Distribution Agreement

Signature:

______________________________ _______________

Jessica Anne Korona Date

A Geospatial Analysis of Community Sanitation Infrastructure on Child Health Outcomes

By

Jessica Anne Korona
Master of Public Health

Epidemiology

____
Thomas F. Clasen
Committee Chair

____
Heather Reese
Committee Member

A Geospatial Analysis of Community Sanitation Infrastructure and Child Health Outcomes

By

Jessica Anne Korona

BS, Biology
Baylor University
2015

Thesis Committee Chair: Thomas F. Clasen, PhD

An abstract of
a thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Epidemiology
2017

Abstract

A Geospatial Analysis of Community Sanitation Infrastructure and Child Health Outcomes

By
Jessica Anne Korona

Background: An estimated 2.4 billion people lack access to improved sanitation facilities. 60% of those practicing open defecation reside in India. The Millennium Development Goals made progress, however, as of 2015 less than 50% of India's population has access to improved sanitation. While sanitation coverage is believed to be protective against child disease, high levels of community coverage may be necessary to realize health gains. This can be explored through spatial analysis of community sanitation coverage and child disease.
Methods: This is a secondary analysis of geospatial data from households in 45 intervention villages in a matched-cohort study designed to assess the effectiveness of combined community-level water and sanitation intervention implemented by Gram Vikas. Clusters of high coverage improved sanitation coverage and low coverage unimproved sanitation coverage were calculated using Bernoulli's spatial scan statistic in SaTScan at distances of 250, 500, 750, and 1000 meters. Binary variables were created to designate presence in a cluster of improved sanitation at each distance. This exposure was used to model diarrhea, child stunting, underweight, and continuous HAZ and WAZ in multivariate logistic and linear regression adjusting for random effects of clustering.
Results: Presence in a cluster of improved sanitation coverage at 500m was protective against child stunting (OR=0.83, 95%CI:0.73-0.94). This relationship remained the same when adjusting for child's sex and age, but decreased when adjusting for household caste and wealth quintiles (OR=0.91, 95%CI:0.91-1.02). The effect was the similar for child underweight. A significant relationship was determined between presence in a cluster of improved sanitation and height and weight for age z-scores (HAZ, WAZ). When present in a cluster, there is a 0.32 increase in HAZ adjusting for child's sex, age, household caste, and wealth quintile (p=0.0154). The effect is a 0.38 increase looking at WAZ (p=0.0003).
Conclusion: This study illuminates the importance of achieving community level sanitation in rural India. Residing in a cluster of improved sanitation is protective for HAZ and WAZ. Future research and sanitation programs should work to promote 100% sanitation coverage and use in communities, consistent with the Sustainable Development Goals.

A Geospatial Analysis of Community Sanitation Infrastructure and Child Health Outcomes

By

Jessica Anne Korona

BS, Biology
Baylor University
2015

Thesis Committee Chair: Thomas Clasen, PhD

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Epidemiology
2017

Table of Contents

I. Literature Review

Global Sanitation

An estimated 2.4 billion people are without access to improved sanitation facilities (1). The Millennium Development Goals (MDGs) designated goal 7 to ensure environmental sustainability through reducing the proportion of people without sustainable access to basic sanitation by half by 2015. However, the world has missed the MDG sanitation target of 77% sanitation coverage by 9%, the equivalent of 700 million people. Since 1990, 2.1 billion people have gained access to improved sanitation. However, in rural areas, seven out of ten people are still without improved sanitation facilities and nine out of ten people still practice open defecation (1). The countries with the lowest sanitation coverage are concentrated in Sub-Saharan Africa and South Asia.

With the end of the MDGs in 2015, the United Nations and other parties put into action the (SDGs), which are an additional set of goals to achieve and surpass the unfinished MDGs while keeping in mind equity, human rights, and non-discrimination (2). Goal 6 of the SDGs is to ensure access to water and sanitation for all. By 2030, goal 6 aims to “achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations”(3).

Sixty percent of the 2.4 billion people worldwide practicing open defecation reside in India (1). Moderate sanitation progress has been made in India according to the 2015 Update and Millennium Development Goals Assessment. However, as of 2015, less than 50% of India has access to improved sanitation (1).

The deficiencies in latrine coverage are apparent in the eastern state of Orissa. In 2001, 85.1% of households in Orissa had no latrine, while in 2011, 75.4% had no latrine. These statistics show that latrine coverage has increased by 7.5% to 24.6% in Orissa however, the state still lags behind the rest of India who's country wide average of latrine coverage is 46.9% as of the 2011 census report. (4).

Moreover, there is a large gap between rural and urban sanitation coverage, with 49% of the urban population having access while only 6% of the rural population has access to improved sanitation. The rural discrepancy in sanitation coverage is apparent in Orissa where 10.5% of the rural population has access to a toilet facility while 61.3% of the urban population has access (5). India has had a number of sanitation campaigns in the past with the goal of increasing latrine coverage, however, these endeavors have not kept up with the expansive population growth in India. Over 44% of the population in Orissa is categorized as below the poverty line (BPL) (6). Different initiatives have developed access to improved drinking water sources, the majority of which are community level, however sanitation facilities lag behind (5).

Disease Burden

Inadequate water, sanitation, and hygiene are responsible for a significant disease burden. Worldwide, the World Health Organization (WHO) estimates that, 3.6% of the total disability adjusted life years (DALYs) is due to diarrheal diseases. This includes an estimated 1.5 million deaths each year (7). 842,000 deaths, or 58% of the disease burden is associated with unsafe water supply, sanitation, and hygiene and includes 361,000 deaths of children under age five in developing countries (7).

Open defecation practices have been linked with childhood stunting. One ecological analysis from 112 districts in India showed a 0.7% increase in stunting and severe stunting (10). Poor sanitation in the environment can be damaging to child health. Children living in areas with poor sanitation are at risk for diarrhea, helminth infections, and also persistent exposure and infection from environmental pathogens (11). Persistent exposure to these pathogens can lead to a condition called environmental enteropathy, which causes decreased absorptive capacity leading to a reduction in nutrient absorption. This could ultimately result in slow growth when coupled with poor nutrition and continued infections (12). Repeated diarrheal infections can have lasting impacts on the growth of children during critical stages of development.

About 25% of children under age five worldwide have an increased mortality associated with stunted growth, cognitive dysfunction, and loss of productivity (13). According to a study by Caulfield and colleagues (2004), the relative risk of mortality because of low weight-for-age was elevated for each cause of death for all cause mortality. In younger children, 52.5% of deaths are connected to malnutrition with 60.7% of deaths connected to diarrhea.

In Southeast Asia, the WHO's region for India, 2,658,000 DALY's are attributed to inadequate water, sanitation, and hygiene (14). Southeast Asia ranks highest for death attributed to both diarrheal diseases and soil transmitted helminth infections. There are 600,000 deaths associated with diarrheal diseases and 3,000 deaths associated with soil-transmitted helminth infections (7).

In India alone, the total number of DALYs attributable to water, sanitation, and hygiene is 305 million. 1,562 per 100,000 DALYs are attributed to diarrheal diseases and 610 per 100,000 DALYs are attributed to intestinal nematode infections (15). Post neonatally, 9% of deaths are attributed to diarrheal diseases. Childhood malnutrition and underweight are among the top 15 risk factors for the burden of disease in India. About 3% of wasting is due to diarrheal diseases and nearly 1% is due to nutritional deficiencies (16). These diseases are all preventable with proper sanitation practices, however, those are lacking in much of the world.

Transmission Pathways

The WHO defines improved sanitation as facilities that separate human excreta from human contact (1). If improved sanitation facilities are not available, and are not being utilized, enteric pathogens can be introduced into the environment. Disease transmission can occur through direct person-to-person contact, or indirect contact through fomites, food, water, or insect vectors of disease. Transmission can occur by mouth through contaminated food or water or by skin through STHs (17). Human excreta can travel in the environment infecting individuals far from the source of environmental exposure making it important to treat, or dispose of waste near the source discontinuing further exposure (17).

Open defecation

Open defecation is a common practice in rural communities. If no latrine facility is available, women many defecate outside the household at night since they do not need to walk far for privacy, and because it may not be safe to walk long distances in the dark (18). This increases occurrence of open defecation near the home at night, which means more transmission of fecal pathogens near the household. Alternatively, for the elderly, sick, or disabled it is culturally acceptable to defecate near the home, and young children and infants generally defecate indoors with their waste being disposed of near the house (18). Defecation near the home or disposal of waste near the home adds fecal pathogens that can get on children's toys or hands when playing on the ground causing them to become infected and spread infection (20).

Even if there is access to sanitation, there is oftentimes a necessity to perform cleansing rituals after defecation making it necessary to travel from the home and defecate near a water source (18). Open defecation occurs regardless of presence of a household latrine with 44% of households having a working latrine having at least one member practicing open defecation (21). Defecation can be perceived as shameful and disgusting which causes individual household latrines to be built far from the home making open defecation more convenient (18). Improved sanitation may be the key to reducing transmission of fecal pathogens however; there are still many sociocultural barriers to modifying practices.

Latrine use and other routes of exposure

Although much effort has been placed towards improving sanitation, coverage is still inadequate or uptake is not present allowing for fecal contamination to be continuous in the environment. Building improved sanitation resources will have no effect on the health of a community if there is no uptake of behavior change (22,23). A recent study using latrine use monitors shows that people tend to over-report latrine usage (24). Similarly, in the study discussed above by Patil et al 2014, in Madhya Pradesh open defecation rates in intervention villages were lower than in control villages, however rates still remained high at 75% for men, 73% for women, and 84% for children (23).

Barnard et al. (2013) evaluated the Total Sanitation Campaign (TSC) in Orissa after three years of implementation and found that although there was 72% latrine coverage, 37% of households reported continuing to practice open defecation. Most people reported that there were health benefits associated with latrine use, however, no association was found between latrine usage and perceived benefits (25). Routray et al. (2015) discussed the rituals necessary for cleansing post defecation and the barriers to latrine adoption in focus group discussion groups (18). One issue posed was the functional quality of the latrine. Some studies noted only 53% functionality, which is a notable deterrent for usage (25).

