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An Exploratory Analysis of the Risk Factors for

Diarrhea and Acute Lower Respiratory Infections in Odisha, India

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Abstract

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Background: Diarrhea was the eighth leading cause of death among all ages worldwide in 2016, with approximately 1.66 million deaths. Acute lower respiratory infections (ALRI) were the sixth leading cause of death among all ages worldwide in 2016, with approximately 2.4 million deaths. India has the highest number of deaths in the world due to acute lower respiratory infections and diarrheal diseases.
Methods: This analysis was completed based on data collected for a previous study. The goal of the parent study was to assess the combined effects of a household-level piped water and sanitation intervention on the prevalence of diarrhea and ALRI. This study employed a matched-cohort design and included 45 villages in the intervention group and 45 in the control group. Diarrhea and acute lower respiratory infections were recorded as a 7-day self-reported prevalence.
Results: There was a negligible difference in the levels of 7-day diarrhea and ALRI prevalence between the intervention and control villages. There was an increase in the prevalence of diarrhea when people used an unimproved water source versus an improved water source (AOR: 1.33, 95% CI: 1.05, 1.67) and when people don't have access to a handwashing station (AOR: 1.30, 95% CI: 1.08, 1.57). The data showed that richer families had decreased odds of ALRI (AOR: 0.74, 95% CI: 0.61, 0.91). The type of sanitation (AOR: 1.15, 95% CI: 0.91, 1.44) and type of water source (AOR: 1.05, 95% CI: 0.84, 1.31) were shown to have a negligible effect on the prevalence of ALRI.
Discussion: The biggest limitation in this research was the reliance on self-reported data, especially for the outcomes of interest. Self-reported data is prone to social desirability bias, where the participant is likely to answer the question based on what the researcher wants to hear, rather than the truth. Another limitation to this study is the lack of consideration of microbiological data in the results. Future research should also focus on risk factors specifically for children under the age of five, and should explore if there is any effect measure modification based on other ages.

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Background

BURDEN OF DISEASE

Diarrhea was the eighth leading cause of death among all ages worldwide in 2016, with approximately 1.66 million deaths attributed to the disease[1]. In 2005, diarrhea was the sixth leading cause of death among all ages, with approximately 2.2 million deaths. There were approximately 446,000 deaths due to diarrhea for children under the age of five in 2016, which was the fifth deadliest disease for this age group[1], compared to 875,000 deaths in 2005, when diarrhea was the second deadliest disease for the age group. The number of deaths due to diarrhea decreased by 25% among all ages, and 49% among children under the age of five between the years of 2005 and 2016[1].

Acute lower respiratory infections (ALRI) were the sixth leading cause of death among all ages worldwide in 2016, with approximately 2.4 million deaths (652,000 of which were children under the age of five). In 2005, ALRIs were ranked as the fourth leading cause of death, with approximately 2.6 million deaths (with 1.2 million children under the age of five). The number of deaths due to ALRI decreased by 9% among all ages, and 44% among children aged less than five between the years of 2005 and 2016.

India has the highest number of deaths in the world due to acute lower respiratory infections and diarrheal diseases[1].In 2016, there were approximately 778,000 deaths due to diarrheal diseases in India. In 2005, there were approximately 1.05 million deaths due to diarrheal diseases, a drop of 26%. There were approximately 66,000 children under the age of five who died of diarrheal diseases in India in 2016, compared to 219,000 deaths for children under the age of five in 2005. Diarrheal diseases remain the third ranked cause of death overall in India for all ages, and the fifth ranked cause of death for children under the age of five. There were approximately 496,000 deaths due to ALRI in India among all ages in 2016, while there were approximately 618,000 deaths in 2005, a drop of 20%. There was a larger drop in the number of deaths for children under the age of five. There were 150,000 deaths due to ALRI in 2016, and 355,000 deaths in 2005, a drop of 58%. Despite this drop in the numbers, ALRI remains the leading cause of death for children under the age of five in India.

The State of Odisha currently ranks third in India for total number of deaths due to diarrheal diseases, with approximately 59,000 total deaths, although it is first for rate of deaths due to diarrheal diseases, with 129 people per 100,000[1]. Women have a higher rate of death due to diarrheal diseases, with approximately 149 deaths per 100,000 women, compared to approximately 111 deaths per 100,000 men. In terms of lower respiratory infections, there was a total of 21,000 deaths in Odisha, which is the seventh highest burden of disease in India. The rates of death for males and females for lower respiratory infections was approximately even, with approximately 45.5 deaths per 100,000 for males and approximately 46.25 deaths per 100,000 for females[1].

POTENTIAL RISK FACTORS FOR DIARRHEAL DISEASES

According to the WHO/UNICEF Joint Monitoring Program (JMP), 12% of the global population (892 million people) still practice open defecation[2]. As of 2015, approximately 40% of Indians openly defecate on a regular basis[2]. The rate of open defecation still remains high in rural areas compared to urban areas, with 56% of rural residents openly defecating compared to only 7% of urban residents openly defecating.

