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Research article

Access to sanitary toilets and health outcomes: A panel data analysis using two-way fixed effects model

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Abstract: Based on the data regarding the renovation of the toilets of 30 provinces (municipalities) in rural China from 2005 to 2017, this study utilized a two-way fixed effect model to empirically test the impact of access to sanitary toilets on health, which include intestinal infectious diseases (consisting of hepatitis A, dysentery, and typhoid) and child mortality (consisting of perinatal mortality, infant mortality, and the mortality rate of children under 5). This study attempted to assess the health outcomes of the "toilet revolution" in rural China. The results showed that: (1) Access to sanitary toilets effectively reduced the incidence of hepatitis A and dysentery. For every 1% increase in the rate of access to sanitary toilets, the incidence of hepatitis A was reduced by 5.6%, and the incidence of dysentery was reduced by 36.5%. (2) Access to sanitary toilets does not significantly reduce child mortality. (3) There are obviously regional differences in the impact of access to sanitary toilets on the health outcomes. The renovation of sanitary toilets has shown the most significant effect on reducing the incidence of intestinal infectious diseases in the central region as well as the effect on reducing child mortality in the western region. It is implied that the health outcomes of China's "toilet revolution" may provide supporting evidence and experience for other developing countries and regions in implementing toilet renovation projects.

Keywords: rate of access to sanitary toilets; intestinal infectious diseases; child mortality; two-way fixed effects model

1. Introduction

According to the United Nations International Children's Emergency Fund (UNICEF) and World Health Organization joint test report (2012), 15% of the global population and 19% of the population in developing countries defecated in the open without using any toilets in 2010. Of these 1.1 billion people, nearly 60% lived in India, accounting for more than half of the Indian population. Despite the rapid economic growth in India, there has been little decline in open defecation [1]. Excreta can contaminate food and water and cause intestinal diseases, and this kills 1.5 million children under the age of five every year, which is higher than the number of deaths caused by AIDS and malaria. For developing countries, whether the investment in sanitary toilets and other facilities can promote population health is a common concern of the government and academics.

Since the 1980s, China has vigorously promoted the "trinity" sanitation project of water improvement, toilet improvement, and health education in rural areas. As of 2020, the penetration rate for sanitary toilets in China increased from 7.5% in 1993 to 68%[1]. However, in the rural areas of northern China, collectible dry toilets still represent the majority of facilities. In 2015, China launched the "toilet revolution" project and carried out the construction and transformation of rural household sanitary toilets, and simultaneously implemented fecal pollution control and accelerating the realization of full coverage of harmless sanitary toilets in rural areas. At the same time, financial funds have been given to reward and subsidize entire villages taking part in the "toilet revolution" in rural areas, to support and guide all regions to promote access to sanitary toilets in rural areas, to achieve the basic treatment and resource utilization of toilet waste, and to improve the rural living environment effectively.

The access to sanitary toilets can effectively prevent or reduce the contamination of food and water by excrement, thereby reducing the incidence of intestinal diseases and the resulting deaths of children. We utilized China's provincial panel data to assess the extent of the health effects of the access to sanitary toilets in order to guide the design, implementation, adjustment, and assessment of public health policy in China and around the world.

2. Literature review

The academic literature has a wealth of research results about the effect of sanitation facilities on health. As the gap is relatively small and the level of sanitation facilities is equivalent between urban and rural areas in developed countries, the difference in urban and rural health brought about by toilets and other sanitation facilities is not significant. The researches mainly focus on developing countries, but the results are not consistent.

Several studies have found that the improvement of sanitary toilet facilities can significantly increase health outcomes. First, the high incidence of intestinal infectious diseases is closely related to the lack of sanitary toilet facilities. Lower levels of sanitation coverage increase human fecal pollution and pathogen exposure and the pathogen content in community drinking water sources [2], resulting in a significant increase in the incidence of diarrhea in children and adolescents [3,4]. Similarly, the incidence of worm infections also increases significantly [5,6]. The construction of household sanitary toilet facilities not only has a direct impact on health—that is, reducing the probability of diarrheal infection among family members, reducing the prevalence of diarrhea by 10%—but also has obvious positive externalities, reducing the prevalence of diarrhea in the community by an additional 37% [7]. These results are not only obvious in the short term but continue for 5 years or more [8].

[1] The achievements in agricultural modernization have been remarkable, the foundation of comprehensive construction affluent society have been solidified, Report of Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2021. Available from: http://www.moa.gov.cn/xw/zxfb/202105/t20210510_6367489.htm.