An additional issue with open defecation is disposal of child feces. A cross sectional study in Orissa following the TSC showed that the majority of children defecated on the ground inside or near the home. Less than a quarter of participants owning a household latrine reported using a latrine for disposal of child feces (26). Feces were frequently disposed of in piles or pits near the house that could cause dispersion of fecal material into the environment causing continued exposure and disease (26). More recently, a cluster-randomized trial looking at the impact of a rural sanitation program on disposal of child feces was completed in Odisha. This study showed that though latrine coverage increased, safe disposal of child feces did not, leading to no health benefits (27). This study confirms that behavior change is a necessary next step to target the safe disposal of child feces in rural areas.

Evidence for improved health benefits

Improvements in diarrhea health outcomes, and malnutrition have been found in intervention studies aiming to improve water, sanitation, and hygiene (Table 1). A series of systematic reviews of combined interventions show improvements in health outcomes. Combined interventions include an effort to improve sanitation in communities alongside water treatment or a water quality improvement intervention. These interventions are generally put into place to reduce diarrheal disease outcomes, and stunting.

Table 1. Evidence for Improved Health Benefits

Review	No. Studies	Type of Intervention	Health Outcome	Key Findings
Esrey[28] 1985	67	Water quality, water supply, sanitation	Diarrhea, growth, mortality	Increased water supply and improved sanitation combined interventions yield greatest reduction in diarrhea.
Esrey[29] 1986	54	Water quality, water supply, sanitation	Child morbidity, growth, mortality	Sanitation has a greater impact on child health than water.
Esrey[30] 1991	144	Water quality, water supply, hygiene, sanitation	Diarrhea, parasitic infections, trachoma	Water supply interventions yielded greatest reduction in parasite infections and sanitation yielded greatest reduction in diarrhea morbidity and mortality
Fewtrell[31] 2005	46	Water quality, water supply, hygiene, sanitation	Diarrhea	Point of use treatment significantly reduced diarrhea; source treatment has no effect; hygiene interventions yield greatest reduction in diarrhea
Cairncross[32] 2010	56	Water quality, hand-washing with soap and excreta disposal.	Diarrhea, severe enteric infections, diarrhea mortality	Hand-washing interventions yield reduction in diarrhea.
Ziegelbauer[33] 2012	36	Sanitation access	STH	Sanitation is associated with a reduced risk of STH transmission.
Dangour[34] 2013	14	WASH interventions	STH	WASH interventions slightly but significantly improve height for

Dangour (cont.)				age z-scores with girls being the most responsive.
Wolf[35] 2014	72	Drinking water, sanitation	Diarrhea	Water filters with safe storage, quality piped water, and sewer connections yield greatest reduction in diarrhea
Strunz[9] 2014	95	Drinking water, hygiene, sanitation	STH infections	Sanitation access yields reduction in T. trichiura and A. lumbricoides but not hookworm, sanitation impact is weak.

[#]designates source

While evidence from the above studies suggests health benefits from improvements in sanitation in reducing diarrhea, and stunting, most studies are of low epidemiologic quality. There were issues with comparison groups, randomization, control of confounding variables, sample size and external validity. This is supported by Clasen et al. (2010) who argue that most sanitation studies include an insufficient number of clusters or fail to adjust for clustering in concordant analysis compromising the internal validity of results (36). Additionally, the length of time the intervention is implemented and follow-up time have an impact on the efficacy of the intervention.

Community coverage and use

The benefit of improved sanitation is for the community not simply for the individual. There is evidence that health benefits occur if 70% coverage is achieved in a community (37). Hunter et al. (2016) hypothesized that community level sanitation access is more critical than results from trials. The impacts of sanitation occur differently than that of drinking water. The use of improved sanitation does not directly protect the user, but rather the neighbor. Ultimately, this paper found that sanitation coverage is one of the most important predictors of all-cause child mortality and that the most health benefits, specifically in stunting and underweight, are gained from increasing sanitation coverage to 70% (37).

While the Hunter paper showed a benefit to sanitation coverage, some research by Oswald shows otherwise. Oswald et al. (2017) looked at the proportion of households in a community with in use latrines and concordant STH infections (38). This paper found that community level sanitation coverage was not protective against STH infections. On the other hand, another paper by Oswald et al. (2017) looks at sanitation use and hypothesizes that higher community sanitation use could be associated with a lower prevalence of trachoma (39). Community wide sanitation usage between 60-80% was associated with a lower odds of trachoma compared to sanitation use at less than 20% (39).

The need for a minimum level of coverage before achieving health effects may be due to herd immunity. This is supported by Fuller et al. (2016) who demonstrates that herd protection from sanitation is attainable in situations where the community sanitation coverage is vast (40). This study showed that improved sanitation coverage in villages was strongly associated with child height with a protective effect against stunting. Sanitation coverage in surrounding households within 500 meters of a residence was a stronger predictor compared to the household's own sanitation status for childhood stunting (40).

Indian government sanitation initiatives

As summarized above, India did not meet the MDG sanitation target by 2015, much as past projections showed that current progress would fall short (1). To combat this deficit, the government of India initiated India's (TSC) in 1999. The TSC was designed to improve access to sanitation as well as education of sanitation in rural areas. The hope was to use subsidies to gain household participation in below poverty line (BPL) households (41). Community incentives are given to local governments or Gram Panchayats when achieving a status of no open defecation (42).

Numerous studies have been conducted to determine the efficacy of the TSC. Nearly a decade after implementation, Arnold et al. conducted a non-randomized matched cohort study in Tamil Nadu. Though latrine coverage was increased to 60% in intervention villages, there was no difference in anthropometric indicators of nutrition or prevalence of diarrhea (43). In 2013, Barnard et al., conducted a cross-sectional study to investigate latrine coverage among villages in Orissa. Latrine coverage neared 72% in study villages (3 villages had less than 50% coverage) compared to less than 10% for studies where TSC had yet to be implemented. Though latrine construction was completed, many households reported being non-compliant in usage with 39% reporting never using the latrine (25). In 2014, Patil et al., conducted a cluster-randomized control trial in Madhya Pradesh evaluated household drinking water quality (23).

Though the presence of fecal indicator bacteria *Escherichia coli* was lower in intervention villages the difference was not significant between village types or when looking at 7-day caregiver reported diarrhea prevalence, STH infections, anemia, or anthropometric measurements (22). Likewise, in 2014 Clasen et al. conducted a cluster-randomized control trial in Orissa, which found no difference in sanitation measurements, or disease outcomes such as 7-day caregiver reported diarrhea, STH infections, and anthropometric measurements (22). More recently, Odagiri et al., conducted a sub study from Clasen et al.'s 2014 trial. This cross-sectional cluster-randomized controlled sanitation trial in 60 villages in Odisha noted a 27% increase in functional latrine coverage however, there was no decrease in human fecal contamination in community tube wells or ponds using microbial source tracking (44).

The results of these studies put the effectiveness of the TSC at question. Latrines were constructed but not in an all-encompassing manner. As the studies above suggest, there is still a disparity in latrine presence as construction is a lengthy process and not all households practice latrine usage. The reason for deciding whether or not to build or use latrines is yet to be determined. Focus group discussions were conducted in Orissa after implementation of the TSC. The participants cited insufficient monetary supply as an obstacle to latrine construction and that open defecation was practiced when lack of access to a latrine occurred (18). Regardless, inadequate sanitation coverage leaves gaps allowing for fecal contamination in the environment. Garn et al., 2016 competed a systematic review of literature to characterize how different sanitation interventions impacted latrine coverage and use. They found that sanitation interventions currently implicated only slightly increased coverage and that a further understanding of interventions, coverage, and how they affect use in necessary to improve health (45).

Recently, the TSC was revised and renamed to *Nirmal Bharat Abhiyan* (46). With the name change, these subsidies were extended to groups beyond BPL households; however, most households above the poverty line still do not qualify and must build their own latrines. This leads to reduced community-level latrine coverage. According to the total sanitation report, latrine coverage has increased from 21% in 2001 to more than 65% in 2010 (47). 90 million household latrines have been built thus far, however, there is still a gap in households being reached, with less than 50% of households in India having access to improved sanitation in as of 2015 (1).

Gram Vikas MANTRA.

Local non-governmental organizations (NGOs) have also joined in and created campaigns to improve sanitation. Gram Vikas has been working in the region of Orissa since 1979 primarily in rural development among the impoverished. Community-based sanitation implementation has been the focus of Gram Vikas since 1992 with an emphasis on including lower castes of society and women (48). MANTRA (Movement and Action Network for Transformation in Rural Areas) has been the background of Gram Vikas development. The MANTRA approach was used in Odisha. Every household in a village was required to participate and contribute 60% of the costs and construction of a toilet, bathing room, and 24-hour piped water supply to both (48). The approach assumes that if the community contributes to the cost and construction efforts, they will be more likely to utilize the resources, improving sanitation in their villages.

Spatial analysis in Water, Sanitation, and Hygiene (WASH)

Spatial analysis is an innovative way to look at the relationship between space, time and fecal contamination in the environment. It allows the researcher to map where disease is occurring in a particular study area by using software tools to map presence of environmental attributes, assess spatial relationships, test for statistically significant hot spots of disease or particular outcome factor, and allows for comparison of disease over different time points (49). Spatial analysis is particularly useful in WASH related research as it can look at relationships between environmental components and where disease is occurring. Spatial analysis has been used to enhance surveillance of enteric infections in a timelier manner as it has been used as a complement to traditional surveillance methods in an effort to view clusters of disease suggesting a possible outbreak (50). Apart from outbreak surveillance, spatial analysis has been used to assess the spatial-temporal distribution of disease. This was done in Canada to describe the distribution of enteric pathogens in New Brunswick to assess significant geographic risk factors as well as peaks in disease incidence (51). Looking at clustering of disease can get beyond the individual or household level risk factors and look at the influence of neighbors on disease presence as well as the larger geographic picture and how it changes over time.

