Distribution Agreement

In presenting this thesis or dissertation as a partial fulfillment of the requirements for an advanced degree from Emory University, I hereby grant to Emory University and its agents the non-exclusive license to archive, make accessible, and display my thesis or dissertation in whole or in part in all forms of media, now or hereafter known, including display on the world-wide web. I understand that I may select some access restrictions as part of the online submission of this thesis or dissertation. I retain all ownership rights to the copyright of the thesis or dissertation. I also retain the right to use in future works (such as articles or books) all or part of this thesis or dissertation.

Signature:

_____ _____

William Koehne Date

The Effect of Latrine Features and Characteristics on Latrine Use in Rural Odisha, India

By

William Joseph Koehne III

Master of Public Health

Global Epidemiology

_____

Thomas F. Clasen, J.D., Ph.D.

Committee Chair

_____

Bethany A. Caruso, PhD, MPH

Committee Member

The Effect of Latrine Structure and Improvements on Latrine Use in Rural Odisha, India

By

William Joseph Koehne III

B.S., University of Wisconsin—Eau Claire, 2015

Faculty Thesis Advisor: Thomas F. Clasen, J.D., Ph.D.

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 Global Epidemiology

2019

Abstract

The Effect of Latrine Structure and Improvements on Latrine Use in Rural Odisha, India

By William Joseph Koehne III

Open defecation is common worldwide, being practiced by 892 million people, and is of particular concern in rural India where it is estimated that half of the population practices open defecation. A lack of sanitation and open defecation contribute to a variety of acute and chronic diseases and poor health outcomes. While there have been large scale efforts by the Indian government to improve latrine coverage, these programs often do not have the desired effect on decreasing levels of open defecation, in part due to latrine construction that does not meet the needs or align with the desires of users.

This study is a secondary analysis of the baseline data collected as part of a cluster randomized trial evaluating the impact of an intervention designed to increase latrine use in rural Odisha, India with a household's latrine being in use as the outcome of interest. 3676 households and their latrines were analyzed using both generalized estimating equation (GEE) multivariate logistic regression and conditional inference trees (CIT), a form of recursive partitioning.

Various latrine characteristics were identified to be associated with a latrine being in use by both multivariate regression and CIT, including the presence of hand washing stations (odds ratio of 2.78, 95% CI: 2.13, 3.62), and doors (odds ratio of 1.98, 95% CI: 1.41, 2.79). The presence of lights inside of the latrine, though not statistically significant in the multivariate analysis (odds ratio of 1.92, 95% CI:0.96, 3.85), was identified by CIT as associated with latrines being in use for certain households. Tiled latrine floors were not identified in CIT, but were associated with a latrine being in use (odds ratio 1.94, 95% CI: 1.19, 3.17) in the multivariate model.

Though some of these latrine characteristics are not necessary for the latrine to hygienically separate feces from humans and the environment, they may be important drivers of latrine use. This study adds to research that show efforts to decrease open defecation should take into account latrine features and improvements that serve the user experience.

The Effect of Latrine Structure and Improvements on Latrine Use in Rural Odisha, India

By

William Joseph Koehne III

B.S., University of Wisconsin—Eau Claire, 2015

Faculty Thesis Advisor: Thomas F. Clasen, J.D., Ph.D.

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 Global Epidemiology

2019

Acknowledgments:

The author would like to thank Bethany Caruso for her support and insight through the entire study, from development of a research question, to its writing and review, as well as Thomas Clasen for his unique insights and review of the manuscript. The author would also like to acknowledge Corey Nagel for his insight into and assistance with analysis methods as well as Gloria Sclar, Paramita Routray, and Steven Sola for their assistance in familiarizing the author with the underlying study.

Table of Contents

Background

Summary

The aim of this study is to determine what specific components of a latrine or other measures of usability are most strongly associated with a household's use of latrines. Latrine access is necessary to end open defecation, which contributes to the burden of disease across the world and is a practice that is particularly prevalent in rural India. However, access to latrines does not always equate to latrine use. There is a need to understand if the presence or absence of certain features of a latrine have a meaningful impact on latrine use. Understanding associations will inform future latrine construction and interventions aimed at increasing latrine use and ending open defecation.

Global Burden of Open Defecation

Open defecation, defined as "disposal of human feces in fields, forests, bushes, open bodies of water, beaches or other open spaces, or with solid waste," is common globally. According to the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF)'s *Progress on Drinking Water, Sanitation, and Hygiene* report, across the world, 892 million people practice open defecation. The report further outlines the burden of open defecation as an especially large issue in rural settings—nine out of ten (812 million people) of those who practice open defecation, live in rural areas. Although the world has made steady progress in eliminating open defecation, open defecation has been declining at a rate of just 0.7 percentage points per year in rural areas. The rate at which open defecation declines will need to sustainably increase for it to be eliminated by 2030 as part of the United Nations Sustainable Development Goals (1).

India as a whole has a high rate of open defecation with an estimated 39% of households not using any toilet facility and thus practicing open defecation (2). In rural India specifically, open defecation is prevalent with an estimated half of individuals practicing open defecation (3,4). In rural Odisha, the proportion of the population that contributes to open defecation is even higher. An estimated 65% of households do not use a sanitation facility to defecate, meaning they practice open defecation (5). Another study estimates that 73%

of individuals practice open defecation (4). A cross sectional study of 20 villages in Odisha where the Total Sanitation Campaign had been implement at least three years previously found a mean latrine coverage of 72%, but over a third of households with latrines did not use them and most individuals still practiced open defecation (6).

Effects of Open Defecation

A lack of access to sanitation and the practice of open defecation are associated with a variety of diseases, both acute and chronic. Pathogens associated with improper disposal of human feces include many varieties of viruses, bacteria, parasitic protozoa, and helminths, also known as parasitic worms. These pathogens contribute to diarrheal disease, chronic abdominal pain, malnutrition, stunting, and other diseases. These pathogens can be spread from person to person through contamination of food and water, or through contamination of the broader environment (7).

Diarrheal diseases cause 1.6 million deaths a year (8). Within India, 9.0 % of children under the age of 5 were reported to have had diarrhea in the two weeks prior to the National Family Health Survey 2015-16 (5). Within Puri, Odisha, India the prevalence of diarrhea in children over the previous two weeks was 7.3% (9). Improvements in sanitation can decrease incidence of diarrheal and other diseases (10), and elimination of open defecation specifically has been linked to significant decreases in diarrheal disease (11).

Soil-transmitted helminth infections are common globally and are associated with poor sanitation. Caused by different species of parasitic worms, they can be transmitted by eggs in human feces which then contaminate the soil. These infections, such as ascariasis, trichuriasis, and hookworm disease, account for 1.9 million disability adjusted life years (DALYs). (12)

Diarrheal disease, STH infections, and other diseases associated with poor sanitation also have lasting developmental effects, such as stunting, that can negatively impact an individual's health and economic standing for the rest of their life (10,13). Data form India specifically point to an association between open defecation and stunting. Spears, and colleagues (2013) found in an ecological analysis that, after adjustment

for typical confounding factors such as maternal education and calorie availability, a 10% increase in open defecation was associated with 0.7% increase in stunting and severe stunting. In multiple regressions, open defecation was a more important predictor of district level stunting than other measures such as calorie availability or female literacy (14).

