)
Sex of the child		Male=7354 (57) Female= 5448 (43)	Male= 30214 (50) Female= 30761 (50)	Male=12396(56) Female= 9667 (44)	Male= 25173 (49) Female= 26543 (51)	Male=31565 (52) Female= 28768 (48)	Male= 6004 (45) Female= 7441 (55)
Age of the child (in months)		Mean=33, Range=(6,59)	Mean = 33, Range=(6,59)	Mean =31, Range=(6,59)	Mean= 32, Range=(6,59)	Mea=33, Range=(6,59)	Mean = 27, Range=(6,59)
Age of the mother (in years)		Mean=30, Range = (15,60)	Mean = 30, Range = (15,60)	Mean=30, Range = (15,60)	Mean = 30, Range = (15,60)	Mean =30, Range = (15,60)	Mean = 30, Range = (15,60)
MUAC of mother in cm		Mean =21, Range(18,38)	Mean = 22, Range(18,38)	Mean=22, Range(18,38)	Mean= 22, Range(18,38)	Mean=22, Range(18,38)	Mean = 23, Range(18,38)
Household data		**Mean (Range)**		**Mean (Range)**		**Mean (Range)**	
Household size		6 (2, 50)		6 (2, 50)		6 (2, 50)	
Number of under5		2 (1, 5)		2 (1, 5)		2 (1, 5)	

Household head gender	Male=60128 (81%)		Male=60128 (81%)		Male=60128 (81%)	
Food access data	**Number (%)**		**Number (%)**		**Number (%)**	
Carbohydrate in the last 24 hours	12389 (97)	58891 (97)	21622(98)	49657 (96)	58633(97)	12646(94)
Protein in the last 24 hours	10918 (85)	53097 (87)	19106 (87),	44909 (87)	52444 (87),	11572(86)
Fats in the last 24 hours	10030 (78)	48616 (80)	17223 (78),	41422 (80)	47848 (79),	10797 (80)
Fruits and vegetables in the last 24 hours	5226 (41)	26090 (43)	10377 (47)	20939 (40)	26400 (44)	4916 (37)
Cluster data	**Mean (Range)**		**Mean (Range)**		**Mean (Range)**	
Distance to water to major water bodies (km)	97 (0,508)		97 (0,508)		97 (0,508)	
Enhanced Vegetation Index (EVI)	0.18 (0,0.45)		0.18 (0,0.45)		0.18 (0,0.45)	
Precipitation (mm/year)	138 (0,350)		138 (0,350)		138 (0,350)	
Mean Temperature (˚c)	28 (21,31)		28 (21,31)		28 (21,31)	
Urbanization	Urban = 3318 (5%), Rural = 70460		Urban = 3318 (5%), Rural = 70460		Urban = 3318 (5%), Rural = 70460	
Season	April to June (Gu) = 47327(64%), October to November (Deyr) = 26451 (36%)		April to June (Gu) = 47327(64%), October to November (Deyr) = 26451 (36%)		April to June (Gu) = 47327(64%), October to November (Deyr) = 26451 (36%)	

The effects of predictors from the shared component model, shown in Table II, being male was associated with decreased risk of all the three indicators of malnutrition (odds ratio (OR)=0.75, 95% credible interval (CrI): 0.72 - 0.79; OR=0.75, 95% CrI: 0.72 - 0.79; OR=0.83, 95% CrI: 0.79 - 0.87 for wasting, stunting and underweight respectively). Age 24 months or more was associated with decreased risk of wasting (OR=0.80, 95% CrI: 0.73 - 0.87) and increased risk of stunting (OR=1.76, 95% CrI: 1.61 – 1.91) and underweight (OR=1.99, 95% CrI: 1.84 -2.16). The risk of stunting was higher in children aged 12 – 24 months age group than the 24 – 59 months age group with 6 - 11 months. Children who had diarrhoea, acute respiratory infection and fever in the last two weeks had a higher risk of wasting, stunting and underweight. Increase in age of the mother was associated with decreased rates of wasting, stunting and underweight until at the age of 40 years where further increase in age did not show significant association.

Increase in the household size and number of under-fives in the household were associated with increased risk of wasting and stunting, but not with underweight. Children who had consumed any of the staple sources of carbohydrates or proteins within the 24 hours prior to the survey had a lower risk of all the three indicators of malnutrition. Vitamin A supplementation was associated with low risk of wasting (OR=0.80, 95% CI: 0.75 - 0.85) but was not associated with stunting and underweight. There was a significant association between the vegetation index (OR=0.66, 95% CrI: 0.45 -0.95), (OR=0.59, 95% CrI: 0.42 -0.82), (OR=0.69, 95% CrI: 0.67 – 0.72) and temperature (OR=1.07, 95% CrI: 1.03 – 1.11), (OR=1.05, 95% CrI: 1.01 -1.10), (OR=1.12, 95% CrI: 1.07 – 1.17) with wasting, stunting and underweight respectively. Season was associated with wasting (OR=1.11, 95% CrI: 1.04 – 1.18) and underweight (OR=0.57, 95% CrI: 0.53-0.61), but had no association with stunting. Urbanization was associated with increased risk of stunting (OR=1.29, 95% CrI: 1.07 – 1.56), but decreased risk of underweight (OR=0.64, 95% CrI: 0.52 – 0.79) and no association with wasting.

Table II: Multivariate adjusted posterior odds ratio (POR) and 95% credible interval of wasting, stunting and underweight among children aged 6 – 59 months in Somalia

Predictors		Wasting		Stunting		Underweight	
		Odds ratio	CrI	Odds ratio	CrI	Odds ratio	CrI
Child data							
Vitamin A supplementation		**0.80**	**(0.75,0.85)**	1.00	(0.94,1.05)	1.01	(0.94,1.08)
Measles vaccination		1.04	(0.97,1.11)	0.96	(0.91,1.02)	0.93	(0.87,1.00)
Polio vaccination		**0.88**	**(0.82,0.95)**	**1.07**	**(1.00,1.14)**	**1.09**	**(1.01,1.18)**
Diarrhoea		**1.30**	**(1.22,1.38)**	**1.24**	**(1.18,1.31)**	**1.26**	**(1.17,1.35)**
Acute Respiratory Infection (ARI)		**1.10**	**(1.04,1.17)**	**1.21**	**(1.15,1.27)**	**1.08**	**(1.01,1.15)**
Febrile Illness		**1.15**	**(1.09,1.22)**	**0.98**	**(0.93,1.03)**	**1.02**	**(0.95,1.09)**
Suspected measles		1.05	(0.93,1.18)	0.97	(0.87,1.07)	0.98	(0.86,1.11)
Sex of the child (Male)		**0.75**	**(0.72,0.79)**	**0.75**	**(0.72,0.79)**	**0.83**	**(0.79,0.87)**
Child age (24 -59 months as	< 12 months	**1.14**	**(1.03,1.25)**	**1.34**	**(1.28,1.41)**	**1.26**	**(1.17,1.36)**
reference)	12 - < 24 months	**0.88**	**(0.82,0.94)**	**0.57**	**(0.52,0.62)**	**0.73**	**(0.65,0.81)**
Age of the mother	< 12 years	**1.24**	**(1.09,1.42)**	**1.04**	**(1.02,1.06)**	**1.08**	**(1.01,1.16)**
(20-30 years as reference)	31-40 years	**0.91**	**(0.83,0.99)**	**0.87**	**(0.83,0.91)**	**0.94**	**(0.93,0.95)**
	41-50	**0.88**	**(0.83,0.93)**	**0.91**	**(0.84,0.99)**	1.01	(0.88,1.15)
	> 50 years	0.92	(0.85,1.01)	0.76	(0.49,1.17)	1.01	(0.49,2.08)
MUAC of mother		0.99	(0.99,1.00)	1.00	(1.00,1.00)	**0.99**	**(0.98,0.99)**
Household data							
Household size		**1.14**	**(1.13,1.15)**	**1.27**	**(1.25,1.28)**	1.00	(0.99,1.01)
Number of under5		**1.06**	**(1.03,1.09)**	**1.80**	**(1.76,1.85)**	1.00	(0.97,1.04)
Female household head		0.95	(0.89,1.02)	**0.87**	**(0.82,0.92)**	0.98	(0.92,1.05)
Food access data							
Carbohydrate		**0.83**	**(0.79,0.88)**	**0.82**	**(0.78,0.86)**	**0.92**	**(0.87,0.97)**
Protein		**0.57**	**(0.55,0.59)**	**0.51**	**(0.49,0.52)**	**0.90**	**(0.87,0.93)**
Fats		1.04	(0.98,1.12)	**0.92**	**(0.87,0.98)**	**1.10**	**(1.02,1.18)**
Fruits and vegetables		0.97	(0.93,1.01)	**1.04**	**(1.01,1.08)**	**1.07**	**(1.03,1.12)**
Cluster data							
Season (October to November as reference)		**1.11**	**(1.04,1.18)**	1.04	(0.98,1.10)	**0.57**	**(0.53,0.61)**
Distance to water		1.00	(1.00,1.00)	1.00	(1.00,1.00)	1.00	(1.00,1.00)
Enhanced Vegetation Index (EVI)		**0.66**	**(0.45,0.95)**	**0.59**	**(0.42,0.82)**	**0.69**	**(0.67,0.72)**
Rainfall		1.00	(1.00,1.00)	1.01	(1.00,1.01)	1.00	(1.00,1.00)
Temperature		**1.07**	**(1.03,1.11)**	**1.05**	**(1.01,1.10)**	**1.12**	**(1.07,1.17)**
Urbanization		1.05	(0.87,1.27)	**1.29**	**(1.07,1.56)**	**0.64**	**(0.52,0.79)**

As shown in Figure 2, all the indicators showed a positive correlation. Stunting and underweight had the strong correlations at 71% followed by wasting and underweight at 66%. However, correlation between wasting and stunting was low at 32%.

Estimated common spatial patterns are shown in Figure 3. The maps reveal geographical variation of the common latent field of the three indicators. The shared component displayed a strong spatial gradient in the South-North direction in all the shared components examined in this study. This confirms a high risk of all forms of malnutrition in the south region especially along the two main rivers in Somalia: Juba and Shabelle as compared to northern region of Somalia. The posterior means correlation in space from the joint model ranged from 36% to 64%, 12% to 92% and 22% to 74% for shared component between stunting and wasting; stunting and underweight; wasting and underweight respectively. The distribution of shared component has a larger effect on stunting and underweight prevalence in the south region in Somalia. Maps of marginal excursion probabilities based on the estimated posterior distribution for areas with shared component above 50% and below 20% are shown in Figure 4. The standard deviations ranged from 0.04 to 0.42 in Somalia (Figure SI. 1).

Discussion

We applied a joint spatial analysis of malnutrition among children under the age of five years in Somalia to identify specific and shared components of wasting, stunting and underweight. The result obtained from the joint modelling indicates that there are common latent components for the three measures which cause the distribution patterns to be similar in most regions. The highest correlation was observed between stunting and underweight followed by wasting and underweight while the correlation between wasting and stunting was low. Access to protein and vegetation cover, a proxy of rainfall or drought, were strong predictors of wasting and stunting. Age, gender, illness, access to carbohydrates and temperature were also common predictors of all three indicators.

Stunting decreases throughout the first 2-3 years of life in many developing countries, whereas wasting occurs during the first year of life after which it stabilizes[31]. Wasting is also noted to have a relatively shorter duration and greater seasonal variability when compared with stunting[31]. This may explain the observed low association between wasting and stunting. Thus, the use of cross sectional studies data in describing wasting trends may have some limitations. This is because the prevalence of wasting varies within a short duration and therefore the prevalence captured in these type of studies depends on time

of survey. As a result, a large incidence of wasting of short duration might be missed, misrepresenting the relationship of wasting with the other indicators[31]. Longitudinal data which follow children's growth from birth looking at the wasting, stunting and the combination of the two can provide better understanding of the relationships[12 31].

Food insecurity and infectious disease differ between region and livelihoods system resulting from a combination of harsh environmental conditions and prolonged conflict and civil insecurity. In this study, access to food and infections were major factors associated across the three indicators of malnutrition and this reaffirms the strong shared component of wasting, stunting and underweight in the south as compared to the north in Somalia[23]. For example, there are currently about 400,000 internally displaced people (IDPs) in Somalia, mostly from the southern minority groups. Half of this population lives in Mogadishu almost completely out of reach of any concrete internal assistance[23]. This is one area that has been seen to consistently have strong shared component of the malnutrition indicators in this study. Kismaayo, also another consistent hotspot has been host to numerous internally displaced persons (IDPs) fleeing the harsh effects of drought and conflict in the Juba and other neighboring regions[32]. IDPs are considered to be among the poorest population groups in the country with high levels of food insecurity with poor living conditions which predisposes them to various infectious diseases[32].

Enhanced vegetation index (EVI) is a satellite imagery derived variable and effectively characterizes the global range of vegetation state. High EVI values indicates vegetated areas that reflect forested areas, riverine vegetation and more importantly local agriculture which has a direct relationship with the local food security. Highly vegetated areas (as demarcated by high EVI values) are a product of a combination of several variables including rainfall, seasonal and permanent water sources and to some extent underground water. In arid and semi-arid areas, agricultural activities are limited to areas with reliable water supply. According to 2010 estimates, agriculture accounts for 65% of the gross domestic product (GDP), with livestock representing 40% of the GDP and 65% of the export earnings in Somalia. Due to long standing civil war and droughts which led to human displacements, and inadequate agricultural inputs has mostly affected farmers of the riverine and agro-pastoral livelihood zones and as well as the cattle-rearing pastoralists who have experienced significant livestock losses due to lack of pasture and water. Agricultural recovery is also hindered by the presence of large numbers of IDPs[32]. Temperature was also found to be an important predictor of malnutrition. Temperature is directly linked to aridity [33] which in turn has an impact on malnutrition[34]. High temperature values are reported in Somalia rising

upto 40°c in the Hagaa dry season[35] between the months of July and September. In this study, high temperature values were observed in surveys conducted during the same period.

Seasonal variation was also seen to significantly affect levels wasting and not stunting in Somalia. This is echoed in other studies that have shown that incident and prevalence of wasting are more sensitive to seasonal variation than those of stunting and vary with seasonal variation of diseases, activity levels, food availability and time of care. At population level, children grow in height only when their weight-for-height improves at the end of the hunger season[31]. The pastoralist communities in Somalia predominantly live in the Northern region. Following prolong drought and famine in the region which has led to massive livestock losses, the pastoralists have been seen seasonally to migrate with their livestock to other regions with water and pasture. The seasonal migration is reflected in the shifting of the hotspots from one region to another[32].

Conclusion

This study has demonstrated that the three indicators largely share common risk factors and that there is evidence of correlation in space[31 36]. The emergency response funding is by nature short term but there is compelling evidence to implement timely intervention of spatial patterns and trends of wasting and stunting depending on seasonal variation, the age and gender of the child. Our evidence supports integrated programming and interventions. Although emergency nutrition response in Somalia focus on wasting, it is important to implement more joined-up program of the indicators. This will require political will, appropriate financing, policies and programmatic links between the indicators.

Contributors: DKK, N-BK, SOM, AMN and JAB were responsible for the concept and design of the study. DKK, ETK and GAF were responsible for the development of the model. DKK led the data assembly process, data analysis and interpretation of results. GMM was responsible for conducting the surveys, cleaning and archiving the data. AMN N-BK, SOM and JAB were responsible for overall scientific oversight. All authors reviewed the manuscripts and contributed to the final submission.

Competing Interests: None declared

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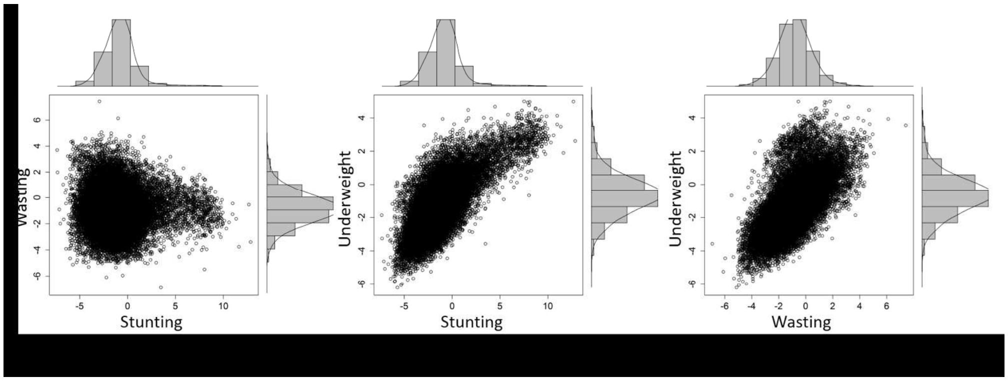
Figure legends

Figure 1: Correlation plots of wasting, stunting and underweight Z-scores among children under the age of five years in Somalia.

Figure 2: Maps showing the crude prevalence of wasting, stunting and underweight by clusters for FSNAU nutrition surveys conducted between 2007 and 2010 in Somalia. The country is divided into three main zones: Northwest, Northeast and South-central. 78 clusters were sampled in Northwest zone, 85 clusters in the Northeast zone and 903 clusters in the South-central. The country's two main rivers, Juba and Shabelle are located in the South-central zone. Map 1= Wasting, 2 = Stunting and 3 = Underweight.

Figure 3: There are three maps here: i) Posterior residual shared spatial prevalence common to wasting and stunting; ii) Posterior residual shared spatial prevalence common to stunting and underweight; iii) Posterior residual shared spatial prevalence common to wasting and underweight. The estimates are in percentage. Each map is plotted at 1 x 1 km spatial resolution among children aged 6 - 59 months in Somalia. A=South-central zone, B=Northeast (Puntland) zone, C=Northwest (Somaliland) zone. 1=Wasting and Stunting, 2=Stunting and Underweight, 3=Wasting and Underweight.

Fig. 4: Estimated areas with shared component above 50% and below 20% at 95% confidence level for children aged 6 - 59 months using the excursion contour functions [30]**.** The maps were developed from extracting the >=50% produced from the maps of simultaneous marginal excursion probabilities. A=South-central zone, B=Northeast (Puntland) zone, C=Northwest (Somaliland) zone.