Geographic Information Systems (GIS) are a tool used for visualizing spatial relationships. A basic way to use GIS in WASH research is to map out sanitation coverage and inequalities in access to water or sanitation (52,53). An additional way to incorporate GIS is to look for clusters of disease. STH clustering has been studied in numerous locations (54-65). Kaliappan et al. (2013) looked at spatial clustering of hookworm and ascaris cases through a discrete poisson model using villages as units in southern India (60). This analysis yielded no evidence of household clustering of STH infections. Pullan et al. (2010) used negative binomial spatial modeling to look at spatial variation in intensity of hookworm infections at the individual and household level in a rural community in Uganda (58). Tsiko (2015) used geoadditive semi-parametric Bayesian models to estimate the probability of a child contracting disease given sanitation characteristics (54). Clustering of diarrheal disease was also reviewed in several studies (54,62, 66). Azage (2015) combined GIS research methods looking at spatial, temporal, and spatio-temporal clusters using SaTScan software and a poisson model (66).

Some spatial analysis incorporates sanitation as a risk factor for health outcomes (54, 60-61). The sanitation factor can be used to predict disease outcomes. Additionally, logistic regression models can be used to predict presence in a disease cluster adjusting for other variables of interest in that particular analysis. This kind of analysis was completed to look at risk maps of domestic *Triatoma infestans*, Chagas disease, in Argentina. A logistic regression model was built to predict disease clustering using risk map elements such as density and elevation (67).

Spatial analysis assumes that objects closer in space are more likely to be associated since they are more likely to come into contact with one another. This is the case of WASH related research as proximity to contamination is necessary to come into contact with fecal material. It is crucial with this fundamental assumption to adjust for clustering of disease at the level of interest such as village or country to obtain an unconfounded analytic result.

II. Research Goal, Rationale and Specific Aims

Research Goal

The goal of the research presented in this thesis is to assess the extent to which diarrhea and growth in children under 5 years are associated with the sub-village level of sanitation coverage.

Rationale

Recent evidence has shown that community sanitation coverage can have the protective impact of herd immunity on community and child health (37, 39, 40). Health benefits have been shown when community sanitation coverage reaches 70% (37). Oswald et al. (2017) found similar benefits at between 60 and 80% coverage (39). Fuller et al. (2016) showed that sanitation coverage within 500 meters of an individual was a stronger predictor for child stunting compared to the sanitation status of the household the child lived in (40). This analysis will look into how geospatial clusters of sanitation infrastructure at a sub-village level impact child health in this particular study situation.

Specific Research Aims

The specific aims of this research are:

1. To determine how clusters of improved sanitation infrastructure and clusters of unimproved sanitation infrastructure affect child diarrhea and stunting.
2. To determine what factors have the most influence on diarrhea and stunting in children under five in this setting and assess where the most effective public health efforts can be implemented.

III. Methods

Study Population

This is a sub-analysis of data from a matched-cohort study designed to assess the effectiveness of the Gram Vikas MANTRA project (hereinafter, the "MANTRA study'). The design and rationale of the MANTRA study have been reported (Reese et al. 2017). The study collected data from 90 villages across four study rounds in Ganjam and Gajapati districts located in eastern Orissa, India. Over 44% of the population of these districts is considered below the poverty line (BPL) by the Government of India (6). Data from the MANTRA project was collected from June 2015 through October 2016. Results have not yet been published.

Sanitation variables and covariate data

The MANTRA study assessed households with children under five years in 45 randomly selected intervention villages and 45 matched control villages. These households were followed over 17 months and data was continuously collected for diarrhea and nutritional status information, coverage access, and use of WASH infrastructure. Individual, household, and community level risk factors were measured through surveys, interviews, or collection of environmental samples. Surveys were conducted in the primary local language to the primary care givers of children under five. Household survey questions assessed reported water and sanitation practices. GPS coordinates for households were collected using Garmin eTrex 10 or 20 devices (Garmin Ltd., Olathe, KS, USA).

Diarrheal Disease

Diarrheal prevalence was recorded as seven-day period prevalence for all household members. Diarrheal disease was measured using the WHO definition of three or more loose stools in a 24-hour period with or without presence of blood. The primary care giver was asked to report for the child.

Anthropometry

Anthropometric data was collected using standard WHO methods. Recumbent length was measured for children under two years of age using Seca 417 measuring boards with 1mm increment. Standing height was measured for children two to five years of age using Seca 213 portable stadiometers with 1mm increment. Weight was measured for all children under five years using Seca 385 digital scales with a 20 g increment for weight below 20 kg and a 50 g increment for weight between 20 and 50 kg. Height-for-age (HAZ) and weight-for-age (WAZ) z-scores were calculated based on WHO reference standards. <-2 SD classified stunting and underweight. <-3 SD classified severe stunting and severe underweight.

Statistical Analyses

Data for this sub-analysis is solely from round 3 of the MANTRA study. Round 3 involved data collection of anthropometric outcomes for all children under age five, while other rounds included only children under two years of age. The analysis was restricted to the intervention group, which had the sanitation intervention with the hope of capturing more heterogeneity in latrine coverage among clusters. Restricting to the intervention group allowed the intervention status to be controlled for in the analysis. Information on sanitation infrastructure was gained from survey data. Improved sanitation was defined as access to a toilet that met the JMP criteria of improved sanitation.

Village level clustering of sanitation infrastructure was assessed using SaTScan version 9.4.4. SaTScan uses Kulldorf's Bernoulli spatial scan to assess clustering over specified distances. A spatial scan statistic is a cluster detection test, which detects clusters and evaluates the statistical significance of them. This study used the spatial scan to detect clusters of areas of high sanitation coverage as well as clusters of low sanitation coverage or unimproved sanitation. A cluster is considered high if it has a trend that is higher than that outside the cluster, and is considered low sanitation coverage if it has a trend that is lower compared to outside the cluster. SaTScan gives the user the ability to define an upper limit for the percent of the population at risk, to define cluster size, and suggests using a limit of 50% of the population. SaTScan then scans for circles with a given kilometer radius to assess clustering. Clustering was used to assess the community's sanitation coverage around an individual. Recent papers have looked at community level sanitation coverage and how coverage affects disease (39). Clusters of sanitation coverage can be used as a proxy for community sanitation coverage, but more specific to the distance an individual child may travel and come in contact with. Clusters allow for a more intimate look into how sanitation coverage affects health below the village level. In this analysis, distances of 250 meters, 500 meters, 750 meters, and 1000 meters were assessed at both the 0.10 and 0.05 significance level (SaTScan 2017). These distances were chosen based on prior papers looking at community level sanitation affects (40). To gain more villages in clusters to enhance the power of the analysis, the 0.10 significance level clustering was also recorded. Sanitation clusters were detected in square meter distances of 250 meters, 500 meters, 750 meters, and 1000 meters. Clusters were described as higher than average coverage of improved infrastructure (high coverage) or lower than average coverage (low coverage) in each square area of distance.

Eight binary variables were then created for each household to indicate presence in a cluster of improved sanitation infrastructure or presence in a cluster of unimproved sanitation infrastructure at each distance. Binary cluster variables were created at both the 0.05 and 0.10 significance level in an effort to gain more clusters. Bivariate relationships were examined separately for each possible predictor variable and outcomes. The cluster variables included in the final analysis were all at the 0.10 significance level as that level was more likely to detect sub neighborhood level clusters.

The final analysis involved logistic regression to predict the odds of diarrhea and moderate stunting using presence in a sanitation cluster as the exposure. One survey per household was included in the models, which were adjusted for clustering at the village level. Models were built using a forward selection process beginning with the sanitation clustering variables. Individual level covariates considered included child age and gender. Household level covariates included caste/tribe, house type, wealth quintile, religion, and possession of an Antodaya card. The best fitting model was chosen based on AIC values. In addition to the logistic regression models, linear regression was used to model continuous child stunting and underweight z scores. Simple linear regression with just the sanitation clustering as the exposure was run after which multilinear regression was run adjusting for child age, gender, household caste, and wealth quintile. All statistical analysis other than the cluster analysis was conducted using SAS version 9.1 (Cary, NC 2017, USA).

IV. Results

Sample Characteristics

The sample consisted of 1,090 children under five with 50.04% male. Age was stratified into 0-11 months (8.81%), 12-23 months (22.94%), and 24-60 months (68.26%) in accordance with literature and developmental stages. 0.01% of information was missing for child's age. 0.16% of the observations were missing on child's sex. 16.9% of data was missing on caste, 17.8% on religion, 28.8% on wealth information, and 15.7% on household type. See Table 2 below for descriptive information on the intervention group stratified presence in a 500 meter cluster of high coverage sanitation. All levels of caste were significantly different between cluster and non-cluster groups. Hindu and Christian religions were significantly different as well (p=0.0008, p=0.0022). The lowest quintile and the two highest quintiles were significantly different (p<0.0001). Household type was also significantly different for Pucca and Kucha (p<0.0001, p=0.0005).