The association between open defecation and prevalence of diarrhea has been exhaustively studied recently, with most of these studies either showing null or minor gains in the rates of diarrhea among the target populations who receive interventions based on latrine access and improved sanitation compared with control groups who do not receive these interventions[3–11]. An intervention can either be single or combined; a single intervention studies only one aspect of water, sanitation, or hygiene, such as improving access to latrines, while a combined intervention studies two or more aspects, such as providing soap to families and installing a piped water supply to the family home. According to a systematic review conducted by Wolf et al., combined interventions are more effective at reducing the prevalence of diarrhea compared to single interventions (RR: 0.59, 95% CI: 0.43, 0.81)[12]. A Cochrane systematic review[13] that included 45 cluster-RCTs (randomized control trials), 2 quasi-RCTs, and 8 CBA (controlled before-and-after) studies, including over 84,000 participants, found insufficient evidence of the effectiveness of source-based improvements, such as protecting ground-based water sources or using rainwater as the primary water source, on the levels of diarrhea among the participants. Stronger evidence for the reduction in diarrhea was found amount point-of-use-based interventions, such as chlorinating water in a safe storage container and using flocculation and disinfection sachets before use. A big factor in any study on the effectiveness of interventions on diarrhea rely on the self-reporting of diarrheal prevalence for each subject. The Cochrane meta-analysis noted that there was a high risk of bias in the studies analyzed due to a lack of blinding in over 80% of the studies.

A primary cause of diarrhea in the under 5 population are enteropathogens, such as rotavirus, *Cryptosporidium* spp, and *Shigella* spp. An estimated 261,300 deaths of children under the age of 5 were attributed to these three pathogens in 2015, which was 50% of the deaths due to diarrhea in this age group[14]. The primary transmission route for these pathogens is the fecal-oral route. Open defecation in fields has been shown to increase the amount of *Cryptosporidium* and *Giardia* in nearby surface water in Puri district, Odisha[15]. Other risk factors that have been associated with diarrhea include water contaminated with bacteria and viruses, wasting (less than 2 standard deviations from the median weight-for-height reference population), suboptimal breastfeeding, vitamin A deficiency, and zinc deficiency[14], as well as low socioeconomic status and absence of prenatal examination[16]. The MAL-ED birth cohort study of approximately 1,300 children showed that enteropathogens detections were often associated with a reduced mean length after 24 months, although there was no similar effect with weight[17]. It is well documented that latrine access doesn't necessary translate into latrine use[3,18], even though Routray *et al.* found that a lack of access to a latrine was the main reason why people practiced open defecation[19]. India is currently increasing access to latrines at a rate of 1% per year, which is a far slower pace when compared to other countries around the world[18]. One of the fastest ways that the government has increased access to latrines is by building them entirely with government funds, without villager support. Coffey et al. found that the latrines that are least likely to be used by open defecators are those that are built in this manner[20]. According to a longitudinal study conducted by Sinha et al. among 25 villages and 310 households in Odisha, 80% of participants that didn't use latrines gave the reason that they preferred to openly defecate, rather than use a latrine[21]. Also in the study, women were more likely than men to always (AOR: 2.24, 95% CI: 1.87, 2.68) and sometimes (AOR: 1.99, 95% CI: 1.48, 2.70) use a latrine compared to never using a latrine[21]. The authors also found a difference in latrine use by season. The odds of using a latrine were greater in the winter and rainy season, than in the summer season. This corroborates the findings of the Routray *et al.* study[19]. Seventy-one percent of the global population, or 5.2 billion people, use a safely managed drinking water source, which is defined as one that is located on the premises and has water freely available when it is needed. Eighty-eight percent of the population in India has at least basic access to a drinking water source, which is defined as water from an improved source (one that is at least from a protected borehole) and is available on the premises[2]. Out of those using an improved water source, 59% of rural Indians use a non-piped system, and 31% use a piped water system[2]. A piped water source does not guarantee a clean water supply, as shown in the research conducted by Daniels et al.[15]. Pressure drops in a piped water supply (less than 10 psi) are associated with an increase in the concentrations of indicator bacteria, which are used to indirectly measure the amount of fecal coliforms in a water source. Although an increase in indicator bacteria does not necessarily represent an increase in harmful pathogens in the water, it is a one way to test the quality of a water source and estimate whether a chlorine supply is able to inactivate the number of potential bacteria present[22].

POTENTIAL RISK FACTORS FOR ALRI

Acute lower respiratory infections (ALRI) also play a role in the morbidity and mortality in rural areas. One of the main causes of ALRI is household air pollution (HAP) and $PM_{2.5}$[23]. Unimproved cookstoves that use biomass (wood or other agricultural substances) or kerosene have been shown to emit more $PM_{2.5}$ than other types of cookstoves[24].

Although these two fuel types have been shown to increase the amount of ALRI in children where they are used, the types of fuel also affect if children remain in the kitchen while the caretaker is cooking. The authors of the study note that many children in biomass-burning houses are in the kitchen a lot less than in households that use gas or kerosene to cook[24]. Pathogens, such as respiratory syncytial virus (RSV) have also been found to cause ALRI in young children. Previous hospital-based studies in India have shown a prevalence rate of 9% to 30% for RSV infection across India[25]. According to a meta-analysis conducted by Shi *et al*., prematurity, being male, no breastfeeding, and household crowding are all associated with an increased prevalence of RSV[26]. Another major factor that has been shown to be associated with acute lower respiratory infections has been maternal education level[27,28]. A study in neighboring Bangladesh found that families are more likely to take their children to the doctor if they are suffering from acute lower respiratory infections than if the children was suffering from a diarrheal episode, thus increasing the cost of burden of respiratory infections for poorer families[29]. Other risk factors that have been shown to be associated with an increased risk in ALRI are unclean fuel, such as wood and agricultural waste, poor sanitation practices, poor drinking water source, type of house lived in[30]. These factors can also be influenced by the family's socioeconomic profile as well; families that are living below the poverty line are more likely to have less access to latrines (especially those that are connected to a sewer), less access to clean drinking water, and more likely to be exposed to indoor air pollution from the burning of solid fuels during cooking[28].