Correlation plots of wasting, stunting and underweight Z-scores among children under the age of five years in Somalia.
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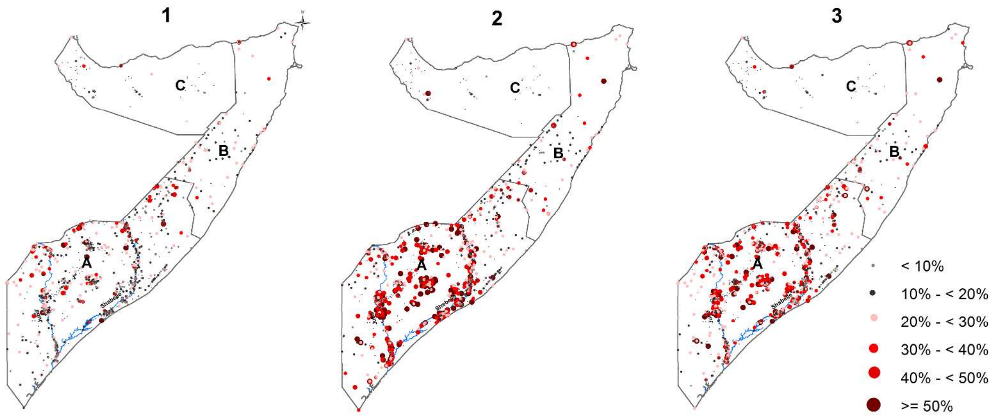
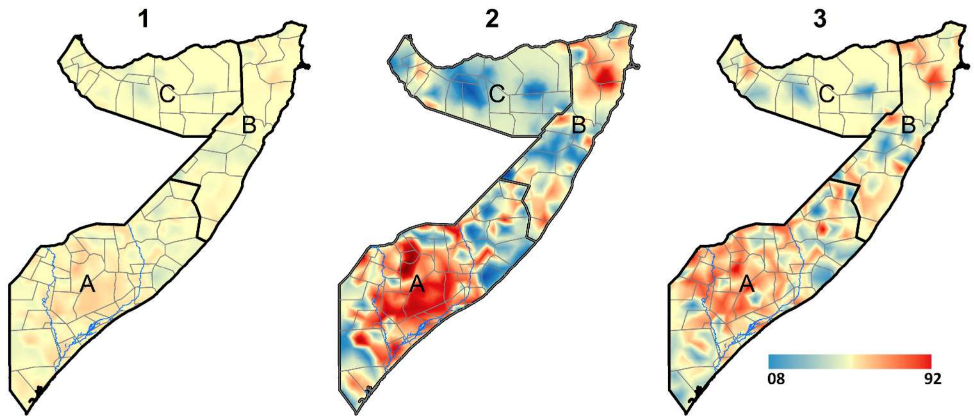
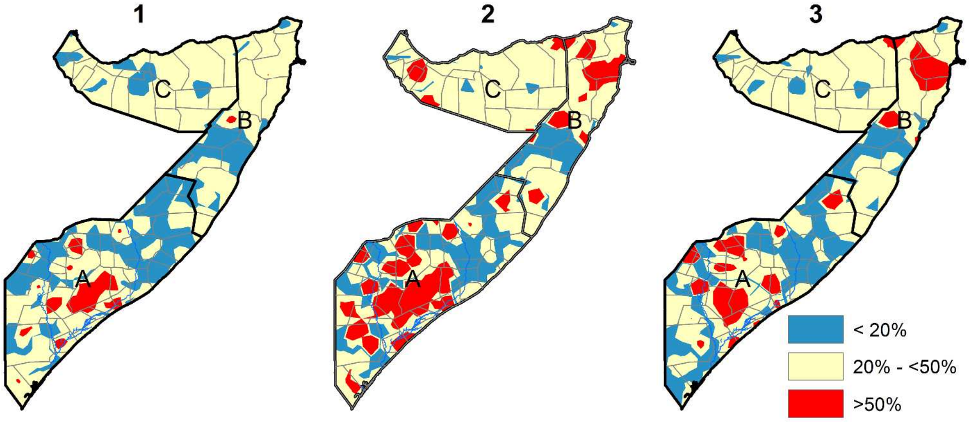


Maps showing the crude prevalence of wasting, stunting and underweight by clusters for FSNAU nutrition surveys conducted between 2007 and 2010 in Somalia. The country is divided into three main zones: Northwest, Northeast and South-central. 78 clusters were sampled in Northwest zone, 85 clusters in the Northeast zone and 903 clusters in the South-central. The country's two main rivers, Juba and Shabelle are located in the South-central zone. Map 1= Wasting, 2 = Stunting and 3 = Underweight.
657x279mm (300 x 300 DPI)



There are three maps here: i) Posterior residual shared spatial prevalence common to wasting and stunting; ii) Posterior residual shared spatial prevalence common to stunting and underweight; iii) Posterior residual shared spatial prevalence common to wasting and underweight. The estimates are in percentage. Each map is plotted at 1 x 1 km spatial resolution among children aged 6 - 59 months in Somalia. A=South-central zone, B=Northeast (Puntland) zone, C=Northwest (Somaliland) zone. 1=Wasting and Stunting, 2=Stunting and Underweight, 3=Wasting and Underweight.
523x241mm (300 x 300 DPI)



Estimated areas with shared component above 50% and below 20% at 95% confidence level for children aged 6 - 59 months using the excursion contour functions 30. The maps were developed from extracting the >=50% produced from the maps of simultaneous marginal excursion probabilities. A=South-central zone, B=Northeast (Puntland) zone, C=Northwest (Somaliland) zone.
523x241mm (300 x 300 DPI)

Supplementary Information: Model procedures and model output

SI.1 Space-time Bayesian Geo-statistical shared component model

Disease mapping mainly focuses on modelling single disease yet many disease share common risk factors[1]. This underscores the importance of joint analysis of health conditions to identify similar patterns in geographical variation and provide more substantial evidence on clustering of the underlying risk surface for integrated interventions[2]. Non-Bayesian multilevel models have been used to present joint spatial analyses of diseases[3]. Knor-Held suggested joint modelling approaches in Bayesian perspective as an improvement of Besag *et al* formulations[4]. Shared spatial component methods have been used extensively to jointly model risk of more than disease outcome[2 5 6]. Lindgren et al 2013 suggested that one can express a large class of random field models as a solution to continuous domain stochastic partial differential equations (SPDEs), and develop explicit links between the parameters of each SPDE and the elements of precision matrices for the weights in a discrete basis function representation[7]. This SPDE is formulated as a link between Gaussian random fields (GRFs) and the Gaussian Markov Random Fields (GMRFs)[7].

In this study, we implemented the Bayesian geo-statistical shared component model of three nutritional indicators through SPDE approach using R-INLA library[7]. Suppose using logit model for wasting, stunting and underweight, effect of covariates and latent spatial effect,

$$\log it(p_{i1}) = \alpha_1 + \beta_1^T x_i + S_{i1} \quad (1)$$

$$\log it(p_{i2}) = \alpha_2 + \beta_2^T x_i + S_{i2} \quad (2)$$

$$\log it(p_{i3}) = \alpha_3 + \beta_3^T x_i + S_{i3} \quad (3)$$

This is where p_{i1}, p_{i2}, p_{i3} were the relative risks for wasting, stunting and underweight in cluster i respectively. The parameter α_j is the disease-specific intercept, β_j s are the indicator specific risk coefficients associated with the risk vector x; and S is the latent spatial effect. The spatial effects in this model can be expressed as:

$$S_{i1} = \delta_{1i}u_{1,1} + \delta_{2i}u_{2,1} \quad (4)$$

$$S_{i2} = \delta_{1i}u_{1,2} + \delta_{3i}u_{3,1} \quad (5)$$

$$S_{i3} = \delta_{2i}u_{2,2} + \delta_{3i}u_{3,2} \quad (6)$$

This is where u_{1i} is the shared component for wasting and stunting; u_{2i} is the shared component for wasting and underweight; u_{3i} is the shared component for stunting and underweight. An unknown scaling parameter u was introduced to the shared component to allow for differential gradient of the shared components[2 5].

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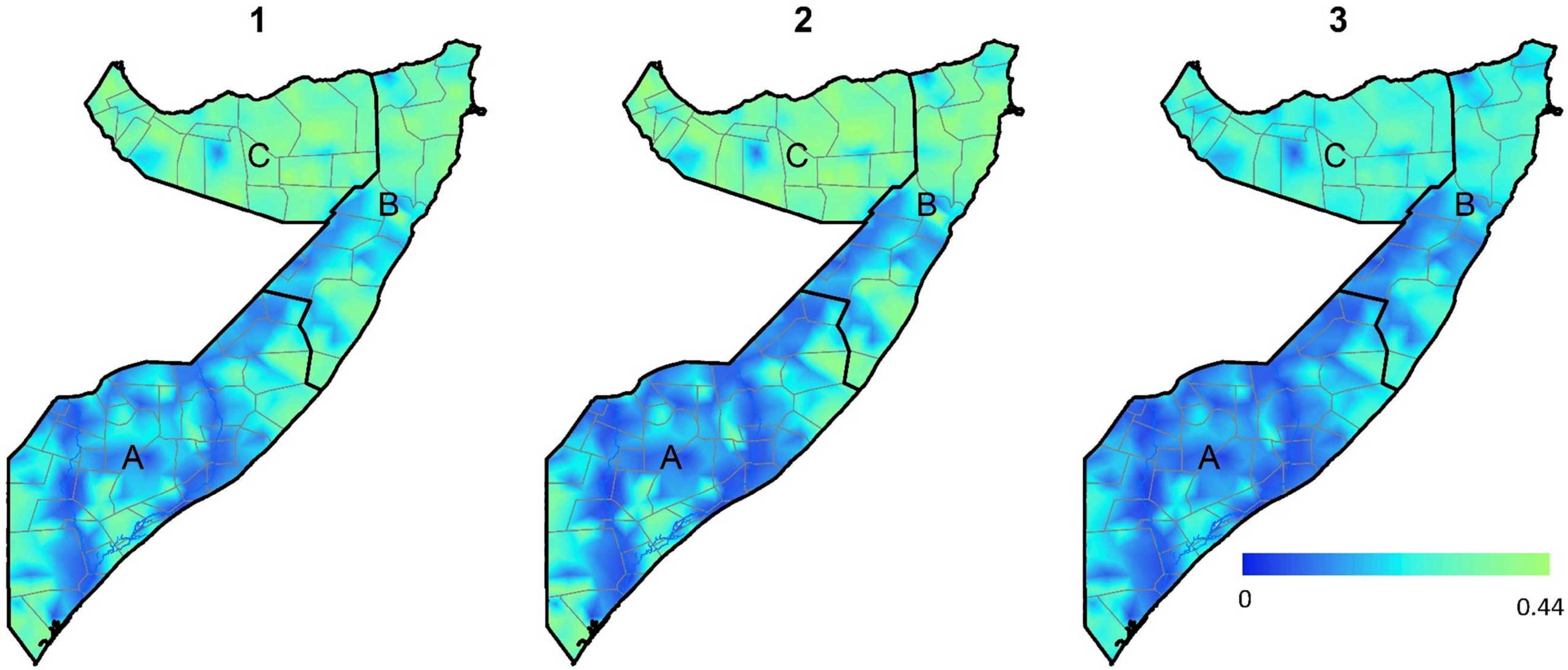

Figure SI. 1: Coefficients of variation at 1 x 1 km spatial resolution among children aged 6 - 59 months in Somalia. 1=Wasting and Stunting, 2=Stunting and Underweight, 3=Wasting and Underweight. A=South-central zone, B=Northeast (Puntland) zone, C=Northwest (Somaliland) zone. 1=Wasting, 2=Stunting, 3=Underweight.

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The joint distribution of wasting, stunting and underweight among children in Somalia

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Abstract

Objective: Wasting, stunting and underweight may co-occur at individual child level, however their spatial association is uncertain. Understanding shared and non-shared determinants may inform interventions. We aimed to assess the correlation between wasting, stunting and underweight, and investigate their shared determinants among children under the age of five years in Somalia.

Setting: Cross-sectional nutritional assessments surveys using structured interviews were conducted among communities in Somalia each year from 2007 to 2010. A two-stage cluster sampling methodology was used to select children aged 6-59 months from households across three livelihood zones (pastoral, agro-pastoral and riverine). We used the recently developed multivariate mapping techniques to estimate common and uncommon risks of wasting, stunting and underweight at 1 x 1 km spatial resolution.

Participants: 73,778 children aged 6-59 months from 1,066 survey clusters in Somalia.

Results: Observed pairwise child level ecological correlations of nutrition status were 0.32, 0.71 and 0.66 between wasting and stunting; stunting and underweight; and wasting and underweight respectively. Access to protein and vegetation cover, a proxy of rainfall or drought, were strong predictors of wasting and stunting. Age, gender, illness, access to carbohydrates and temperature were predictors of all three indicators. Posterior spatial effects were highest for underweight, followed by stunting, and lowest for wasting. Spatially, the posterior residual effects ranged from 0.26 to 4.32, 0.15 to 6.20, and 0.18 to 5.18 for stunting and wasting; stunting and underweight; wasting and underweight respectively.

Conclusion: The determinants of wasting and stunting are largely shared, but the correlation is relatively variable in space. Although nutrition response in Somalia has traditionally focused on the wasting, integrated programming and interventions should be directed at the common risk factors, this will reduce and streamline a lot of effort.

Strengths and limitations of this study

- This study examines the risk factors common to wasting, stunting and underweight and determine the shared spatial distribution to show regions where the co-distribution of the indicators are highly prevalent to inform programming, policing and interventions.

- The use of individual level data improved the estimates in our analysis as it accounted for the variability between children ensuing more accurate estimates than using of aggregated data.

- Sustained conflict that might exacerbate malnutrition in Somalia and which continues to be the primary reason for displacement affecting the Southern-central zone was not accounted for in this study.

Introduction

Malnutrition is one of the major causes of childhood deaths in developing countries[1 2]. Globally, in 2011, one in four children (26%, 165 million) were stunted, one in six (16%, 101 million) were underweight, and one in twelve (8%, 52 million) were wasted. More than 90% undernourished people live in developing countries[3]. In Somalia, 35% (2.85 million) of the population was estimated to be affected by food security crisis in 2011. In southern regions of the country, the prevalence of acute malnutrition was estimated to be at least 30%[4].

There are a number of measurements of nutritional status including biomarkers, body composition analysis, and simple anthropometry[5]. Wasting (low weight-for-length/height) and stunting (low height-for-age) are the most commonly used indicators for individual assessment, designing programs and assessing impact[6 7]. Stunting is thought to be an indicator of chronic or long-term nutritional inadequacy, while wasting is an indicator of an acute situation related to illness or lack of food[7]. Therefore, stunting is referred to as chronic malnutrition while wasting is acute malnutrition[7]. Wasting and stunting are normally presented as distinct nutritional problems, contributing separately to mortality and disease[8]. Studies emphasize the evaluation of long-term consequences of stunting for adult health and human capital while wasting has been interpreted as a predictor of short-term mortality[9]. Strategies are usually targeted at a single indicator[10].

Studies in developed countries have shown that wasting and stunting may be dependent of each other when compared to a standard population[11 12]. This is because growth potential of healthy young children is largely similar across ethnic groups and within regions in developing countries[13 14]. If linear growth falters due to infection or poor diet, catch-up growth might be attained once the infection is eliminated or the diet improves. However in resource-poor settings, where dietary intake may be consistently inadequate and there exists high rates of infectious diseases, the process of catch-up growth may never be possible and this results to high level of stunting[12 15]. In this context, wasting might precede linear growth retardation and therefore it is possible that wasting directly influences linear growth[16] however, currently this is uncertain. A third indicator of malnutrition, underweight defined as low weight-for-age combines information on linear growth and bulk[10]. In general terms, the worldwide variation of low weight-for-age and its age distribution are similar to those of low height-for-age[17]. This means that over the long term, the prevalence of underweight largely describes linear growth faltering in young children[18].

Due to prolonged drought, famine and conflict in Somalia, the rates of malnutrition persistently remain at "critical" levels and have been cited as the highest in the world[19 20]. The distribution of malnutrition varies across regions mainly influenced by climatic conditions[21]. In addition, malnutrition rates in a region are influenced by the nutrition status of the neighbouring regions. In Somalia, for example, conflict and drought lead to frequent displacement of vulnerable people into safer regions[22]. Stunting and underweight may be affected by the cumulative effect of intermittent rates of wasting. The UNICEF conceptual framework has been used to define the causal factors of indicators of malnutrition[23]. However, the framework is not translated to integrated policy and programming for common intervention[8 24]. Understanding the common drivers and extent of coexistence of the indicators geographically would help formulate effective strategies for intervention.

In this study, we aimed to describe the spatial co-distribution between the rates of wasting, stunting and underweight among children under the age of five years in Somalia from 2007 to 2010 using Bayesian Geo-statistical modelling approach[25]. We used a shared-component model to fit common unobserved and unmeasured spatial risks to determine the areas that the indicators are strongly correlated and identify common risk factors.

Methods

Survey Data

The data used for this study were obtained from Food Security and Nutrition Unit (FSNAU). Our study focuses on survey data ranging from the year 2007 to 2010 [FSNAU 2007-2010]. Within this period, FSNAU in partnership with UNICEF conducted a bi-annual seasonal nutrition assessment surveys where they used standard methods, indicators and tools for data collection[26 27]. Detailed descriptions of the survey methods and data collection are described elsewhere[27]. We considered three outcome measurements describing the anthropometric indicators of malnutrition: low weight-for-height (wasting), low height-for-age (stunting), and low weight-for-age (underweight) as defined in WHO 2006 references[28]. A child was defined as wasted or stunted or underweight when he/she was below -2 Z scores[28].

The underlying predictors used in this study were related to child, household, maternal and environmental factors. At child-level, Vitamin A supplementation in the last six months, diarrhoea, acute

respiratory infections (ARI) and incidence of febrile illness in the last two weeks before the survey, polio and measles vaccination history, gender and age of the child were examined. At household level, the predictors used were household size and age structure, gender of the household head, and access to different types of foods in the last 24 hours. Five environmental covariates associated with vector-borne diseases[29] and food security[30] were examined for modelling. These were rainfall, enhanced vegetation index (EVI), mean temperature, distance to water and urbanization. Rainfall and mean temperature were derived from the monthly average grid surfaces obtained from WorldClim database[31]. The EVI values were derived from the MODerate-resolution Imaging Spectroradiometer (MODIS) sensor imagery[32] for period 2007-2010 while the urbanization information was obtained from Global Rural Urban Mapping Project (GRUMP)[33]. All the environmental covariates were extracted from 1 x 1 km spatial resolution grids to data points. Rainfall, temperature and EVI were summarized to compute seasonal averages using the two main rainy seasons in Somalia.

In Somalia, the livelihoods are broadly based on subsistence farming and pastoralism with limited opportunities to earn wages. Therefore livelihoods zones in Somalia are mainly: agro-pastoral, pastoral and riverine. Communities were defined as pastoral if they engaged primarily in livestock production and were nomadic (moved with their livestock from place to place in search of water and pasture); agro-pastoral if they practiced mixed crop and livestock production; and riverine if they lived along the river and were primarily involved in crop production and river-based economy [34].

The season of survey was as well derived from the FSNAU surveys depending the month of survey. Somalia has four main seasons around which pastoral and agricultural activities depend: December to March is the 'Jilal' season, a harsh dry season; 'Gu' which is the main rainy season from April to June; from July to September is the second dry season, the 'Hagaa'; and the short rainy season known as 'Deyr' from October to December[35]. FSNAU conducted bi-annual cross-sectional surveys during the long (April to June) and short (October to November) rainy seasons between 2007 and 2010. Therefore seasonality was controlled in the model using two unordered level to reflect the time of surveys (Gu and Deyr).

Ethical approval

Ethical approval was provided through permission by the Ministry of Health Somalia, Transitional Federal Government of Somalia Republic, Ref: MOH/WC/XA/146./07, dated 02/02/07. Due to the high

illiteracy rate of the population, informed verbal consent was sought from all participating households and individuals. An additional 10% was added to the sample size to allow for drop out or refusal to participate.

Statistical methods

Our analysis used joint modelling for multiple conditions approach[36-38] to investigate the co-distribution of the three malnutrition indicators using the Integrated Nested Laplace Approximation (INLA) as implemented in R-INLA library to produce risk maps at 1 x 1 km spatial resolution[36 39]. This was done controlling for the main putative predictors of malnutrition. In this approach the relative risk of each condition is assumed to depend on a latent spatial component shared by three conditions in addition to a condition-specific component[36]. The shared component is considered to contribute to the overall risk scaled by additional unknown weights where a risk gradient is associated with the common field. We modelled three latent spatial components common to the three pairs of the conditions (wasting and stunting; stunting and underweight; wasting and underweight). These underlying interactions between the three indicators of malnutrition contribute to the levels, trends and patterns of malnutrition in children. Further, the marginal excursion probabilities based on the estimated posterior distribution of the shared component were simultaneously calculated using quintile correction (QC) method as implemented by Bolin and Lindgren 2012[40]. Using the excursion contour function, the spatial residual shared components were further classified in four categories including less than 20%; 20% - <40%; 40% - <60% and > 60% using the excursion function in QC method and the parametric family of excursion sets[40]. Detailed description of the methods and output from the shared component model can be found in the supplementary information for this paper.

Results

A total of 73,778 children under the age of five years were examined from 1066 clusters and of which 15,735 (21%), 22,739 (31%) and 60,333 (82%) were wasted, stunted and underweight respectively. A total of 6640 (9%) children had both wasting and stunting; 21396 (29%) children had both stunting while underweight and 14756 (20%) had both wasting and underweight. Fifty two percent of children were boys and the mean age of the children was 33 months. Other characteristics of the children measured during the surveys are shown in Table I. By livelihood zones, 42%, 27% and 16% of children were from areas of agro-pastoral, pastoral and riverine livelihoods respectively while 11% lived in internally displaced people (IDP) camps and 4% lived in urban areas.

Table I: Summary of survey data aggregated for the period 2007-2010 (FSNAU 2007-2010). *Gu* is a harsh dry season and *Deyr* is the short rainy season from October to December in Somalia.