Table 2. Descriptive characteristics of sample

	In Cluster N(%)[a,b]	Not in Cluster N(%)	Total N(%)	p-value[d]
Individual Characteristics				
Child's Age in Months				
0-11	18(6.98)	49(8.22)	96(8.81)	0.8462
12-23	61(23.64)	137(22.99)	250(22.94)	0.6401
24-60	179(69.38)	410(68.79)	744(68.26)	0.1744
Child's Sex				
Male	136(43.87)	373(50.20)	645(50.04)	0.0610
Household Characteristics				
Caste				
Scheduled Caste	5(1.77)	105(16.72)	110(12.07)	<0.0001*
Scheduled Tribe	0(0)	115(18.31)	115(12.62)	<0.0001*
Backward Caste	126(44.52)	225(35.83)	351(38.53)	0.0010*
Other Caste	152(53.71)	183(29.14)	335(36.77)	<0.0001*
Religion				
Hindu	280(100.00)	612(95.33)	892(96.75)	0.0008*
Christian	0(0)	22(3.43)	22(2.39)	0.0022*
Other	0(0)	8(1.25)	8(0.87)	0.1138
Wealth Quintile				
1 (lowest)	15(5.77)	112(20.07)	127(15.53)	<0.0001*
2	39(15.00)	104(18.64)	143(17.48)	0.5511
3	36(13.85)	107(19.18)	143(17.48)	0.2347
4	81(31.15)	112(20.07)	193(23.59)	<0.0001*
5	89(34.23)	123(22.04)	212(25.92)	<0.0001*
Antodaya Card				
Yes	309(99.68)	741(99.60)	1050(99.62)	1.000
Household Type				
Pucca	241(83.97)	433(68.73)	674(73.50)	<0.0001*
Semi-Pucca	25(8.71)	89(14.13)	114(12.43)	0.0643
Kucha	21(7.32)	108(17.14)	129(14.07)	0.0005*

[a]household presence in a high coverage cluster of 500m with improved sanitation.
[b]clusters were detected using the SaTScan method described above.
[d]Chi-square test
*p-value<0.05

More households in the high coverage sanitation clusters had access to improved sanitation (93.23% compared to 84.27%)(Table 3), although this difference was not significant (p=0.1378). Overall improved sanitation access was 86.9%. On average only 24.48%% of child feces were disposed of safely in a latrine. The majority of people had access to improved drinking water sources, although more people in not in the clusters had access to piped water to the home (9.57% vs. 2.26%).

Table 3. Household Sanitation Characteristics

Characteristic	High Coverage Cluster N(%)[a]	Not in cluster N(%)	Total N(%)	p-value
Improved Sanitation Access[b]	289(93.23)	627(84.27)	916(86.91)	0.1378
Safe Disposal of child Feces[b]	103(33.23)	213(28.59)	316(24.48)	0.1343
Improved Drinking Water[b]				
Piped Water to Home	7(2.26)	71(9.57)	78(7.41)	<0.0001*
Other Improved sources	302(97.42)	597(80.46)	899(85.46)	<0.0001*
Unimproved sources	1(0.32)	74(9.97)	75(7.13)	<0.0001*
Improved water and sanitation[b]	736(81.15)	151(14.13)	887(44.89)	0.0004*
Latrine use weighted proportion Mean(std)[c]	0.66(0.28)	0.55(0.36)	0.58(0.34)	<0.0001*
Household density[c]	3.30(1.57)	3.84(1.78)	3.68(1.74)	<0.0001*

[a]Presence in high coverage cluster of 500m with improved sanitation
[b]p-value from chi-square test
[c]p-value from t-test
*p-value<0.05

Sanitation Infrastructure

See table 4 below, which displays the number of households in clusters at each distance. In the intervention arm of the study, there were more households in clusters of high coverage at each distance compare to households in low coverage clusters.

Table 4. Households in Sanitation Infrastructure Clusters

Cluster and Distance	In Cluster N(%)
High coverage 250m	255(24.17)
Low coverage 250m	6(0.57)
High coverage 500m	310(29.38)
Low Coverage 500m	6(0.57)
High Coverage 750m	316(29.95)
Low Coverage 750m	6(0.57)
High Coverage 1000m	368(34.88)
Low Coverage 1000m	4(0.38%)

[a]clusters detected at the 0.10 significance level

An example of sanitation clustering can be seen below. The first map (Figure 1) shows the entire study area and villages with clusters of improved sanitation infrastructure at 500 meters. The second map (Figure 2) shows an example of a village with households present in a cluster of sanitation infrastructure at 500 meters.

Figure 1

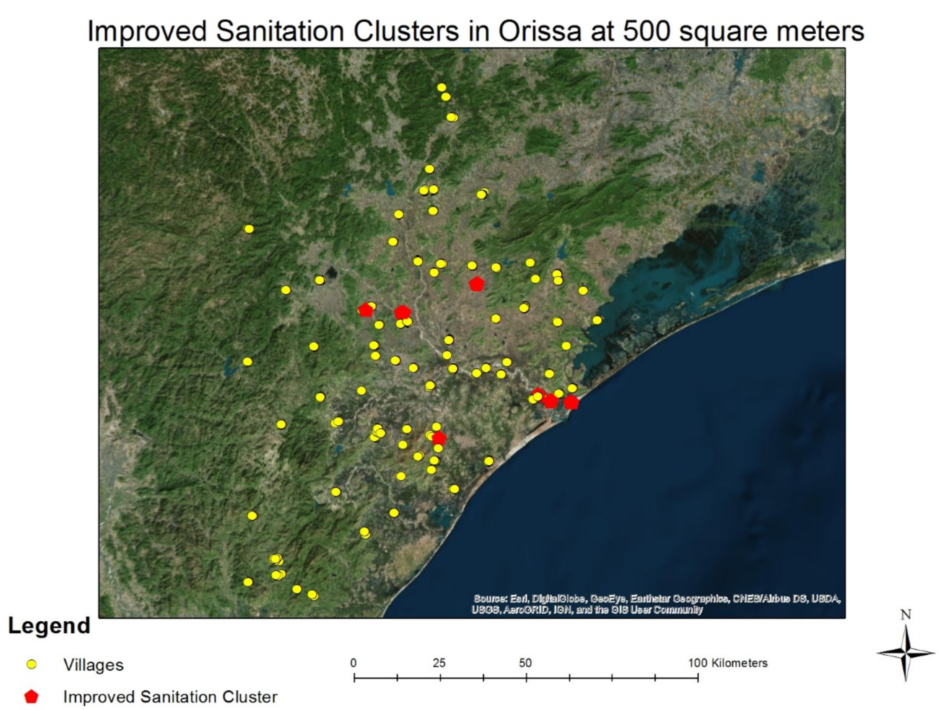
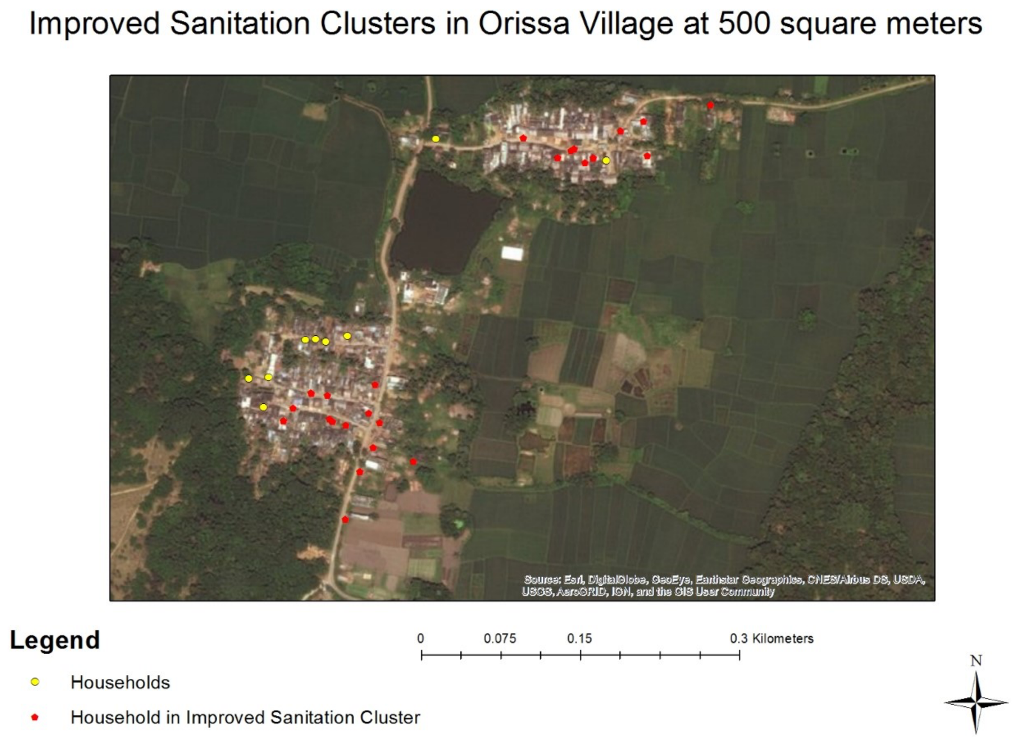


Figure 2



Child Outcomes

Seven day period prevalence of diarrhea was 4.3% overall and similar between the clusters and non-clusters (3.6% v.3.8%), p-value (0.8847). Prevalence of moderate stunting was 32.8% overall and slightly higher in non-cluster children (26.9% v. 18.1%), p-value (0.0001). Severe stunting was less prevalent in the total population, 7.6%. 25.8% of children were moderately underweight with 13.9% in cluster of sanitation and 31.7% not in clusters. Overall, 5.6% of children were severely underweight with 0.6% in clusters and 8.3% not in a cluster.

Table 5. Child health data

	In cluster N(%)[a]	Not in cluster N(%)	Total N(%)	p-value[d]
7-day diarrhea prevalence	8(3.6)	20(3.8)	42(4.3)	0.8847
Moderate stunting	32(18.1)	169(26.9)	269(32.8)	<0.0001*
Severe stunting	4(2.3)	44(9.6)	62(7.6)	0.0017*
Moderate underweight	25(14.0)	149(31.7)	217(25.8)	<.0001*
Severe underweight	1(0.6)	39(8.3)	47(5.6)	0.0002*
HAZ[b] Mean (std)	-1.08(1.02)	-1.61(1.15)	-1.46(1.16)	<0.0001*
WAZ[c] Mean (std)	-0.97(1.06)	-1.50(1.10)	-1.34(1.04)	<0.0001*

[a]Presence in high coverage cluster of 500m with improved sanitation.
[b]Height for Age z-score
[c]Weight for Age z-score
[d]p-values computed through chi-square test for dichotomized outcomes and t-test for continuous
*p-value <0.05

All z score values are below the mean. Cluster z scores for height and weight appear to be higher than those not in a cluster ($p<0.0001$). There is a significant difference in all health outcomes by cluster presence for all health outcomes except for diarrhea.