Second, the heterogeneity of open defecation rates in developing countries can explain a large part of the difference in average child height [9]. Although stunting is often referred to as an indicator of "malnutrition", there is increasing evidence that the environment plays an important role in shaping nutritional outcomes [10]. The medical and epidemiological literature has shown that intestinal diseases such as diarrhea or dysentery caused by fecal pathogens can reduce nutrient absorption, cause malnutrition in children, retard children's growth, and ultimately affect children's height [11–13]. The studies found that the average height of Indian children is generally abnormally short, which is closely related to the low coverage of sanitary toilets [14,15], and this causal relationship is particularly evident for girls [16]. The coverage and rate of utilization of sanitary toilets will not only affect the height development of children in the short term but also affect the development of human capital in the long term [17–19].

Third, diseases such as diarrhea due to the low penetration rate of sanitary toilets have become an important cause of rising child mortality, which is estimated to cause 760,000 child deaths every year [20]. Poor water quality and sanitation are the main causes of death and disease in developing countries [8]. Especially in India, the high rural population density may worsen the externalities of the disease [21]. Compared with children who have access to clean drinking water and sanitary toilets, children under 5 and newborns in households without access to clean water and sanitary toilets are at higher risk of death, and the weights of newborns in rural areas and poor families are lower [22–24].

A small number of studies have found that the health outcomes of sanitary toilets is small or that there are only short-term effects and no long-term effects. Two clustered randomized trials on India found that, although the proportion of households with improved sanitation facilities increased by an average of 19% and adults' open defecation decreased by an average of 10%, the intervention did not improve children's health as measured by multiple health outcomes (diarrhea, HCGI, parasitic infection, anemia, and growth). Some scholars have suggested that this result may be due to incomplete sample coverage and the low utilization of sanitation facilities [8].

A large number of studies in China have proven that the improvement of sanitary toilet facilities has obvious health effects. The use of tap water and flushing toilets has a significant positive impact on the physical and psychological health of rural residents, and the health benefits to children from poor families are even greater [25]. The incidence of intestinal infectious diseases among residents in villages without sanitary toilets is 41.67% higher than that of residents in villages with sanitary toilets, and the incidence of parasitic diseases is 32.96% higher [26].

This study used data regarding the renovation of toilets for 30 provinces (municipalities) in rural China from 2005 to 2017, expanded the research area of previous studies, and used the two-way fixed effect model to make up for the endogenous problems caused by the omitted variables in previous studies; furthermore, the effectiveness of China's "toilet revolution" is evaluated from the perspective of the incidence of intestinal infection diseases and child mortality. Our research hypothesis is the access to sanitary toilets could improve health outcomes, including reducing the incidence of intestinal infectious and child mortality. This study can not only provide theoretical support for China to further improve the toilet renovation program in rural areas but also provide experience for other developing countries with relatively backward toilet sanitation facilities in the world to implement toilet renovation projects.

3. Methodology

3.1. Data

The provincial panel data of 30 provinces in China (excluding Tibet, Hong Kong, Macao, and Taiwan) from 2005 to 2017 were used in this study with a total sample size of 390[2]. The health indicators were taken from the China Health Statistical Yearbook, Statistical Yearbook of provinces, and Statistical Bulletin of National Economic and Social Development[3]. The toilet indicators were mainly taken from the China Social Statistics Yearbook, and the control variables were mainly taken from the China Statistical Yearbook.

3.2. Variable

3.2.1. Dependent Variables

The incidences of three legally reported infectious diseases—hepatitis A (HAIR), dysentery (DIR), and typhoid fever (ITR)—as well as perinatal mortality (PMR), infant mortality (IMR), and the mortality rate for children under 5 (MR_5) were used as indicators for measuring health outcomes. Hepatitis A, dysentery, and typhoid are all intestinal infectious diseases for which fecal–oral transmission is one of the main transmission routes, which is directly related to the sanitary conditions of toilets. The incidence for infectious diseases was calculated as the number of infectious diseases divided by the population of the area times 100,000. Perinatal mortality, infant mortality, and the mortality rate of children under 5 are all important indicators that reflect the national health level of a country or region. The perinatal mortality rate refers to the ratio of the number of neonatal deaths to the number of live births (pregnancy and lying-in women) for fetuses (including stillbirth and stillbirth) at 28 weeks of gestation or with a birth weight⩾1000g up to 7 days after delivery. The infant mortality rate was calculated as the number of deaths of infants under 1 year-old in a certain region in the year divided by the number of total live births born in the same year, and multiplied by 1,000. The mortality rate of children under 5 refers to the ratio of the number of deaths of children under the age of 5 years to the number of total live births during the same year and multiplied by 1,000.