Characteristic	**Number**					
Total number of children examined	73778					
Total number of clusters examined	1066					
Summary by livelihood	**Wasting; n=15735, (%)**		**Stunting; n=22739 (%)**		**Underweight; n=60333 (%)**	
Livelihood: Agro-pastoral	4406(28)		7276(32)		17546 (29)	
Pastoral	4878 (31)		5230 (23)		17271 (29)	
Riverine	2990 (19)		5685 (25)		12772 (21)	
Urban areas	787 (5)		910 (4)		3270 (5)	
Internally Displaced Persons	2518 (16)		3638 (16)		9473 (16)	
Child data	**Wasted; n = 15735 (21%)**	**Not wasted; n=40685 (79%)**	**Stunted; n =22739 (31%)**	**Not stunted ; n =51715 (69%)**	**Underweight; n = 60333 (82%)**	**Not underweight n=13445 (18)**
Vitamin A supplementation	8995 (57)	33356 (57)	12853 (57)	29498 (58)	34610 (57)	7750 (58)
Measles vaccination	8367 (53)	30875 (53)	11919 (52)	27317 (54)	32008 (53)	7234 (54)
Polio vaccination	12346 (78)	46519 (80)	18272(80)	40647 (80)	48400 (80)	10514 (78)
Diarrhoea in the last 2 weeks	3749 (24)	10674 (18)	5136 (23)	9159 (18)	12192 (20)	2071 (15)
Acute Respiratory Infection	3797 (24)	12029(21)	5090 (22)	10647 (21)	13213 (22)	2513 (19)
Febrile Illness in the last 2 weeks	3793 (24)	11912 (21)	4849 (21)	10753 (21)	12771 (21)	2830 (21)
Suspected measles in last 1 month	788 (5),	2487 (4)	1026 (5)	2229 (4)	2692 (4)	562 (4)
Sex of the child	Male=9039(57) Female= 6696 (43)	Male= 28761 (50) Female= 29282 (50)	Male=12776(56) Female= 9963 (44)	Male= 24844 (49) Female= 26195 (51)	Male=31565 (52) Female= 28768 (48)	Male= 6004 (45) Female= 7441 (55)
Age of the child (in months)	Mean=33, Range=(6,59)	Mean = 33, Range=(6,59)	Mean =31, Range=(6,59)	Mean= 32, Range=(6,59)	Mea=33, Range=(6,59)	Mean = 27, Range=(6,59)
Age of the mother (in years)	Mean=30, Range = (15,60)	Mean = 30, Range = (15,60)	Mean=30, Range = (15,60)	Mean = 30, Range = (15,60)	Mean =30, Range = (15,60)	Mean = 30, Range = (15,60)
MUAC of mother in cm	Mean =21, Range(18,38)	Mean = 22, Range(18,38)	Mean=22, Range(18,38)	Mean= 22, Range(18,38)	Mean=22, Range(18,38)	Mean = 23, Range(18,38)
Household data	**Mean (Range)**		**Mean (Range)**		**Mean (Range)**	
Household size	6 (2, 50)		6 (2, 50)		6 (2, 50)	

Number of under5	2 (1, 5)		2 (1, 5)		2 (1, 5)	
Household head gender	Male=60128 (81%)		Male=60128 (81%)		Male=60128 (81%)	
Food access data	**Number (%)**		**Number (%)**		**Number (%)**	
Carbohydrate in the last 24 hours	15227 (97)	56059 (97)	22285(98)	49008 (96)	58633(97)	12646(94)
Protein in the last 24 hours	13420 (85)	50543 (87)	19691 (87),	44322 (87)	52444 (87),	11572(86)
Fats in the last 24 hours	12327 (78)	46277(80)	17751 (78),	40880 (80)	47848 (79),	10797 (80)
Fruits and vegetables in the last 24 hours	6423(41)	24835 (43)	10695 (47)	20665 (40)	26400 (44)	4916 (37)
Cluster data	**Mean (Range)**		**Mean (Range)**		**Mean (Range)**	
Distance to water to major water bodies (km)	97 (0,508)		97 (0,508)		97 (0,508)	
Enhanced Vegetation Index (EVI)	0.18 (0,0.45)		0.18 (0,0.45)		0.18 (0,0.45)	
Precipitation (mm/year)	138 (0,350)		138 (0,350)		138 (0,350)	
Mean Temperature (˚c)	28 (21,31)		28 (21,31)		28 (21,31)	
Urbanization	Urban = 3318 (5%), Rural = 70460		Urban = 3318 (5%), Rural = 70460		Urban = 3318 (5%), Rural = 70460	
Season	April to June (*Gu*) = 47327(64%), October to November (*Deyr*) = 26451 (36%)		April to June (*Gu*) = 47327(64%), October to November (*Deyr*) = 26451 (36%)		April to June (*Gu*) = 47327(64%), October to November (*Deyr*) = 26451 (36%)	

The effects of predictors from the shared component model, shown in Table II, male gender was associated with lower risk of all the three indicators of malnutrition (odds ratio (OR)=0.75, 95% credible interval (CrI): 0.72 - 0.79; OR=0.75, 95% CrI: 0.72 - 0.79; OR=0.83, 95% CrI: 0.79 - 0.87 for wasting, stunting and underweight respectively). Age 24 months or more was associated with decreased risk of wasting (OR=0.80, 95% CrI: 0.73 - 0.87) and increased risk of stunting (OR=1.76, 95% CrI: 1.61 – 1.91) and underweight (OR=1.99, 95% CrI: 1.84 -2.16). The risk of stunting was higher in children in the 12 – 24 months age group compared to the 24 – 59 months age group with 6 - 11 months as the reference group. Children who had diarrhoea and acute respiratory infection in the last two weeks had a higher risk of wasting (OR=1.30, 95% CrI: 1.22 – 1.38; OR=1.10, 95% CrI: 1.04 – 1.17), stunting (OR=1.24, 95% CrI: 1.18 – 1.31; OR=1.21, 95% CrI: 1.15 – 1.27), and underweight (OR=1.09, 95% CrI: 1.01 – 1.18; OR=1.26, 95% CrI: 1.17 – 1.35). Increase in age of the mother was associated with decreased rates of wasting, stunting and underweight until at the age of 40 years where further increase in age did not show significant association.

Increases in the household size and number of under-fives in the household were associated with increased risk of wasting and stunting, but not with underweight. Children who had consumed any of the staple sources of carbohydrates or proteins within the 24 hours prior to the survey had a lower risk of all the three indicators of malnutrition. Vitamin A supplementation was associated with low risk of wasting (OR=0.80, 95% CI: 0.75 - 0.85) but was not associated with stunting and underweight. There was a significant association between the vegetation index (OR=0.66, 95% CrI: 0.45 -0.95), (OR=0.59, 95% CrI: 0.42 -0.82), (OR=0.69, 95% CrI: 0.67 – 0.72) and temperature (OR=1.07, 95% CrI: 1.03 – 1.11), (OR=1.05, 95% CrI: 1.01 -1.10), (OR=1.12, 95% CrI: 1.07 – 1.17) with wasting, stunting and underweight respectively. Season was associated with wasting (OR=1.11, 95% CrI: 1.04 – 1.18) and underweight (OR=0.93, 95% CrI: 0.91-0.94), but had no association with stunting. Urbanization was associated with decreased risk of wasting (OR=0.96, 95% CrI: 0.94 – 0.99), but was not associated with stunting and underweight.

Table II: Multivariate adjusted posterior odds ratio (POR) and 95% credible interval (CrI) of wasting, stunting and underweight among children aged 6 – 59 months in Somalia.

Predictors		Wasting		Stunting		Underweight	
		Odds ratio	CrI	Odds ratio	CrI	Odds ratio	CrI
Child data							
Vitamin A supplementation		**0.80**	**(0.75,0.85)**	1.00	(0.94,1.05)	1.01	(0.94,1.08)
Measles vaccination		1.04	(0.97,1.11)	0.96	(0.91,1.02)	0.93	(0.87,1.00)
Polio vaccination		**0.88**	**(0.82,0.95)**	**1.07**	**(1.00,1.14)**	**1.09**	**(1.01,1.18)**
Diarrhoea		**1.30**	**(1.22,1.38)**	**1.24**	**(1.18,1.31)**	**1.26**	**(1.17,1.35)**
Acute Respiratory Infection (ARI)		**1.10**	**(1.04,1.17)**	**1.21**	**(1.15,1.27)**	**1.08**	**(1.01,1.15)**
Febrile Illness		**1.15**	**(1.09,1.22)**	0.98	(0.93,1.03)	1.02	(0.95,1.09)
Suspected measles		1.05	(0.93,1.18)	0.97	(0.87,1.07)	0.98	(0.86,1.11)
Sex of the child (Male)		**0.75**	**(0.72,0.79)**	**0.75**	**(0.72,0.79)**	**0.83**	**(0.79,0.87)**
Child age (< 12 months as reference)	12 -< 24 months	**0.80**	**(0.73,0.88)**	**2.35**	**(2.15,2.57)**	1.05	(0.96,1.14)
	24 – 59 months	**0.80**	**(0.73,0.87)**	**1.76**	**(1.61,1.91)**	**1.99**	**(1.84,2.16)**
Age of the mother (20-30 years as reference)	< 20 years	**1.24**	**(1.09,1.42)**	**1.04**	**(1.02,1.06)**	**1.08**	**(1.01,1.16)**
	31-40 years	**0.91**	**(0.83,0.99)**	**0.87**	**(0.83,0.91)**	**0.94**	**(0.93,0.95)**
	41-50	**0.88**	**(0.83,0.93)**	**0.91**	**(0.84,0.99)**	1.01	(0.88,1.15)
	> 50 years	0.92	(0.85,1.01)	0.76	(0.49,1.17)	1.01	(0.49,2.08)
MUAC of mother		0.99	(0.99,1.00)	1.00	(1.00,1.00)	**0.99**	**(0.98,0.99)**
Household data							
Household size		**1.14**	**(1.13,1.15)**	**1.27**	**(1.25,1.28)**	1.00	(0.99,1.01)
Number of under5		**1.06**	**(1.03,1.09)**	**1.80**	**(1.76,1.85)**	1.00	(0.97,1.04)
Female household head		0.95	(0.89,1.02)	**0.87**	**(0.82,0.92)**	0.98	(0.92,1.05)
Food access data							
Carbohydrate		**0.83**	**(0.79,0.88)**	**0.82**	**(0.78,0.86)**	**0.92**	**(0.87,0.97)**
Protein		**0.57**	**(0.55,0.59)**	**0.51**	**(0.49,0.52)**	**0.90**	**(0.87,0.93)**
Fats		1.04	(0.98,1.12)	**0.92**	**(0.87,0.98)**	**1.10**	**(1.02,1.18)**
Fruits and vegetables		0.97	(0.93,1.01)	**1.04**	**(1.01,1.08)**	**1.07**	**(1.03,1.12)**
Cluster data							
Season (October to November as reference)		**1.11**	**(1.04,1.18)**	1.04	(0.98,1.10)	**0.93**	**(0.91,0.94)**
Distance to water		1.00	(1.00,1.00)	1.00	(1.00,1.00)	1.00	(1.00,1.00)
Enhanced Vegetation Index (EVI)		**0.66**	**(0.45,0.95)**	**0.59**	**(0.42,0.82)**	**0.69**	**(0.67,0.72)**
Rainfall		**0.88**	**(0.79,0.98)**	1.09	(0.96,1.22)	0.95	(0.86,1.06)

Temperature	**1.07**	**(1.03,1.11)**	**1.05**	**(1.01,1.10)**	**1.12**	**(1.07,1.17)**
Urbanization	**0.96**	**(0.94,0.99)**	1.00	(0.97,1.04)	0.97	(0.94,1)

As shown in Figure 1, all the indicators showed a positive correlation. Stunting and underweight had the strong correlations at 0.71 followed by wasting and underweight at 0.66. However, correlation between wasting and stunting was low at 0.32. Figure 2 shows the spatial distribution of the observed prevalence of wasting, stunting and underweight by cluster for FSNAU nutrition surveys conducted from 2007 to 2010.

The shared spatial residual effects were significant with (OR=2.58, 95% CrI: 1.32 – 5.01); (OR=3.93, 95% CrI: 3.37 – 4.59) and (OR=2.04, 95% CrI: 1.92 – 2.17) for wasting and stunting; stunting and underweight and wasting and underweight respectively. Estimated common spatial patterns are shown in Figure 3. The maps reveal geographical variation of the common latent field of the three indicators. The shared component displayed a strong spatial gradient in the South-North direction in all the shared components examined in this study. This confirms a high risk of all forms of malnutrition in the south region especially along the two main rivers in Somalia: Juba and Shebelle as compared to northern region of Somalia. The shared spatial residual effects from the joint modelling ranged from 0.26 - 4.32, 0.15 - 6.20 and 0.18 - 5.18 for wasting and stunting; stunting and underweight and wasting and underweight respectively. The distribution of residual component has a larger effect on stunting and underweight in the south region in Somalia. Maps showing areas where the categorized shared spatial residual effects were statistically significant are shown in Figure 4. The standard deviations ranged from 0.04 to 0.40 in Somalia (Figure SI. 1).

Discussion

We applied a joint spatial analysis of malnutrition among children under the age of five years in Somalia to identify shared components of wasting, stunting and underweight. There are common latent components for the three measures which cause the distribution patterns to be similar in most regions. The highest shared spatial residual effect was observed between stunting and underweight, followed by wasting and underweight, while the correlation between wasting and stunting was relatively low. Access to protein and vegetation cover, a proxy of rainfall or drought, were strong predictors of wasting and stunting. Age, gender, illness, access to carbohydrates and temperature were also common predictors of all three indicators.

Stunting increases throughout the first 2-3 years of life in many developing countries, whereas wasting occurs during the first year of life after which it stabilizes[11]. Wasting is also noted to have a relatively

shorter duration and greater seasonal variability when compared with stunting[11]. This may explain the observed low association between wasting and stunting. Thus, the use of cross sectional studies data in describing wasting trends may have some limitations. This is because the prevalence of wasting varies within a short duration and therefore the prevalence captured in these type of studies depends on time of survey. As a result, a large incidence of wasting of short duration might be missed, misrepresenting the relationship of wasting with the other indicators. Longitudinal data which follow children's growth from birth looking at the wasting, stunting and the combination of the two can provide better understanding of the relationships[12].

Food insecurity and infectious disease differ between region and livelihoods system resulting from a combination of harsh environmental conditions and prolonged conflict and civil insecurity. In this study, access to food and infections were major factors associated across the three indicators of malnutrition and this reaffirms the strong shared component of wasting, stunting and underweight in the south as compared to the north in Somalia[27]. For example, there are currently about 400,000 internally displaced people (IDPs) in Somalia, mostly from the southern minority groups. Half of this population lives in Mogadishu almost completely out of reach of any concrete internal assistance[27]. This is one area that has been seen to consistently have strong shared component of the malnutrition indicators in this study. Kismaayo, also another consistent hotspot has been host to numerous internally displaced persons (IDPs) fleeing the harsh effects of drought and conflict in the Juba and other neighbouring regions[41]. IDPs are considered to be among the poorest population groups in the country with high levels of food insecurity with poor living conditions which predisposes them to various infectious diseases[41].

Enhanced vegetation index (EVI) is a satellite imagery derived variable and effectively characterizes the global range of vegetation state. High EVI values indicates vegetated areas that reflect forested areas, riverine vegetation and more importantly local agriculture which has a direct relationship with the local food security. Highly vegetated areas (as demarcated by high EVI values) are a product of a combination of several variables including rainfall, seasonal and permanent water sources and to some extent underground water. In arid and semi-arid areas, agricultural activities are limited to areas with reliable water supply. According to 2010 estimates, agriculture accounts for 65% of the gross domestic product (GDP), with livestock representing 40% of the GDP and 65% of the export earnings in Somalia. Due to long standing civil war and droughts which led to human displacements, and inadequate agricultural inputs has mostly affected farmers of the riverine and agro-pastoral livelihood zones and as well as the

cattle-rearing pastoralists who have experienced significant livestock losses due to lack of pasture and water. Agricultural recovery is also hindered by the presence of large numbers of IDPs[41]. Temperature was also found to be an important predictor of malnutrition. Temperature is directly linked to aridity [42] which in turn has an impact on malnutrition[30]. High temperature values are reported in Somalia rising up to 40°c in the Hagaa dry season[43] between the months of July and September. In this study, high temperature values were observed in surveys conducted during the same period.

Seasonal variation was also seen to significantly affect levels wasting and not stunting in Somalia. This is echoed in other studies that have shown that incident and prevalence of wasting are more sensitive to seasonal variation than those of stunting and vary with seasonal variation of diseases, activity levels, food availability and time of care[44]. At population level, children grow in height only when their weight-for-height improves at the end of the hunger season[11]. The pastoralist communities in Somalia predominantly live in the Northern region. Following prolong drought and famine in the region which has led to massive livestock losses, the pastoralists have been seen seasonally to migrate with their livestock to other regions with water and pasture. The seasonal migration is reflected in the shifting of the hotspots from one region to another[41].

This study has shown that wasting, stunting and underweight in children share similar spatial distribution in most of the regions of Somalia. In addition, the study provides risk factors common to each pair of the indicators. It is held that whereas wasting describes a recent and severe process that has led to significant weight loss, usually as a consequence of acute starvation and/or severe disease and stunting reflects the process of failure to reach linear growth potential as a result of suboptimal health and/or chronic nutritional deficiency[5], the etiology of both indicators may be similar at community level[11] and hence similar spatial distribution. This evidence therefore supports integrated programming and interventions focused on the common risk factors of the three indicators and specifically in regions where the co-distribution is highly prevalent. Wasting and stunting have been noted to vary differently depending on seasonal variations and age of the child. It is important to implement timely interventions those coincide with the peaks of the different indicators in different times of the year and also at different stages of life of the child.

The consistency and timeliness of FSNAU survey data provides an opportunity to analyse the trends of malnutrition in Somalia. The use of individual level data has improved the estimates in our analysis as it

accounted for the variability between children ensuing more accurate estimates than using of aggregated data. However the effect of conflict on malnutrition was not controlled in this study because the information was not captured during the FSNAU surveys. Further research should include conflict, and longitudinal studies should be undertaken to provide a better understanding of the relationship between wasting and stunting.

Conclusion

This study has demonstrated that the three indicators largely share common risk factors and that there is evidence of correlation in space[21 45]. The emergency response funding is by nature short term but there is compelling evidence to implement timely intervention of spatial patterns and trends of wasting and stunting depending on seasonal variation, the age and gender of the child. Although emergency nutrition response in Somalia focus on wasting, our evidence suggests implementing a more joined-up program of the indicators. This will require political will, appropriate financing, policies and programmatic links between the indicators.

Contributors: DKK, N-BK, SOM, AMN and JAB were responsible for the concept and design of the study. DKK, ETK and GAF were responsible for the development of the model. DKK led the data assembly process, data analysis and interpretation of results. GMM was responsible for conducting the surveys, cleaning and archiving the data. AMN N-BK, SOM and JAB were responsible for overall scientific oversight. All authors reviewed the manuscripts and contributed to the final submission.

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Figure legends

Figure 1: Correlation plots of wasting, stunting and underweight Z-scores among children under the age of five years in Somalia using survey data from 2007-2010

Figure 2: Maps showing the crude prevalence of wasting (I), stunting (II) and underweight (II) by clusters surveys between 2007 and 2010 in Somalia. The country is divided into three main zones: South-central (A), Northeast (B) and Northwest (C). 78 clusters were sampled in Northwest zone, 85 clusters in the Northeast zone and 903 clusters in the South-central. The country's two main rivers, Juba and Shebelle are located in the South-central zone. Map I= Wasting, II = Stunting and III = Underweight.

Figure 3: There are three maps here: i) Posterior residual shared spatial relative risk common to wasting and stunting; ii) Posterior residual shared spatial prevalence common to stunting and underweight; iii) Posterior residual shared spatial prevalence common to wasting and underweight. The estimates are in percentage. Each map is plotted at 1 x 1 km spatial resolution among children aged 6 - 59 months in Somalia. South-central (A), Northeast (B) and Northwest (C). I=Wasting and Stunting, II=Stunting and Underweight, III=Wasting and Underweight.

Figure: 4: Estimated areas with shared component classified in four categories at 95% confidence level for children aged 6 - 59 months using the marginal probabilities calculated from the excursion contour functions [40]. South-central (A), Northeast (B) and Northwest (C). I=Wasting and Stunting, II=Stunting and Underweight, III=Wasting and Underweight.