Additionally, in India a lack of sanitation and proper latrine construction have impacts not just on physical health, but social and mental health as well due to issues surrounding privacy and safety (15). These issues have a disproportionally large impact on women, who avoid risking their safety by going away from the home to defecate (16) or alternatively use latrines during menstruation to clean their menstrual cloth (17,18).

Latrine Building Campaigns

Due to the high rates of open defecation in India and the variety of detrimental health effects that result from it, the Indian government has run programs for over three decades in an effort to decrease and eliminate open defecation. The Total Sanitation Campaign (TSC) was launched in 1999 with the goal of eliminating open defecation by 2017. Before this program, increases in latrine coverage in rural India had not greatly changed, but under the TSC, increases in latrine coverage were substantial. Only one in five households had latrines during the 2001 census, but by 2009, a decade after the TSC began, rural latrine coverage more than tripled with 65% of households having an individual latrine (19). Even as national coverage increased, certain districts lagged behind in latrine coverage and among areas with high latrine coverage, open defecation was often considered the norm (6,20).

Launched in 2014, the Swachh Bharat Mission is the current program supported by the Government of India that seeks to end open defecation. Its goal is to have India be open defecation free by Mahatma Gandhi's 150th birthday, October 2, 2019 (21). The Indian government stated in April of 2019 on their Swachh Bharat Mission dashboard that over 92 million toilets have been built during this campaign, resulting in monumental increases in latrine coverage across the country (22). Additionally, over time the strategies of campaigns aimed at eliminating open defecation have moved from being focused only on establishing latrine coverage to also

include behavior change programs and more community-led approaches (19). Studies done by non-governmental groups have shown that while latrine coverage has drastically increased, many latrines tallied by the government may never have been completed or are currently nonfunctional. Sanitation campaigns that occurred in the past, such as India's Total Sanitation Campaign, sometimes fell well short of their intended goals for levels of latrine coverage (23). Even when these campaigns achieved high levels of coverage, many latrines still lacked important components such as doors (6).

What Constitutes an Improved Latrine?

The WHO/UNICEF Joint Monitoring Program on Water, Sanitation and Hygiene (JMP) classifies latrines according to a sanitation ladder, building on their previous classification of "improved" and "unimproved" (7,24). An improved latrine is one that "hygienically separate excreta from human contact." The sanitation ladder expands on this with the top rung, "Safely Managed" defined as "Use of improved facilities which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site." The next two rungs are "Basic" and "Limited", both of which include improved facilities not shared or shared by multiple households respectively but do not include the safe disposal or transportation offsite for treatment stipulation. "Unimproved" is the next rung. It includes use of pit latrines without slabs or platforms. The last rung is "Open Defecation," which is defined by JMP as "Disposal of human feces in fields, forests, bushes, open bodies of water, beaches and other open spaces or with solid waste." This is an expansion beyond the "improved" and "unimproved" facility type classification better represents safety and utility of sanitation facilities.

There has been much debate around what standards should be used to define safe and effective sanitation. This classification has evolved beyond improved and unimproved to the Sanitation Ladder in an effort to more accurately classify facility type. There has been considerable study and debate on whether the "improved" and "unimproved" classification reflects differences in the safety of latrines with one study indicating the shared facilities are as safe as other improved facilities, (25) and that latrine classification should reflect function instead of the technology and structure (26).

The Indian Ministry of Drinking Water and Sanitation's published requirements for latrine construction include three main parts: "i) a sanitary substructure (that safely confines human faeces and eliminates the need for human handling before it is fully decomposed), ii) a super structure with water facility, and iii) a hand wash unit for cleaning and handwashing." (27)

This classification falls into the "Basic" JMP category for latrines, provided the facility is not shared by more than one family. Beyond the JMP classification, it additionally includes a requirement for a superstructure and handwashing facility.

Latrine Design

The substructure design for pour flush latrines, the most commonly constructed latrine in rural India, have remained virtually unchanged over the past few decades. The substructure generally includes a squatting platform, a pan for defecation, a water-seal trap, a pipe to the pits, and the leach pits. The pan serves as the location where an individual defecates. Water is poured into the pan to flush (hence the name "pour flush latrine") the feces into the pipe and pit. The water-seal trap, usually an S-shaped pipe, serves to keep insects or gas from entering or escaping from the pit while allowing waste to pass through. The squat pan, water trap, and pipes leading to pits need an appropriate slope in order to allow feces to travel to the pits (28,29).

Pit design is important to the functionality of a latrine. Pits most often have "honeycomb" pattern brickwork for walls. This construction is recommended to allow liquids to leach out of the pit latrine over time while still containing the feces until it decomposes. Alternatives to honeycomb brickwork patterns are common, such as concrete rings with gaps between rings, but all recommended designs still include many small openings to allow liquid to seep out over time. Latrines without pit designs that allow liquids to easily seep out may quickly fill and overflow. Twin pit latrines are generally recommended with a junction chamber to allow alternation between pits once one is filled. Additionally, India's Ministry of Drinking Water and Sanitation encourages the construction of twin pit latrines (27). Lastly, a slab or cover is needed to cover the

pit and create a barrier between the disposed feces and the environment. These slabs or covers can be made from a variety of materials (28,30).

A latrine's superstructure generally serves to provide privacy and protection from weather. The major components of a latrine superstructure include walls, a roof, a door, and some sort of handwashing facility, though other requirements are often present, such as facilities to store water for flushing or a parapet, an extension of the wall outwards where the wall and roof meet. Wall heights should be tall enough to accommodate a household's users comfortably. In addition, sufficient wall heights are necessary for roofs and doors to be part of a latrine's superstructure. Both roofs and doors provide protection from the elements and an increased degree of privacy. Roofs may be especially important during the rainy season as users may prefer a sheltered latrine to defecating in the open in the rain or to a latrine without a roof, where they would exposed to the rain and the latrine may flood. Additionally, they protect from the sun and other elements. Roofs can be constructed from a variety of materials, such as corrugated metal, wood shingles, bamboo, or thatch, though some materials, like corrugated metal, will provide more protection from the elements than others, such as thatch. Doors are especially important in increasing the privacy of latrines. Latrine doors are often metal or wood, though other types of latrine closures, such as plastic, cloth, or woven grass curtains, can be found as well. Caruso, et al. found that women in rural Odisha were concerned about privacy when latrines lacked doors and concerned about the weather when latrines lacked roofs (31). Even among those with functioning substructures, many latrines lack proper superstructures as they are without roofs, doors, and sometimes even adequate walls.

Handwashing facilities should always have water and soap present. Actual water and handwashing related sections of latrine superstructures vary widely. Most households in rural India do not have running water necessitating individuals to fetch water for use at the latrine. Some latrines are constructed with water storage facilities, but these often do not hold an adequate amount of water for multiple flushes.

Building Latrines is Not Enough—Why Design Matters

A variety of studies have focused on the impact of different interventions on open defecation and latrine use. As discussed earlier, these interventions often define a "minimally functional latrine" as a latrine with a pan that is not broken or blocked, a latrine pit with a cover, and a pan-to-pit pipe connection, though some include additional aspects of construction such as walls of sufficient height and the presence of a door. The components of the substructure are the minimum needed to safely dispose of human feces. However, some latrines in rural India are left unfinished or unconstructed and as such, do not meet this minimal functionality standard as pits lay unfinished or pipe connections from pan to pit are missing (29). Detailed additional functionality issues such as insufficient slope of pipes from pan to pit. Pour flush latrines with insufficient slopes do not allow feces to travel from the pan to the pit resulting in a non-functional latrine (29).