We used data from a matched cohort study evaluating a combined piped water and sanitation intervention in Odisha state, India to conduct a secondary analysis of the risk factors that are associated with the prevalence of diarrhea and ALRI. The main goal of this study was to estimate the effects of these associations and to propose a direction for future research in the research of these risk factors.

Methods

STUDY POPULATION

This analysis was completed based on data collected for a larger study conducted by Reese et al. in the Ganjam and Gajapati districts, Odisha state, India[31]. The goal of the parent study was to assess the combined effects of a household-level piped water and sanitation intervention on the prevalence of diarrhea and ALRI. This study employed a matched-cohort design and included 45 villages in the intervention group and 45 in the control group. The intervention villages underwent Gram Vikas' MANTRA intervention, which on average occurred over the course of 3 years, whereas the control villages did not. The control villages were not located in the same Gram Panchayat or bordering the intervention villages[31].

Seventy-one percent of people living in Ganjam district and 61.7% of people living in Gajapati district have access to improved drinking water, which includes water piped into the dwelling or yard, a public tap, or a cart with small tank and bottled water[32]. Twenty-three of people living in the Ganjam district and 8.1% of people living in the Gajapati district live with any type of toilet facility[32]. Fourty-five percent of people living in the Ganjam district and 44% of people living in the Gajapati district have a BPL (Below Poverty Line) card, which provide families with subsidized food and fuel.

The intervention is implemented by Gram Vikas, a local NGO working on water and sanitation improvement projects across Odisha[33]. Their MANTRA (Movement and Action Network for Transformation of Rural Areas) approach encourages every household in a community to build a toilet and bathing room. Once construction is complete, every household is connected to the community piped water distribution system, with taps in the toilet room, bathing room, and in the kitchen. Along with this, the village must form a Water and Sanitation Committee and a village corpus fund to help with repairs and building new latrines for families moving into the area.

OUTCOME DEFINITIONS

Diarrhea was recorded as a 7-day period prevalence. The WHO definition for diarrhea (presence of three or more loose stools in a 24-hour period, with or without the presence of blood) was used to determine the presence or absence of diarrhea for each member of the household.

ALRI was recorded as a 7-day period prevalence. The WHO's Integrated Management of Childhood Illness (IMCI) definition of respiratory infections (presence of cough and/or shortness of breath or difficulty breathing) was used to assess the presence or absence of ALRI. Individual respiratory rate and other respiratory danger signs were not observed due to a lack of technical skill in the field.

DATA COLLECTION

Data for the study were collected approximately every four months starting in June 2015 and ending in October 2016. The survey was administered by a trained enumeration team in the local language of Oriya using Open Data Kit, a mobile data collector that runs on Android phones[34]. The primary outcomes for this study, diarrhea and ALRI, were self-reported by each family member in the household, or by the caregiver for children under 5 years.

Covariates concerning the conditions and types of toilets, bathing areas, availability of water, and presence of a cleansing agent were initially collected through a direct question and later confirmed through enumerator observations. Additionally, participants were asked about any interruptions in accessing the water supply in a 24-hour period during the previous two weeks.

Aggregate measures, such as those concerning a proportion of a household, a wealth index, and village-level factors were calculated from the data collected. A binary variable accounting for whether the data were collected during the rainy season (June until September) was created during the analysis phase.

The Joint Monitoring Plan (JMP) definitions[2] were used to determine whether a household's sanitation and water practices were improved or unimproved. Unimproved sanitation facilities do not necessarily separate human excreta from contact and includes pit latrines without a slab. Improved sanitation facilities separate human excreta from touch and include flush/pour pit latrines and pit latrines with slabs. An unimproved drinking water source includes unprotected wells/springs and surface water. An improved drinking water source includes public taps, tube wells, or piped household water connections.