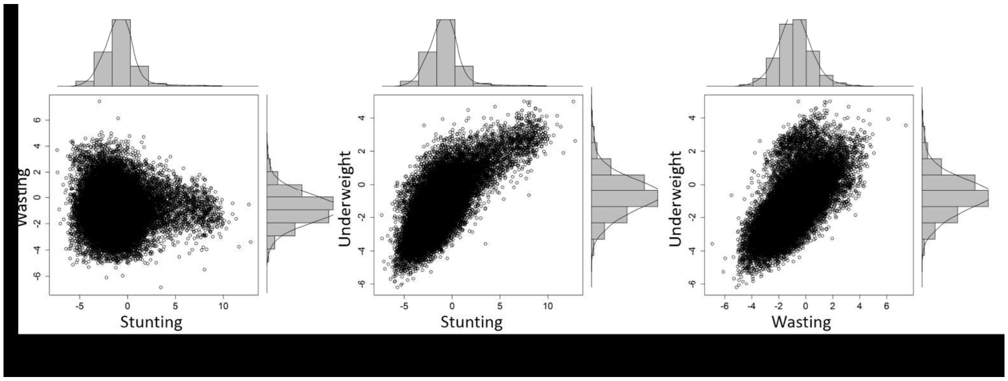

Figure 1: Correlation plots of wasting, stunting and underweight Z-scores among children under the age of five years in Somalia using survey data from 2007-2010
307x114mm (150 x 150 DPI)

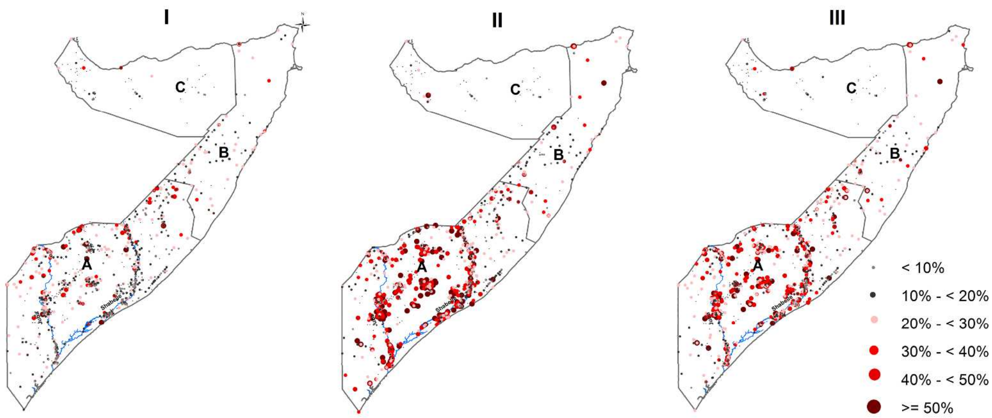

Figure 2: Maps showing the crude prevalence of wasting (I), stunting (II) and underweight (II) by clusters surveys between 2007 and 2010 in Somalia. The country is divided into three main zones: South-central (A), Northeast (B) and Northwest (C). 78 clusters were sampled in Northwest zone, 85 clusters in the Northeast zone and 903 clusters in the South-central. The country's two main rivers, Juba and Shebelle are located in the South-central zone. Map I= Wasting, II = Stunting and III = Underweight.
279x118mm (300 x 300 DPI)

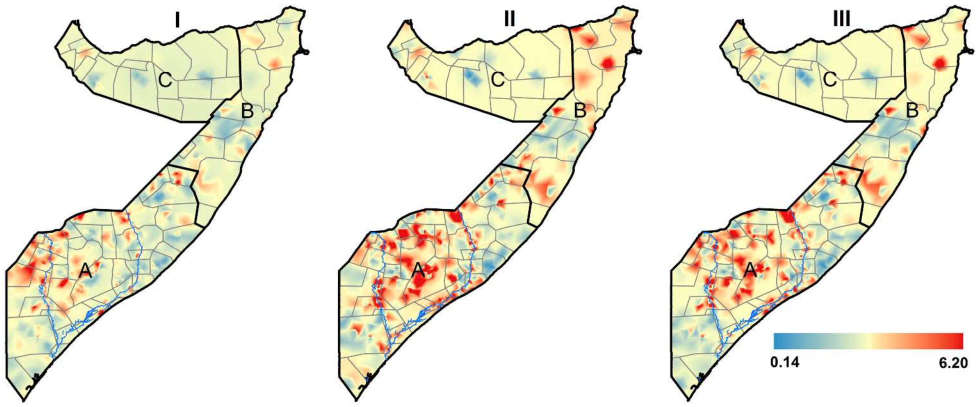

Figure 3: There are three maps here: i) Posterior residual shared spatial relative risk common to wasting and stunting; ii) Posterior residual shared spatial prevalence common to stunting and underweight; iii) Posterior residual shared spatial prevalence common to wasting and underweight. The estimates are in percentage. Each map is plotted at 1 x 1 km spatial resolution among children aged 6 - 59 months in Somalia. South-central (A), Northeast (B) and Northwest (C). I=Wasting and Stunting, II=Stunting and Underweight, III=Wasting and Underweight.
266x117mm (300 x 300 DPI)

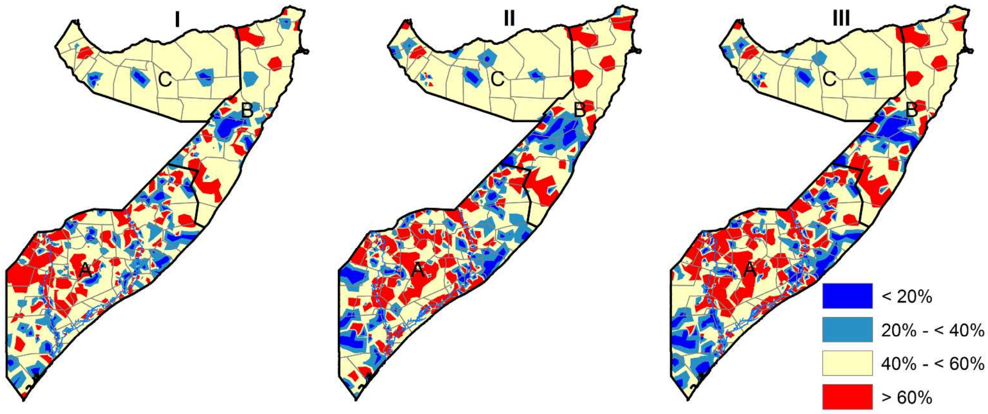

Figure: 4: Estimated areas with shared component classified in four categories at 95% confidence level for children aged 6 - 59 months using the marginal probabilities calculated from the excursion contour functions 40. South-central (A), Northeast (B) and Northwest (C). I=Wasting and Stunting, II=Stunting and Underweight, III=Wasting and Underweight.
266x117mm (300 x 300 DPI)

Supplementary Information: Model procedures and model output

SI.1 Space-time Bayesian Geo-statistical shared component model

Disease mapping mainly focuses on modelling single disease yet many diseases share common risk factors[1]. This underscores the importance of joint analysis of health conditions to identify similar patterns in geographical variation and provide more substantial evidence on clustering of the underlying risk surface for integrated interventions[2]. Non-Bayesian multilevel models have been used to present joint spatial analyses of diseases[3]. Knor-Held suggested joint modelling approaches in Bayesian perspective as an improvement of Besag *et al* formulations[4]. Shared spatial component methods have been used extensively to jointly model risk of more than one disease outcome[2 5 6]. Lindgren et al 2013 suggested that one can express a large class of random field models as a solution to continuous domain stochastic partial differential equations (SPDEs), and develop explicit links between the parameters of each SPDE and the elements of precision matrices for the weights in a discrete basis function representation[7]. This SPDE is formulated as a link between Gaussian random fields (GRFs) and the Gaussian Markov Random Fields (GMRFs)[7].

In this study, we implemented the Bayesian geo-statistical shared component model of three nutritional indicators through SPDE approach using R-INLA library[7]. Suppose using logit model for wasting, stunting and underweight, effect of covariates and latent spatial effect,

$$\log it(p_{i1}) = \alpha_1 + S_{i1} \quad (1)$$

$$\log it(p_{i2}) = \alpha_2 + S_{i2} \quad (2)$$

$$\log it(p_{i3}) = \alpha_3 + S_{i3} \quad (3)$$

This is where p_{i1}, p_{i2}, p_{i3} were the relative risks for wasting, stunting and underweight in cluster i respectively. The parameter α_j is the disease-specific intercept, β_j s are the indicator specific risk coefficients associated with the risk vector x; and S is the latent spatial effect. The spatial effects in this model can be expressed as:

$$S_{1i} = u_{1i} + \beta_{12} u_{2i} \quad (4)$$

$$S_{2i} = u_{2i} + \beta_{23} u_{3i} \quad (5)$$

$$S_3 = u_3 + \beta_{31} u_{1i} \quad (6)$$

This is where u_{1i} is the shared component for wasting and stunting; u_{2i} is the shared component for stunting and underweight; u_{3i} is the shared component for wasting and underweight. β_{12}, β_{23} and β_{31} are the covariates effects of the shared components of wasting and stunting; stunting and underweight and wasting and underweight respectively[2 5].

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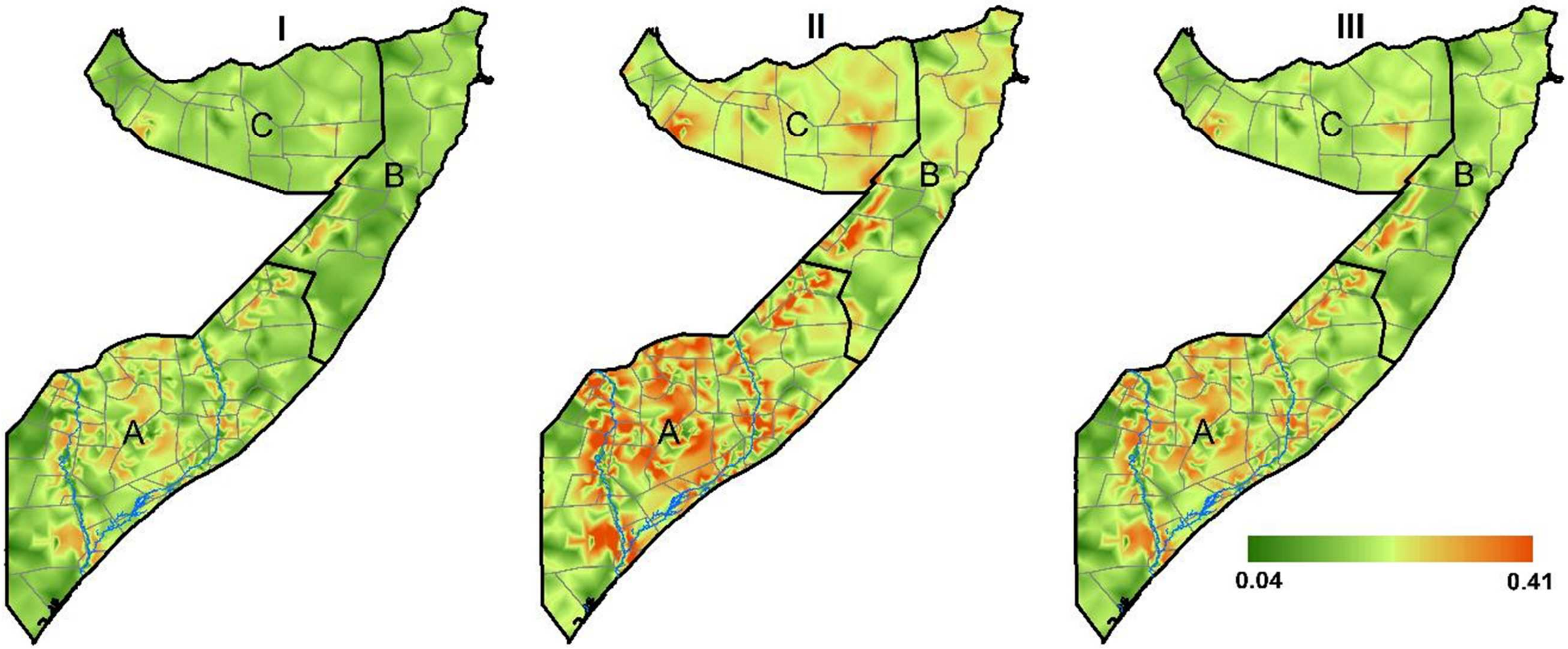

Figure SI. 1: Coefficients of variation at 1 x 1 km spatial resolution among children aged 6 - 59 months in Somalia. I=Wasting and Stunting, II=Stunting and Underweight, III=Wasting and Underweight. A=South-central zone, B=Northeast (Puntland) zone, C=Northwest (Somaliland) zone. 1=Wasting, 2=Stunting, 3=Underweight.

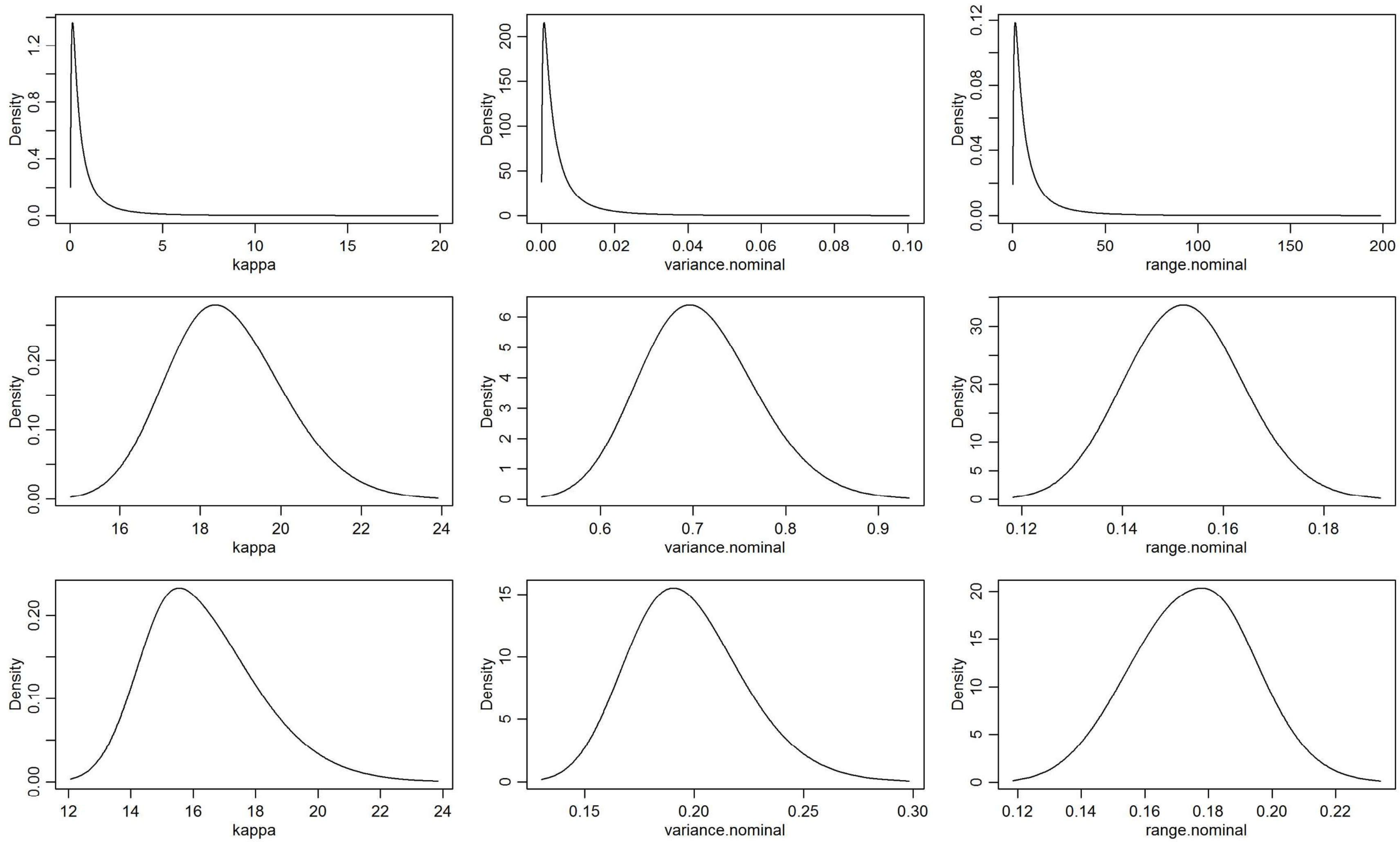

Figure SI. 2: Summary of the posterior marginal for kappa, variance and range of the three fields for the wasting, stunting and underweight.

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Assessing co-morbidity and correlates of wasting and stunting among children in Somalia

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Abstract

Objective: Wasting and stunting may occur together at individual child level, however, their shared geographic distribution and correlates remains unexplored. Understanding the shared and non-shared correlates may inform interventions. In this study, we aimed to assess the correlation between wasting and stunting and investigate their shared correlates among children under the age of five years in Somalia.

Setting: Cross-sectional nutritional assessments surveys using structured interviews were conducted among communities in Somalia each year from 2007 to 2010. A two-stage cluster sampling methodology was used to select children aged 6-59 months from households across three livelihood zones (pastoral, agro-pastoral and riverine). Using this data, we implement multivariate spatial-temporal techniques to estimate the co-distribution and divergence of the risks and correlates of wasting and stunting at 1 x 1 km spatial resolution.

Participants: 73,778 children aged 6-59 months from 1,066 survey clusters in Somalia.

Results: Observed pairwise child level empirical correlations were 0.30, 0.70 and 0.73 between weight-for-height and height-for-age; height-for-age and weight-for-age, and weight-for-height and weight-for-age respectively. Access to foods with high protein content and vegetation cover, a proxy of rainfall or drought, were strong correlates of wasting and stunting. Age, gender, illness, access to carbohydrates and temperature were correlates of all three indicators. The relationship in spatial distribution was highest between stunting and underweight with correlation values ranging between 0.15 and 6.20, followed by wasting and underweight (range: 0.18 - 5.18) and lowest between wasting and stunting (range: 0.26 – 4.32).

Conclusion: The determinants of wasting and stunting are largely shared, but the correlation is relatively variable in space. Significant hotspots of different forms of malnutrition have been highlighted in the south and central regions of the country. Although nutrition response in Somalia has traditionally focused on wasting rather than stunting, integrated programming and interventions can address common risk factors.

Strengths and limitations of this study

- This study examines the risk factors common to wasting and stunting and determine the shared spatial distribution to show regions where the co-distribution of the indicators are highly prevalent to inform programming, policing and interventions.

- The use of individual level data improved the estimates in our analysis as it accounted for the variability between children ensuing more accurate estimates than using of aggregated data.

- Sustained conflict that might exacerbate malnutrition in Somalia and which continues to be the primary reason for displacement affecting the Southern-central zone was not accounted for in this study.

Introduction

Malnutrition is one of the major causes of childhood deaths in developing countries[1 2]. Globally, in 2011, one in four children (26%, 165 million) were stunted, one in six (16%, 101 million) were underweight, and one in twelve (8%, 52 million) were wasted. More than 90% undernourished people live in developing countries[3]. In Somalia, 35% (2.85 million) of the population was estimated to be affected by food security crisis in 2011. In southern regions of the country, the prevalence of acute malnutrition was estimated to be at least 30%[4].

Indicators of nutritional status include biomarkers, body composition analysis, and simple anthropometry[5]. Wasting (low weight-for-length/height) and stunting (low height-for-age) are the most commonly used indicators for individual assessment, designing programs and assessing impact[6 7]. Stunting is thought to be an indicator of chronic or long-term nutritional inadequacy, while wasting is usually assumed to reflect an acute situation related to illness or lack of food[7]. Wasting and stunting are normally presented as distinct nutritional problems, contributing separately to mortality and disease[8].

Studies in developing countries have shown that wasting and stunting may be dependent on each other when compared to a standard population[9 10]. If linear growth falters due to infection or poor diet, catch-up growth might be attained once the infection is eliminated or the diet improves. However in resource-poor settings, where dietary intake may be consistently inadequate or there is a high rate of infectious diseases, catch-up growth may be impossible, resulting in stunting[10 11]. In this context, wasting might precede linear growth retardation and therefore it is possible that wasting directly influences linear growth[12] however, currently this is uncertain. A third indicator of malnutrition, underweight defined as low weight-for-age combines information on linear growth and bulk[13]. In general terms, the worldwide variation of low weight-for-age and its age distribution are similar to those of low height-for-age[14].

Due to prolonged drought, famine and conflict in Somalia, the rates of malnutrition persistently remain at "critical" levels and have been cited among the highest in the world[15 16]. The distribution of malnutrition varies across space and time mainly influenced by climatic conditions and other factors with definable spatial and temporal dependencies[17]. In Somalia, for example, conflict and drought lead to frequent displacement of vulnerable people into safer regions[18]. Stunting and underweight may be affected by the cumulative effect of intermittent rates of wasting. The UNICEF conceptual framework has been used to define the causal factors of indicators of malnutrition[19]. However, the framework is

not translated to integrated policy and programming for common intervention[8 20]. Children presenting with multiple forms of malnutrition have been reported to be at a higher risk of mortality when compared to one form of malnutrition[21]. This additive effect highlights the need to understand the common drivers and extent of coexistence of the indicators geographically in order to formulate effective strategies for intervention.

Previous analyses of the predictors of malnutrition have largely focussed on separate anthropometric measures and not common correlates[17]. In this study, we aimed to describe the spatial co-distribution between the rates of wasting and stunting controlling for the effect of underweight and other risk factors among children under the age of five years in Somalia from 2007 to 2010 using Bayesian geostatistical modelling approach[22]. We used a shared-component model to fit common unobserved and unmeasured spatial risks to determine the areas that the indicators are strongly correlated and identify common risk factors.

Methods

Survey Data

The data used for this study were obtained from Food Security and Nutrition Unit (FSNAU). Our study focuses on survey data ranging from the year 2007 to 2010 [FSNAU 2007-2010]. Within this period, FSNAU in partnership with UNICEF conducted a bi-annual seasonal nutrition assessment surveys where they used standard methods, indicators and tools for data collection[23 24]. Detailed descriptions of the survey methods and data collection are described elsewhere[24]. We considered three outcome measurements describing the anthropometric indicators of malnutrition: low weight-for-height (wasting), low height-for-age (stunting), and low weight-for-age (underweight) as defined in WHO 2006 references[25]. A child was defined as wasted or stunted or underweight when he/she was below -2 Z scores[25].

The underlying covariates used in this study were related to child, household, maternal and environmental factors. At child-level, Vitamin A supplementation in the last six months, diarrhoea, acute respiratory infections (ARI) and incidence of febrile illness in the last two weeks before the survey, polio and measles vaccination history, gender and age of the child were examined. At household level, the covariates used were household size and age structure, gender of the household head, and access to different types of foods in the last 24 hours. Five environmental covariates associated with vector-borne

diseases[26] and food security[27] were examined for modelling. These were rainfall, enhanced vegetation index (EVI), mean temperature, distance to water and urbanization. Rainfall and mean temperature were derived from the monthly average grid surfaces obtained from WorldClim database[28]. The EVI values were derived from the MODerate-resolution Imaging Spectroradiometer (MODIS) sensor imagery[29] for period 2007-2010 while the urbanization information was obtained from Global Rural Urban Mapping Project (GRUMP)[30]. All the environmental covariates were extracted from 1 x 1 km spatial resolution grids to data points. Rainfall, temperature and EVI were summarized to compute seasonal averages using the two main rainy seasons in Somalia.

In Somalia, the livelihoods are broadly defined as: agro-pastoral, pastoral and riverine. Pastoral communities are those engage primarily in livestock production and are nomadic. Agro-pastoral communities practice mixed crop and livestock production and; those defined as riverine live along the two main rivers of the Juba and Shebelle and are primarily involved in crop production and river-based economy [31].

Somalia has four main seasons around which pastoral and agricultural activities depend: December to March is the 'Jilal' season, a harsh dry season; 'Gu' which is the main rainy season from April to June; from July to September is the second dry season, the 'Hagaa'; and the short rainy season known as 'Deyr' from October to December[32]. The surveys were conducted bi-annually during the long (April to June) and short (October to November) rainy seasons between 2007 and 2010. Therefore seasonality was controlled in the model using two unordered level to reflect the time of surveys (Gu and Deyr).