3.2.2. Explanatory Variables

The core explanatory variable of this study was the rate of access to sanitary toilets (STAR). That is, the proportion of the total number of toilets that meet the sanitation standards to the total number of local rural households[4]. In addition, the indicator of the rate of access to harmless sanitary toilets in rural areas was used to conduct a robustness test[5]. The rate of access to harmless toilets (HSTAR) was calculated as the number of harmless sanitary toilets divided by the total number of rural household times 100%.

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[2] As many provinces have not published the data on toilet improvement after 2017, and the data of industrial wastewater discharge and sulfur dioxide discharge were only published until 2017, only the data from 2005 to 2017 were used.

[3] In some years, not every region disclosed perinatal mortality rates, infant mortality rates, and the mortality rates of children under 5, so there are some deficiencies in these indicators.

[4] A sanitary toilet must have walls and roofs; the manure storage tank must be impervious, leak-proof, closed, and covered; and the toilet must be clean, free of fly maggots, and generally odorless.

[5] A harmless toilet should not only meet the basic requirements of the sanitary toilet but also be equipped with facilities for the harmless treatment of feces.

3.2.3. Control Variables

We also selected other variables that may affect the dependent variables and explanatory variables as control variables. The choice of control variables mainly refers to the research of Chay & Greenstone [27], which includes three categories: (1) reflecting the level of social and economic development, including per capita GDP (Per_GDP), the degree of population aging (Aging), urbanization rate (Urb_rate) and population density (DP); (2) reflecting the development level of medical and health services and government financial investment, including medical technical personnel in health care institutions (MTH) and proportion of government expenditure on health (GHE); and (3) environmental indicators affecting the health of the population, including sulfur dioxide emissions (SDE) and total wastewater discharged (IWD). Population aging degree is used to measure the age structure distribution of population. Given the consideration that intestinal infectious diseases have significant differences in different age groups [28], this paper takes it as one of the influencing factors of intestinal infectious diseases and puts it into the model. Sulfur dioxide is a common and harmful air pollutant, the greater the emission, the greater the risk to human health. It is one of the important factors affecting infant mortality [27], so we take sulfur dioxide emission (SDE) as one of the control variables.

In order to eliminate the impact of price factors or inflation, this study considered per capita GDP in 2005 as the base period and deflated the per capita GDP according to the GDP deflator. To reduce the impact of outliers, the natural logarithms of the GDP per capita, the natural logarithms of the industrial wastewater discharge, and the natural logarithms of the sulfur dioxide discharge was taken. The definition and descriptive statistics of the variables are shown in Table 1.

Table 1. Descriptive statistics of variables.

Variable	Definition of the Variable (Unit)	Obs	Mean	SD	Min	Max
Panel A:	Dependent Variables					
HAIR	Incidence of hepatitis A (1/100,000)	390	3.89	5.26	0.09	39.83
DIR	Incidence of dysentery (1/100,000)	390	24.80	30.12	0.33	243.58
ITR	Incidence of typhoid fever (1/100,000)	389	1.17	2.38	0.02	21.07
PMR	Perinatal mortality rate (‰)	390	7.42	3.36	2.02	19.97
IMR	Infant mortality rate (‰)	240	9.14	6.09	2.21	49.00
MR_5	Mortality rate of children under 5 (‰)	226	11.61	6.69	2.64	32.60
Panel B:	Explanatory Variables					
STAR	Rate of access to sanitary toilets (%)	390	67.48	17.78	27.10	99.20
HSTAR	Rate of access to harmless sanitary toilets (%)	390	48.02	26.22	4.10	99.10
Panel C:	Control Variables					
Per_GDP	The natural logarithms of GDP per capital	390	9.69	0.46	8.53	10.85
Aging	Aging (%)	390	9.50	1.86	5.47	14.41
Urb_ rate	Urbanization rate (%)	390	52.96	13.96	26.87	89.60
MTH	Medical technical personnel in health care institutions (1/1000)	390	8.24	2.97	3.36	19.10
DP	Density of population (per km^2)	390	439.16	627.06	7.23	3827.10
GHE	Proportion of government expenditure on health (%)	390	6.48	1.72	2.80	10.56
SDE	The natural logarithms of sulfur dioxide emissions	390	3.92	0.94	0.36	5.30
IWD	The natural logarithms of total wastewater discharged	390	11.06	1.08	8.66	13.75

3.3. Statistical Model

The data used in this paper are panel data of 30 provinces from 2015 to 2017. Firstly, since each province has great heterogeneity in the degree of economic development and health policy, the province fixed effect can't be ignored, so the pooled regression model is excluded. Secondly, the Hausman test showed that the fixed effect model was better than the random effect model (see Table 2, Hausman test P-value). Thirdly, when using fixed effect model to estimate panel data, we should consider not only the influence of individual effect, but also the influence of time effect. Two-way fixed effects model (TW-FE) can simultaneously solve the problem of omitted variables that do not change with time, but change with individual, and do not change with individual, but change with time.