Meta-analyses of current literature have found that even when higher levels of latrine coverage are achieved, rates of disease do not significantly change. This may in part be a result of modest changes in latrine use as individuals decide not to use newly constructed latrines and instead continue to practice open defecation (17,32). Additionally, even if some progress is made in decreasing levels of open defecation incidence of disease may not measurably fall, indicating large reductions in the level of open defecation may be needed to result in meaningfully improved health in a community (33–35).

Even when the substructure is intact, incomplete or broken parts of superstructures can be present. Besides functionally, latrines are more likely to be used when they are well maintained, private, and offer amenities for hygienic practices such as anal cleansing and menstrual management (18). Issues identified by both owners of latrines and researchers include issues with the latrine superstructure: lack of doors, roofs, and walls. These all contribute to a lack of privacy for those using the latrine as well as a lack of protection against inclement weather. Additionally, in some latrines the cubicles were too small making their use difficult. Many of these issues were common among government funded latrines (29).

Moreover, some latrines that are considered functional by the government or scientific studies are considered inadequate by their owners. In instances where a latrine's construction is not on par with an individual or

household's expectations, the newly constructed latrine remains unused and as such, open defecation continues to be practiced (36).

Some research has been done regarding which parts of latrine construction are most associated with higher use in India, as well as which parts of latrines are most desired by those without latrines. Multiple studies have found that doors and roofs can greatly increase latrine use (6,17,29). One study found that doors and roofs ranked the highest in improvements desired by latrine owners (36). Some studies have found that walls of sufficient height (>1.5m), were associated with latrine use (6). However, another study found that wall height (dichotomized as greater or less than four feet) was not associated with increased latrine use (17). Examining these studies that have addressed structural factors, we see there is agreement in the current literature regarding the association between doors and roofs and latrine use, there is disagreement in the current literature regarding the effect of other aspects of construction, such as the presence of walls of a sufficient height. Additionally, many other parts of a latrine's construction remain unexamined for an association between their presence and latrine use.

Because there is limited understanding of what structural factors impact latrine use there is a need to investigate which aspects of latrines are most associated with use to better understand past interventions and inform future interventions on latrine use and open defecation.

Water availability also can play a large part in whether a latrine is used or used properly. An examination of the results of the Total Sanitation Campaign found most latrines constructed in one district were pour-flush, single pit latrines. Due to a lack of water to flush, households removed water-seal trap in the pipe connecting the pan to the pit (19). Even when water is available nearby, fetching water to flush the latrine is seen as an additional task and may discourage household members from using their latrine (29).

The Goals of This Research Project

The aim of this project is to determine what specific components of a latrine or other measures of usability are most strongly associated with a household's use of latrines. It is important to understand which latrine

amenities are likely to increase use. Garn et al suggests that structure and design characteristics of latrines desired by the user may be important in assessing whether a latrine can provide "adequate sanitation"(18). The data analyzed are from an important target population: those who live in rural India. One strength of this data is that, unlike many other studies, this study's measure of use will rely on reported use, enumerator opinion, and recorded signs of use to have a more conservative and less subjective measure of use.

Introduction

Open defecation, defined as "disposal of human feces in fields, forests, bushes, open bodies of water, beaches or other open spaces, or with solid waste", is common globally with 892 million people practicing open defecation (1). Open defecation is especially prevalent in rural India where an estimated half of individuals practice open defecation (3,4).

A lack of access to sanitation and the practice of open defecation are associated with a variety of diseases, both acute and chronic. Pathogens associated with improper disposal of human feces include many varieties of viruses, bacteria, parasitic protozoa, and helminths, also known as parasitic worms. These pathogens contribute to diarrheal disease, chronic abdominal pain, malnutrition, stunting, and other diseases. These pathogens can be spread from person to person through contamination of food and water, or through contamination of the broader environment (7).

Additionally, in India, a lack of sanitation and proper latrine construction have impacts not just on physical health, but social and mental health as well due to issues surrounding privacy and safety, especially for women (15–18).

Due to the high rates of open defecation in India and the variety of detrimental health effects that result from it, the Indian government has run programs for over three decades in an effort to decrease and eliminate open defecation. Studies done by non-governmental groups have shown that while latrine coverage has drastically increased, many latrines tallied by the government may never have been completed or are currently nonfunctional.(23) Even when these campaigns achieved high levels of coverage, many latrines still lacked important components such as doors (6) and individuals often continue to practice open defecation (17,32).

The aim of this project is to determine what specific components of a latrine or other measures of usability are most strongly associated with a household's use of latrines. It is important to understand which latrine

amenities are likely to increase use. Garn et al suggests that structure and design characteristics of latrines desired by the user may be important in assessing whether a latrine can provide "adequate sanitation"(18).

The data for this study are from a cluster-randomized trial of a multilevel intervention to increase latrine use and safe child feces disposal (37). One strength of this data is that, unlike many other studies, this study's measure of use will rely on both reported use, enumerator opinion, and recorded signs of use to have a more conservative and less subjective measure of use.

Analysis methods include multivariate logistic regression using generalized estimating equations as well as conditional inference trees (CIT), a recursive partitioning method. Each method has specific strengths: multivariate regression estimates measures of effects for the overall study population while CIT finds which variables are most strongly associated with the outcome for both the overall population as well as interactions and variables that are strongly associated with the outcome within specific groups.

Methods

Data Source

This study uses baseline data from a large cluster randomized trial led by Emory of a multilevel intervention to increase latrine use and safe feces disposal among latrine-owning households in rural Odisha, India (37). This study took place in the Delang, Nimapada, and Pipili blocks of Puri district, Odisha, India. In the Puri district, 86% of the population live in rural areas (38) and only 37% of the population have an improved sanitation facility (9).

A total of 280 villages were assessed for the baseline survey. The eligibility criteria for villages included: village size between 50 to 150 households, at least 60 percent latrine coverage, and village was not previously declared Open Defecation Free (ODF). During the rapid assessment, field supervisors visited 280 villages and spoke with village leaders to gather estimates of village size and latrine coverage. Out of the villages assessed, 130 potentially met eligibility. A village mapping exercise was conducted to confirm the number of households and latrine coverage to determine actual eligibility. Altogether, 81 villages were selected that either met the inclusion criteria or were slightly larger or smaller than the preferred size and/or had at least 50% latrine coverage. Out of those villages, 66 were selected for inclusion in the trial based on the power calculations for the cluster randomized trial. An additional six villages had also been selected for qualitative research.

All households in the villages were censused and those with latrines were asked to participate in a survey to assess latrine use and other information about the household and household members. A total of 5864 households were censused, and 3978 households were eligible for the baseline survey. This analysis focused only on households with one latrine and whose surveys indicated whether a latrine was in use or not, yielding 3662 households for analysis.

Data Collection

A team of 13 enumerators and two supervisors carried out data collection. All survey team members were from rural Puri and six of the enumerators and both supervisors had previously been part of Emory study teams and had experience working in sanitation studies. The data were collected using smartphones programmed with open data kit.

The survey began with questions about household size, caste, and latrine ownership. If a household did not own a latrine, then the survey was ended. Those with a latrine were asked to participate in an expanded survey which included questions about demographics, defecation practices of each household member, household water and hygiene facilities, and latrine characteristics and history. After the in-person survey was completed, the enumerator observed and recorded additional information about a household's latrine. This information included latrine location, type, construction or improvements, and signs of use.