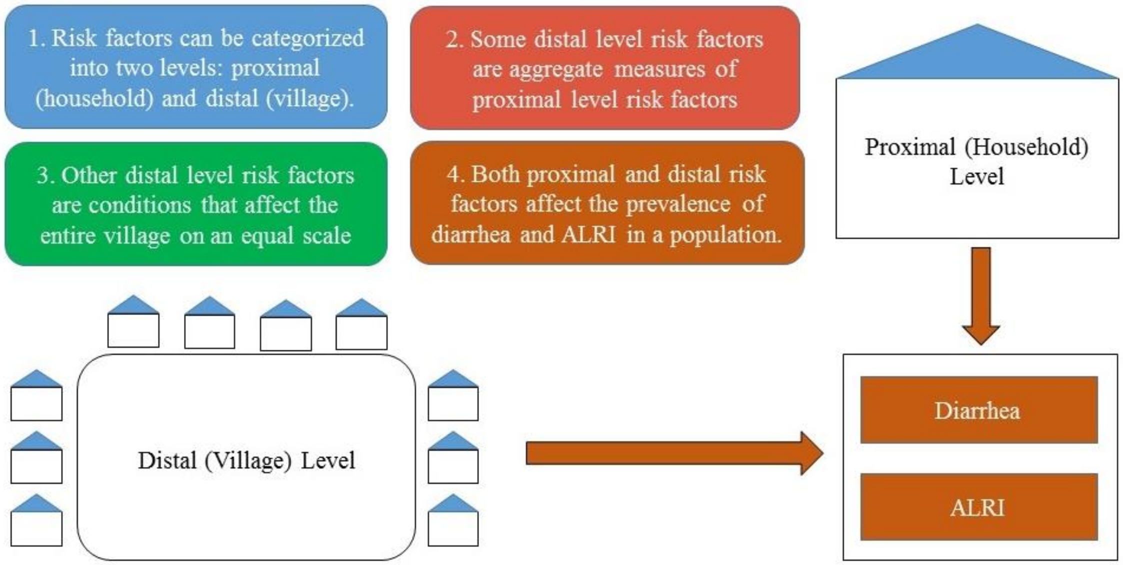
ANALYSIS

A literature review was initially conducted that looked at previously completed interventions in both India and throughout the world, as well as findings regarding the risk factors for each outcome. After the completion of the review, directed acyclic graphs (DAGs)[35] were created to identify potential covariates of interest and biasing paths in the collected data. Potential covariates of interest from the DAGs were assessed for inclusion into the models through a bivariate analysis using a χ^2 test with a p-value cut-off of 0.10 (see appendices 1 and 2).

The covariates were organized into two distinct groups: proximal factors and distal factors. Proximal factors are also known as household-level factors because they have a greater effect on the people that live within a specific household compared to those that live outside of the household. These factors included the type of water source and sanitation in the household, the availability of a handwashing station, the household density, female caregiver's education level, and the principal source of fuel for cooking. These factors have a direct and immediate impact on the prevalence of diarrhea and ALRI for those people who live within the household.

Distal factors are also known as village-level factors because they have a greater effect on the people that live in the village as a whole, compared to the effect that they have on any one specific household. Some distal factors are an aggregation of proximal factors, such as village improved sanitation coverage (the percent of households within a village that have an improved sanitation method), or factors that affect the village on a roughly equal scale, such as the amount of rainfall in the village over a specific time period. Other distal factors include the village's improved water coverage and population density.

Figure 1. An explanation of the differences between proximal and distal level covariates



A total of 12 models were created in order to assess the odds of a participant having diarrhea or an ALRI within the past seven days compared to the odds of a participant not having diarrhea or an ALRI within the past seven days. Covariates of interest in the models were group according to a similarity of types, such as those covariates concerning water, sanitation, fuel used within the household, and background covariates that don't have an immediate effect on the participant. Six models were created for diarrhea, which was further split into three models for proximal factors and three models for distal factors. Six models were also created for ALRI, again being further split into three models for proximal factors and three models for distal factors. Each model was controlled for age, sex, and whether the participant lived in an intervention or control village.

After the initial models were created, collinearity was assessed using a non-statistical method. Covariates, such as whether a household had access to a toilet facility, whose measure was already included as a part of another aggregated covariate, such as whether a household met the JMP definition for improved sanitation, were not included in the model.

To analyze our data, we used multilevel logistic regression models with random effects for village and household levels in order to account for the clustering in each of these levels. Dummy variables were created for each categorical predictor that had more than two levels for use in the logistic regression. All statistical analyses were done in R (version 3.4.3)[36] and with the lme4 package (version 1.1-17)[37].

Results

There were 22,335 observations in the intervention group and 23,736 observations in the control group across all four rounds of data collection (Table 1). The intervention and control groups were roughly equal across gender and in the proportion of children under the age of 5.

There was a negligible difference in the levels of 7-day diarrhea and ALRI prevalence between the intervention and control villages. The intervention villages had a higher coverage for improved sanitation and water services (65.3% and 92.5%, respectively) compared to the control villages (17.1% and 73.5%, respectively). The intervention villages also have a higher handwashing station coverage percentage and fewer interruptions reported in their water sources. The intervention villages were also more likely than the control villages to use cleaner burning materials (such as electricity and LPG or natural gas) for fuel when cooking.

Table 2. Descriptive characteristics of study population.

	Control (n= 23,736)	Intervention (n=21,335)	Total (n=45,071)
	Mean (SD)	**Mean (SD)**	**Mean (SD)**
Age	24.77 (21.24)	25.41 (20.66)	25.07 (20.97)
	n (%)	**n (%)**	**n (%)**
Gender			
Male	11253 (47.4)	10192 (47.8)	21445 (47.6)
Female	12406 (52.3)	11065 (51.9)	23471 (52.1)
Diarrhea*			
Yes	593 (2.5)	458 (2.1)	1051 (2.3)
No	20646 (87)	18712 (87.7)	39358 (87.3)
ALRI*			
Yes	1103 (4.6)	995 (4.7)	2098 (4.7)
No	20456 (86.2)	18445 (86.5)	38901 (86.3)
Sanitation			
Improved	4069 (17.1)	13925 (65.3)	17994 (39.9)
Unimproved	13733 (57.9)	2067 (9.7)	15800 (35.1)
Water			
Improved	17451 (73.5)	19728 (92.5)	37179 (82.5)
Unimproved	6264 (26.4)	1592 (7.5)	7856 (17.4)
Handwashing station coverage			
Station available‡	11357 (47.8)	14707 (68.9)	26064 (57.8)
None available	6597 (29.3)	2304 (10.8)	8901 (19.7)
Interruptions in water source			
Interruptions reported	21969 (92.6)	17710 (83.0)	39679 (88.0)
None reported	1737 (7.32)	3621 (17.0)	5358 (11.9)
Fuel used for cooking			
Electricity	539 (2.3)	915 (4.3)	1454 (3.2)
LPG/natural gas	2678 (11.3)	3668 (17.2)	6346 (14.1)
Kerosene	32 (0.1)	47 (0.2)	79 (0.2)
Charcoal/wood	17734 (74.7)	14432 (67.6)	32166 (71.4)