Therefore, the two-way fixed effects model was used to investigate the impact of the rate of access to sanitary toilets on the incidence of intestinal infectious diseases and child mortality, and the model was set as follows:

$$IR_{it} = \beta_1 + \beta_2 Sanitation_{it} + \delta Z_{it} + \mu_i + T_t + \varepsilon_{it} \tag{1}$$

where IR_{it} indicates the incidence of hepatitis A, dysentery and typhoid fever, perinatal mortality, infant mortality rate, and the mortality rate of children under 5 of age. Sanitation_{it} indicates the rate of access to sanitary toilets, Z_{it} is the control variable, μ_i is the province fixed effect that does not change with time, T_t refers to the time fixed effect, which reflects the influence of the omitted variables that change with time but not with provinces on the dependent variables and ε_{it} represents random noise terms that vary with time. β_1 is a constant term, and β_2 and δ are the coefficients of explanatory variables and control variables.

4. Results

4.1. Basic results

4.1.1. The impact of the rate of access to sanitary toilets on the incidence of infectious diseases

The correlation coefficients show a negative relationship between the rate of access to sanitary toilets and the incidence of hepatitis A, dysentery, and typhoid, but the slope of the scattered trend line is quite different (see Figure 1). The slope of the trend line between the rate of access to sanitary toilets and the incidence of hepatitis A is the largest, indicating that the negative correlation between the two is strongest; the slope of the trend line between the rate of access to sanitary toilets and typhoid is the second; and the negative correlation between the rate of access to sanitary toilets and incidence of dysentery is the weakest and the trend line is relatively flat.

The measurement results for the effect of the rate of access to sanitary toilets on the incidence of infectious diseases are shown in Table 2. It can be seen that increased access to sanitary toilets significantly reduced the incidence of hepatitis A and dysentery. Specifically, the incidence of hepatitis A (1/100,000) decreased by 5.6% for every 1.0% increase in the rate of access to sanitary toilets; column (2) of Table 2 shows that the incidence of dysentery decreased by 36.5%; column (3) of Table 2 shows that the rate of access to sanitary toilets has a negative effect on the incidence of typhoid, but not a significant one. The results show that an increase in the rate of access to sanitary toilets has the greatest effect in terms of reducing the incidence of dysentery.

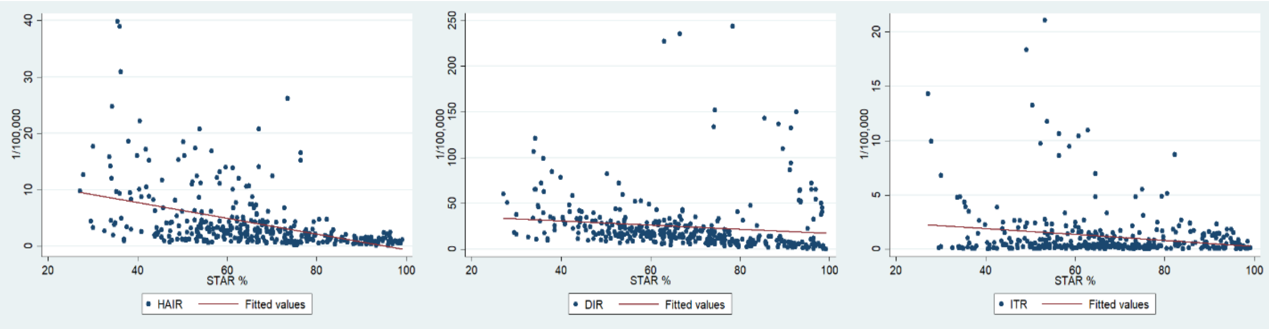

Figure 1. Scatter diagram of prevalence of sanitary latrines and incidence of hepatitis A, dysentery, and typhoid.

In terms of control variables, per capita GDP, urbanization rate, medical technical personnel in health care institutions per 1000 persons, and government health expenditure have significant negative effects on the incidence of intestinal infectious diseases. Higher per capita GDP and urbanization rate mean higher income and better health outcomes; the numbers of medical technical personnel in health care institutions per 1000 persons and government health expenditure represent the government's human and financial investment and resource allocation in public health. Extensive health and epidemic prevention and health knowledge publicity have improved the residents' healthy living behavior and effectively reduced the transmission risk of intestinal infectious diseases.