Disease Models

Bivariate analysis was conducted to determine if an association existed between each outcome and predictors. Sanitation coverage was not associated with diarrheal disease in children under five. See table 6 below.

Table 6. Chi-Square test for association with 7 day diarrhea prevalence

Variable	χ^2 value	p-value
250m High coverage[a]	1.788	0.1898
250m low coverage[a]	0.0309	0.8604
500m high coverage[a]	1.4065	0.2356
500m low coverage[a]	0.0026	0.9596
750m high coverage[a]	1.7470	0.1863
750m low coverage[a]	0.0071	0.9330
1000m high coverage[a]	1.3225	0.2501
1000m low coverage[a]	0.0461	0.8300

[a] 0.10 significance level

Sanitation clusters were associated with moderate stunting. The most significant associations with stunting occurred at 750meters of improved high coverage sanitation, 500meters of improved high coverage sanitation, and 250meters of improved high coverage sanitation with clusters being detected at the 0.10 significance level. See table 7 below.

Table 7. Chi-Square test for association with moderate stunting

Variable	χ^2 value	p-value
250m high coverage[a]	14.5485	0.0001*
250m low coverage[a]	3.0591	0.0803
500m high coverage[a]	16.7624	0.0001*
500m low coverage[a]	3.5148	0.0608
750m high coverage[a]	16.4473	<0.0001*
750m low coverage[a]	2.8125	0.0935
1000m high coverage[a]	7.2880	0.0069*
1000m low coverage[a]	2.7286	0.0986

[a] 0.10 significance level
*$p<0.05$

Clusters were associated with severe stunting of children under five. The most significant association occurred with 500 meters of high coverage improved sanitation with cluster detection occurring at the 0.10 significance level. See table 8 below.

Table 8. Chi-Square test for association with severe stunting

Variable	χ^2 value	p-value
250m high coverage[a]	7.4449	0.0064*
250m low coverage[a]	0.3463	0.5562
500m high coverage[a]	10.8154	0.0010*
500m low coverage[a]	0.0807	0.7763
750m high coverage[a]	9.7159	0.0018*
750m low coverage[a]	0.5537	0.4568
1000m high coverage[a]	2.8572	0.0910
1000m low coverage[a]	0.0761	0.7826

[a]0.10 significance level
* $p<0.05$

Clusters were also associated with children under five being moderately underweight. The most significant associations occurred at clusters of 500 meters of improved sanitation and clusters of 750 meters of high coverage improved sanitation at the 0.10 significance level for clustering. See table 9 below.

Table 9. Chi Square test for association with moderate underweight

Variable	χ^2 value	p-value
250m high coverage[a]	12.9838	0.0003*
250m low coverage[a]	2.5097	0.1131
500m high coverage[a]	16.6718	<0.0001*
500m low coverage[a]	2.7332	0.0983
750m high coverage[a]	16.3309	<0.0001*
750m low coverage[a]	3.5511	0.0595
1000m high coverage[a]	9.3630	0.0022*
1000m low coverage[a]	1.6699	0.1963

[a]0.10 significance level
*$p<0.05$

Clusters were associated with children under five being severely underweight. The most significant associations occurred at 750 meters and 500 meters of high coverage improved sanitation. Clusters were once again detected at the 0.10 significance level. See table 10 below.

Table 10. Chi-Square test for association with severe underweight

Variable	χ^2 value	p-value
250m high coverage[a]	8.6555	0.0033*
250m low coverage[a]	0.0266	0.8705
500m high coverage[a]	11.4522	0.0007*
500m low coverage[a]	0.0100	0.9202
750m high coverage[a]	12.2630	0.0005*
750m low coverage[a]	0.2773	0.5985
1000m high coverage[a]	8.2037	0.0042*
1000m low coverage[a]	0.0020	0.9645

[a]0.10 significance level
*p<0.05

Clusters were associated with continuous HAZ. The most significant associations occurred at 250 meters, 500 meters, 750 meters, and 1000 meters of high coverage improved sanitation. Clusters were detected at the 0.10 significance level. See table 11 below.

Table 11. T-test for HAZ and Cluster Distances

Variable	t-value	p-value
250m high coverage[a]	-6.01	<0.0001*
250m low coverage[a]	-2.07	0.0382*
500m high coverage[a]	-6.94	<0.0001*
500m low coverage[a]	-1.87	0.0622
750m high coverage[a]	-6.48	<0.0001*
750m low coverage[a]	-1.91	0.0559
1000m high coverage[a]	-5.45	<0.0001*
1000m low coverage[a]	-1.28	0.1992

[a]0.10 significance level
*p<0.05

Clusters were associated with continuous WAZ. The most significant associations occurred at 250 meters, 500 meters, 750 meters, and 1000 meters of high coverage improved sanitation. Clusters were detected at the 0.10 significance level. See table 12 below.

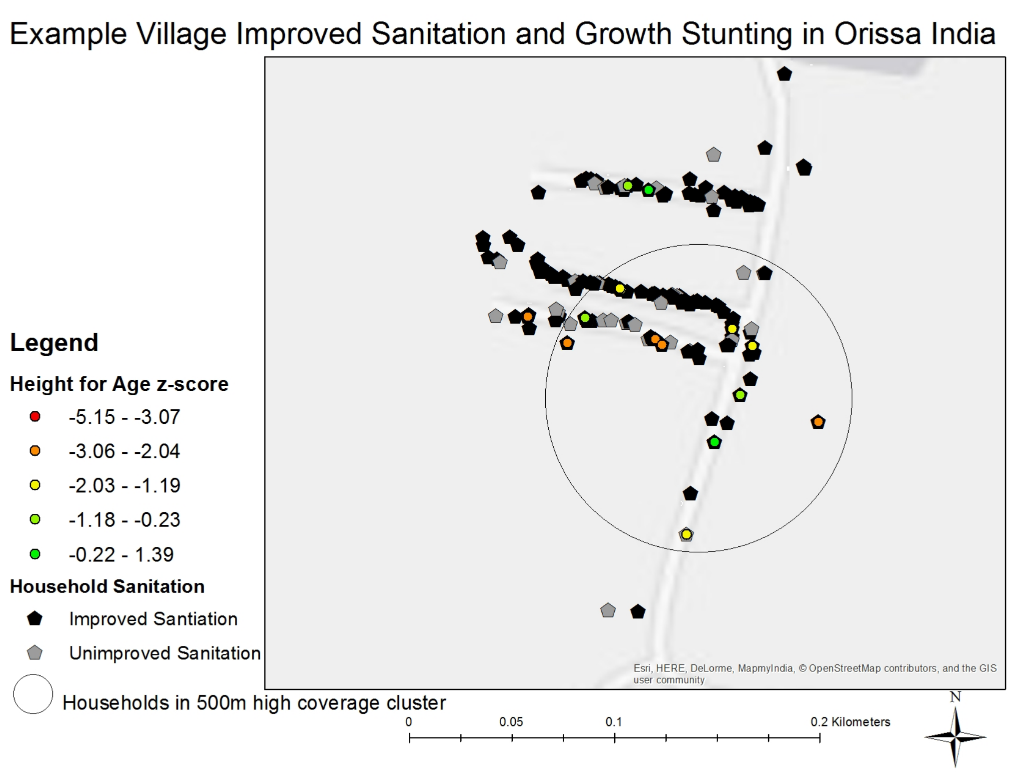
Table 12. T-test for WAZ and Cluster Distances

Variable	t-value	p-value
250m high coverage[a]	-6.28	<0.0001*
250m low coverage[a]	-2.56	0.0106*
500m high coverage[a]	-6.78	<0.0001*
500m low coverage[a]	-2.66	0.0078*
750m high coverage[a]	-6.60	<0.0001*
750m low coverage[a]	-2.60	0.0093*
1000m high coverage[a]	-4.99	<0.0001*
1000m low coverage[a]	-1.92	0.0553

[a]0.10 significance level
*p<0.05

Figure 3 shows an example village in the study. The circle encompasses households that were in the 500 meter cluster of high coverage of improved sanitation. Height for age z-scores are shown with a color gradient with red showing the most severe values.

Figure 3



Regression models were run using sanitation infrastructure clusters that were detected at significance level 0.10. Sanitation infrastructure clustering was not a significant predictor of diarrhea prevalence. Stunting could be modeled through logistic regression. Models were adjusted for village level clustering and only unique household observations were used. Only one child was present per household. The best fitting model for moderate stunting is shown in Table 13 below. Model 1, table 13 shows that presence in a cluster of improved sanitation at 500 meters had a 17% reduction in moderate stunting (OR=0.83, 95%CI:0.73-0.94). This relationship was not affected by adjusting for child's sex and age demonstrated in model 2, table 12 (OR=0.83, 95%CI:0.73-0.94). However, the effect was decreased in model 3, table 13, which adds adjustment for household caste and wealth quintiles (OR=0.91, 95%CI:0.91-1.02).

Table 13: Odds ratios (and 95% confidence intervals) for moderate stunting (height-for-age z score <-2) among children < 5 years of age in Orissa, India 2016.

Variable	Model 1	Model 2	Model 3
Sanitation cluster[a,b]	0.83(0.73-0.94)*	0.83(0.73-0.94)*	0.91(0.81-1.02)
Child's sex (male)		1.00(0.95-1.05)	1.01(0.94-1.10)
Child's age			
0-11 months		1.02(1.00-1.04)	1.02(0.99-1.04)
12-23 months		1.04(1.00-1.09)	1.03(0.99-1.08)
25-60 months		1.11(0.99-1.24)	1.09(0.97-1.22)
Household Caste			
Scheduled caste			0.95(0.91-0.99)
Scheduled tribe			0.90(0.82-0.98)
Backward caste			0.85(0.75-0.97)
Other caste			0.81(0.68-0.95)
Wealth Quintile			
1 (lowest)			0.94(0.92-0.97)
2			0.88(0.84-0.94)
3			0.83(0.77-0.90)
4			0.78(0.70-0.87)
5			0.72(0.64-0.85)
AIC	807.25	820.53	701.10

[a] Presence in a 500m cluster of improved sanitation
[b]cluster significant 0.10
*p<0.05

The best fitting model for severe stunting is shown in Table 14 below. Model 1, table 14 shows that presence in a cluster of improved sanitation at 500 meters had a 9% reduction in severe stunting (OR=0.91, 95%CI:0.84-0.99). This relationship stayed the same when adjusting for child's sex and age demonstrated in model 2, table 13 (OR=0.90, 95%CI:0.84-1.00). However, the effect was decreased in model 3, table 14, which adds adjustment for household caste and wealth quintiles (OR=0.95, 95%CI:0.88-1.03).