*Recorded 7-day point prevalence

‡ Includes stations with water, water and soap, or ash

Potential risk factors for inclusion into the models were first identified in previous literature and DAGs were created to model potential pathways of the exposure's effect on the outcome. Covariates that were assessed for inclusion into the model where seven-day point prevalence of diarrhea was the outcome of interest, but were not significant according to a χ^2 test of homogeneity and an alpha level of 0.10, include the location where the primary caregiver does the cooking, whether the child had ever been breastfed, the frequency of smoking indoors, location of disposal for solid waste/garbage, head of household education, and proportion of household members older than the age of five years old using an improved toilet.

Covariates that were assessed for inclusion into the model where seven-day point prevalence of ALRI was the outcome of interest, but were not significant according to a χ^2 test of homogeneity, include the location where the cooking is usually done, whether the child had ever been breastfed, the frequency of someone smoking inside the house, reported drinking water storage, female and head of household education level, and whether there was a smoker in the household.

There was an increase in the prevalence of diarrhea when people used an unimproved water source versus an improved water source (AOR: 1.33, 95% CI: 1.05, 1.67) and when people don't have access to a handwashing station (AOR: 1.30, 95% CI: 1.08, 1.57) (Table 3). The results in table 3 underscore the importance of a family's wealth on the prevalence of diarrhea, as wealthier people had lower odds of having diarrhea compared to poorer people (AOR: 0.63, 95% CI: 0.50, 0.81). Another important factor for the decrease in the prevalence of diarrhea is the proportion of household members who used an improved toilet (AOR: 0.50, 95% CI: 0.28, 0.92). The data showed that when people reported an interruption in their water source in the previous 24 hours, the odds of having diarrhea over the previous seven days were decreased, although non-significantly, compared to the odds of having diarrhea over the previous seven days when people did not have any interruptions in their water source (AOR: 0.79, 95% CI: 0.61, 1.02). A female caregiver's education level was a significant factor in the increased odds of diarrhea, although the effect of the female caregiver's education level became non-significant when the mother had less than one year of education completed.

Table 3. Proximal Models for Diarrhea*

	Variable Type	Estimate (95% CI)
Model 1		
Type of water source	Categorical	
Unimproved		1.33 (1.05, 1.67)
Handwashing station coverage‡	Categorical	
None available		1.30 (1.08, 1.57)
Interruptions in water source	Categorical	
Any reported interruptions		0.79 (0.61, 1.02)
Model 2		
Type of sanitation	Categorical	
Unimproved		0.87 (0.60, 1.26)
Child feces disposal	Categorical	
No proper disposal		1.15 (0.80, 1.66)
Proportion of household members using an improved toilet	Continuous	0.50 (0.28, 0.92)
Model 3		
Female caregiver education level	Categorical	
Completed secondary (10 years)		1.71 (1.03, 3.00)
Completed primary (>4 years)		1.86 (1.04, 3.45)
Less than 1 year complete		1.39 (0.81, 2.51)
Household population density	Continuous	0.88 (0.79, 0.98)
Standardized wealth index	Continuous	0.63 (0.50, 0.81)

*Each model was controlled for age, sex, and intervention/control status

‡ Includes stations with water, water and soap, or ash

The data concerning ALRI in the study population showed that richer families had a decreased odds of ALRI (AOR: 0.74, 95% CI: 0.61, 0.91) (Table 4). The density of the household was also shown to be an significant factor (AOR: 0.87, 95% CI: 0.79, 0.95) for the reduction of the odds of ALRI in the study population. The type of sanitation (AOR: 1.15, 95% CI: 0.91, 1.44) and type of water source (AOR: 1.05, 95% CI: 0.84, 1.31) were shown to have a negligible effect on the prevalence of ALRI when an improved type was used compared to when an unimproved type was used. Other factors that were shown to not have a significant effect on the odds of having prevalent diarrhea include the fuel used for lighting the home, the fuel used for cooking, or whether the child was carried while the female primary caregiver was cooking.

Table 4. Proximal Models for Acute Respiratory Infections*

	Variable Type	Estimate (95% CI)
Model 1		
Principal source of household lighting	Categorical	
LPG / gas		0.60 (0.11, 2.39)
Kerosene		0.90 (0.70, 1.16)
Coal / wood / agricultural waste		3.03 (0.45, 19.17)
Fuel used for cooking	Categorical	
LPG / gas		1.17 (0.73, 1.90)
Kerosene		1.39 (0.28, 5.97)
Coal / wood / agricultural waste		1.52 (0.99, 2.39)
Carrying child while cooking†	Categorical	
Yes		1.13 (0.96, 1.34)
Model 2		
Type of sanitation	Categorical	
Unimproved		1.15 (0.91, 1.44)
Type of water source	Categorical	
Unimproved		1.05 (0.84, 1.31)
Handwashing station coverage‡	Categorical	
None available		0.89 (0.74, 1.07)
Model 3		
Female caregiver education level	Categorical	
Completed secondary (10 years)		1.19 (0.82, 1.75)
Completed primary (>4 years)		1.05 (0.67, 1.64)
Less than 1 year complete		1.06 (0.71, 1.61)
Household population density	Continuous	0.87 (0.79, 0.95)
Standardized wealth index	Continuous	0.74 (0.61, 0.91)