4.1.2. The impact of the rate of access to sanitary toilets on child mortality

This study also selected perinatal mortality, infant mortality, and the mortality rate of children under 5 as health measurement indicators to investigate the effect of access to sanitary toilets on the health of rural residents. Through the scatter trend line (see Figure 2), we can see that there is a negative correlation between the rate of access to sanitary toilets and perinatal mortality, infant mortality, and the mortality rate of children under 5 in rural areas, and the three relationships are similar.

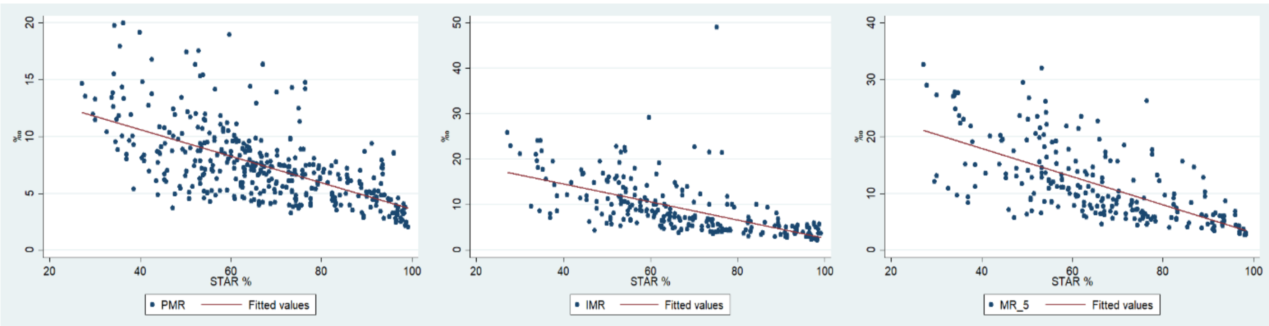

Figure 2. Scatter plot of rate of access to sanitary toilets and perinatal mortality, infant mortality, and mortality rate of children under 5.

The measurement results are slightly different from the descriptive statistics. Access to sanitary toilets has a significant negative impact on the mortality rate of children under 5. For each increase in the rate of access to sanitary toilets, the mortality rate of children under 5 is reduced by 5.3%. Columns (4) and (5) of Table 2 show that the impact of the rate of access to sanitary toilets on perinatal mortality and the infant mortality rate is not significant; this may be due to the fact that the rate of access to sanitary toilets only reduces the risk of infectious diseases at the facility level, but has a limited effect on the improvement of the healthy living habits of residents. The results suggest that if residents do not develop healthy living habits such as washing hands after defecation, there might still be risks of intestinal pathogen transmission.

Table 2. The impact of rate of access to sanitary toilets on the health of rural residents.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Variable	**Hepatitis A**	**Dysentery**	**Typhoid**	**Perinatal Mortality**	**Infant Mortality Rate**	**Mortality Rate of Children under 5**
STAR	−0.056**	−0.365***	−0.017	0.007	−0.027	−0.053*
	(0.027)	(0.136)	(0.011)	(0.010)	(0.051)	(0.030)
Per_GDP	−12.996***	−9.998	−2.575**	−4.276***	−13.631***	−14.467***
	(2.568)	(12.896)	(1.079)	(0.912)	(4.052)	(2.723)
Aging	0.048	0.979	0.157**			
	(0.158)	(0.793)	(0.066)			
Urb_rate	−0.187*	0.626	−0.089**	−0.120***	−0.225	−0.383***
	(0.108)	(0.535)	(0.045)	(0.038)	(0.168)	(0.105)
MTH	−0.225**	−0.943*	−0.030	0.014	0.478*	0.089
	(0.099)	(0.483)	(0.040)	(0.050)	(0.252)	(0.148)
DP	−0.003	0.019**	0.001	0.001**	0.001	0.004
	(0.002)	(0.009)	(0.001)	(0.001)	(0.003)	(0.004)
GHE	−0.792***	−8.405***	−0.260***	0.163*	0.254	0.230
	(0.237)	(1.156)	(0.096)	(0.085)	(0.442)	(0.296)
SDE				−0.687***	−1.551	−1.853**
				(0.244)	(1.392)	(0.837)
IWD	0.059	3.134	0.576**	0.411**	0.672	0.340
	(0.553)	(2.782)	(0.232)	(0.194)	(1.099)	(0.655)
Constant	147.923***	126.741	33.695***	62.731***	163.303***	179.019***
	(23.403)	(116.023)	(9.704)	(8.286)	(35.601)	(24.976)
Province fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Obs	390	390	389	390	240	226
R-squared	0.502	0.575	0.270	0.829	0.538	0.842
Hausman test P-value	0.000	0.000	0.003	0.000	0.018	0.000

Note: The cluster robust standard errors are used in the estimation[6]. *** $p \le 0.01$, ** $p \le 0.05$, * $p \le 0.1$.