Table 14: Odds ratios (and 95% confidence intervals) for severe stunting (height-for-age z score <-3) among children < 5 years of age in Orissa, India 2016.

Variable	Model 1	Model 2	Model 3
Sanitation cluster[a,b]	0.91(0.84-0.99)*	0.90(0.84-1.00)*	0.95(0.88-1.03)
Child's sex (male)		1.0010.96-1.03)	0.99(0.95-1.04)
Child's age			
0-11 months		1.00(0.99-1.01)	1.00(0.99-1.01)
12-23 months		1.00(0.98-1.03)	1.00(0.97-1.03)
25-60 months		1.01(0.95-1.07)	1.00(0.94-1.08)
Household Caste			
Scheduled caste			0.97(0.94-0.99)
Scheduled tribe			0.93(0.89-0.98)
Backward caste			0.90(0.83-0.98)
Other caste			0.87(0.79-0.97)
Wealth Quintile			
1 (lowest)			0.98(0.97-1.00)
2			0.97(0.94-1.00)
3			0.95(0.91-1.00)
4			0.94(0.89-1.00)
5			0.92(0.85-1.00)
AIC	104.52	123.62	124.39

[a] Presence in a 500m of sanitation infrastructure
[b] Cluster significance level 0.10
*p<0.05

The best fitting model for a child being moderately underweight is shown in Table 15 below. Model 1, table 15 shows that presence in a cluster of improved sanitation at 500 meters had a 16% reduction in a child being underweight (OR=0.84, 95%CI:0.76-0.94). This relationship stayed the same when adjusting for child's sex and age demonstrated in model 2, table 15 (OR=0.85, 95%CI:0.76-

0.96). However, the effect was decreased in model 3, table 15, which adds adjustment for household caste and wealth quintiles (OR=0.90, 95%CI:0.81-1.00).

Table 15: Odds ratios (and 95% confidence intervals) for moderate underweight (weight-for-age z score <-2) among children < 5 years of age in Orissa, India 2016.

Variable	Model 1	Model 2	Model 3
Sanitation cluster[a,b]	0.84(0.76-0.94)*	0.85(0.76-0.96)*	0.90(0.81-1.00)
Child's sex (male)		1.05(0.99-1.13)	1.52(0.98-1.12)
Child's age			
0-11 months		1.02(1.00-1.04)	1.02(1.00-1.04)
12-23 months		1.04(1.00-1.09)	1.05(1.00-1.09)
25-60 months		1.11(1.00-1.24)	1.12(1.00-1.25)
Household Caste			
Scheduled caste			0.96(0.92-1.00)
Scheduled tribe			0.93(0.85-1.01)
Backward caste			0.89(0.79-1.00)
Other caste			0.86(0.73-1.01)
Wealth Quintile			
1 (lowest)			0.95(0.92-0.97)
2			0.90(0.85-0.95)
3			0.85(0.79-0.92)
4			0.81(0.73-0.90)
5			0.76(0.66-0.87)
AIC	770.27	781.12	688.40

[a] Presence in a 500m cluster of improved sanitation infrastructure
[b] cluster significance level 0.10
*p<0.05

The best fitting model for a child being severely underweight is shown in Table 16 below. Model 1, table 16 shows that presence in a cluster of improved sanitation at 500 meters had an 7% reduction in a child being severely underweight (OR=0.93, 95%CI:0.87-1.00). This relationship stayed the same when adjusting for child's sex and age demonstrated in model 2, table 16 (OR=0.93,95%CI:0.87-

0.99). However, the effect was decreased in model 3, table 16, which adds adjustment for household caste and wealth quintiles (OR=0.95, 95%CI:0.0.89-1.02).

Table 16: Odds ratios (and 95% confidence intervals) for severe underweight (weight-for-age z score <-3) among children < 5 years of age in Orissa, India 2016.

Variable	Model 1	Model 2	Model 3
Sanitation cluster[a,b]	0.93(0.87-1.00)	0.93(0.87-0.99)	0.95(0.89-1.02)
Child's sex (male)		0.97(0.95-1.00)	0.98(0.95-1.02)
Child's age			
0-11 months		1.00(0.99-1.01)	1.00(0.99-1.01)
12-23 months		1.01(0.98-1.03)	1.00(0.98-1.03)
25-60 months		1.02(0.96-1.08)	1.01(0.95-1.07)
Household Caste			
Scheduled caste			0.98(0.96-1.00)
Scheduled tribe			0.96(0.92-1.00)
Backward caste			0.94(0.88-1.01)
Other caste			0.92(0.84-1.01)
Wealth Quintile			
1 (lowest)			0.98(0.97-1.00)
2			0.97(0.94-1.00)
3			0.96(0.91-1.00)
4			0.94(0.89-1.00)
5			0.93(0.86-1.00)
AIC	-11.75	7.11	-6.47

[a] Presence in a cluster of 500m improved sanitation
[b] cluster significance level 0.10

Continuous z scores for stunting and wasting were also modeled using linear regression and the clusters of sanitation infrastructure as predictors. See Table 18-19 below. The average HAZ for those not in a cluster of improved sanitation is -1.61. Presence in a sanitation cluster increases the HAZ by 0.52 for a 500 meter cluster. The average WAZ is -1.51 for those children not in a cluster of improved sanitation. Presence in a sanitation cluster improves the WAZ by 0.54 for a 500 meter cluster of sanitation. Being in a sanitation cluster improves child HAZ and WAZ, although, overall, the z-scores are already below the mean value. Table 18 below shows three models for HAZ with just the exposure, sanitation cluster, in model 1, adjusting for child's age and gender in model 2, and adding household caste and wealth quintile to model 3. Sanitation clusters at 500 meters were used for consistency. Presence in a sanitation cluster remains significant for all models. Model 3 yields the best fit and shows a 0.32 increase HAZ for child height adjusting for membership in a sanitation cluster, child's sex, age, household caste, and wealth quintile.

Table 18: Linear Regression z-score coefficients and standard errors for Height for Age z-scores among children < 5 years of age in Orissa, India 2016.

Variable	Model 1		Model 2		Model 3	
	β $SE(\beta)$	p-value	β $SE(\beta)$	p-value	β $SE(\beta)$	p-value
Intercept	-1.61(0.08)	<0.001*	-1.30(0.15)	<0.0001*	-2.24(0.24)	<0.0001*
Sanitation cluster[a,b]	0.52(0.15)	0.0006*	0.52(0.16)	0.0008*	0.32(0.13)	0.0154*
Child's sex (male)			-0.06(0.10)	0.5125	0.002(0.11)	0.9890
Child's age			-0.01(0.002)		-0.01(0.002)	0.0095*
Household Caste				0.0033*	0.16(0.05)	0.0023*
Wealth Quintile					0.17(0.04)	<0.0001*
QIC	642.38		644.86		572.67	
QICu	637.00		639.00		568.00	

[a] Presence in a cluster of 500m improved sanitation
[b] cluster significance level 0.10
*p<0.05

Table 19 below shows three models for WAZ with just the exposure, sanitation cluster, in model 1, adjusting for child's age and gender in model 2, and adding household caste and wealth quintile to model 3. Sanitation clusters at 500 meters were used for consistency. Presence in a sanitation cluster remains significant for all models. Model 3 yields the best fit and shows a 0.38 increase in z-score for child weight adjusting for membership in a sanitation cluster, child's sex, age, household caste, and wealth quintile.

Table 19: Linear Regression z-score coefficients and standard errors for Weight for Age z-scores among children < 5 years of age in Orissa, India 2016.

Variable	Model 1		Model 2		Model 3	
	β (SE)	p-value	*β (SE)*	p-value	*β (SE)*	p-value
Intercept	-1.51(0.08)	<0.0001*	-1.19(0.16)	<0.0001*	-1.95(0.31)	<0.0001*
Sanitation cluster[a,b]	0.54(0.12)	<0.0001*	0.53(0.28)	<0.0001*	0.38(0.10)	0.0003*
Child's sex (male)			-0.10(0.09)	0.2605	-0.06(0.10)	0.5116
Child's age			-0.01(0.002)	0.0130*	-0.01(0.003)	0.0111*
Household Caste					0.10(0.05)	0.0562
Wealth Quintile					0.17(0.04)	<0.0001*
QIC	655.78			658.31		587.17
QICu	652.00			654.00		583.00

[a] Presence in a cluster of 500m improved sanitation
[b] cluster significance level 0.10
*p<0.05

V. Discussion

The purpose of this study was to evaluate how community level sanitation coverage can have an impact on the health of children under five years. Sub-community level sanitation coverage is an important indicator of fecal contamination in the environment.

This study supports evidence that presence of improved sanitation coverage is protective against child stunting in concordance with a previous study by Spears which found that increases in open defecation were associated with increases in child stunting (10). The final results indicate that there is an association between presence in a cluster of improved sanitation and child stunting and being underweight, but this relationship does not hold for the adjusted models. Unadjusted, presence in a sanitation cluster of 500m has a protective effect on child stunting, and a child being underweight. There is an association between presence in a cluster of improved sanitation and both HAZ and WAZ. This relationship holds true when adjusting for other covariates. The effect of sanitation coverage was null for diarrhea outcomes in accordance with literature (36).