Measures

The outcome of interest, whether a latrine was in use, was dichotomized, requiring three factors: (1) household member reported using the latrine, (2) the enumerator considered the latrine to be in use, and (3) at least two signs of use and no signs of non-use (e.g. the latrine is being used for storage) were observed. This was done to create a more conservative measure of latrine use that did not rely solely on the survey respondent.

Latrine features and characteristics that were examined for their association with whether a latrine was in use were selected due to their importance to latrine functionality and past research indicating a potential association with latrine use. A pit slab cover, the pan-pit connection, whether the pan is broken, and water are all aspects of a latrine that are needed for proper latrine construction (28) and the presence or absence of these aspects were examined with water being categorized as whether or not there was a water source within 30 ft of the latrine. One pit, two pits, or septic tanks are also required for most latrines to safely dispose of feces (28) and so the presence of one of these categories was included. A place for handwashing is also part

of the Indian Ministry of Drinking Water and Sanitation's published requirements for latrine construction (27) so it was included as a variable. Past studies suggest additional latrine characteristics that may influence latrine use include presence of a latrine door (6,17,29,36), latrine roof (6,17,29), sufficient wall height (6,36), lighting (29), latrine age (6), and whether the latrine was self-financed (39). Whether there were tiled floors was also included as a variable since tiled floors have been noted as a potential upgrade to latrines (28,40). The presence of doors, roofs, wall height over five feet, outdoor lighting, indoor lighting, tiled flooring, and whether a latrine was self-financed were all dichotomized. Descriptive analysis suggested that the association between latrine use and latrine age was not linear. For this reason, the measure of latrine age was categorized into four categories: less than one year, one to two years, two to three years, or three or more years since the latrine's construction was completed to better fit the association with whether a latrine was in use. The location of the latrine was also included as past literature suggests that a latrine's location and distance from the house may influence latrine use (31,41) and so a categorical variable of distance from the house (inside, < 100 ft, > 100 ft, and in another plot) was examined.

Confounders were selected to be included in the models because they are hypothesized to influence, or past literature indicates they influence, both latrine use and latrine characteristics or features. The first of these is household population. The number of household members is hypothesized to influence the condition of a latrine or whether latrines have improvements that suit large or small households. Additionally, descriptive analysis suggest larger households are means are more likely to use their latrine. Caste, religion, and wealth are all associated with latrine use as well as how likely a household is to build or improve a latrine or specific latrine components (3,29,32,36). The occupations of household members may impact latrine use practices as those that work outside the household may not find using a household latrine as convenient (29) which impacts use while this or other aspects of their occupation may influence their household's latrine characteristics. Education levels of household members influence latrine use as well as how willing household members are to invest money into a latrine (32). All confounders other than household population and wealth were categorical. Categories with fewer than ten households in them were included in the category of "Other" if such a category existed. Household population was kept as a continuous variable. Household wealth

quintiles were calculated using principal component analysis (PCA)(42) using items owned by the household such as a pressure cooker or TV, and connection to electricity.

Data Analysis

Initial descriptive analysis was performed on the variable to understand the study population including the distribution of different latrine aspects, potential confounders, and the selected dependent variable, whether a latrine was in use.

Two analyses were then conducted to estimate the association between specific latrine components and whether a latrine is in use: generalized estimating equation (GEE) multivariate logistic regression and conditional inference trees (CIT), a form of recursive partitioning.

A GEE with empirical standard errors and an independent correlation structure was used to account for the clustering at the village level.

CIT is a recursive partitioning and nonparametric analytical approach. It was used to determine which structural components and combinations of components are most associated with a latrine being in use. In addition, CIT determines complex interactions among variables of interest without the need to specify interactions terms a priori. Partitioning in CITs is based on statistical significance. The null hypothesis for CITs is independence between all variables of interest and the outcome being tested. For each node, beginning with the root node, or overall sample data, if the null hypothesis can be rejected, the node is partitioned based on the most strongly associated variable of interest. Each child node continues to be partitioned until the null hypothesis can no longer be rejected. A major advantage of CIT over other recursive partitioning methods is that these partitions are selected adjusting for all other variables, allowing CIT to account for confounding. For this reason, all confounding variables were analyzed alongside variables of interest. Unlike other recursive portioning methods, this can account for confounding (43). This also makes it an ideal analysis technique for WASH studies where complex relationships and highly correlated data are common (44). For this analysis, statistical significance tests were conducted with Bonferroni adjustment for

multiple comparisons and a significance cutoff of $p < 0.01$., CIT analysis was conducted with the ctree function of the "partykit" R package version 1.2-3.

https://cran.r-project.org/web/packages/partykit/index.html

Ethics

This study is a secondary analysis of data from a cluster randomized study (37) whose study protocols have been reviewed and approved by the Institutional Review Board at Emory University in Atlanta Georgia (00098293) and the Ethics Review Committee at Xavier Institute of Management in Bhubaneswar, Odisha, India.

Results

Of the households included in the study, a majority (95.4%) had a household religion of Hinduism (see Table 1). Households of the Brahmin or General caste made up 35.8% of the sample, with 13.9% being scheduled cast, 46.5% being an other backwards caste, and the remaining population classified as a scheduled tribe or other. Although education levels varied, most male heads of households were self-employed (66%) working in agriculture, as potters, etc. and most female heads of household were unemployed or did not engage in work that earned income (88.9%). The most common highest level of education completed by a male head of household was secondary education (30.0%) followed by both upper primary (19.7%) and primary (24.7%). For female heads of household, the most common levels of education were having never attended school (30.4%) or having completed primary school (29.1%).

Table 1. Selected characteristics of study households (N = 3662).

Variable	n	(%)	Mean (ds)
Number of household members			4.25 (1.68)
Household religion			
Hindu	3492	(95.4)	
Muslim	110	(3.0)	
Other	57	(1.6)	
Caste			
Brahmin/General	1250	(35.8)	
Other Backwards Caste	1623	(46.5)	
Scheduled Caste	484	(13.9)	
Scheduled Tribe	32	(0.9)	
Other	103	(2.9)	
Male head of household occupation			
Unemployed (no work that earns money)	438	(12.5)	
Self-employed (work in home: agriculture, potter, etc.)	2316	(66.0)	
Employed (Work outside of home: office, laborer, factory, etc.)	751	(21.4)	
Student	6	(0.2)	
Female head of household occupation			
Unemployed (no work that earns money)	3214	(88.9)	
Self-employed (work in home: agriculture, potter, etc.)	262	(7.2)	
Employed (Work outside of home: office, laborer, factory, etc.)	139	(3.8)	

Student	0	(0)
Highest education male head of household completed		
Never attended	376	(11.3)
Anganwadi	128	(3.9)
Primary	821	(24.7)
Upper primary	655	(19.7)
Secondary	994	(30.0)
Senior secondary	143	(4.3)
Graduate / post-graduate	201	(6.1)
Highest education female head of household completed		
Never attended	1081	(30.4)
Anganwadi	112	(3.2)
Primary	1035	(29.1)
Upper primary	582	(16.4)
Secondary	601	(16.9)
Senior secondary	84	(2.4)
Graduate / post-graduate	56	(1.6)

A latrine was considered to be in use if it met four criteria: the household member taking the survey stated the latrine was in use, one or more of the household members were reported to have used the latrine the last time they defecated, if there were at least two signs of use observed by the enumerator, and whether the latrine was in use according to the enumerator's judgement. In the study data, 2240 (61.2%) of the latrines were in use while 1422 (38.8%) were not in use (See Table 2).