[6] Since the disturbance items of the same province in different years generally have autocorrelation, and the default calculation method of common standard error assumes that the disturbance items are independent and identically distributed, the estimation of common standard error is not accurate, so this paper reports the cluster robust standard error.

Table 3. Robustness (2): replacement of explanatory variables.

	(1)	(2)	(3)	(4)	(5)	(6)
Variable	**Hepatitis A**	**Dysentery**	**Typhoid**	**Perinatal Mortality**	**Infant Mortality Rate**	**Mortality Rate of Children under 5**
HSTAR	−0.108***	−0.390***	−0.002	−0.009	−0.027	−0.035*
	(0.018)	(0.090)	(0.008)	(0.007)	(0.032)	(0.020)
Per_GDP	−12.943***	−7.632	−2.621**	−4.279***	−13.854***	−15.141***
	(2.578)	(12.573)	(1.085)	(0.910)	(4.058)	(2.749)
Aging	0.038	1.093	0.160**			
	(0.158)	(0.773)	(0.067)			
Urb_rate	−0.197*	0.731	−0.079*	−0.130***	−0.249	−0.403***
	(0.111)	(0.541)	(0.047)	(0.039)	(0.172)	(0.107)
MTH	−0.216**	−1.281***	−0.029	0.013	0.462*	0.088
	(0.099)	(0.485)	(0.042)	(0.050)	(0.253)	(0.148)
DP	0.002	0.003	0.001	0.001*	0.001	0.002
	(0.002)	(0.010)	(0.001)	(0.001)	(0.003)	(0.004)
GHE	−0.848***	−9.089***	−0.226**	0.169**	0.310	0.195
	(0.237)	(1.157)	(0.100)	(0.085)	(0.446)	(0.291)
SDE				−0.651***	−1.492	−1.774**
				(0.244)	(1.381)	(0.834)
IWD	0.001	4.098	0.602**	−0.388**	−0.578	−0.239
	(0.558)	(2.721)	(0.234)	(0.195)	(1.107)	(0.664)
Constant	145.031***	66.757	35.605***	62.704***	165.276***	186.598***
	(23.437)	(114.307)	(9.867)	(8.245)	(35.489)	(24.971)
Province fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Obs	390	390	389	390	240	226
R-squared	0.498	0.598	0.265	0.830	0.539	0.842

Note: The cluster robust standard errors are used in the estimation. *** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.1$.

4.2. Robustness

This study used the rate of access to harmless sanitary toilets to measure the degree of success of the "toilet revolution", and the two-way fixed effects method was used to verify the basic conclusion of this paper. Table 3 shows that fecal harmless treatment has a significant negative impact on the incidence of hepatitis A and dysentery but has no significant effect on the incidence of typhoid. For every increase in the rate of access to harmless sanitary toilets, the incidence of hepatitis A is reduced by 10.8% and the incidence of dysentery is reduced by 39.0%. Compared with the results of the baseline model, the estimated coefficient is increased[7], which is still consistent with the basic conclusions of this paper. Thus, the conclusion that the rate of access to sanitary toilets can effectively reduce the incidence of hepatitis A and dysentery is stable. Compared with an ordinary sanitary toilet, the sanitary standard of harmless sanitary toilets is higher; the improvement of toilet hygiene standards

[7] The effect on the incidence of hepatitis A increased by 50% and the incidence of dysentery increased by 9.6%.

is helpful to control the spread of intestinal infectious disease. The rate of access to harmless sanitary toilets has a negative effect on the mortality rate of children under 5, and the estimated coefficient is slightly smaller than the baseline regression results. On the one hand, the results confirm the robustness of the benchmark regression results; on the other hand, they confirm that sanitary toilets have little effect on reducing perinatal mortality, infant mortality, and the mortality rate of children under 5.

Table 4. Regional differences in the impact of the rate of access to sanitary toilets on the incidence of intestinal infectious diseases.