These results are comparable to Fuller's study, which showed that 100% community sanitation coverage at 500m was protective for stunting (40). Improved sanitation in one household is beneficial to the households around it as contamination is being reduced in the environment. Similar to Fuller's paper, this study shows that being in an environment of sanitation coverage higher than the surrounding area is protective for HAZ. Fuller also conducted a threshold analysis to see at what level sanitation coverage proved to be protective. He found that beyond 31-40% there was no added benefit from living in an area of sanitation coverage (40). This study reached 70% sanitation coverage as specified in, Hunter et al., and showed a protective unadjusted effect, see tables 12, 13, 14,15, 16, and 17 (37).

These results are supportive of those shown by Hunter and Oswald. Hunter et al. came to the conclusion that community sanitation coverage at 70% resulted in the most health benefits. Similarly, Oswald shows in one study that community sanitation use had to reach 60-80% for a lower prevalence in odds of disease (39). Oswald's paper differs from this current analysis in that sanitation use was the main exposure variable where in this analysis; the main exposure is being in a cluster of community sanitation coverage. Sanitation use is definitely an important indicator of environmental contamination and should be considered alongside coverage. Sanitation use was not the main focus of this analysis. It was not found to be a significant predictor in the disease models. Though it seems intuitive that sanitation use would be an important predictor, Oswald also found that there was no overall association between community sanitation usage and STH infection (38). One analysis suggested that sanitation usage was needed at 80% for a protective effect with coverage being an important factor. Sanitation coverage in the present study was 86.9% while use was only 60%. This suggests that further research needs to be conducted looking at the intersection of sanitation coverage and usage and concordant disease outcomes.

Strengths and Limitations

This analysis was able to support previous studies conducted by Hunter, Fuller, and Oswald. It shows that community sanitation coverage can be beneficial to children under five using a different technique from published literature. Looking at clusters of sanitation coverage allows for analysis of a smaller unit area around children to capture the area that they most likely interact with. If households around a child's are using improved sanitation, environmental contamination is less likely which could lead to reduced disease in children allowing them to reach their full growth potential.

This analysis was stratified to focus on only the intervention villages since that is where the majority of significant clusters were. This reduced the sample size by half but does not seem to change the results from an unstratified analysis. Additionally, dichotomization of continuous height into indicators of moderate and severe stunting sacrifices power as well, which could explain why results were stronger with the continuous z-score outcomes. The clusters of sanitation were assessed in SaTScan at the 0.10 significance level rather than the 0.05 significance level, which could have weakened the analysis. Since clusters of improved sanitation infrastructure only fell in intervention villages, and clusters of unimproved sanitation only fell in control villages, it is difficult to determine the difference of the impact of sanitation between the two arms of the study but would prove interesting for future analyses.

It appears that the intervention did ultimately improve sanitation presence in this population, however, in the control group, sanitation infrastructure appeared to have a null effect on disease. This could be because this study did not assess the question of use of improved sanitation facilities and use, though harder to assess does have an impact of disease status.

All of the information in this study with the exception of the anthropometric measurements were collected in the form of survey information and are thus subject to recall bias. However, the culture in India permits discussion of sanitation information to be not as stigmatized as outside the country so the results may not be so biased (6). The only variable unable to be used in the analysis was possession of an Antodaya card as it was discovered that the holding of a card is not representative of income level as cards are sold on the black market to allow for additional governmental subsidies. This variable was also determined to be collinear and was unable to be used in the analysis.

The relationship between child disease status and sanitation infrastructure presence was assessed by looking at child age, gender, household caste, and wealth quintile. However, it did not take into account any nutritional characteristics. Though nutrition would not confound the effect of being in a cluster of improved sanitation it does have an important effect on child anthropometric outcomes and would be an interesting addition for future analyses.

This analysis only looked at disease and sanitation relationship at one point in time, one study round, however, it would be more informative to look at this relationship over all rounds of the study to assess the temporality of disease.

VI. Conclusions and Recommendations

This study illuminates the importance of achieving community level sanitation in rural India. Being in a 500 meter cluster of improved sanitation was associated with improved child nutritional health measured through both height-for-age and weight-for-age z scores, adjusting for socio-demographic characteristics. Future research and sanitation programs should work to promote 100% sanitation coverage and use in communities, consistent with the SDGs.

VII. References

1. UNICEF & WHO (2015). Progress on sanitation and drinking water – 2015 update and MDG assessment. World Health Organization, Geneva. ISBN 978 92 4 150914 5.
2. Kumar S, Kumar N, Vivekadhish S. (2016) Millennium Development Goals(MDGs) to Sustainable Development Goals (SDGs): Addressing Unfinished Agenda and Strengthening Sustainable Development and Partnership. *Indian Journal Community Medicine*. 41(1);1-4.
3. Sustainable Development Goals. (2017) UN.org. Retrieved from http://www.un.org/sustainabledevelopment/water-and-sanitation/
4. Census of India (2011). Availability and Type of Latrine Facility: 2001-2011. Retrieved from http://censusindia.gov.in/2011census/hlo/hlo_highlights.html
5. International Institute for Population Sciences (IIPS). District level household and facility survey (DHLS-3), 2007-08: India, Orissa. Mumbai: International Institute for Population Studies (IIPS), 2010.
6. Reese H, Routray P, Torondel B, et al. Design and rationale of a matched cohort study to assess the effectiveness of a combined household-level piped water and sanitation intervention in rural Odisha, India. *BMJ Open* 2017;7e012719
7. WHO (2016). Mortality and burden of disease from water and sanitation. Retrieved from http://www.who.int/gho/phe/water_sanitation/burden/en/

8. GAHI (2016). Global burden. Retrieved from http://www.thiswormyworld.org/worms/global-burden
9. Strunz, E. C., Addiss, D. G., Stocks, M. E., Ogden, S., Utzinger, J., & Freeman, M. C. (2014). Water, sanitation, hygiene, and soil-transmitted helminth infection: a systematic review and meta-analysis. *PLoS Med*, *11*(3), e1001620.
10. Spears D, Ghosh A, Cumming O (2013) Open Defecation and Childhood Stunting in India: An Ecological Analysis of New Data from 112 Districts. PLoS ONE 8(9): e73784. doi:10.1371/journal.pone.0073784
11. Schmidt CW. (2014). Beyond Malnutrition: The Role of Sanitation in Stunted Growth. *Environmental Health Perspectives*; 122(11)
12. Humphrey JH. Child undernutrition, tropical enteropathy, toilets, and handwashing. *Lancet* 2009;374:1032-5
13. Owino V, Ahmed T, Freemark M, et al. (2016). Environmental Enteric Dysfunction and Growth Failure/Stunting in Global Child Health. Pediatrics;138(6)
14. WHO (2014). Global Health Observatory (GHO) data 2014.
15. WHO (2009). Global burden of disease deaths DALYs county estimates 2004.
16. GBD Profile: India (2010) health metrics and evaluation.org http://www.healthdata.org/sites/default/files/files/country_profiles/GBD/ihme_gbd_country_report_india.pdf
17. WHO (2001). Water Quality: Guidelines, Standards and Health. Edited by Lorna Fewtrell and Jamie Bartram. [Chapter 5]. IWA Publishing, London,

UK. ISBN: 1 900222 28 0. Retreived from http://www.who.int/water_sanitation_health/dwq/iwachap5.pdf

18. Routray, P., Schmidt, W. P., Boisson, S., Clasen, T., & Jenkins, M. W. (2015). Socio-cultural and behavioral factors constraining latrine adoption in rural coastal Odisha: an exploratory qualitative study. BMC public health,15(1), 1.
19. Jadhav A, Weitzman A, Smith-Greenaway E. (2016). Household sanitation facilities and women's risk of non-partner sexual violence in India. *BMC Public Health*, 16:1139.
20. Ambesh P, Ambesh SP. (2016). Open Defecation in India: A Major health Hazard and Hurdle in Infection Control. *Journal of Clinical and Diagnostic Research*. 10(7).
21. Coffey, D., Gupta, A., Hathi, P., Spears, D., Srivastav, N., & Vyas, S. (2014). Culture and the health transition: Understanding sanitation behavior in rural north India. In IGC-ISI Development Conference (Delhi)
22. Clasen, T., Boisson, S., Routray, P., Torondel, B., Bell, M., Cumming, O., ... & Ray, S. (2014). Effectiveness of a rural sanitation programme on diarrhoea, soil-transmitted helminth infection, and child malnutrition in Odisha, India: a cluster-randomised trial. The Lancet Global Health, 2(11), e645-e653.
23. Patil, S. R., Arnold, B. F., Salvatore, A. L., Briceno, B., Ganguly, S., Colford Jr, J. M., & Gertler, P. J. (2014). The effect of India's total sanitation campaign on defecation behaviors and child health in rural Madhya Pradesh: a cluster randomized controlled trial. PloS Med, 11(8), e1001709.

24. Sinha A, Nagel CL, Thomas E, Schmidt WP, Torondel B, Boisson S, Clasen TF. (2016). Assessing Latrine Use in Rural India: A Cross-Sectional Study Comparing Reported Use and Passive Latrine Use Monitors. Am. J. Trop. Med. Hyg., 95(3).
25. Barnard S, Routray P, Majorin F, Peletz R, Boisson S, Sinha A, & Clasen T. (2013) Impact of Indian Total Sanitation Campaign on latrine coverage and use: a cross-sectional stud in Orissa three years following programme implementation. *PloS one*, 8(8), e71438
26. Majorin F, Freeman MC, Barnard S, Routray P, Boisson S, et al. (2014) Child Feces Disposal Practices in Rural Orissa: A Cross Sectional Study. PLoS ONE 9(2): e89551. doi:10.1371/journal.pone.0089551
27. Freeman MC, Majorin F, Boisson S, Routry P, Torondel B, Clasen T. (2016). The impact of a rural sanitation programme on safe disposal of child faeces: a cluster randomized trial in Odisha, India. Trans R Soc Trop Med Hyg; 110:386-392 doi:10.1093/trstmh/trw043
28. Esrey, S. A., Feachem, R. G., & Hughes, J. M. (1985). Interventions for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities. *Bulletin of the World Health organization*, *63*(4), 757.
29. Esrey, S. A. & Habicht, J. P. (1986). Epidemiologic evidence for health benefits from improved water and sanitation in developing countries. *Epidemiologic reviews*, *8*, 117-128.
30. Esrey, S. A., Potash, J. B., Roberts, L., & Shiff, C. (1991). Effects of improved water supply and sanitation on ascariasis, diarrhoea,

dracunculiasis, hookworm infection, schistosomiasis, and trachoma. *Bulletin of the World Health organization*, *69*(5), 609.

31. Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L., & Colford, J. M. (2005). Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *The Lancet infectious diseases*, *5*(1), 42-52.
32. Cairncross, S., Hunt, C., Boisson, S., Bostoen, K., Curtis, V., Fung, I. C., & Schmidt, W. P. (2010). Water, sanitation and hygiene for the prevention of diarrhoea. *International journal of Epidemiology*, *39*(1), i193-i205.
33. Ziegelbauer K, Speich B, Mausezahl D, Bos R, Keiser J, et al. (2012). Effect of Sanitation of Soil-Transmitted Helminth Infection: Systematic review and Meta-Analysis. PLoS Med 9(1).
34. Dangour AD, Watson L, Cumming O, Boisson S, Che Y, Velleman Y, Cavill S, Allen E, Uauy R. Interventions to improve water quality and supply, sanitation and hygiene practices, and their effects on the nutritional status of children. *Cochrane Database ofSystematic Reviews* 2013, Issue 8. Art. No.: CD009382. DOI: 10.1002/14651858.CD009382.pub2.
35. Wolf, J., Prüss-Ustün, A., Cumming, O., Bartram, J., Bonjour, S., Cairncross, S., ... & Fewtrell, L. (2014). Systematic review: assessing the impact of drinking water and sanitation on diarrhoeal disease in low-and middle-income settings: systematic review and meta-regression. *Tropical Medicine & International Health*, *19*(8), 928-942.
36. Clasen, T. F., Bostoen, K., Schmidt, W. P., Boisson, S., Fung, I. C., Jenkins, M. W., & Cairncross, S. (2010). Interventions to improve disposal of

human excreta for preventing diarrhoea. *Cochrane Database Syst Rev*, *6*.

37. Hunter PR, Ramirez Toro GI, Minnigh HA (2010
38. Oswald WE, Steward AE, Kramer MR, Endeshaw T, et al. (2017) Active trachoma and community use of sanitation, Ethiopia. *Bulletin of the World Health Organization*; 95:250-260
39. Oswald WE, Steward AE, Kramer MR, Endeshaw T, et al. (2017) Association of community sanitation usage with soil-transmitted helminth infections among school-age children in Amhara Region, Ethiopia. *Parasites & Vectors* 10:91
40. Fuller et al (2016). I get height with a little help from my friends: herd protection from sanitation on child growth in rural Ecuador. International Journal of Epidemiology, 460-469
41. Government of India (2012). Guidelines for Nirmal Bharat Abhiyan. Ministry of Drinking Water and Sanitation. Retrieved from http://tsc.gujarat.gov.in/tsc_news_website/NBA_guideline_new.htm
42. TARU/UNICEF (2008) Impact Assessment of Nirmal Gram Puraskar Awarded Panchayats, FinalReport.Vol 1:Main report.Available: http://www.indiawaterportal.org/sites/indiawaterportal.org/files/Impact%20Assessment%20of%20Nirmal%20Gram%20Puraskar%20awarded%20panchayats_TARU_2008.pdf. Accessed 8 August 2012.
43. Arnold, B. F., Khush, R. S., Ramaswamy, P., London, A. G., Rajkumar, P., Ramaprabha, P., ... & Colford, J. M. (2010). Causal inference methods to study nonrandomized, preexisting development interventions. *Proceedings of the National Academy of Sciences*, *107*(52), 22605-22610.

44. Odagiri et al. (2016). Human fecal and pathogen exposure pathways in rural Indian villages and the effect of increased latrine coverage. Water Research 100; 232-244.

45. Garn et al. (2016). The impact of sanitation interventions on latrine coverage and latrine use: A systematic review and meta-analysis. International Journal of Hygiene and Environmental Health; article in press.

46. Government of India Ministry for Drinking Water and Sanitation (2012) Guidelines on Nirmal Bharat Abhiyan (NBA). Available:http://ddws.gov.in/sites/upload_files/ddws/files/pdfs/Final%20Guidelines%20(English).pdf. Accessed17 November 2012.

47. Water and Sanitation Program. A Decade of the Total Sanitation Campaign: Rapid Assessment of Processes and Outcomes. 2010.

48. MANTRA 2016. Gramvikas.org. http://gramvikas.org/docs/MANTRA-2016.pdf

49. A Getis. Spatial Statistics. *Geos*. Retrieved from http://www.geos.ed.ac.uk/~gisteac/gis_book_abridged/files/ch16.pdf

50. Glatman-Freedman A, Kaufman Z, Kopel E, Bassal R, Taran D, et al. (2016). Near real-time space-time cluster analysis for detection of enteric disease outbreaks in a community setting. Journal of Infection, 73;99-106

51. Valcour JE, Charron DF, Berke O, Wilson JB, Ede T, Waltner-Toews D. (2016). A descriptive analysis of the spatio-temporal distribution of enteric diseeases in New Brunswick, Canada. *BMC Public Health*. 16:204

52. Ntozini, R., Marks, S. J., Mbuya, M. N., Gerema, G., Mutasa, B., Julian, T.

R., ... & Helyar, W. (2015). Using geographic information systems and spatial analysis methods to assess household water access and sanitation coverage in the SHINE trial. *Clinical Infectious Diseases*, *61*(suppl 7), S716-S725.

53. Yu, W., Bain, R. E., Mansour, S., & Wright, J. A. (2014). A cross-sectional ecological study of spatial scale and geographic inequality in access to drinking-water and sanitation. *International journal for equity in health*, *13*(1), 113.
54. Tsiko, R. G. (2015). Bayesian spatial analysis of childhood diseases in Zimbabwe. *BMC public health*, *15*(1), 1.
55. Karagiannis-Voules, D. A., Biedermann, P., Ekpo, U. F., Garba, A., Langer, E., Mathieu, E., ... & Sacko, M. (2015). Spatial and temporal distribution of soil-transmitted helminth infection in sub-Saharan Africa: a systematic review and geostatistical meta-analysis. *The Lancet Infectious Diseases*, *15*(1), 74-84.
56. Chammartin, F., Scholte, R. G., Guimarães, L. H., Tanner, M., Utzinger, J., & Vounatsou, P. (2013). Soil-transmitted helminth infection in South America: a systematic review and geostatistical meta-analysis. *The Lancet Infectious Diseases*, *13*(6), 507-518.
57. Ngui, R., Shafie, A., Chua, K. H., Mistam, M. S., Al-Mekhlafi, H. M., Sulaiman, W. W., ... & Lim, Y. A. (2014). Mapping and modelling the geographical distribution of soil-transmitted helminthiases in Peninsular Malaysia: implications for control approaches. *Geospatial health*, *8*(2), 365-376.

58. Pullan, R. L., Kabatereine, N. B., Quinnell, R. J., & Brooker, S. (2010). Spatial and genetic epidemiology of hookworm in a rural community in Uganda. *PLoS Negl Trop Dis*, *4*(6), e713.
59. Davis, S. M., Worrell, C. M., Wiegand, R. E., Odero, K. O., Suchdev, P. S., Ruth, L. J., ... & Montgomery, J. M. (2014). Soil-Transmitted Helminths in Pre-School-Aged and School-Aged Children in an Urban Slum: A Cross-Sectional Study of Prevalence, Distribution, and Associated Exposures. *The American journal of tropical medicine and hygiene*, *91*(5), 1002-1010.
60. Kaliappan, S. P., George, S., Francis, M. R., Kattula, D., Sarkar, R., Minz, S., ... & Muliyil, J. (2013). Prevalence and clustering of soil-transmitted helminth infections in a tribal area in southern India. *Tropical Medicine & International Health*, *18*(12), 1452-1462.
61. Rajeshwari (2008). Sanitation situation and disease pattern in Haryana: a spatial analysis. *Demography India, 37*(1), 79-94.
62. Santos, C. B., Araújo, K. C. G., Jardim-Botelho, A., Santos, M. B., Rodrigues, A., Dolabella, S. S., & Gurgel, R. Q. (2014). Diarrhea incidence and intestinal infections among rotavirus vaccinated infants from a poor area in Brazil: a spatial analysis. *BMC public health*, *14*(1), 399.
63. Chammartin, F., Guimarães, L. H., Scholte, R. G., Bavia, M. E., Utzinger, J., & Vounatsou, P. (2014). Spatio-temporal distribution of soil-transmitted helminth infections in Brazil. *Parasites & vectors*, *7*(1), 1-16.
64. Brooker, S., Alexander, N., Geiger, S., Moyeed, R. A., Stander, J., Fleming, F., ... & Bethony, J. (2006a). Contrasting patterns in the small-scale heterogeneity of human helminth infections in urban and rural

environments in Brazil. *International journal for parasitology*, *36*(10), 1143-1151.

65. Souza, E. A. D., Silva-Nunes, M. D., Malafronte, R. D. S., Muniz, P. T., Cardoso, M. A., & Ferreira, M. U. (2007). Prevalence and spatial distribution of intestinal parasitic infections in a rural Amazonian settlement, Acre State, Brazil. *Cadernos de Saúde Pública*, *23*(2), 427-434.
66. Azage, M., Kumie, A., Worku, A., & Bagtzoglou, A. C. (2015). Childhood Diarrhea Exhibits Spatiotemporal Variation in Northwest Ethiopia: A SaTScan Spatial Statistical Analysis. *PloS one*, *10*(12), e0144690.
67. Vazquez-Prokopec GM, Spillmann C, Zaidenberg M, Gurler RE, Kitron U (2012) Spatial Heterogeneity and Risk Maps of Community Infestation by Triatoma infestans in Rural Northwestern Argentina. PLoS Negl Trop Dis 6(8): e17788. Doi:10.1371/journal.pntd.0001788.