Table 2. Measures of latrine use among study households (N = 3662)

Measure	Number in use	(%)
Overall measure of whether a latrine is in use	**2240**	**(61.2)**
Household member states latrine is in use	2788	(76.2)
One or more household members were reported to have used the latrine the last time they defecated	2671	(73.0)
At least two signs of use were present (smell, pan is wet, slippers present, etc.)	2405	(65.9)
According to enumerator's judgement, latrine seems to be in use	2940	(69.6)

Multivariate Analysis

All results of the associations of variables of interest from the multivariate analysis are shown in **Table 3.** The single strongest association in the multivariate analysis was whether there was a connection between the pan and pit. Latrines that had a visible connection from their pan to their pit had 13.07 (95% CI:3.97, 43.08) the odds of being in use compared to latrines that had broken or missing connections. Similarly, if the connection was not observed to be broken or missing but instead not visible, the odds of a latrine being in use are 11.16 (95% CI: 3.41, 36.52) times the odds of latrines with missing or broken connections being in use.

Other aspects of latrine functionality include whether the pit is covered and whether the latrine's pan is intact. Latrines with pit slab covers have an odds of being in use of 2.68 (95% CI: 1.65, 4.37) times that of latrines that have no pit cover. Latrines with an intact pan have an odds of 2.21 (94% CI: 1.45, 3.38) of being in use compared to those with a broken pan.

Components of a latrine superstructure include the walls, roof, door may also be associated with latrine use. A latrine with a door has twice the odds (1.98 95% CI: 1.41, 2.79) of being in use compared to latrines without doors. The association between latrine use and the presence of a roof has a similar point estimate, though the estimate has substantially higher uncertainty. The odds of a latrine with a roof being in use is 1.97 (95% CI: 0.71, 5.46) compared to the odds of a latrine without a roof being in use. The odds of a latrine with cubicle walls of >5 ft being in use is 1.41 (95% CI: 0.45, 4.46) times the odds of a latrine with cubicle walls <5 ft being in use. Latrines without roofs and latrines with walls shorter than 5ft are relatively uncommon in this sample leading to higher uncertainty.

Older latrines have a notably higher odds of use when compared to newly constructed latrines. For example, latrines that were built more than 3 years ago have 2.81 (95% CI: 1.97, 4.01) times the odds of being in use when compared to latrines that had been built in the past year. All categories of latrine age, 1-2 years old, 2-3 years old and 3 years old or older, are significantly associated with the latrine being in use. Though the point

estimates of the odds of use compared to latrines built in the past year are higher for older latrines, there is not a statistically significant difference between these categories.

Improvements to latrines come in a variety of forms, from lighting to tiled flooring. Of the potential improvements to a latrine examined, handwashing facilities were most strongly associated with a latrine being in use. The odds of latrine being in use were 2.78 (95% CI: 2.13, 3.62) for latrines with handwashing facilities compared to those without. Latrines with tiled floor had 1.94 (95% CI: 1.19, 3.17) times the odds of being used when compared to latrines without tiled floor. Latrines with lights inside had 1.92 (95% CI: 0.96, 3.85) times the odds of being in use compared to latrines without lights. Latrines with an outside light had 1.23 (95% CI: 0.55, 2.73) times the odds of being in use when compared to latrines without lights outside.

Although not a physical part of a latrine, whether a household helped finance their latrine is associated with whether the latrine is in use. Latrines that were financed in part or in full by the household have 1.51 (95% CI: 1.16, 1.98) times the odds of being in use compared to latrines where the household did not finance the latrine.

Some characteristics of latrines had no association with whether a latrine is in use. A latrine with a water source within 30ft of it has an odds of being in use 1.04 (95% CI: 0.79, 1.37) times that of a latrine without a water source within 30ft. Compared to latrines with a single pit, latrines with two pits have 1.06 (95% CI: 0.61, 1.84) times the odds of being in use and latrines with a septic tank have 1.03 (95% CI: 0.70, 1.53) times the odds of being in use.

Table 3. Multivariate adjusted associations of latrine characteristics and whether a latrine is in use, using generalized estimating equations (N = 3662).

	n (%)	OR*	95% CI
Handwashing place			
Present	1462 (49.6)	2.78	2.13, 3.62
No handwashing place	2138 (59.4)	ref	
Number of latrine pits			
One pit	2642 (72.2)	ref	
Two pits	290 (7.9)	1.06	0.61, 1.84
Septic Tank	475 (13.0)	1.03	0.70, 1.53

No pit or tank	238 (6.5)	0.74	0.13, 4.35
Latrine roof			
Present	3439 (94.2)	1.97	0.71, 5.46
No roof	211 (5.8%)	ref	
Latrine wall >5ft high			
>5 ft high	3547 (97.2)	1.41	0.45, 4.46
<5 ft high	103 (2.8)	ref	
Latrine door			
Present	3188 (87.3)	1.98	1.41, 2.79
No Door	462 (12.7)	ref	
Pan intact			
Intact	2950 (91.2)	2.21	1.45, 3.38
Broken	283 (8.8)	ref	
Connection between pan and pit			
Connected	2105 (62.8)	13.07	3.97, 43.08
Not Visible	1106 (33.0)	11.16	3.41, 36.52
Broken or missing	139 (4.1)	ref	
Pit slab cover			
Has slab cover	2896 (85.8)	2.68	1.65, 4.37
Not visible	165 (4.9)	3.75	1.93, 7.28
No slab cover	316 (9.4)	ref	
Tiled Floor			
Has tiled floor	597 (16.3)	1.94	1.19, 3.17
No tiles	3065 (83.7)	ref	
Latrine Location			
In a different plot	96 (2.6)	0.65	0.27, 1.61
More than 100 ft from house	229 (6.3)	0.80	0.45, 1.43
Within 100 ft of house	2862 (78.3)	1.28	0.88, 1.85
Inside House	466 (12.8)	ref	
Age of Latrine			
<1 year old	522 (16.8)	ref	
1-2 years old	898 (28.8)	1.78	1.19, 2.65
2-3 years old	673 (21.6)	1.96	1.34, 2.86
>3 years old	1022 (32.8)	2.81	1.97, 4.01
Light inside latrine			
Light inside present	459 (12.5)	1.92	0.96, 3.85
No light inside	3203 (87.5)	ref	
Light outside latrine			
Light outside latrine present	352 (9.61)	1.23	0.55, 2.73
No light outside	3310 (90.4)	ref	
Water source within 30 ft of latrine			
Water source within 30 ft	2465 (67.5)	1.04	0.79, 1.37
No water source within 30 ft	1185 (32.5)	ref	
Latrine was in part or all self-financed			
Self-financed	1747 (47.7)	1.51	1.16, 1.98
Not self-financed	1915 (53.2)	ref	

Measures that are statistically significant at $p < 0.05$ are highlighted

*Odds ratio with 95% confidence interval adjusting for household population, household religion, household caste, male and female heads of household's highest level of education achieved, main and female heads of household's occupation, social economic status quintiles calculated through principal component analysis, and accounting for clustering on the village level

Conditional Inference Tree

The conditional inference tree (**Figure 1**), has 18 partitions and 20 terminal nodes. Ten of these partitions use a total of six different variables related to latrine structure. Six other partitions use three different household characteristic measures. One partition uses a variable related to latrine improvements and one partition uses the age of the latrine.