Ethical approval

Ethical approval was provided through permission by the Ministry of Health Somalia, Transitional Federal Government of Somalia Republic, Ref: MOH/WC/XA/146./07, dated 02/02/07. Due to the high illiteracy rate of the population, informed verbal consent was sought from all participating households and individuals. An additional 10% was added to the sample size to allow for drop out or refusal to participate.

Statistical methods

Our analysis used joint modelling for multiple conditions approach[33-35] to investigate the co-distribution of wasting and stunting. We used Integrated Nested Laplace Approximation (INLA) as implemented in R-

INLA library to produce risk maps at 1 x 1 km spatial resolution[33 36]. In the prediction model, we controlled for the main putative correlates of malnutrition. In this approach the relative risk of each condition is assumed to depend on an underlying spatial element shared by the three forms of malnutrition that contributes to overall risk, in addition to condition-specific elements[33]. We modelled three underlying spatial elements common to the three pairs of the conditions (wasting and stunting; stunting and underweight; wasting and underweight). We also compute the degree of uncertainty in predicted prevalence based on the estimated distribution of the shared components using quintile correction (QC) method as implemented by Bolin and Lindgren 2012[37]. We stratified the predicted prevalence of the shared components to generate maps that assigned each pixel into either of four classes: less than 20%; 20% - <40%; 40% - <60% and > 60% based on the predicted probabilities of class membership using QC method[37]. Detailed description of the methods and additional outputs from this analysis can be found in the supplementary information (SI.1).

Results

A total of 73,778 children under the age of five years were examined from 1066 clusters and of which 15,735 (21%), 22,739 (31%) and 60,333 (82%) were wasted, stunted and underweight respectively. A total of 6640 (9%) children had both wasting and stunting; 21396 (29%) children had both stunting and underweight and 14756 (20%) had both wasting and underweight. Fifty two percent of children were boys and the mean age of the children was 33 months. Other characteristics of the children measured during the surveys are shown in Table I. By livelihood zones, 42%, 27% and 16% of children were from areas of agro-pastoral, pastoral and riverine livelihoods respectively while 11% lived in internally displaced people (IDP) camps and 4% lived in urban areas.

Table I: Summary of survey data aggregated for the period 2007-2010 (FSNAU 2007-2010). *Gu* is a harsh dry season and *Deyr* is the short rainy season from October to December in Somalia.

Characteristic	**Number**					
Total number of children examined	73778					
Total number of clusters examined	1066					
Child data	**Wasted; n = 15735 (21%)**	**Not wasted; n=58043 (79%)**	**Stunted; n =22739 (31%)**	**Not stunted ; n =51039 (69%)**	**Underweight; n = 60333 (82%)**	**Not underweight n=13445 (18)**
Vitamin A supplementation	8995 (57)	33356 (57)	12853 (57)	29498 (58)	34610 (57)	7750 (58)
Measles vaccination	8367 (53)	30875 (53)	11919 (52)	27317 (54)	32008 (53)	7234 (54)
Polio vaccination	12346 (78)	46519 (80)	18272(80)	40647 (80)	48400 (80)	10514 (78)
Diarrhoea in the last 2 weeks	3749 (24)	10674 (18)	5136 (23)	9159 (18)	12192 (20)	2071 (15)
Acute Respiratory Infection	3797 (24)	12029(21)	5090 (22)	10647 (21)	13213 (22)	2513 (19)
Febrile Illness in the last 2 weeks	3793 (24)	11912 (21)	4849 (21)	10753 (21)	12771 (21)	2830 (21)
Suspected measles in last 1 month	788 (5),	2487 (4)	1026 (5)	2229 (4)	2692 (4)	562 (4)
Sex of the child	Male=9039(57)	Male= 28761 (50)	Male=12776(56)	Male= 24844 (49)	Male=31565 (52)	Male= 6004 (45)
Age of the child (in months)	Mean=33, Range=(6,59)	Mean = 33, Range=(6,59)	Mean =31, Range=(6,59)	Mean= 32, Range=(6,59)	Mean=33, Range=(6,59)	Mean = 27, Range=(6,59)
Age of the mother (in years)	Mean=30, Range = (15,60)	Mean = 30, Range = (15,60)	Mean=30, Range = (15,60)	Mean = 30, Range = (15,60)	Mean =30, Range = (15,60)	Mean = 30, Range = (15,60)
MUAC of mother in cm	Mean =21, Range(18,38)	Mean = 22, Range(18,38)	Mean=22, Range(18,38)	Mean= 22, Range(18,38)	Mean=22, Range(18,38)	Mean = 23, Range(18,38)
Household data	**Mean (Range)**		**Mean (Range)**		**Mean (Range)**	
Household size	6 (2, 50)		6 (2, 50)		6 (2, 50)	
Number of under5	2 (1, 5)		2 (1, 5)		2 (1, 5)	
Household head gender	Male=60128 (81%)		Male=60128 (81%)		Male=60128 (81%)	
Food access data	**Number (%)**		**Number (%)**		**Number (%)**	
High carbohydrate foods in the last 24 hours	15227 (97)	56059 (97)	22285(98)	49008 (96)	58633(97)	12646(94)
High protein foods in the last 24 hours	13420 (85)	50543 (87)	19691 (87),	44322 (87)	52444 (87),	11572(86)
Fats in the last 24 hours	12327 (78)	46277(80)	17751 (78),	40880 (80)	47848 (79),	10797 (80)
Fruits and vegetables in the last	6423(41)	24835 (43)	10695 (47)	20665 (40)	26400 (44)	4916 (37)

24 hours			
Cluster data	**Mean (Range)**	**Mean (Range)**	**Mean (Range)**
Distance to water to major water bodies (km)	97 (0,508)	97 (0,508)	97 (0,508)
Enhanced Vegetation Index (EVI)	0.18 (0,0.45)	0.18 (0,0.45)	0.18 (0,0.45)
Precipitation (mm/year)	138 (0,350)	138 (0,350)	138 (0,350)
Mean Temperature (˚c)	28 (21,31)	28 (21,31)	28 (21,31)
Urbanization	Urban = 3318 (5%), Rural = 70460	Urban = 3318 (5%), Rural = 70460	Urban = 3318 (5%), Rural = 70460
Season	April to June (*Gu*) = 47327(64%), October to November (*Deyr*) = 26451 (36%)	April to June (*Gu*) = 47327(64%), October to November (*Deyr*) = 26451 (36%)	April to June (*Gu*) = 47327(64%), October to November (*Deyr*) = 26451 (36%)

The analysis of the correlates of malnutrition from the shared component model (Table II) shows that, male gender was associated with lower risk of all the three indicators of malnutrition (odds ratio (OR)=0.75, 95% credible interval (CrI): 0.72 - 0.79; OR=0.75, 95% CrI: 0.72 - 0.79; OR=0.83, 95% CrI: 0.79 - 0.87 for wasting, stunting and underweight respectively). Age 24 months or more was associated with decreased risk of wasting (OR=0.80, 95% CrI: 0.73 - 0.87) and increased risk of stunting (OR=1.76, 95% CrI: 1.61 – 1.91) and underweight (OR=1.99, 95% CrI: 1.84 -2.16). The risk of stunting was higher in children in the 12 – 24 months age group compared to the 24 – 59 months age group with 6 - 11 months as the reference group. Children who had diarrhoea and acute respiratory infection in the last two weeks had a higher risk of wasting (OR=1.30, 95% CrI: 1.22 – 1.38; OR=1.10, 95% CrI: 1.04 – 1.17), stunting (OR=1.24, 95% CrI: 1.18 – 1.31; OR=1.21, 95% CrI: 1.15 – 1.27), and underweight (OR=1.09, 95% CrI: 1.01 – 1.18; OR=1.26, 95% CrI: 1.17 – 1.35). Increase in age of the mother was associated with decreased rates of wasting, stunting and underweight until at the age of 40 years where further increase in age did not show significant association.

Increases in the household size and number of under-fives in the household were associated with increased risk of wasting and stunting, but not with underweight. Children who had consumed any of the staple sources of carbohydrates or proteins within the 24 hours prior to the survey had a lower risk of all the three indicators of malnutrition. Vitamin A supplementation was associated with low risk of wasting (OR=0.80, 95% CI: 0.75 - 0.85) but was not associated with stunting and underweight. There was a significant association between the vegetation index (OR=0.66, 95% CrI: 0.45 -0.95), (OR=0.59, 95% CrI: 0.42 -0.82), (OR=0.69, 95% CrI: 0.67 – 0.72) and temperature (OR=1.07, 95% CrI: 1.03 – 1.11), (OR=1.05, 95% CrI: 1.01 -1.10), (OR=1.12, 95% CrI: 1.07 – 1.17) with wasting, stunting and underweight respectively. Season was associated with wasting (OR=1.11, 95% CrI: 1.04 – 1.18) and underweight (OR=0.93, 95% CrI: 0.91-0.94), but had no association with stunting. Urbanization was associated with decreased risk of wasting (OR=0.96, 95% CrI: 0.94 – 0.99), but was not associated with stunting and underweight.

Table II: Multivariate adjusted odds ratio (POR) and 95% credible interval (CrI) of wasting, stunting and underweight among children aged 6 – 59 months in Somalia. The estimates were derived from joint distribution modelling and the results are indicative of the effect of the shared components.

Correlates		Wasting		Stunting		Underweight	
		Odds ratio	CrI	Odds ratio	CrI	Odds ratio	CrI
Child data							
Vitamin A supplementation		**0.80**	**(0.75,0.85)**	1.00	(0.94,1.05)	1.01	(0.94,1.08)
Measles vaccination		1.04	(0.97,1.11)	0.96	(0.91,1.02)	0.93	(0.87,1.00)
Polio vaccination		**0.88**	**(0.82,0.95)**	**1.07**	**(1.00,1.14)**	**1.09**	**(1.01,1.18)**
Diarrhoea		**1.30**	**(1.22,1.38)**	**1.24**	**(1.18,1.31)**	**1.26**	**(1.17,1.35)**
Acute Respiratory Infection (ARI)		**1.10**	**(1.04,1.17)**	**1.21**	**(1.15,1.27)**	**1.08**	**(1.01,1.15)**
Febrile Illness		**1.15**	**(1.09,1.22)**	0.98	(0.93,1.03)	1.02	(0.95,1.09)
Suspected measles		1.05	(0.93,1.18)	0.97	(0.87,1.07)	0.98	(0.86,1.11)
Sex of the child (Female)		**0.75**	**(0.72,0.79)**	**0.75**	**(0.72,0.79)**	**0.83**	**(0.79,0.87)**
Child age (< 12 months as reference)	12 -< 24 months	**0.80**	**(0.73,0.88)**	**2.35**	**(2.15,2.57)**	1.05	(0.96,1.14)
	24 – 59 months	**0.80**	**(0.73,0.87)**	**1.76**	**(1.61,1.91)**	**1.99**	**(1.84,2.16)**
Age of the mother (20-30 years as reference)	< 20 years	**1.24**	**(1.09,1.42)**	**1.04**	**(1.02,1.06)**	**1.08**	**(1.01,1.16)**
	31-40 years	**0.91**	**(0.83,0.99)**	**0.87**	**(0.83,0.91)**	**0.94**	**(0.93,0.95)**
	41-50	**0.88**	**(0.83,0.93)**	**0.91**	**(0.84,0.99)**	1.01	(0.88,1.15)
	> 50 years	0.92	(0.85,1.01)	0.76	(0.49,1.17)	1.01	(0.49,2.08)
MUAC of mother		0.99	(0.99,1.00)	1.00	(1.00,1.00)	**0.99**	**(0.98,0.99)**
Household data							
Household size		**1.14**	**(1.13,1.15)**	**1.27**	**(1.25,1.28)**	1.00	(0.99,1.01)
Number of under5		**1.06**	**(1.03,1.09)**	**1.80**	**(1.76,1.85)**	1.00	(0.97,1.04)
Female household head		0.95	(0.89,1.02)	**0.87**	**(0.82,0.92)**	0.98	(0.92,1.05)
Food access data							
High carbohydrate foods		**0.83**	**(0.79,0.88)**	**0.82**	**(0.78,0.86)**	**0.92**	**(0.87,0.97)**
High protein foods		**0.57**	**(0.55,0.59)**	**0.51**	**(0.49,0.52)**	**0.90**	**(0.87,0.93)**
Fats		1.04	(0.98,1.12)	**0.92**	**(0.87,0.98)**	**1.10**	**(1.02,1.18)**
Fruits and vegetables		0.97	(0.93,1.01)	**1.04**	**(1.01,1.08)**	**1.07**	**(1.03,1.12)**
Cluster data							
Season (October to November as reference)		**1.11**	**(1.04,1.18)**	1.04	(0.98,1.10)	**0.93**	**(0.91,0.94)**
Distance to water		1.00	(1.00,1.00)	1.00	(1.00,1.00)	1.00	(1.00,1.00)
Enhanced Vegetation Index (EVI)		**0.66**	**(0.45,0.95)**	**0.59**	**(0.42,0.82)**	**0.69**	**(0.67,0.72)**

Rainfall	**0.88**	**(0.79,0.98)**	1.09	(0.96,1.22)	0.95	(0.86,1.06)
Temperature	**1.07**	**(1.03,1.11)**	**1.05**	**(1.01,1.10)**	**1.12**	**(1.07,1.17)**
Urbanization	**0.96**	**(0.94,0.99)**	1.00	(0.97,1.04)	0.97	(0.94,1)

As shown in Figure 1, all the indicators showed a positive correlation. Weight-for-age and weight-for-height had the strong correlations at 0.73 followed by height-for-age and weight-for-age at 0.70. However, correlation between weight-for-height and weight-for-age was low at 0.30. Figure 2 shows the spatial distribution of the observed prevalence of wasting, stunting and underweight by cluster for FSNAU nutrition surveys conducted from 2007 to 2010.

The relationship in spatial distributions were significant for the three pairs with (OR=2.58, 95% CrI: 1.32 – 5.01) for wasting and stunting; (OR=3.93, 95% CrI: 3.37 – 4.59) for stunting and underweight and (OR=2.04, 95% CrI: 1.92 – 2.17) for wasting and underweight. Estimated common spatial patterns are shown in Figure 3. The maps reveal geographical variation in relative risk of the three indicators. The shared component displayed a strong spatial gradient in the South-North direction in all the shared components examined in this study. This confirms a high risk of all forms of malnutrition in the south region especially along the two main rivers in Somalia: Juba and Shebelle as compared to northern region of Somalia. The relationship in spatial distribution was highest between stunting and underweight with correlation values ranging between 0.15 and 6.20, followed by wasting and underweight (range: 0.18 - 5.18) and lowest between wasting and stunting (range: 0.26 – 4.32) with larger effects observed in the southern region of Somalia. The risk stratified maps of the predicted prevalence are shown in Figure 4. The standard deviations ranged from 0.04 to 0.40 (Figure SI. 2). Summaries of the parameters used in the joint modelling for the three indicators of nutrition status are shown in Figure SI. 3.

Discussion

We applied a joint spatial analysis of malnutrition among children under the age of five years in Somalia to identify shared components of wasting, stunting and underweight. There are common underlying components for the three measures which cause the distribution patterns to be similar in most regions. The correlation between regional means was highest between stunting and underweight, followed by wasting and underweight, while the correlation between wasting and stunting was relatively low. Access to foods high in protein and vegetation cover, a proxy of rainfall or drought, were strong correlates of wasting and stunting. Age, gender, illness, access to carbohydrates and temperature were also common correlates of all three indicators.

Stunting increases throughout the first 2-3 years of life in many developing countries, whereas wasting occurs during the first year of life after which it stabilizes[9]. Wasting is also noted to have a relatively

shorter duration and greater seasonal variability when compared with stunting[9]. This may explain the observed low association between wasting and stunting. Thus, the use of cross sectional studies data in describing wasting trends may have some limitations since the prevalence captured depends on time of survey. As a result, a large incidence of wasting of short duration might be missed, misrepresenting the relationship of wasting with the other indicators. Longitudinal data which follow children's growth from birth looking at the wasting, stunting and the combination of the two can provide better understanding of the relationships[10].

Food insecurity and infectious disease differ between region and livelihoods system resulting from a combination of harsh environmental conditions and prolonged conflict and civil insecurity. In this study, access to food and infections were major factors associated across the three indicators of malnutrition and this reaffirms the strong shared component of wasting, stunting and underweight in the south as compared to the north in Somalia[24]. For example, there are currently about 400,000 internally displaced people (IDPs) in Somalia, mostly from the southern minority groups. Half of this population lives in Mogadishu almost completely out of reach of any concrete internal assistance[24]. This is one area that has been seen to consistently have strong shared component of the malnutrition indicators in this study. Kismaayo, also another consistent hotspot has been host to numerous internally displaced persons (IDPs) fleeing the harsh effects of drought and conflict in the Juba and other neighbouring regions[38]. IDPs are considered to be among the poorest population groups in the country with high levels of food insecurity with poor living conditions which predisposes them to various infectious diseases[38].

Enhanced vegetation index (EVI) is a satellite imagery derived variable and effectively characterizes the global range of vegetation state. High EVI values indicates vegetated areas that reflect forested areas, riverine vegetation and more importantly local agriculture which has a direct relationship with the local food security. Highly vegetated areas (as demarcated by high EVI values) are a product of a combination of several variables including rainfall, seasonal and permanent water sources and to some extent underground water. In arid and semi-arid areas, agricultural activities are limited to areas with reliable water supply. According to 2010 estimates, agriculture accounts for 65% of the gross domestic product (GDP), with livestock representing 40% of the GDP and 65% of the export earnings in Somalia. Due to long standing civil war and droughts which led to human displacements, and inadequate agricultural inputs has mostly affected farmers of the riverine and agro-pastoral livelihood zones and as well as the cattle-rearing pastoralists who have experienced significant livestock losses due to lack of pasture and

water. Agricultural recovery is also hindered by the presence of large numbers of IDPs[38]. Temperature was also found to be an important correlate of malnutrition. Temperature is directly linked to aridity [39] which in turn has an impact on malnutrition[27]. High temperature values are reported in Somalia rising up to 40°c in the Hagaa dry season[40] between the months of July and September. In this study, high temperature values were observed in surveys conducted during the same period.

Seasonal variation was also seen to significantly affect levels wasting and not stunting in Somalia. This is echoed in other studies that have shown that incident and prevalence of wasting are more sensitive to seasonal variation than those of stunting and vary with seasonal variation of diseases, activity levels, food availability and time of care[41]. Somalia is dependent on rain-fed agriculture, which makes it particularly susceptible to climate variability. Almost 70% of the population is engaged in agricultural work, accounting for 65% of the gross domestic product. The impacts of drought on agriculture and water resources directly have negative effects on the nutritional status in children[42]. These impacts are exacerbated by the generally high vulnerability of the local population and enhanced by prevailing local and external economic and political conditions[43], which may be accompanied by disease[44]. At population level, children grow in height only when their weight-for-height improves at the end of the hunger season[9]. The pastoralist communities in Somalia predominantly live in the Northern region. Following prolong drought and famine in the region which has led to massive livestock losses, the pastoralists have been seen seasonally to migrate with their livestock to other regions with water and pasture. The seasonal migration is reflected in the shifting of the hotspots from one region to another[38].

This study has shown that wasting, stunting and underweight in children share similar spatial distribution in most of the regions of Somalia. In addition, the study provides risk factors common to each pair of the indicators. It is held that whereas wasting describes a recent and severe process that has led to significant weight loss, usually as a consequence of acute starvation and/or severe disease and stunting reflects the process of failure to reach linear growth potential as a result of suboptimal health and/or chronic nutritional deficiency[5], the etiology of both indicators may be similar at community level[9] and hence similar spatial distribution. This evidence therefore supports integrated programming and interventions focused on the common risk factors of the three indicators and specifically in regions where the co-distribution is highly prevalent. Wasting and stunting have been noted to vary differently depending on seasonal variations and age of the child. It is important to

implement timely interventions those coincide with the peaks of the different indicators in different times of the year and also at different stages of life of the child.

The consistency and timeliness of FSNAU survey data provides an opportunity to analyse the trends of malnutrition in Somalia. The use of individual level data has improved the estimates in our analysis as it accounted for the variability between children ensuing more accurate estimates than using of aggregated data. However, the use of WHO reference population may have limitations in some populations. It has been previously noted that children in Somalia have lower weight at birth and by 12-24 month these children are thinner and taller with half the stunting prevalence when compared to other children in the neighbouring East Africa countries [45]. Pastoral children's growth patterns may differ from those of children in populations with agricultural livelihoods for example[46]. The references may therefore underestimate malnutrition in some areas. The effect of conflict on malnutrition was not controlled in this study because the information was not captured during the FSNAU surveys. Further research should include conflict, and longitudinal studies should be undertaken to provide a better understanding of the relationship between wasting and stunting.

Conclusion

This study has demonstrated that the three indicators largely share common risk factors and that there is evidence of correlation in space[17 47]. The emergency response funding is by nature short term but there is compelling evidence to implement timely intervention of spatial patterns and trends of wasting and stunting depending on seasonal variation, the age and gender of the child. Although emergency nutrition response in Somalia focus on wasting, our evidence suggests implementing a more joined-up program of the indicators. This will require political will, appropriate financing, policies and programmatic links between the indicators.