	Eastern			**Central**			**Western**		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
Variable	**Hepatitis A**	**Dysentery**	**Typhoid**	**Hepatitis A**	**Dysentery**	**Typhoid**	**Hepatitis A**	**Dysentery**	**Typhoid**
STAR	−0.009	−0.485	-0.042***	−0.125***	−0.298**	−0.026**	0.011	−0.294 **	0.013
	(0.015)	(0.301)	(0.013)	(0.033)	(0.118)	(0.011)	(0.064)	(0.143)	(0.027)
Per_GDP	−10.432***	9.714***	−0.270	−3.439	11.511	−2.033***	−14.962*	−18.854 ***	−3.877
	(1.596)	(1.551)	(1.320)	(2.232)	(7.981)	(0.738)	(7.570)	(7.020)	(3.242)
Aging	0.139	−1.195	0.048	−0.251**	0.293	−0.067*	−0.216	−1.070	0.343
	(0.087)	(1.712)	(0.072)	(0.107)	(0.383)	(0.035)	(0.534)	(1.201)	(0.229)
Urb_rate	0.003	1.910	−0.018	−0.049	−0.159	−0.022	0.637	−5.839 ***	0.097
	(0.062)	(1.229)	(0.051)	(0.067)	(0.239)	(0.022)	(0.548)	(1.231)	(0.235)
MTH	0.018	−0.229	−0.083	−0.231**	−0.256	−0.015	−0.292	−0.867 **	0.044
	(0.072)	(1.418)	(0.059)	(0.097)	(0.348)	(0.032)	(0.193)	(0.435)	(0.083)
DP	−0.001	0.031**	0.001**	−0.008	0.126**	0.012**	0.004	0.461 ***	0.022
	(0.001)	(0.015)	(0.001)	(0.014)	(0.050)	(0.005)	(0.073)	(0.165)	(0.031)
GHE	0.093	−18.282***	−0.225**	−0.471*	−1.632*	−0.011	−1.263**	0.784	0.045
	(0.124)	(2.451)	(0.102)	(0.245)	(0.876)	(0.081)	(0.546)	(1.229)	(0.234)
IWD	0.190	10.462	−0.043	0.366	4.351***	0.134	−0.759	−0.877	1.422 ***
	(0.416)	(8.216)	(0.342)	(0.435)	(1.557)	(0.144)	(1.208)	(2.717)	(0.517)
Constant	10.485***	−9.680***	1.306	49.151**	9.211	25.449***	12.729***	10.121***	4.4339
	(1.550)	(3.477)	(1.285)	(20.928)	(7.485)	(6.917)	(4.354)	(144.696)	(2.756)
Province fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Obs	143	143	142	104	104	104	143	143	143
R-squared	0.667	0.687	0.309	0.798	0.865	0.612	0.614	0.791	0.370

Note: The cluster robust standard errors are used in the estimation. *** $p \le 0.01$, ** $p \le 0.05$, * $p \le 0.1$.

4.3. Regional heterogeneity analysis

In order to further investigate the possible regional differences in the impact of the rate of access to sanitary toilets on the incidence of infectious diseases in China, 30 provinces were grouped according to the eastern, central and western regions. As shown in Table 4, there is a significant regional difference in the impact of the rate of access to sanitary toilets on the incidence of infectious diseases. In the eastern region, the rate of access to sanitary toilets only significantly reduces the incidence of typhoid ($p \leq 0.01$), but has no significant effect on the incidence of hepatitis A and dysentery; in the central region, the rate of access to sanitary toilets significantly reduces the incidence of hepatitis A, dysentery, and typhoid; in the western region, the rate of access to sanitary toilets only significantly reduces the incidence of dysentery ($p \leq 0.05$), but has no significant effect on hepatitis A and typhoid fever.

Table 5. Regional differences in the impact of the rate of access to sanitary toilets on child mortality**.**

	Eastern	**Central**	**Western**
	(1)	**(2)**	**(3)**
Variable	**Mortality Rate of Children under 5**	**Mortality Rate of Children under 5**	**Mortality Rate of Children under 5**
STAR	−0.035	0.012	−0.181***
	(0.036)	(0.092)	(0.057)
Per_GDP	2.686	−27.918***	−9.704**
	(4.569)	(8.683)	(4.440)
Urb_rate	0.246	−0.508***	0.019
	(0.167)	(0.160)	(0.442)
MTH	0.046	0.262	−0.369
	(0.175)	(0.259)	(0.334)
DP	0.008	0.070*	0.230***
	(0.005)	(0.036)	(0.068)
GHE	−0.961***	−0.382	−1.321*
	(0.353)	(0.651)	(0.693)
SDE	−5.482***	−8.075***	−2.096
	(1.310)	(2.400)	(1.431)
IWD	−1.589	−1.244	4.692***
	(0.974)	(1.332)	(1.221)
Constant	10.889	318.038***	50.479
	(44.626)	(81.692)	(36.592)
Province fixed effects	YES	YES	YES
Time fixed effects	YES	YES	YES
Obs.	81	61	84
R-squared	0.870	0.929	0.940

Note: The robust standard errors are used in the estimation. *** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.1$.