The first partition in the CIT is related to latrine type with latrines that flush to pits, septic systems, and elsewhere, or pit latrines with slabs being used more often while those that "flush to unknown place", are in construction, or are open pits are used significantly less. This partition is similar to the classification of improved and unimproved latrines. Among the groups of improved latrines, the next partition is based on the SES quintiles, splitting observations at the 1st and 2nd quintiles from those at the 3rd to 5th quintile. Among both SES groups, the next strongest association with a latrine being in use is with whether there is a handwashing facility present. As the tree expands, interpretations grow more complex. That being said, among both SES groups, whether there was a pan-pit connection present as well as whether a latrine was wholly or in part funded by the household were both used as partitioning criteria indicating they are important factors in whether a latrine is in use for multiple groups of latrines and households.

The terminal node with the largest proportion of latrines in use is improved latrines owned by households of the 3rd SES quintile or higher that have a place for handwashing and lights inside of the latrine with 97.9% of latrines being in use (n = 334). The terminal node with the largest proportion of latrines not in use is latrines that are in construction and latrines that "flush to an unknown place" with 0% of these latrines being in use (n = 250).

Discussion

The overall functionality, safety, and privacy of latrines was determined to be important in both the GEE multivariate analysis as well as in the CIT. Additionally, both analyses found that specific aspects of latrines that are not necessary to safely separate feces from humans and the environment are associated with latrines being in use. Doors, tiled floors, and lights inside latrines are either associated overall or in specific instances with higher instances of latrine use. Other aspects of latrines that were hypothesized to be associated with a latrine being in use, such as the number of pits and whether a water source is nearby the latrine, were found to have no or very little association with latrine use. These results suggest that besides general functionality, a few specific improvements may be drivers of latrine use. While previous literature only looked at a handful of latrine components or described stated preferences, this study examined a more comprehensive set of latrine components and their association with whether a latrine was in use.

The two analysis techniques, regression and CIT, complement each other with each revealing information the other may not. While regression estimates measures of effects of variables in the analysis, recursive partitioning does not find overall measures of effects. CIT's partitioning criteria relies on finding the most strongly associated measure and creating a node based on that variable. Important information may be captured by regression, such as less strongly associated variables may still be important in driving latrine use, or null associations, things that may not appear in a CIT. CIT on the other hand finds strong associations that exists for certain groups or important interactions present in the data without the need for these associations to be defined when building the model. These measures may be diluted or missed altogether by a regression.

The type of latrine, the initial partition in the CIT, was not in the multivariate model due to its similarity and collinearity with other measures: for instance, latrines in construction are likely to lack important components such as a connection from pan to pit, and pit slab covers, much more often than other latrines. CIT however can choose which of these collinear measures is most strongly associated with a latrine being in use. Additionally, among the improved category, the terminal nodes where latrine use was least common were

those that indicated the latrine had a broken pan-pit connection or were missing covers to their pits. For this reason, both the CIT and multivariate model indicate a latrine that is complete and can safely separate feces from humans and the environment is associated with said latrine being in use.

The first partition made in the CIT is identical to the distinction between "improved" and "unimproved" latrines as defined by the sanitation ladder. This is a clear indication that improved latrines are not only safer but also see higher rates of use. This evidence shows that policies that encourage the building of improved latrines protect human health not only through design but also through encouraging latrine use.

Besides basic functionality of latrines, specific improvements may be important drivers of use. Both the CIT and model found that having a place for handwashing was associated with a latrine being in use. This finding lends support to the inclusion of handwashing stations in the Indian Ministry of Drinking Water and Sanitation's requirements for latrine construction (27).

Latrine doors, which previous literature indicates encourage latrine use (6,17,29,36) for a variety of reasons including increased privacy and safety, (15,18,45) were also associated with a latrine being in use according to the multivariate model. The presence of a light inside of a latrine, though not statistically significant in the multivariate model had an odds ratio point estimate similar to that of doors. In the CIT however, lights inside of a latrine was chosen as the strongest association with whether a latrine was in use for a specific group of households – those in the 3rd to 5th quintiles of SES whose latrine also had a place for handwashing. The impact of lights inside of latrines has not been extensively studied in the past, though sources of lights have been recommended by WHO to increase acceptability of latrines (7) and some research has suggested that lights in or near latrines would make women feel safer using latrines at night (31).

The multivariate model indicates that tiled floors have a notable association with whether a latrine is in use. Tiled floor may make a latrine easier to clean, and this in turn may encourage latrine use. This improvement in particular is not addressed in previously literature, indicating the design and quality of latrine floors may be important to latrine use. Together, these associations and previous research have shown that doors are

associated latrines being in use (17,29,31), other improvements that do not necessarily impact whether a latrine safely separates feces from people and the environment can be important drivers of latrine use.

Some studies have shown that roofs and high walls may also be important drivers of latrine use (6,36). Though the point estimates of the association between whether a latrine is in use and either the prescience of a roof or walls taller than 5ft indicate these measures may be associated with latrines being in use, the level of uncertainty in this study is too high to draw any meaningful conclusion.

The associations between the presence of doors, lights inside of latrines, and tiled floors highlight a need for latrine construction programs to take into account more than just building a functioning structure. Latrines are also used for more than just defecation and improvements that increase safety and privacy may be important for women who use latrines to clean their menstrual cloths (17,18) and in general improves mental health and wellbeing (15,16). As seen with other large scale programs, such as clean cookstove campaigns, creating objects that are not only functional but also fit the population's expectations and desires is important to ensuring that the end product is used (46).

The association found between a latrine being self-financed and whether the latrine is in use is consistent with previous research (39).

Two variables are notable for their lack of association with whether a latrine is in use: (1) one pit versus two pit latrines and (2) whether there is water within 30 ft of a latrine. For both measures, a point estimate of an odds ratio of 1 indicate that having two pits or water within 30 ft of a latrine are not associated with whether a latrine is in use. Both measures are important to latrine functionality (28). Having a second pit to switch to once the first pit is filled as well as having water to flush the latrine or wash your hands are both important to having a safe and functional latrine, but these aspects of a latrine may not be associated with whether a latrine is in use or not. Previous literature details that water is necessary not just for anal cleansing and flushing but also needed for purification and cleansing rituals that are practiced after defecation (29). Concern that a latrine with one pit will fill too quickly may discourage latrine use (47).

Strengths and Limitations

One strength of this study is the use of multiple measures to determine whether a latrine was in use. While 76.2% of household members who were surveyed indicated their latrine was in use, only 65.9% of households had latrines with two or more signs of use (smell, pan being wet, slippers present, etc.). Other measures, such as whether any household member had used the latrine the last time they defecated (73.0% of households) and whether and the enumerator's opinion on whether the latrine appeared to be in use (69.6% of latrines), likewise indicated fewer latrines were in use. Measuring whether a latrine is in use in this manner resulted in a more conservative and hopefully more accurate measure of latrine use.

One major limitation of this study is that it relies on cross sectional data and may be prone to reverse causality. The same aspects of a latrine that encourage individuals to use the latrine may also be the improvements or changes regular latrine users are most likely to make. For example, a household that uses, or would use a latrine if one were built, are more likely to build a place for handwashing than households that do not use their latrines are. This could be assessed through a study that repairs or builds specific aspects of latrines, examining latrine use before and after improvements are made to the latrine.