Contributors: DKK, N-BK, SOM, AMN and JAB were responsible for the concept and design of the study. DKK, ETK and GAF were responsible for the development of the model. DKK led the data assembly process, data analysis and interpretation of results. GMM was responsible for conducting the surveys, cleaning and archiving the data. AMN N-BK, SOM and JAB were responsible for overall scientific oversight. All authors reviewed the manuscripts and contributed to the final submission.

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Data sharing: No additional data available.

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Figure legends

Figure 1: Correlation plots of weight-for-height, height-for-age and weight-for-age Z-scores among children under the age of five years in Somalia using survey data from 2007-2010.

Figure 2: Maps showing the crude prevalence of wasting (I), stunting (II) and underweight (II) by clusters surveys between 2007 and 2010 in Somalia. The country is divided into three main zones: South-central (A), Northeast (B) and Northwest (C). 78 clusters were sampled in Northwest zone, 85 clusters in the Northeast zone and 903 clusters in the South-central. The country's two main rivers, Juba and Shebelle are located in the South-central zone. Map I= Wasting, II = Stunting and III = Underweight.

Figure 3: There are three maps here: i) Posterior residual shared spatial relative risk common to wasting and stunting; ii) Posterior residual shared spatial prevalence common to stunting and underweight; iii) Posterior residual shared spatial prevalence common to wasting and underweight. The estimates are in percentage. Each map is plotted at 1 x 1 km spatial resolution among children aged 6 - 59 months in Somalia. South-central (A), Northeast (B) and Northwest (C). I=Wasting and Stunting, II=Stunting and Underweight, III=Wasting and Underweight.

Figure: 4: Estimated areas with shared component classified in four categories at 95% confidence level for children aged 6 - 59 months using the marginal probabilities calculated using quintile correction (QC) method[37]. I=Wasting and Stunting, II=Stunting and Underweight, III=Wasting and Underweight. South-central (A), Northeast (B) and Northwest (C).

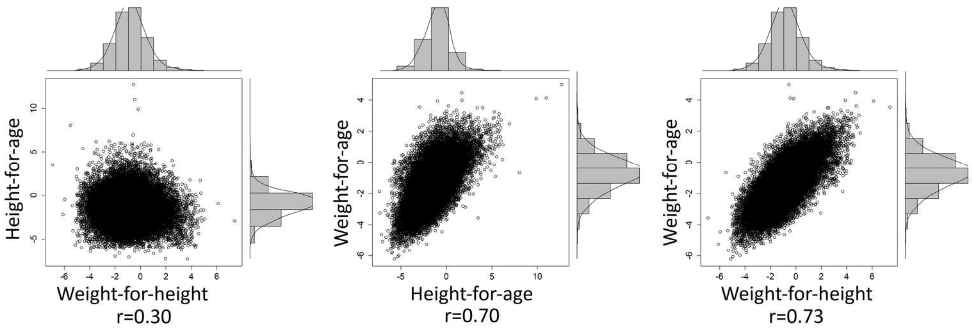
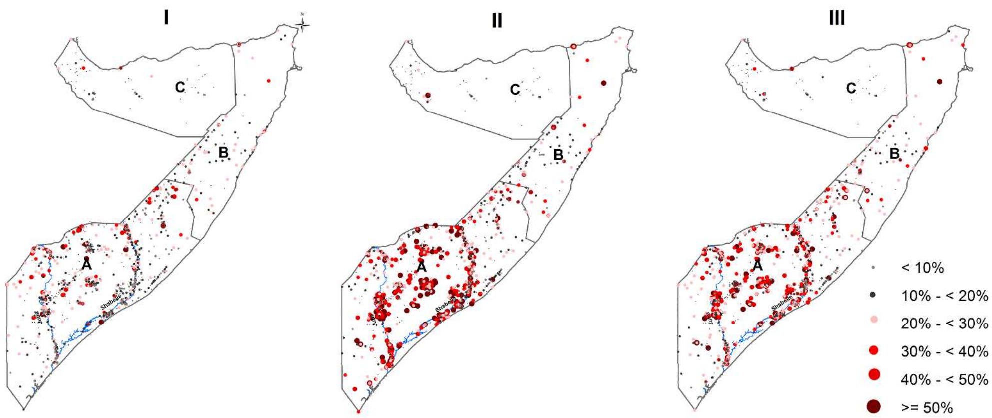


Figure 1: Correlation plots of weight-for-height, height-for-age and weight-for-age Z-scores among children under the age of five years in Somalia using survey data from 2007-2010.
169x57mm (300 x 300 DPI)



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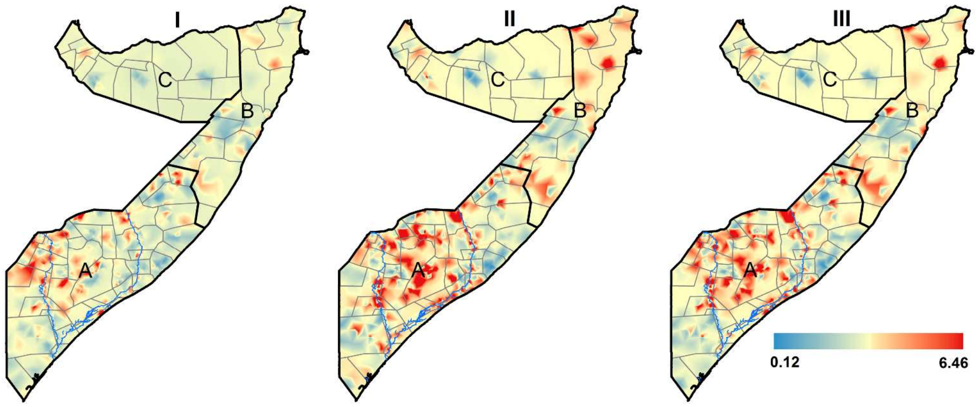
279x118mm (300 x 300 DPI)



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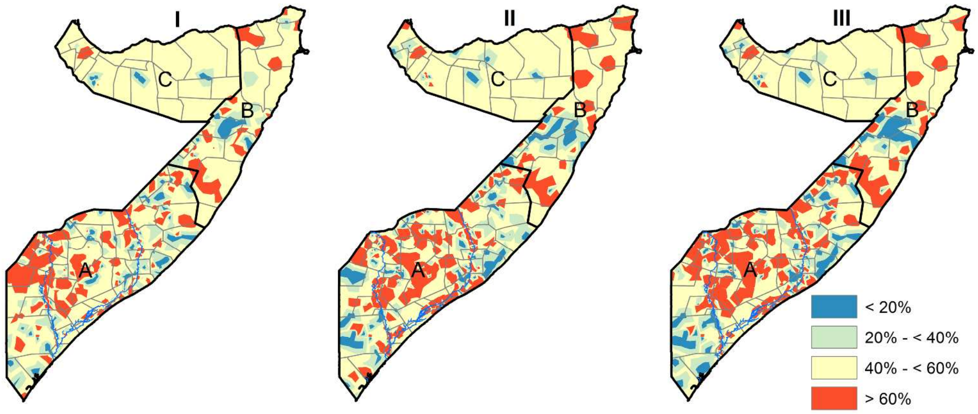
266x117mm (300 x 300 DPI)



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266x117mm (300 x 300 DPI)

Supplementary Information: Model procedures and model output

SI.1 Space-time Bayesian Geo-statistical shared component model

Disease mapping mainly focuses on modelling single disease yet many diseases share common risk factors[1]. This underscores the importance of joint analysis of health conditions to identify similar patterns in geographical variation and provide more substantial evidence on clustering of the underlying risk surface for integrated interventions[2]. Non-Bayesian multilevel models have been used to present joint spatial analyses of diseases[3]. Knor-Held suggested joint modelling approaches in Bayesian perspective as an improvement of Besag *et al* formulations[4]. Shared spatial component methods have been used extensively to jointly model risk of more than one disease outcome[2 5 6]. Lindgren et al 2013 suggested that one can express a large class of random field models as a solution to continuous domain stochastic partial differential equations (SPDEs), and develop explicit links between the parameters of each SPDE and the elements of precision matrices for the weights in a discrete basis function representation[7]. This SPDE is formulated as a link between Gaussian random fields (GRFs) and the Gaussian Markov Random Fields (GMRFs)[7].

In this study, we implemented the Bayesian geo-statistical shared component model of three nutritional indicators through SPDE approach using R-INLA library[7]. Suppose using logit model for wasting, stunting and underweight, effect of covariates and latent spatial effect,

$$\log it(p_{i1}) = \alpha_1 + S_{i1} \quad (1)$$

$$\log it(p_{i2}) = \alpha_2 + S_{i2} \quad (2)$$

$$\log it(p_{i3}) = \alpha_3 + S_{i3} \quad (3)$$

This is where p_{i1}, p_{i2}, p_{i3} were the relative risks for wasting, stunting and underweight in cluster i respectively. The parameter α_j is the disease-specific intercept, β_j s are the indicator specific risk coefficients associated with the risk vector x; and S is the latent spatial effect. The spatial effects in this model can be expressed as:

$$S_{1i} = u_{1i} + \beta_{12} u_{2i} \quad (4)$$

$$S_{2i} = u_{2i} + \beta_{23} u_{3i} \quad (5)$$

$$S_3 = u_3 + \beta_{31} u_{1i} \quad (6)$$

This is where u_{1i} is the shared component for wasting and stunting; u_{2i} is the shared component for stunting and underweight; u_{3i} is the shared component for wasting and underweight. β_{12}, β_{23} and β_{31} are the covariates effects of the shared components of wasting and stunting; stunting and underweight and wasting and underweight respectively[2 5].

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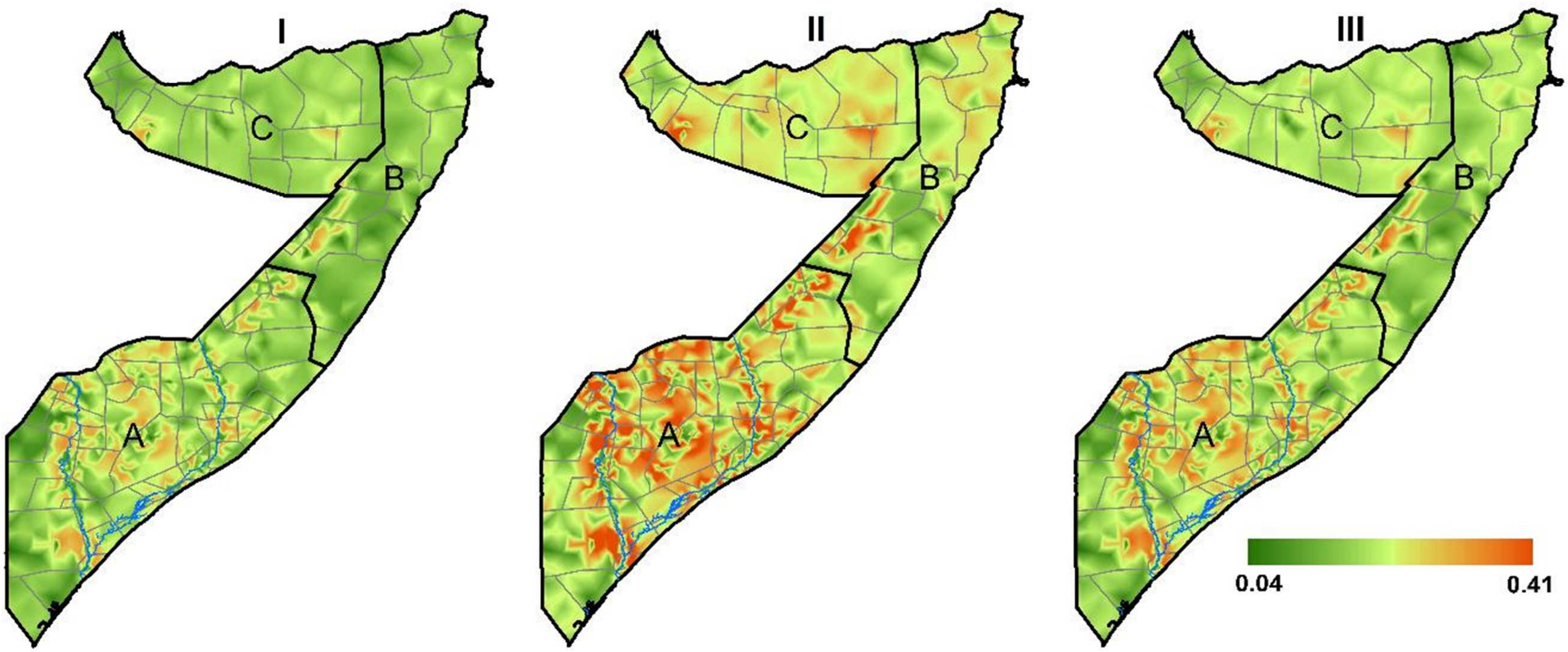

Figure SI. 2: Coefficients of variation at 1 x 1 km spatial resolution among children aged 6 - 59 months in Somalia. I=Wasting and Stunting, II=Stunting and Underweight, III=Wasting and Underweight. A=South-central zone, B=Northeast (Puntland) zone, C=Northwest (Somaliland) zone. 1=Wasting, 2=Stunting, 3=Underweight.

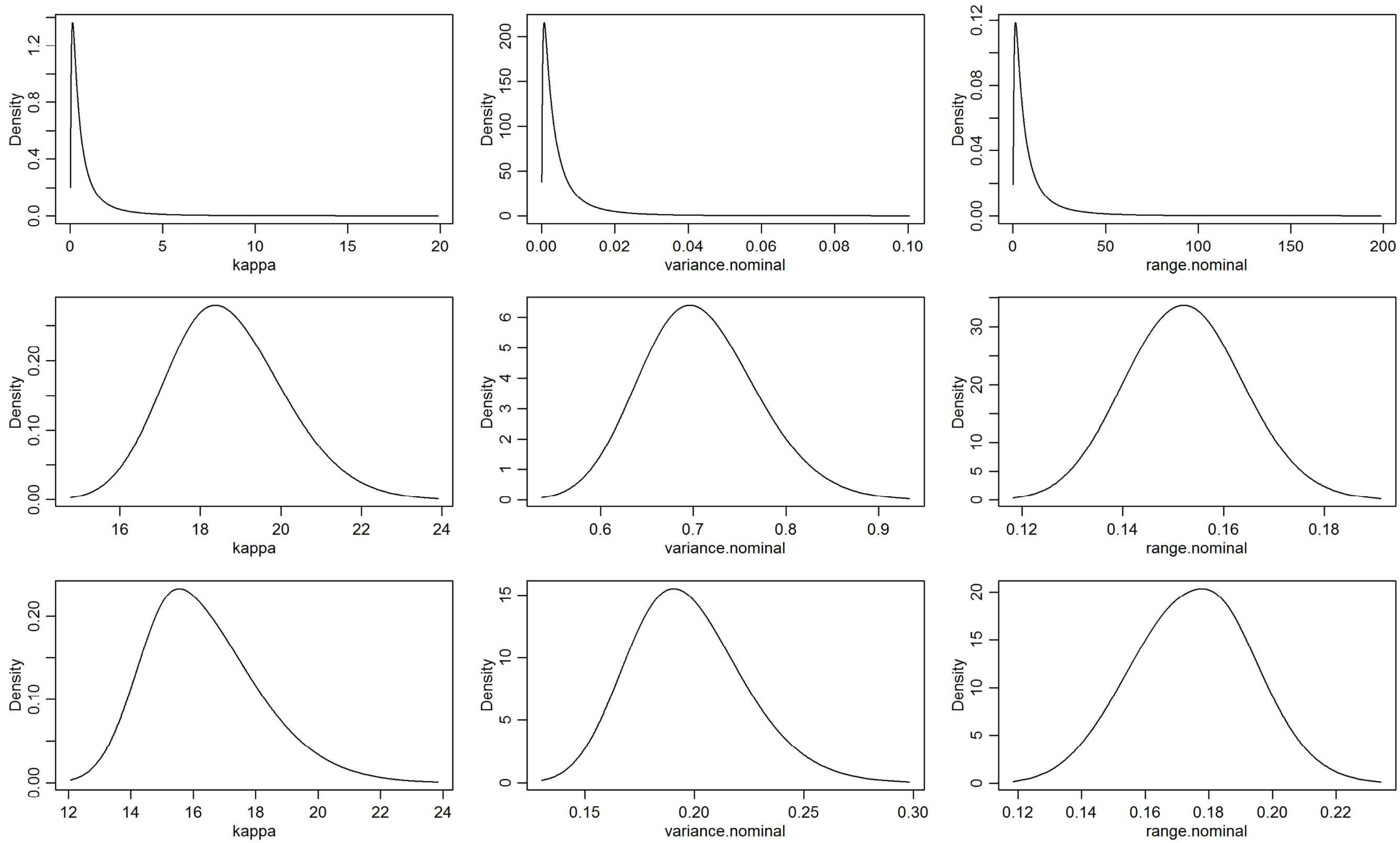

Figure SI. 3: Summary of the posterior marginal for kappa, variance and range of the three fields for the wasting, stunting and underweight.

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Assessing co-morbidity and correlates of wasting and stunting among children in Somalia using cross-sectional household surveys: 2007 to 2010

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Assessing co-morbidity and correlates of wasting and stunting among children in Somalia using cross-sectional household surveys: 2007 to 2010

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Abstract

Objective: Wasting and stunting may occur together at individual child level, however, their shared geographic distribution and correlates remains unexplored. Understanding shared and separate correlates may inform interventions. We aimed to assess the spatial co-distribution of wasting, stunting and underweight and investigate their shared correlates among children aged 6–59 months in Somalia.

Setting: Cross-sectional nutritional assessments surveys were conducted using structured interviews among communities in Somalia bi-annually from 2007 to 2010. A two-stage cluster sampling methodology was used to select children aged 6-59 months from households across three livelihood zones (pastoral, agro-pastoral and riverine). Using this data and environmental covariates, we implemented a multivariate spatial technique to estimate the co-distribution and divergence of the risks and correlates of wasting and stunting at 1 x 1 km spatial resolution.

Participants: 73,778 children aged 6-59 months from 1,066 survey clusters in Somalia.

Results: Observed pairwise child level empirical correlations were 0.30, 0.70 and 0.73 between weight-for-height and height-for-age; height-for-age and weight-for-age, and weight-for-height and weight-for-age respectively. Access to foods with high protein content and vegetation cover, a proxy of rainfall or drought, were strong correlates of wasting and stunting. Age, gender, illness, access to carbohydrates and temperature were correlates of all three indicators. The spatial co-distribution was highest between stunting and underweight with relative risk values ranging between 0.15 and 6.20, followed by wasting and underweight (range: 0.18 - 5.18) and lowest between wasting and stunting (range: 0.26 – 4.32).

Conclusion: The determinants of wasting and stunting are largely shared, but their correlation is relatively variable in space. Significant hotspots of different forms of malnutrition occurred in the South Central regions of the country. Although nutrition response in Somalia has traditionally focused on wasting rather than stunting, integrated programming and interventions can effectively target both conditions to alleviate common risk factors.

Strengths and limitations of this study

- We examined the shared risk factors of wasting, stunting and determined the shared spatial distribution to show regions where the co-distribution of the indicators are highly prevalent to inform policy development and implementation of interventions.

- Individual child level data improved the estimates in our analysis as it accounted for the variability between children ensuing more accurate estimates than using aggregated data.

- Sustained conflict that might exacerbate malnutrition in Somalia and which continues to be the primary reason for displacement affecting the South Central zone was not accounted for in this study.

Introduction

Malnutrition is one of the major causes of childhood deaths in developing countries[1 2]. Globally, in 2011, one in four children (26%, 165 million) were stunted, one in six (16%, 101 million) were underweight, and one in twelve (8%, 52 million) were wasted. More than 90% of undernourished people live in developing countries[3]. In Somalia, it was estimated that 35% of the population, approximately 2.85 million people, were affected by food security crisis in 2011. In Southern regions of the country, the prevalence of acute malnutrition was estimated to be at least 30%[4].

Indicators of nutritional status include biomarkers, body composition analysis, and simple anthropometry[5]. Wasting (low weight-for-length/height) and stunting (low height-for-age) are the most commonly used indicators for individual assessment, designing programs and assessing impact[6 7]. Stunting is thought to be an indicator of chronic or long-term nutritional inadequacy, while wasting is usually assumed to reflect an acute situation related to illness or lack of food[7]. Wasting and stunting are normally presented as distinct nutritional problems, contributing separately to mortality and disease[8]. A third indicator of malnutrition, underweight defined as low weight-for-age combines information on linear growth and bulk[9].

Studies in developing countries have shown that wasting and stunting may be dependent on each other when compared to a standard population[10 11]. If linear growth falters due to infection or poor diet, catch-up growth might be attained once the infection is eliminated or the diet improves. However in resource-poor settings, where dietary intake may be consistently inadequate or there is a high rate of infectious diseases, catch-up growth may be impossible, resulting in stunting[11 12]. In this context, wasting might precede linear growth retardation and therefore it is possible that wasting directly influences linear growth[13] however, currently this is uncertain. In general terms, the worldwide variation of low weight-for-age and its age distribution are similar to those of low height-for-age[14].