*Each model was controlled for age, sex, and intervention/control status

† In the past two days

‡ Includes stations with water, water and soap, or ash

The results from the distal models for estimating the prevalence of diarrhea and ALRI were mixed (Table 5). The data showed that there was an significantly increased odds of diarrhea if there was an increased amount of people using an improved sanitation source

(AOR: 1.48, 95% CI: 1.07, 2.07), while there was a significantly decreased odds of ALRI if there was an increase in the village using an improved sanitation source (AOR: 0.58, 95% CI: 0.47, 0.72). A similar pattern in the data emerged depending on if the data were collected during the rainy season. There was a significantly increased odds of diarrhea during the rainy season compared to the dry season (AOR: 1.78, 95% CI: 1.56, 2.02). On the other hand, there was a significantly decreased odds of ALRI during the rainy season compared to the dry season (AOR: 0.75, 95% CI: 0.68, 0.82). The data also showed that village density was not associated with either diarrhea (AOR: 1.00, 95% CI: 0.92, 1.09) or ALRI (AOR: 1.03, 95% CI: 0.96, 1.11). While having higher improved water coverage was not associated with the odds of having diarrhea (AOR: 1.00, 95% CI: 0.72, 1.38) and a slight increase in the odds of ALRI (AOR: 1.13, 95% CI: 0.86, 1.48), a higher coverage of piped water sources led to a significant decrease of both measures (AOR Diarrhea: 0.64, 95% CI: 0.47, 0.87), (AOR ALRI: 0.79, 95% CI: 0.62, 1.02).

Table 5. Distal Models for Diarrhea and ALRI*

	Variable type	**Estimate (95% CI)**	
		Diarrhea	ALRI
Model 1			
Village improved sanitation coverage	Continuous	0.54 (0.31, 0.94)	0.75 (0.48, 1.18)
Village improved sanitation use	Continuous	1.48 (1.07, 2.07)	0.58 (0.47, 0.72)
Model 2			
Village improved water coverage	Continuous	1.00 (0.72, 1.38)	1.13 (0.86, 1.48)
Village piped water coverage	Continuous	0.64 (0.47, 0.87)	0.79 (0.62, 1.02)
Model 3			
Rainy Season	Categorical		
Yes^		1.78 (1.56, 2.02)	0.75 (0.68, 0.82)
Village density, people / km^2	Continuous	1.00 (0.92, 1.09)	1.03 (0.96, 1.11)

*Each model was controlled for age, sex, and intervention/control status

^Date of data collection occurred from June until September

Discussion

The objective of this research was to explore the risk factors for diarrhea and ALRI in a rural population in eastern India that had 100% latrine and improved water coverage at some point in the past due to a previous intervention by a local NGO, Gram Vikas. The children in the study population had been born into this post-intervention environment, as opposed to other research that studies children before and after the intervention was implemented. The explored risk factors were categorized into proximal (household) level factors and distal (village) level factors. The proximal level factors that had the greatest associations with a decreased odds of 7-day prevalence of diarrhea were the proportion of household members that used an improved toilet and the wealth of the household. The proximal level factors that had the greatest associations with a decreased odds of 7-day prevalence of ALRI were household population density and the wealth of the household. The distal level factors that had the greatest associations with a decreased odds of 7-day prevalence of diarrhea and ALRI were the village's improved sanitation coverage and the village's piped water coverage.

Some findings from this research support the previous literature. There was a significant increase in the odds of diarrhea in households that had unimproved water sources and that didn't have a handwashing station, compared to households that had an improved water source and those that did have a handwashing station, respectively. Previous literature has shown the importance of including handwashing into interventions and its potential at reducing the rate of diarrhea in a population[6,7,12,38]. The analysis also shows that an increase in the proportion of household members that used an improved toilet was associated with a decreased odds of diarrhea. The topic of latrine coverage and its role in decreasing the incidence of diarrhea has been long studied, and while the results have shown that there have been null effects between sanitation interventions and incidence of diarrhea, adherence to using a latrine is thought to be a major confounder in this relationship[3,39].

There were some results from the proximal models for diarrhea that were opposite what the previous literature has found. The female caregiver's education level was concordant with previous literature, as it has been shown that the less educated a female caregiver is, the odds are greater for diarrhea in a household[27]. However, the data showed that the odds of diarrhea decreased for mothers that had less than one year of education complete when compared to mothers that had completed primary school or mothers that had completed secondary school.

Almost all of the results from the proximal models for ALRI showed null results, which stands in contrast with the conclusive results gained from the proximal models for diarrhea. It was expected that the wealthier a household was, the less their odds were of having ALRI. The result that was most unlike the previous literature concerned household population density. Previous literature has shown that an increased amount of people living in a household would results in an increased prevalence of ALRI in that household[26,28]. Our data showed the opposite effect; an increase in the household population density was associated with a decrease in the odds of ALRI in the household.

When analyzing the distal models, it was hoped that the odds for diarrhea and the odds of ALRI would be positively correlated with each other; if the odds for diarrhea went down because of a risk factor, then it was hoped that the odds for ALRI would go down as well. While some results showed this relationship, there were also some other results that showed a negative correlation. This was evident for the rainy season risk factor. The odds for diarrhea increased during the rainy season, whereas the odds for ALRI decreased. It is possible that the rain helped with the PM 2.5 in the air, but a primary causal pathway for ALRI is through unsafe drinking water, which increases during the rainy season. This negative correlation was also seen for the village improved sanitation use risk factor, which is an aggregate measure from all of the surveys collected in the village. The odds for diarrhea increased significantly when there was an increase in the village's improved sanitation use, while the odds for ALRI decreased significantly when there was an increase in the village's improved sanitation use.