An additional limitation of this study is that while it examines whether a latrine is in use, it does not measure associations with other important measures of latrine use. Complete elimination of open defecation in a household or occasional versus frequent latrine use are two measures that are not captured by the outcome variable used here. Some variables, such as the availability of water or the number of pits, were not found to impact whether a latrine is in use but may encourage a high proportion of a household to use a latrine or may encourage more frequent use of the latrine.

Further Research

Further analysis could also be done with this data to better understand latrine aspects that drive latrine use among men and among women, as drivers of use may vary by gender. Additionally, the level of statistical significance associated with partitioning could be changed to be less conservative. This would result in a

much larger tree that may reveal more latrine factors and combinations that are associated with a latrine being in use though large trees become increasingly difficult to interpret.

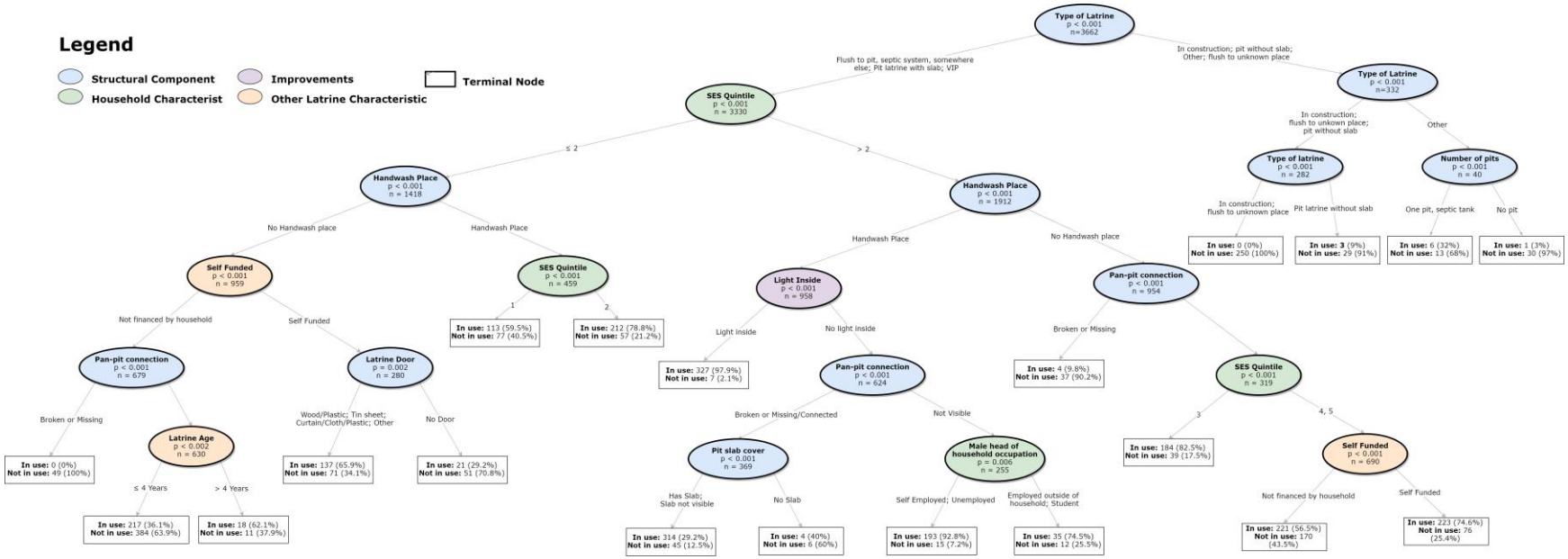
Other opportunities for further research include conducting qualitative or quantitative evaluations on the impact of lights inside of latrines and tiled floors on latrine use. These two improvements were notable in both the multivariate analysis and CIT though there is currently little published research regarding their effects on latrine use.

Conclusions

Latrine characteristics directly related to latrine functionality (pan-pit connection and types of latrine) were found to be strongly associated with whether a latrine was being used. However, the analyses using traditional multivariate analysis and CIT highlighted other aspects of latrines that are not necessary for the latrine to hygienically separate feces from humans and the environment. Handwashing stations, doors, improved floors, and lights inside of latrines may all be important factors in latrine use. Future latrine construction programs should take into account not simply constructing latrines but also the aspects of latrines that are the strongest drivers of latrine use. Additionally, programs that seek to repair or improve existing latrines may also be effective in increasing latrine use.

Figures

Figure 1. Conditional inference tree whether a latrine is in use (N = 3662).



Each internal node includes the name of the variable used to partition the data, the significance of that that variable, and number of observations in the node. The color coding represents whether a variable is a structural component, an improvement to the latrine, a household characteristic, or another category. The square boxes represent the terminal nodes and include the total number of latrines in that node as well as the portion of observations where the latrine is in use vs where the latrine is not in use.

References

1. World Healh Organization; UNICEF. Progress on Drinking Water , Sanitation and Hygiene. 2017.

2. International Institute for Population Sciences (IIPS) and ICF. National Family Health Survey (NFHS-4), 2015-2016: India. Mumbai: IIPS: 2017.

3. Gupta A, Khalid N, Deshpande D, et al. Changes in open defecation in rural north India: 2014-2018. 2019;(October 2014):2014–2018. (https://accountabilityindia.in/sites/default/files/pdf_files/Changes in open defecation.pdf)

4. NSSO. Swachhta Status Report 2016. 2016 1-104 p.(http://mospi.nic.in/Mospi_New/upload/Swachhta_ Status_Report2016.pdf)

5. International Institute for Population Sciences (IIPS) and ICF. National Family Health Survey (NFHS-4), India, 2015-2016: Odisha. Mumbai: IIPS: 2017.

6. Barnard S, Routray P, Majorin F, et al. Impact of Indian Total Sanitation Campaign on Latrine Coverage and Use: A Cross-Sectional Study in Orissa Three Years following Programme Implementation. *PLoS One*. 2013;8(8).

7. World Health Organization. Guidelines on sanitation and health. Geneva: 2018.

8. Roth GA, Abate D, Abate KH, et al. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet*. 2018;392(10159):1736–1788.

9. International Population Sciences. National Family Health Survey - 4 District Fact Sheet Puri Odisha. 2015;

10. Freeman MC, Garn J V., Sclar GD, et al. The impact of sanitation on infectious disease and nutritional status: A systematic review and meta-analysis. *Int. J. Hyg. Environ. Health* [electronic article]. 2017;220(6):928–949. (http://dx.doi.org/10.1016/j.ijheh.2017.05.007)

11. Njuguna J. Effect of eliminating open defecation on diarrhoeal morbidity: An ecological study of Nyando and Nambale sub-counties, Kenya. *BMC Public Health* [electronic article]. 2016;16(1):2–7. (http://dx.doi.org/10.1186/s12889-016-3421-2)

12. Kyu HH, Abate D, Abate KH, et al. Global, regional, and national disability-adjusted life-years (DALYs) for 359 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet*. 2018;392(10159):1859–1922.

13. Guerrant RL, Deboer MD, Moore SR, et al. The impoverished gut—a triple burden of diarrhoea, stunting and chronic disease. *Nat Rev Gastroenterol Hepatol*. 2013;10(4):220–229.

14. Spears D, Ghosh A, Cumming O. Open Defecation and Childhood Stunting in India: An Ecological Analysis of New Data from 112 Districts. *PLoS One*. 2013;8(9):1–9.