Due to prolonged drought, famine and conflict in Somalia, the rates of malnutrition persistently remain at “critical” levels and have been cited among the highest in the world[15 16]. The distribution of malnutrition varies across space and time, influenced by climatic conditions and other factors with definable spatial and temporal dependencies[17]. In Somalia, for example, conflict and drought lead to frequent displacement of vulnerable people leading to disruptions in livelihoods[18]. Stunting and underweight may be affected by the cumulative effect of intermittent rates of wasting. Children presenting with multiple forms of malnutrition have been reported to be at a higher risk of mortality when compared to children with one form of malnutrition[19]. This additive effect highlights the need to understand the common drivers and extent of coexistence of the indicators geographically in order to formulate effective strategies for intervention.

Previous analysis of the predictors of malnutrition in Somalia has focussed on separate anthropometric measures, but not common correlates[17]. In this study, we aimed to describe the spatial co-distribution between the rates of wasting, stunting and underweight controlling for the effect of other risk factors among children under the age of five years in Somalia from 2007 to 2010 using Bayesian geostatistical modelling approach[20]. We used a shared-component model to fit common unobserved and unmeasured spatial risks to determine the areas that the indicators are strongly correlated and identify common risk factors.

Methods

Survey Data

The data used for this study were obtained from surveys undertaken by the Somalia Food Security and Nutrition Unit (FSNAU) and were conducted in partnership with the United Nations Children’s Fund (UNICEF). The surveys were undertaken bi-annually from 2007-2010 to assess nutrition status and help with the planning of interventions[21 22]. Detailed descriptions of the survey methods and data collection are provided elsewhere[22]. A two-stage sampling method was used with livelihoods as the first level of sampling and clusters or villages as the second level. In Somalia, the livelihoods are broadly defined as agro-pastoral, pastoral and riverine.

Pastoral communities are those that engage primarily in livestock production and are nomadic. Agro-pastoral communities practice mixed crop and livestock production while those defined as riverine live along the two main rivers of the Juba and Shebelle and are primarily involved in crop production and river-based economy [23]. Somalia has four main seasons around which pastoral and agricultural activities depend: December to March is the 'Jilal' season, a harsh dry season; 'Gu' which is the main rainy season from April to June; from July to September is the second dry season, the 'Hagaa'; and the short rainy season known as 'Deyr' from October to December[24].

Survey and environmental covariates

The covariates used in this study were related to child, household, maternal and environmental factors. At child-level, Vitamin A supplementation in the last six months, diarrhoea, acute respiratory infections (ARI) and incidence of febrile illness in the last two weeks before the survey, polio and measles vaccination history, gender and age of the child were examined. At household level, the covariates used were household size and age structure, gender of the household head, and access to different types of foods in the last 24 hours. Seasonality and five environmental covariates associated with vector-borne diseases[25] and food security[26] were examined for modelling. These were rainfall, enhanced vegetation index (EVI), mean temperature, distance to water and urbanization. Rainfall and mean temperature were derived from the monthly average grid surfaces obtained from WorldClim database[27]. The EVI values were derived from the MODerate-resolution Imaging Spectroradiometer (MODIS) sensor imagery[28] for period 2007-2010 while the urbanization information was obtained from Global Rural Urban Mapping Project (GRUMP)[29]. All the environmental covariates were extracted from 1 x 1 km spatial resolution grids to data points. Rainfall, temperature and EVI were summarized to compute seasonal averages using the two main rainy seasons in Somalia.

Ethical approval

Ethical approval was provided through permission by the Ministry of Health Somalia, Transitional Federal Government of Somalia Republic, Ref: MOH/WC/XA/146./07, dated

02/02/07. Due to the high illiteracy rate of the population, informed verbal consent was sought from all participating households and individuals. An additional 10% was added to the sample size to allow for drop out or refusal to participate.

Statistical methods

We considered three outcome measurements describing the anthropometric indicators of malnutrition: low weight-for-height (wasting), low height-for-age (stunting), and low weight-for-age (underweight) as defined in WHO 2006 references[30]. A child was defined as wasted, stunted or underweight when he/she was below -2 Z scores[30].

Our analysis used joint modelling techniques for multiple health conditions[31-33] to investigate the geographical co-distribution of wasting, stunting and underweight and compute the shared correlates. The Integrated Nested Laplace Approximation (INLA) as implemented in R-INLA library was used to produce relative risk maps at 1 x 1 km spatial resolution[31 34]. In the prediction model, the main survey and environmental correlates of malnutrition were controlled at individual, household and community level. In this approach the relative risk of each condition is assumed to depend on these correlates and an underlying geographical risk shared by the three forms of malnutrition that contribute to overall risk, in addition to condition-specific risk elements[31]. We modelled three underlying spatial risks common to the three pairs of the conditions (wasting and stunting; stunting and underweight; wasting and underweight). We also computed the degree of uncertainty in the predicted prevalence based on the estimated distribution of the shared components using the quintile correction (QC) method as implemented by Bolin and Lindgren 2012[35]. We stratified the predicted prevalence of the shared components to generate maps that assigned each pixel into either of four classes: less than 20%; 20% - <40%; 40% - <60% and > 60% based on the predicted probabilities of class membership using the QC method[35]. Detailed description of the methods and additional outputs from this analysis can be found in the supplementary information (SI.1).

Results

A total of 73,778 children under the age of five years were examined from 1066 clusters and of which 15,735 (21%), 22,739 (31%) and 42,271 (58 %) were wasted, stunted and underweight respectively. A total of 6,640 (9%) children had both wasting and stunting; 21,396 (29%) children had both stunting and underweight and 14756 (20%) had both wasting and underweight. Fifty two percent of children were boys and the mean age of the children was 33 months. Other characteristics of the children measured during the surveys are shown in Table I. By livelihood zones, 42%, 27% and 16% of children were from areas of agro-pastoral, pastoral and riverine livelihoods respectively while 11% lived in internally displaced people (IDP) camps and 4% lived in urban areas.

Table I: Summary of survey data aggregated for the period 2007-2010 (FSNAU 2007-2010). *Gu* is the long rainy season and *Deyr* is the short rainy season from October to December in Somalia. Values in parentheses, next to the number of children, are percentages.

Characteristic	Number					
Total number of children examined	73778					
Total number of clusters examined	1066					
	Wasted; n = 15735 (21)	**Not wasted; n=58043 (79)**	**Stunted; n =22739 (31)**	**Not stunted ; n =51039 (69)**	**Underweight; n = 42791 (58)**	**Not underweight n=30987 (42)**
Child data	**Number (%)**		**Number (%)**		**Number (%)**	
Vitamin A supplementation	8995 (57)	33356 (57)	12853 (57)	29498 (58)	23771 (56)	17996 (58)
Measles vaccination	8367 (53)	30875 (53)	11919 (52)	27317 (54)	21761 (51)	16739 (54)
Polio vaccination	12346 (78)	46519 (80)	18272(80)	40647 (80)	33315 (78)	24964 (81)
Diarrhoea in the last 2 weeks	3749 (24)	10674 (18)	5136 (23)	9159 (18)	10280 (24)	5475 (18)
Acute Respiratory Infection	3797 (24)	12029(21)	5090 (22)	10647 (21)	9918 (23)	6400 (21)
Febrile Illness in the last 2 weeks	3793 (24)	11912 (21)	4849 (21)	10753 (21)	9483 (22)	6400 (21)
Suspected measles in last 1 month	788 (5),	2487 (4)	1026 (5)	2229 (4)	1901(4)	1363 (4)
Sex of the child	Male=9039 (57)	Male= 28761 (50)	Male=12776 (56)	Male= 24844 (49)	Male=23888 (56)	Male= 15958 (51)
Age of the child (in months)	Mean=33, Range=(6,59)	Mean = 33, Range=(6,59)	Mean =31, Range=(6,59)	Mean= 32, Range=(6,59)	Mean=32, Range=(6,59)	Mean = 33, Range=(6,59)
Age of the mother (in years)	Mean=30, Range = (15,60)	Mean = 30, Range = (15,60)	Mean=30, Range = (15,60)	Mean = 30, Range = (15,60)	Mean =30, Range = (14,60)	Mean = 30, Range = (15,60)
MUAC of mother in cm	Mean =21, Range=(18,38)	Mean = 22, Range=(18,38)	Mean=22, Range=(18,38)	Mean= 22, Range=(18,38)	Mean=22, Range=(18,38)	Mean = 22, Range=(18,38)
Food access data	**Number (%)**		**Number (%)**		**Number (%)**	
High carbohydrate foods in	15227 (97)	56059 (97)	22285(98)	49008 (96)	49009(96)	30023(97)

the last 24 hours						
High protein foods in the last 24 hours	13420 (85)	50543 (87)	19691 (87),	44322 (87)	36098 (84),	27151(88)
Fats in the last 24 hours	12327 (78)	46277(80)	17751 (78),	40880 (80)	32422(76),	25040 (81)
Fruits and vegetables in the last 24 hours	6423(41)	24835 (43)	10695 (47)	20665 (40)	18492 (43)	13068 (42)
Household data	**Mean (Range)**		**Mean (Range)**		**Mean (Range)**	
Household size	6 (2, 50)		6 (2, 50)		6 (2, 50)	
Number of under5	2 (1, 5)		2 (1, 5)		2 (1, 7)	
Household head gender	Male=60128 (81%)		Male=60128 (81%)		Male=60128 (81%)	
Cluster data	**Mean (Range)**		**Mean (Range)**		**Mean (Range)**	
Distance to water to major water bodies (km)	97 (0,508)		97 (0,508)		97 (0,508)	
Enhanced Vegetation Index (EVI)	0.18 (0,0.45)		0.18 (0,0.45)		0.18 (0,0.45)	
Precipitation (mm/year)	138 (0,350)		138 (0,350)		138 (0,350)	
Mean Temperature (˚c)	28 (21,31)		28 (21,31)		28 (21,31)	
Urbanization	Urban = 3318 (5%), Rural = 70460		Urban = 3318 (5%), Rural = 70460		Urban = 3318 (5%), Rural = 70460	
Season	April to June (*Gu*) = 47327(64%), October to November (*Deyr*) = 26451 (36%)		April to June (*Gu*) = 47327(64%), October to November (*Deyr*) = 26451 (36%)		April to June (*Gu*) = 47327(64%), October to November (*Deyr*) = 26451 (36%)	

The analysis of the correlates of malnutrition from the shared component model (Table II) shows that, male gender was associated with higher risk of all the three indicators of malnutrition (odds ratio (OR)=0.75, 95% credible interval (CrI): 0.72 - 0.79; OR=0.75, 95% CrI: 0.72 - 0.79; OR=0.83, 95% CrI: 0.79 - 0.87 for wasting, stunting and underweight respectively). Age 24 months or more was associated with decreased risk of wasting (OR=0.80, 95% CrI: 0.73 - 0.87) and increased risk of stunting (OR=1.76, 95% CrI: 1.61 – 1.91) and underweight (OR=1.99, 95% CrI: 1.84 -2.16). The risk of stunting was higher in children in the 12 – 24 months age group compared to the 24 – 59 months age group with 6 - 11 months as the reference group. Children who had diarrhoea and acute respiratory infection in the last two weeks had a higher risk of wasting (OR=1.30, 95% CrI: 1.22 – 1.38; OR=1.10, 95% CrI: 1.04 – 1.17), stunting (OR=1.24, 95% CrI: 1.18 – 1.31; OR=1.21, 95% CrI: 1.15 – 1.27), and underweight (OR=1.26, 95% CrI: 1.17 – 1.35; OR=1.08, 95% CrI: 1.01 – 1.15). Polio vaccination was found to be associated with decreased risk of wasting but increased risk of stunting and underweight (OR=0.88, 95% CrI: 0.82 – 0.95; OR=1.07, 95% CrI: 1.00 – 1.14; OR=1.09, 95% CrI: 1.01 – 1.18) respectively. Increase in age of the mother was associated with decreased rates of wasting, stunting and underweight until at the age of 40 years where further increase in age did not show significant association.

Increases in the household size and number of under-fives in the household were associated with increased risk of wasting and stunting, but not with underweight. Children who had consumed any of the staple sources of carbohydrates or proteins within the 24 hours prior to the survey had a lower risk of all the three indicators of malnutrition. In addition, children who had consumed fruits and vegetables had a higher risk of stunting and underweight. Vitamin A supplementation was associated with low risk of wasting (OR=0.80, 95% CI: 0.75 - 0.85) but was not associated with stunting and underweight. There was a significant association between the vegetation index (OR=0.66, 95% CrI: 0.45 -0.95), (OR=0.59, 95% CrI: 0.42 -0.82), (OR=0.69, 95% CrI: 0.67 – 0.72) and temperature (OR=1.07, 95% CrI: 1.03 – 1.11), (OR=1.05, 95% CrI: 1.01 - 1.10), (OR=1.12, 95% CrI: 1.07 – 1.17) with wasting, stunting and underweight respectively. Season was associated with wasting (OR=1.11, 95% CrI: 1.04 – 1.18) and underweight (OR=0.93, 95% CrI: 0.91-0.94), but had no association with stunting. Urbanization was associated with

decreased risk of wasting (OR=0.96, 95% CrI: 0.94 – 0.99), but was not associated with stunting and underweight.

Table II: Multivariate adjusted odds ratio (POR) and 95% credible interval (CrI) of wasting, stunting and underweight among children aged 6 – 59 months in Somalia. The estimates were derived from joint distribution modelling and the results are indicative of the effect of the shared components. Values in bold typeface are those that don't contain the value 1 in their 95% CrI and were considered statistically significant.

Correlates		Wasting		Stunting		Underweight	
		Odds ratio	CrI	Odds ratio	CrI	Odds ratio	CrI
Child data							
Vitamin A supplementation		**0.80**	**(0.75,0.85)**	1.00	(0.94,1.05)	1.01	(0.94,1.08)
Measles vaccination		1.04	(0.97,1.11)	0.96	(0.91,1.02)	0.93	(0.87,1.00)
Polio vaccination		**0.88**	**(0.82,0.95)**	**1.07**	**(1.00,1.14)**	**1.09**	**(1.01,1.18)**
Diarrhoea		**1.30**	**(1.22,1.38)**	**1.24**	**(1.18,1.31)**	**1.26**	**(1.17,1.35)**
Acute Respiratory Infection (ARI)		**1.10**	**(1.04,1.17)**	**1.21**	**(1.15,1.27)**	**1.08**	**(1.01,1.15)**
Febrile Illness		**1.15**	**(1.09,1.22)**	0.98	(0.93,1.03)	1.02	(0.95,1.09)
Suspected measles		1.05	(0.93,1.18)	0.97	(0.87,1.07)	0.98	(0.86,1.11)
Sex of the child (Female)		**0.75**	**(0.72,0.79)**	**0.75**	**(0.72,0.79)**	**0.83**	**(0.79,0.87)**
Child age (< 12 months as reference)	12 -< 24 months	**0.80**	**(0.73,0.88)**	**2.35**	**(2.15,2.57)**	1.05	(0.96,1.14)
	24 – 59 months	**0.80**	**(0.73,0.87)**	**1.76**	**(1.61,1.91)**	**1.99**	**(1.84,2.16)**
Age of the mother (20-30 years as reference)	< 20 years	**1.24**	**(1.09,1.42)**	**1.04**	**(1.02,1.06)**	**1.08**	**(1.01,1.16)**
	31-40 years	**0.91**	**(0.83,0.99)**	**0.87**	**(0.83,0.91)**	**0.94**	**(0.93,0.95)**
	41-50	**0.88**	**(0.83,0.93)**	**0.91**	**(0.84,0.99)**	1.01	(0.88,1.15)
	> 50 years	0.92	(0.85,1.01)	0.76	(0.49,1.17)	1.01	(0.49,2.08)
MUAC of mother		0.99	(0.99,1.00)	1.00	(1.00,1.00)	**0.99**	**(0.98,0.99)**
Household data							
Household size		**1.14**	**(1.13,1.15)**	**1.27**	**(1.25,1.28)**	1.00	(0.99,1.01)
Number of under5		**1.06**	**(1.03,1.09)**	**1.80**	**(1.76,1.85)**	1.00	(0.97,1.04)
Female household head		0.95	(0.89,1.02)	**0.87**	**(0.82,0.92)**	0.98	(0.92,1.05)
Food access data							
High carbohydrate foods		**0.83**	**(0.79,0.88)**	**0.82**	**(0.78,0.86)**	**0.92**	**(0.87,0.97)**
High protein foods		**0.57**	**(0.55,0.59)**	**0.51**	**(0.49,0.52)**	**0.90**	**(0.87,0.93)**
Fats		1.04	(0.98,1.12)	**0.92**	**(0.87,0.98)**	**1.10**	**(1.02,1.18)**
Fruits and vegetables		0.97	(0.93,1.01)	**1.04**	**(1.01,1.08)**	**1.07**	**(1.03,1.12)**

Cluster data						
Season (October to November as reference)	**1.11**	**(1.04,1.18)**	1.04	(0.98,1.10)	**0.93**	**(0.91,0.94)**
Distance to water	1.00	(1.00,1.00)	1.00	(1.00,1.00)	1.00	(1.00,1.00)
Enhanced Vegetation Index (EVI)	**0.66**	**(0.45,0.95)**	**0.59**	**(0.42,0.82)**	**0.69**	**(0.67,0.72)**
Rainfall	**0.88**	**(0.79,0.98)**	1.09	(0.96,1.22)	0.95	(0.86,1.06)
Temperature	**1.07**	**(1.03,1.11)**	**1.05**	**(1.01,1.10)**	**1.12**	**(1.07,1.17)**
Urbanization	**0.96**	**(0.94,0.99)**	1.00	(0.97,1.04)	0.97	(0.94,1)

The linear correlation between weight-for-age and weight-for-height was 0.73 and that between height-for-age and weight-for-age was 0.70 (Figure 1). However, at 0.30, the correlation between weight-for-height and height-for-age was low.

Figure 2 shows the spatial distribution of the observed prevalence of wasting, stunting and underweight by cluster for FSNAU nutrition surveys conducted from 2007 to 2010. The relationship in spatial distributions were significant for the three pairs of indicators :(OR=2.58, 95% CrI: 1.32 – 5.01) for wasting and stunting; (OR=3.93, 95% CrI: 3.37 – 4.59) for stunting and underweight and (OR=2.04, 95% CrI: 1.92 – 2.17) for wasting and underweight. Estimated common spatial patterns are shown in Figure 3. The maps reveal geographical variation in relative risk of the three indicators. The shared component displayed a strong spatial gradient in the South-North direction in all the shared components examined in this study. This confirms a high risk of all forms of malnutrition in the southern regions, especially around the two main rivers of Juba and Shebelle, compared to North regions of Somalia. The relationship in the spatial distribution was highest between stunting and underweight with relative risk values ranging between 0.15 and 6.20, followed by wasting and underweight (0.18 - 5.18) and lowest between wasting and stunting (0.26 – 4.32) with larger effects observed in the southern regions of Somalia. The risk stratified maps of the predicted prevalence are shown in Figure 4. The standard deviations ranged from 0.04 to 0.40 (Figure SI. 1). Summaries of the parameters used in the joint modelling for the three indicators of nutrition status are shown in Figure SI. 2.

Discussion

We have implemented a joint spatial analysis of malnutrition among children under the age of five years in Somalia to identify shared and separate covariate and spatial components of wasting, stunting and underweight. The correlation between regional means of relative risks was highest between stunting and underweight, followed by wasting and underweight, while the correlation between wasting and stunting was relatively low. There were several common underlying components of the three measures that influenced the spatial co-distribution of the three indicators of malnutrition in Somalia. Research and nutrition programmes have focused

on wasting and stunting in accessing nutritional status, designing programs, and assessing impact and therefore our discussion will focus on these two indicators[8 36-38]. Access to foods high in protein and vegetation cover, a proxy of rainfall or drought, were strong correlates of wasting and stunting. Age, gender, illness, access to carbohydrates and temperature were also common correlates of all three indicators.

Stunting increases throughout the first 2-3 years of life in many developing countries, whereas wasting occurs during the first year of life after which it stabilizes, as expected[10]. Wasting was also noted to have a relatively shorter duration and greater seasonal variability when compared with stunting[10]. This may explain the observed low association between wasting and stunting. Thus, the use of cross sectional survey data to describe trends in wasting may have some limitations since the observed prevalence has short interval fluctuations and varying substantially between seasons[39]. As a result, a high incidence of wasting of short duration might be missed, misrepresenting the relationship of wasting with the other indicators. Longitudinal data which follow children's growth from birth looking at the wasting, stunting and the combination of the two can provide better understanding of the relationships[11].

Food insecurity and infectious diseases differ between region and livelihoods system resulting from a combination of harsh environmental conditions and prolonged conflict and civil insecurity[38]. In this study, access to food and infections were major factors associated across the three indicators of malnutrition and this reaffirms the strong shared component of wasting and stunting in the southern relative to the northern regions in Somalia[22]. For example, there are currently about 400,000 internally displaced people (IDPs) in Somalia, mostly from the Southern minority groups. Half of this population lives in Mogadishu almost completely out of reach of any concrete internal assistance[22]. This is one area that had consistently strong shared components of the malnutrition indicators in this study. Kismaayo, also another consistent hotspot, has been host to numerous internally displaced persons (IDPs) seeking refuge from drought and conflict in the Juba and other neighbouring regions[40]. IDPs are considered to be

among the poorest population groups in the country with high levels of food insecurity with poor living conditions that predispose them to various infectious diseases[40].