The biggest limitation in this research was the reliance on self-reported data, especially for the outcomes of interest. Self-reported data is prone to social desirability bias, where the participant is likely to answer the question based on what the researcher wants to hear, rather than the truth. The parent study sought to reduce this by using Oriya speakers (the area's local language) for the data collection. Despite this, the participants in the intervention village were more aware of the negative implications of openly defecating compared to the participants in the control villages, and may have given answers to reflect that awareness, despite them potentially openly defecating at the same rate as those in the control villages. In order to control for this self-reported bias, a negative control for the outcome was recorded (presence of bruising/scraping). Because this measure was unrelated to the outcomes of interest, it provides a good measure for measuring self-report bias by intervention / control status. The data from the study showed that there was no difference between intervention and control villages when reporting this negative control for the outcome, so it can be reasonably assumed that self-reporting bias was low for this study.

Another limitation to this study is the lack of consideration of microbiological data in the results. Some current literature for diarrhea and ALRI mention the causal pathways for viruses, protozoans, and bacteria in these diseases[14,25]. This study focused on the macro-scale risk factors for the outcomes of interest, which precludes the microbiological covariates that might be more accurate predictors for the odds of diarrhea and ALRI in the study population.

As third limitation for this study concerns the sparseness of data for some measures. While most of the confidence intervals in the analyses were precise, there were some associations that were relatively imprecise, such as the variables for the fuel used for cooking and the principal source of household lighting in model one of the proximal models for ALRI. Some of our results, such as an increase in the household population density being associated with a decrease in the odds of ALRI, contradicted previously completed research. One (of the many) reasons for these findings could be unmeasured confounding. The major finding in this project is the role of wealth in the prevention of diarrhea and ALRI for a family. The wealthier a household was, the less their odds were of having diarrhea or ALRI. A unique tool for assessing the risk factors for diarrhea and ALRI in this project was splitting the risk into proximal and distal levels. Future research can re-use and adapt this classification system for future research projects as a new way for thinking about risk factors. Future research should also focus on risk factors specifically for children under the age of five, and should explore if there is any effect measure modification based on other ages.

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Appendix 1 – Binary Analysis for Diarrhea Outcome

Variable	Description	P-Value
hh.bld	At any time in the past 7 days, has there been blood in the stool?	1
hh.brs7	At any time in the past 7 days, has [hh.name] had any bruises or scrapes?	0.01
hh.cook	Is the cooking usually done: in the house, in a separate building, or outdoors?	0.284
hh.drt7	Did you observe [hh.name] putting soil, mud, clay, or sand directly in their mouth in the past 7 days?	0.038
hh.fev	At any time in the past 7 days, has [hh.name] had fever?	<0.000001
hh.iycf6	Has [hh.name] ever been breastfed?	0.8487
hh.light	What is the principal source of lighting for your household?	0.00287
hh.sex	Is [hh.name] male or female?	0.564
hh.smk	How often does anyone smoke inside your house?	0.167
sn.01	Does your household have access to a toilet facility?	0.0001
sn.03	Currently, what kind of toilet facility do members of your household usually use?	0.0002
sn.04	Currently, where do household members usually defecate? Elder members (more than 60 years)	0.00027
sn.05	Male adults (18 to 59 years)?	<0.00001
sn.06	Female adults (18 to 59 years)?	<0.00001
sn.07	Children 5 to 17 years?	<0.00001
sn.08	The last time your youngest child under 5 defecated, where did they defecate?	0.00017
sn.09	The last time your youngest child under 5 defecated, what was done to dispose of the stools?	<0.000001
sn.13	How do you dispose of your solid waste/garbage?	0.43
ws.01	What is the main source of drinking water for members of your household?	0.00074
ws.06	What do you usually do to make the water safer to drink? Anything else?	0.025
ws.08	Currently, what is the main source of water used by your household for other purposes such as cooking, bathing and handwashing?	0.00549

Variable	Description	P-Value
ws.imp3	[Improved water source by JMP definition with addition of piped on-premise level]	0.0002
sn.imp3	[Improved sanitation by JMP definition with addition of open defecation level]	0.00025
hw.imp3	[Levels of handwashing station coverage]	<0.000001
ws.stor2	[Drinking water storage, reported]	0.07
ws.stor3	[Safe drinking water storage, observed]	0.17
ws.avail4	[Interruptions in water source availability, levels]	0.00785
sn.4use	[Usual defecation location, ppl >=60 yrs]	0.002
sn.5use	[Usual defecation location, men 18-59 yrs]	<0.00001
sn.6use	[Usual defecation location, women 18-59 yrs]	<0.000001
sn.7use	[Usual defecation location, child 5-17 yrs]	<0.000001
sn.cfd2	[Child feces disposal into improved toilet]	<0.000001
sn.cfd2a	[Child feces disposal into any toilet or buried]	<0.00001
sn.hhuse	[Proportion of household members using an improved toilet]	<0.000001
sn.aduse	[Proportion of household members >5 yrs using an improved toilet]	0.179
brs7	[Bruising/scrapes in previous 7 days]	0.001
hh.fuel4	[Fuel for cooking, categories]	0.003
hh.fuel2	[Fuel for cooking, binary]	0.00044
wom.edu4	[Female caregiver education, categorical]	0.0044
hoh.edu.any	[HoH education, any]	0.414
hoh.edu4	[HoH education, categorical]	0.233
hh.smk4	[Smoker in HH, categorical]	0.134
hh.density	[Household pop density]	0.005
hazc	[HAZ, categorical]	0.256
wazc	[WAZ, categorical]	0.005
whzc	[WHZ, categorical]	0.02
sn.villcov	[Village improved sanitation coverage]	<0.000001
ws.villcov2	[Village improved water coverage]	<0.000001
ws.villcov3	[Village piped water coverage]	<0.000001
ws.pipe2	[On-premise piped water coverage]	<0.0000001
wom.edu.prim	[Female caregiver education, binary]	0.17