15. Caruso BA, Cooper HLF, Haardörfer R, et al. The association between women's sanitation experiences and mental health: A cross-sectional study in Rural, Odisha India. *SSM - Popul. Heal.* [electronic article]. 2018;5(March):257–266. (https://doi.org/10.1016/j.ssmph.2018.06.005)

16. Sclar GD, Penakalapati G, Caruso BA, et al. Exploring the relationship between sanitation and mental and social well- being : A systematic review and qualitative synthesis. *Soc. Sci. Med.* 2018;217(August):121–134.

17. Sinha A, Nagel CL, Schmidt WP, et al. Assessing patterns and determinants of latrine use in rural settings: A longitudinal study in Odisha, India. *Int. J. Hyg. Environ. Health* [electronic article]. 2017;220(5):906–915. (http://dx.doi.org/10.1016/j.ijheh.2017.05.004)

18. Garn J V, Sclar GD, Freeman MC, et al. International Journal of Hygiene and The impact of sanitation interventions on latrine coverage and latrine use : A systematic review and meta-analysis ☙. *Int. J. Hyg. Environ. Health* [electronic article]. 2017;220(2):329–340. (http://dx.doi.org/10.1016/j.ijheh.2016.10.001)

19. WSP, Water and Sanitation Program. A Decade of the Total Sanitation Campaign: Rapid Assessment of Processes and Outcomes. 2010;

20. Bhardwaj A, Surana A, Mithra P, et al. A Community based cross sectional study on use of sanitary latrines in a rural setup in Maharashtra. *Healthline*. 2013;4(1):89–93.

21. Government of India. Major Initatives: Swachh Bharat Abhiyan. (http://www.pmindia.gov.in/en/major_initiatives/swachh-bharat-abhiyan/)

22. Government of India. Swachh Bharat Mission Data Dashboard. (http://sbm.gov.in/sbmdashboard/IHHL.aspx)

23. Boisson S, Sosai P, Ray S, et al. Promoting latrine construction and use in rural villages practicing open defecation: Process evaluation in connection with a randomised controlled trial in Orissa, India. *BMC Res. Notes*. 2014;7(1):1–12.

24. JMP WHO & UNICEF. Sanitation.

25. Exley JLR, Liseka B, Cumming O, et al. The Sanitation Ladder , What Constitutes an Improved Form of Sanitation? *Environ. Sci. Technol.* 2015;

26. Kvarnström E, McConville J, Bracken P, et al. The Sanitation Ladder - a Need for a Revamp. *J. Water Sanit. Hyg. Dev.* [electronic article]. 2011;1(1):3–12. (http://publications.lib.chalmers.se/records/fulltext/192466/local_192466.pdf)

27. Guidelines for Swachh Bharat Mission (Gramin). Ministry of Drinking Water and Sanitation; 2017.

28. United Nations, World Bank. Manual on the Design, Construction and Maintenance of Low-Cost Pour-Flush Waterseal Latrines in India. 1984.

29. Routray P, Schmidt WP, Boisson S, et al. Socio-cultural and behavioural factors constraining latrine adoption in rural coastal Odisha: An exploratory qualitative study Global health. *BMC Public Health* [electronic article]. 2015;15(1). (http://dx.doi.org/10.1186/s12889-015-2206-3)

30. Minsitry of Drinking Water and Sanitation Government of India. Handbook on Technical Options for On-Site Sanitation. 2012.

31. Caruso BA, Clasen TF, Hadley C, et al. Understanding and defining sanitation insecurity: women's gendered experiences of urination, defecation and menstruation in rural Odisha, India. *BMJ Glob.*

Heal. [electronic article]. 2017;2(4):e000414. (http://gh.bmj.com/lookup/doi/10.1136/bmjgh-2017-000414)

32. Coffey D, Spears D, Vyas S. Switching to sanitation: Understanding latrine adoption in a representative panel of rural Indian households. *Soc. Sci. Med.* [electronic article]. 2017;188:41–50. (http://dx.doi.org/10.1016/j.socscimed.2017.07.001)

33. Clasen T, Boisson S, Routray P, et al. Effectiveness of a rural sanitation programme on diarrhoea, soil-transmitted helminth infection, and child malnutrition in Odisha, India: A cluster-randomised trial. *Lancet Glob. Heal.* [electronic article]. 2014;2(11):e645–e653. (http://dx.doi.org/10.1016/S2214-109X(14)70307-9)

34. Patil SR, Arnold BF, Salvatore AL, et al. The Effect of India ' s Total Sanitation Campaign on Defecation Behaviors and Child Health in Rural Madhya Pradesh : A Cluster Randomized Controlled Trial. 2014;11(8).

35. Fuller JA, Eisenberg JNS. Herd protection from drinking water, sanitation, and hygiene interventions. *Am. J. Trop. Med. Hyg.* 2016;95(5):1201–1210.

36. Rashid M, Pandit D. Analysis of service quality of household toilets expected by households practicing open defecation: a study in rural settlements of Bihar, India. *Environ. Dev. Sustain.* [electronic article]. 2018;1–20. (https://doi.org/10.1007/s10668-018-0145-8)

37. Caruso BA, Sclar GD, Routray P, et al. A cluster-randomized multi-level intervention to increase latrine use and safe disposal of child feces in rural Odisha, India: the Sundara Grama research protocol. *BMC Public Health* [electronic article]. 2019;19(1):322. (https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-019-6601-z)

38. MDWS. NGP: Ministry of Drinking Water and Sanitation, Government of india. 2011.(http://www.mdws.gov.in/TSC)

39. Coffey D, Spears D. How can a large sample survey monitor open defecation in rural India for the Swatch Bharat Abhiyan? *RICE Work. Pap.* [electronic article]. 2014;1–13. (http://www.susana.org/_resources/documents/default/3-2176-7-1424791330.pdf)

40. WaterAid. Beyond Construction. 2008 1-412 p.

41. Hulland KRS, Chase RP, Caruso BA, et al. Sanitation, stress, and life stage: A systematic data collection study among women in Odisha, India. *PLoS One.* 2015;10(11).

42. Vyas S, Kumaranayake L. Constructing socio-economic status indices: How to use principal components analysis. *Health Policy Plan.* 2006;21(6):459–468.

43. Venkatasubramaniam A, Wolfson J, Mitchell N, et al. Decision trees in epidemiological research. *Emerg. Themes Epidemiol.* 2017;14(1):1–12.

44. Gass K, Addiss DG, Freeman MC. Exploring the Relationship between Access to Water, Sanitation and Hygiene and Soil-Transmitted Helminth Infection: A Demonstration of Two Recursive Partitioning Tools. *PLoS Negl. Trop. Dis.* 2014;8(6).

45. Sclar GD, Penakalapati G, Amato HK, et al. International Journal of Hygiene and Assessing the impact of sanitation on indicators of fecal exposure along principal transmission pathways : A

systematic review &. *Int. J. Hyg. Environ. Health* [electronic article]. 2016;219(8):709–723. (http://dx.doi.org/10.1016/j.ijheh.2016.09.021)

46. Urmee T, Gyam S. A review of improved Cookstove technologies and programs. *Renew. Sustain. Energy Rev.* 2014;33:625–635.

47. Coffey D, Gupta A, Hathi P, et al. The puzzle of widespread open defecation in rural India : Evidence from new qualitative and quantitative data. 2015;1–47.