According to 2010 estimates, agriculture accounts for 65% of the gross domestic product (GDP), with livestock representing 40% of the GDP and 65% of the export earnings in Somalia. However, farming and pastoralist livelihoods have been hindered by the long-standing civil war and the internal displacements of populations[40]. In addition, unpredictable rainfall seasonality, anomalies and consequent droughts have played a role. In our analysis, EVI, a satellite imagery derived variable which characterizes the global range of vegetation state was a significant common factors across the indicators of malnutrition. High EVI values indicates vegetated areas that reflect forested areas, riverine vegetation and more importantly local agriculture which has a direct relationship with the local food security. Highly vegetated areas (as demarcated by high EVI values) are a product of a combination of several variables including rainfall, seasonal and permanent water sources and to some extent underground water. In arid and semi-arid areas, agricultural activities are limited to areas with reliable water supply. Temperature was also found to be an important correlate of malnutrition. Temperature is directly linked to aridity [41] which in turn has an impact on malnutrition[26]. High temperature values are reported in Somalia rising up to 40°c in the Hagaa dry season[42] between the months of July and September. The seasonal variation in these environmental factors also affect the intra-annual variations of the burden of malnutrition, with wasting particularly sensitive to seasonality in Somalia and other places [39 43]. Seasonality not only affects the general availability of food, the rates of infection, but in Somalia, which is heavily dependent on pastoral and subsistence agriculture, undermines household income and resilience[40]. Among the pastoralist communities in Somalia, who are predominantly in the northern regions, the seasonal migration in search of water and pasture for their livestock has been a mechanism of mitigating the adverse effects of droughts and may contribute to the spatial variability of hotspots from year to year[40].

Our findings suggest that integrated programming and interventions focused on the common risk factors of the three indicators and specifically in regions where the co-distribution is highly

prevalent may be a more effective way of reducing the burden of malnutrition in Somalia. Currently, however, the funding for nutrition programme in Somalia is limited, unstable and often short term, preventing investment in longer term sustainable and resilience-building programmes[38]. As a result, for the large part humanitarian organizations are obliged to focus on high impact, 'life-saving' interventions to treat acute malnutrition without opportunities to invest in preventative programmes to reduce the overall caseloads and risk of undernutrition at scale[38]. Much of this is due to the focus of response in Somalia being emergency-driven. However the information provided by this study on the common drivers and the extent of geographical coexistence of wasting and stunting, can be used to develop more informed and planned interventions to achieve maximum impact within the short term and available funding.

Information generated from this study could also help in the development of an improved nutrition surveillance system with sensitive indicators of the different forms of undernutrition. This would include modifying data collection tools to reflect the main drivers of malnutrition and strategically position surveillance centers in regions that would provide the right information for intervention at the right time to inform the most appropriate response and maximize impact and investment[44].

The consistency and timeliness of FSNAU survey data provides an opportunity to analyse the trends of malnutrition in Somalia. The use of individual level data has improved the estimates in our analysis as it accounted for the variability between children ensuing more accurate estimates than using of aggregated data. However, the use of WHO reference population may have limitations in some populations. It has been previously noted that children in Somalia have lower weight at birth and by 12-24 month these children are thinner and taller with half the stunting prevalence when compared to other children in the neighbouring East Africa countries [45]. Pastoral children's growth patterns may differ from those of children in populations with agricultural livelihoods for example[46]. The references may therefore underestimate malnutrition in some areas. The effect of conflict on malnutrition was not controlled in this study because the information was not captured during the FSNAU surveys. Further research

should include conflict, and longitudinal studies should be undertaken to provide a better understanding of the relationship between wasting and stunting.

Conclusion

This study has demonstrated that wasting, stunting and underweight in children 6-69 months in Somalia share common risk factors with evidence of correlation in space[17 47]. The emergency response funding is by nature short term but there is compelling evidence to implement timely intervention of spatial patterns and trends of wasting and stunting depending on seasonal variation, the age and gender of the child. Although emergency nutrition response in Somalia focuses on wasting, our evidence suggests implementation of a more joined-up program is possible. This will require political will, appropriate financing, policies and programmatic links between the indicators.

Contributors: DKK, N-BK, SOM, AMN and JAB were responsible for the concept and design of the study. DKK, ETK and GAF were responsible for the development of the model. DKK led the data assembly process, data analysis and interpretation of results. GMM was responsible for conducting the surveys, cleaning and archiving the data. AMN N-BK, SOM and JAB were responsible for overall scientific oversight. All authors reviewed the manuscripts and contributed to the final submission.

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Competing Interests: None declared

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Figure legends

Figure 1: Correlation plots of weight-for-height, height-for-age and weight-for-age Z-scores among children aged 6-59 months in Somalia using survey data from 2007-2010.

Figure 2: Maps showing the observed prevalence of wasting (I), stunting (II) and underweight (II) by clusters surveys between 2007 and 2010 in Somalia. The country is divided into three main zones: South Central (A), North East (B) and North West (C). 78 clusters were sampled in North West zone, 85 clusters in the North East zone and 903 clusters in the South Central. The country's two main rivers, Juba and Shebelle are located in the South Central zone. Map I= Wasting, II = Stunting and III = Underweight.

Figure 3: Maps of the relationships of spatial distribution residual relative risks common to: I) wasting and stunting; II) stunting and underweight; and III) wasting and underweight among children aged 6 - 59 months in Somalia. Each map is plotted at 1 x 1 km spatial resolution. South Central (A), North East (B) and North West (C).

Figure: 4: Estimated shared components classified at 95% credible level among children aged 6-59 months using the marginal probabilities calculated using quintile correction (QC) method[35]. I=Wasting and Stunting, II=Stunting and Underweight, III=Wasting and Underweight. South Central (A), North East (B) and North West (C).

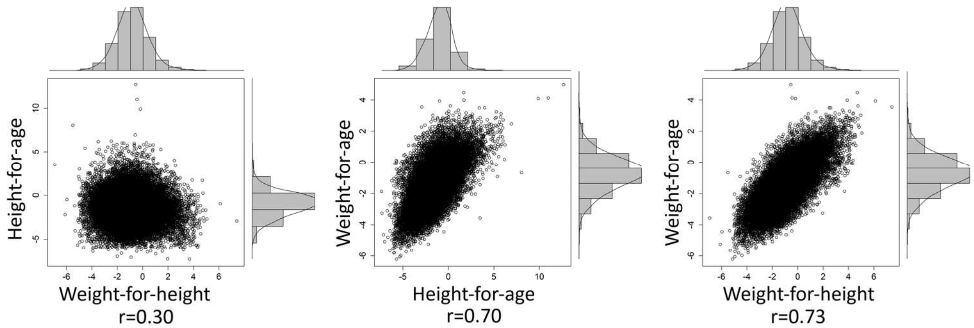

Figure 1: Correlation plots of weight-for-height, height-for-age and weight-for-age Z-scores among children aged 6-59 months in Somalia using survey data from 2007-2010.
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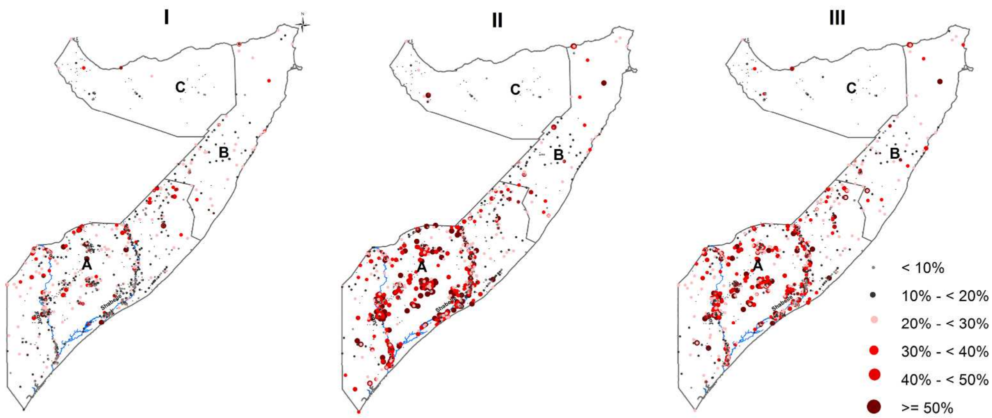

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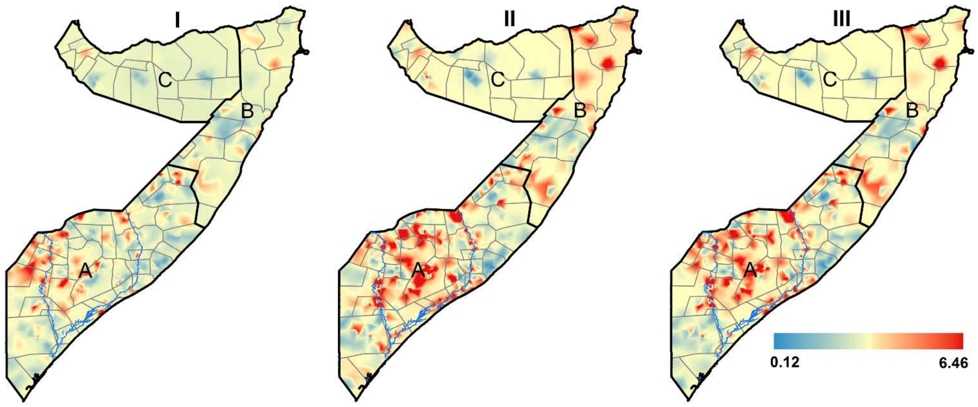

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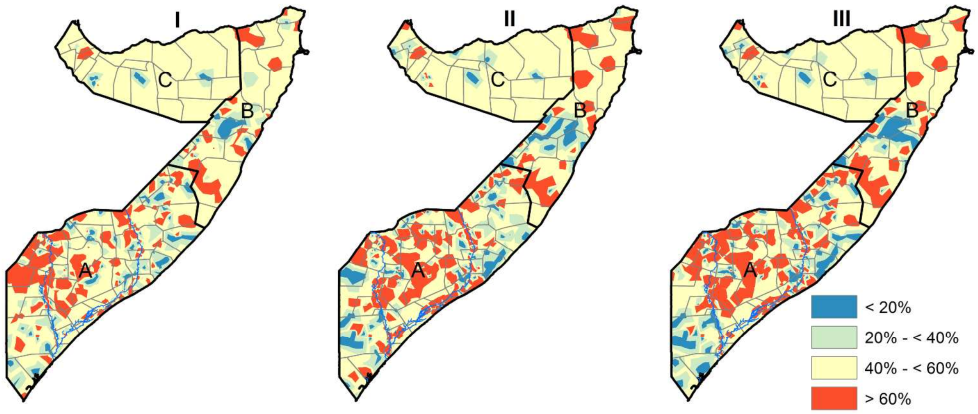

Figure: 4: Estimated shared components classifies at 95% credible level among children aged 6 - 59 months using the marginal probabilities calculated using quintile correction (QC) method35. I=Wasting and Stunting, II=Stunting and Underweight, III=Wasting and Underweight. South Central (A), North East (B) and North West (C).
266x117mm (300 x 300 DPI)

Supplementary Information: Model procedures and model output

SI.1 Space-time Bayesian Geo-statistical shared component model

Disease mapping mainly focuses on modelling single disease yet many diseases share common risk factors[1]. This underscores the importance of joint analysis of health conditions to identify similar patterns in geographical variation and provide more substantial evidence on clustering of the underlying risk surface for integrated interventions[2]. Non-Bayesian multilevel models have been used to present joint spatial analyses of diseases[3]. Knor-Held suggested joint modelling approaches in Bayesian perspective as an improvement of Besag *et al* formulations[4]. Shared spatial component methods have been used extensively to jointly model risk of more than one disease outcome[2 5 6]. Lindgren et al 2013 suggested that one can express a large class of random field models as a solution to continuous domain stochastic partial differential equations (SPDEs), and develop explicit links between the parameters of each SPDE and the elements of precision matrices for the weights in a discrete basis function representation[7]. This SPDE is formulated as a link between Gaussian random fields (GRFs) and the Gaussian Markov Random Fields (GMRFs)[7].

In this study, we implemented the Bayesian geo-statistical shared component model of three nutritional indicators through SPDE approach using R-INLA library[7]. Suppose using logit model for wasting, stunting and underweight, effect of covariates and latent spatial effect,

$$\log it(p_{i1}) = \alpha_1 + S_{i1} \quad (1)$$

$$\log it(p_{i2}) = \alpha_2 + S_{i2} \quad (2)$$

$$\log it(p_{i3}) = \alpha_3 + S_{i3} \quad (3)$$

This is where p_{i1}, p_{i2}, p_{i3} were the relative risks for wasting, stunting and underweight in cluster i respectively. The parameter α_j is the disease-specific intercept, β_j s are the indicator specific risk coefficients associated with the risk vector x; and S is the latent spatial effect. The spatial effects in this model can be expressed as:

$$S_{1i} = u_{1i} + \beta_{12} u_{2i} \quad (4)$$

$$S_{2i} = u_{2i} + \beta_{23} u_{3i} \quad (5)$$

$$S_3 = u_3 + \beta_{31} u_{1i} \quad (6)$$

This is where u_{1i} is the shared component for wasting and stunting; u_{2i} is the shared component for stunting and underweight; u_{3i} is the shared component for wasting and underweight. β_{12}, β_{23} and β_{31} are the covariates effects of the shared components of wasting and stunting; stunting and underweight and wasting and underweight respectively[2 5].

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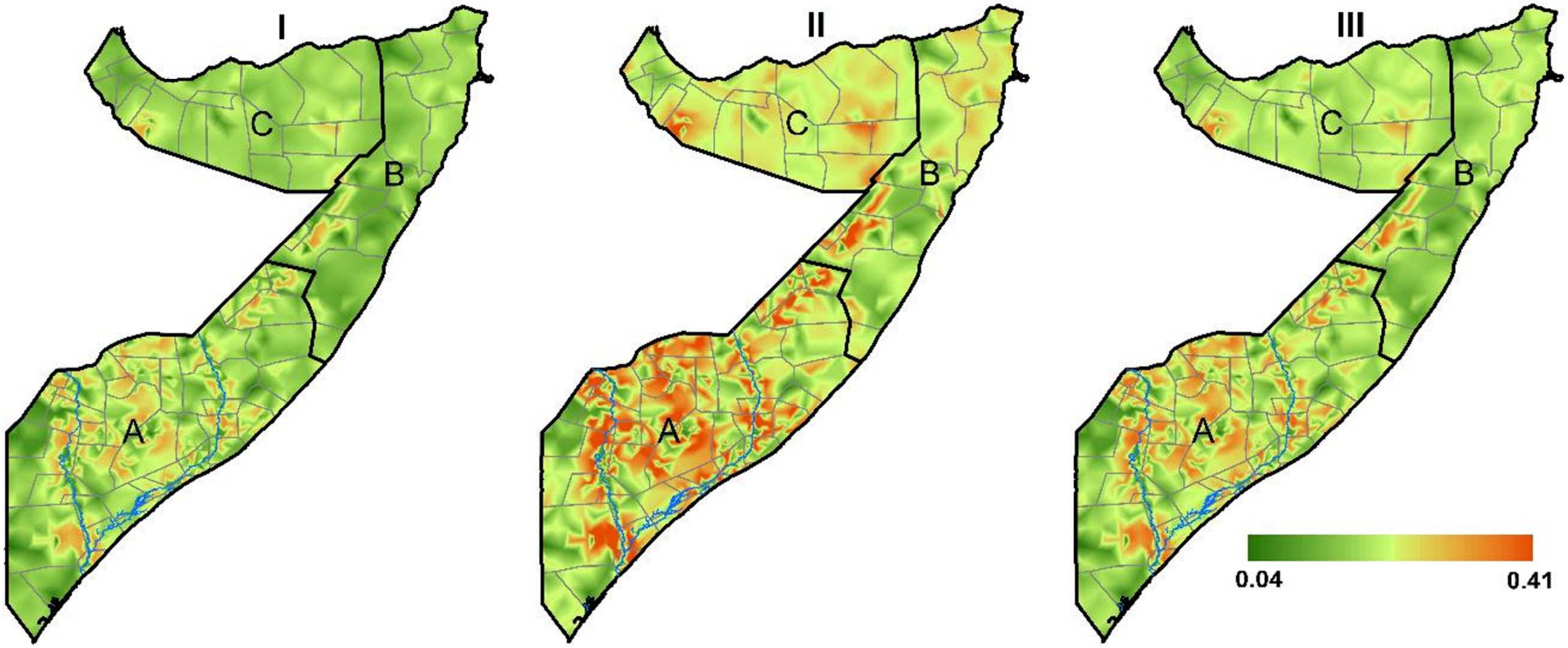

Figure SI. 1: Coefficients of variation at 1 x 1 km spatial resolution among children aged 6 - 59 months in Somalia. I=Wasting and Stunting, II=Stunting and Underweight, III=Wasting and Underweight. A=South-central zone, B=Northeast (Puntland) zone, C=Northwest (Somaliland) zone. 1=Wasting, 2=Stunting, 3=Underweight.

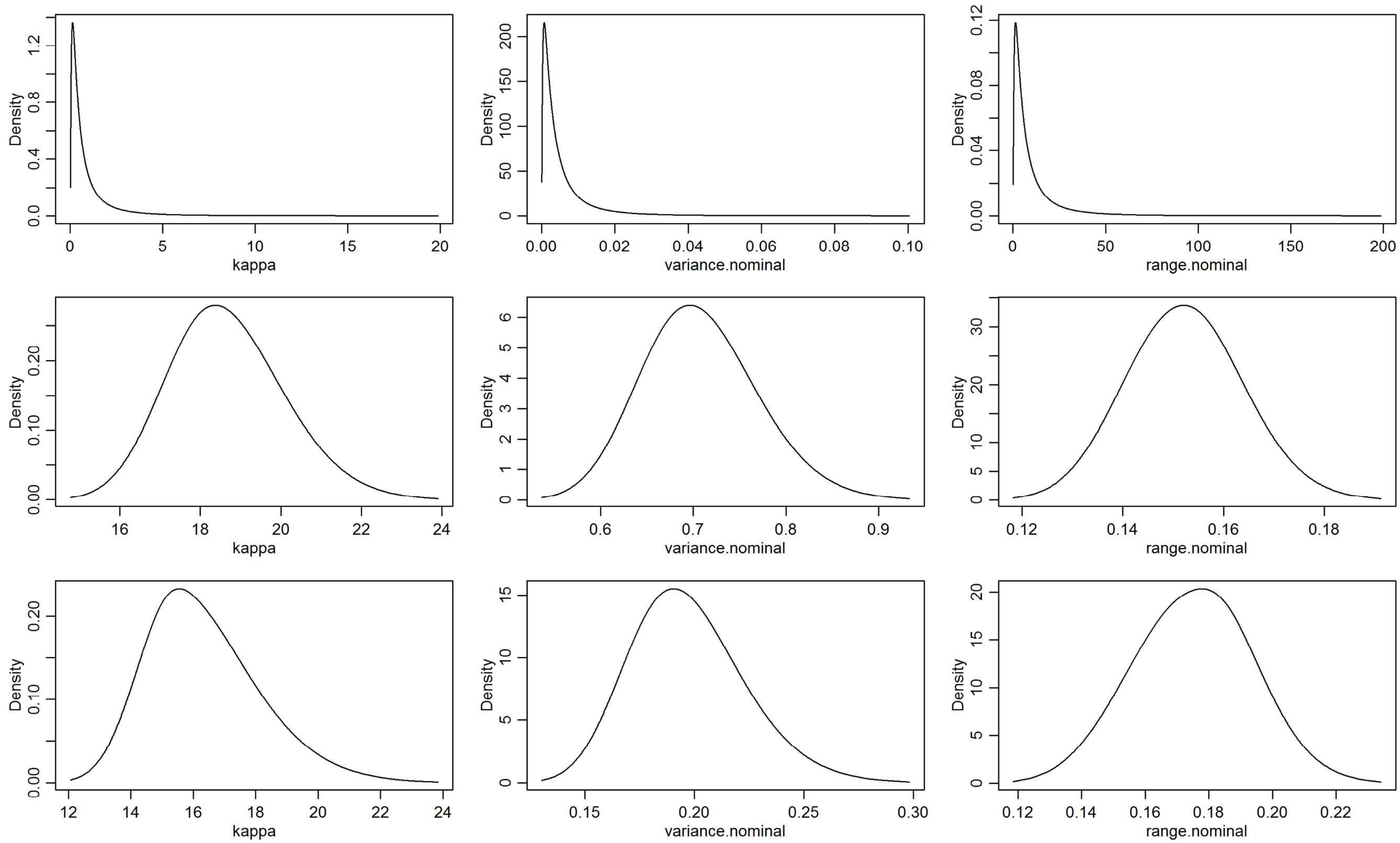

Figure SI. 2: Summary of the posterior marginal for kappa, variance and range of the three fields for the wasting, stunting and underweight.

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Assessing comorbidity and correlates of wasting and stunting among children in Somalia using cross-sectional household surveys: 2007 to 2010

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