Variable	Description	P-Value
hoh.edu.prim	[HoH education, binary]	0.943
sn.villuse2	[Village improved sanitation use]	<0.000001
wealth.ind	[Wealth quintile]	0.0006
wealth	[Wealth index]	<0.000001
wealth.st	[Wealth index, standardized]	<0.0000001

Appendix 2 – Binary Analysis for ALRI Outcome

Variable	Description	P-Value
hh.bld	At any time in the past 7 days, has there been blood in the stool?	0.92
hh.brt	At any time in the past 7 days, has [hh.name] had fast, short, rapid breaths or difficulty breathing?	0
hh.cns	Was the fast or difficult breathing due to a problem in the chest or to a blocked or runny nose?	<0.00001
hh.cof7	At any time in the past 7 days, has [hh.name] had an illness with a cough?	0
hh.cook	Is the cooking usually done: in the house, in a separate building, or outdoors?	0.3778
hh.dia7	At any time in the past 7 days, has [hh.name] had diarrhea (loose motion more than 3 times per day)?	<0.00001
hh.drt7	Did you observe [hh.name] putting soil, mud, clay, or sand directly in their mouth in the past 7 days?	0.002
hh.fev	At any time in the past 7 days, has [hh.name] had fever?	0
hh.iycf6	Has [hh.name] ever been breastfed?	0.713
hh.light	What is the principal source of lighting for your household?	0.146
hh.sex	Is [hh.name] male or female?	0.017
hh.smk	How often does anyone smoke inside your house?	0.4886
hh.stove2	In the past 2 days, have you carried your youngest child under five while cooking?	0.0062
sn.01	Does your household have access to a toilet facility?	0.003
sn.03	Currently, what kind of toilet facility do members of your household usually use?	0.0009
sn.08	The last time your youngest child under 5 defecated, where did they defecate?	0.0001
sn.09	The last time your youngest child under 5 defecated, what was done to dispose of the stools?	<0.0001
sn.13	How do you dispose of your solid waste/garbage?	0.082
ws.01	What is the main source of drinking water for members of your household?	0.00159
ws.06	What do you usually do to make the water safer to drink? Anything else?	<0.0001
ws.08	Currently, what is the main source of water used by your household for other purposes such as cooking, bathing and handwashing?	0.01

Variable	Description	P-Value
ws.imp3	[Improved water source by JMP definition with addition of piped on-premise level]	0.1138
sn.imp3	[Improved sanitation by JMP definition with addition of open defecation level]	0.0012
hw.imp3	[Levels of handwashing station coverage]	0.00146
ws.stor2	[Drinking water storage, reported]	0.368
ws.stor3	[Safe drinking water storage, observed]	0.04
ws.avail4	[Interruptions in water source availability, levels]	0.000136
sn.4use	[Usual defecation location, ppl >=60 yrs]	0.962
sn.5use	[Usual defecation location, men 18-59 yrs]	0.00085
sn.6use	[Usual defecation location, women 18-59 yrs]	0.00726
sn.7use	[Usual defecation location, child 5-17 yrs]	0.0852
sn.cfd2	[Child feces disposal into improved toilet]	0.0149
sn.cfd2a	[Child feces disposal into any toilet or buried]	0.0213
sn.hhuse	[Proportion of household members using an improved toilet]	0.00014
sn.aduse	[Proportion of household members >5 yrs using an improved toilet]	0.000275
dia7	[Diarrhea in previous 7 days]	<0.00001
brs7	[Bruising/scrapes in previous 7 days]	<0.000001
hh.fuel4	[Fuel for cooking, categories]	0.00047
hh.fuel2	[Fuel for cooking, binary]	0.000112
hh.rms5	[Rooms in HH, restricted to >5=5]	0.000112
wom.edu4	[Female caregiver education, categorical]	0.1253
hoh.edu.any	[HoH education, any]	0.272
hoh.edu4	[HoH education, categorical]	0.807
hh.smk4	[Smoker in HH, categorical]	0.43
hh.density	[Household pop density]	<0.00001
hazc	[HAZ, categorical]	0.735
wazc	[WAZ, categorical]	0.0348
whzc	[WHZ, categorical]	0.108
sn.villcov	[Village improved sanitation coverage]	<0.0001
ws.villcov2	[Village improved water coverage]	<0.0001
ws.villcov3	[Village piped water coverage]	<0.0001

Variable	Description	P-Value
ws.pipe2	[On-premise piped water coverage]	0.04
wom.edu.prim	[Female caregiver education, binary]	0.06
hoh.edu.prim	[HoH education, binary]	0.43
sn.villuse2	[Village improved sanitation use]	<0.0001
wealth.ind	[Wealth quintile]	0.0005
wealth	[Wealth index]	<0.00001
wealth.st	[Wealth index, standardized]	<0.00001