Because the results of the baseline model show that the rate of access to sanitary toilets has a significant impact on the mortality rate of children under 5, and the impact on perinatal mortality and the infant mortality rate is not significant, only the mortality rate of children under 5 was used to analyze the regional heterogeneity of the impact of the rate of access to sanitary toilets on child mortality. The results of Table 6 show that the rate of access to sanitary toilets in the eastern and central regions has no significant impact on the mortality rate of children under 5, while the influence of the rate of access to sanitary toilets on the mortality rate of children under 5 in the western region is significantly negative: the mortality rate of children under 5 decreased by 18.1% with a 1% increase in the rate of access to sanitary toilets. This shows that the rate of access to sanitary toilets has a great effect on improving the health level of the western region.

5. Discussion

5.1. Access to sanitary toilets can reduce the incidence of intestinal infectious among rural residents

Increasing the access to sanitary toilets can reduce the incidence of intestinal infectious diseases [29,30], especially hepatitis A and dysentery. Feces exposed to breeding mosquitoes and flies can contaminate water sources, fecal infiltration can contaminate soil and water, and toilet hygiene conditions will directly reduce soil pollution and water pollution [31]. In addition, although rural household toilets are considered private goods, the renovation project of rural toilets has a strong positive externality. The transformation of sanitary toilets can not only reduce the incidence of intestinal infectious diseases in rural residents but also produce positive externalities for the farmers who have not changed their toilets. In the case of the traditional rural dry toilet, feces are exposed to breeding mosquitoes and bacteria; then, mosquitoes and flies with the bacteria fly and cause food pollution [26]. Then, bacteria follow the food and water into the human body and easily cause intestinal infectious diseases [32]. In addition, fecal infiltration pollutes soil and water sources and destroys the living environment and circulatory system. With an increase in the rate of access to sanitary toilets, the effect of the intestinal infection rate is diminished. The higher the rate of access to sanitary toilets in rural areas, the stronger the positive externality, and the more conducive this is to reduce intestinal infectious disease incidence.

5.2. Access to sanitary toilets has little impact on child mortality

Access to sanitary toilets has little or no significant impact on perinatal mortality, infant mortality, and the mortality rate of children under 5 in rural areas. This finding might be explained by or related to a couple of reasons below: (1) The effect of sanitary toilet popularization on health indicators such as the mortality rate has a “lag effect”, which leads to the effect not being significant in the short term. (2) The improvement of the rate of access to sanitary toilets in rural areas in China has only improved the sanitary conditions at the facility level, and the hygienic behavior of rural residents has not been effectively improved through such processes as health education [33]. Residents often do not wash their hands after visiting the toilet; thus, they leave the pathogen on the surfaces of objects by touch and infect others, increasing the incidence of intestinal infectious diseases. This offset the health effects of toilet renovation. (3) At present, the goals of toilet improvement in China mainly focus on medium-term construction and result acceptance and pay less attention to the later management and maintenance [25,26]. After completing the task of changing the toilet access rate, the harmless treatment of feces is often not taken seriously. Because the cost of fecal transportation is too high, feces are discarded casually in the field, which can easily cause soil and water pollution and still generate environmental and health problems. This reduces the positive impact of rural toilet improvement on health.

It is worth noting that although we have used control variables and two-way fixed effect model to solve some endogeneity problems caused by omitted variables, there may still be other omitted variable bias. There can be province-specific shocks (time-varying by their own nature) which influence both investment in toilets and health outcomes and which are not captured by province and time fixed effects. For example, a province may encounter public health events in a certain year, so as to improve the popularity of sanitary toilets, reduce intestinal infections and child mortality. So the estimates could still be biased.

5.3. There are significant regional differences in the health outcomes of the "toilet revolution"

There are significant regional differences in the impact of the rate of access to sanitary toilets on the incidence of intestinal infections and child mortality. The main manifestation of this is that the popularization of sanitary toilets has been beneficial to the reduction of intestinal morbidity in both of the central and western regions, as well as to the reduction of the perinatal mortality rate, infant mortality rate, and the mortality rate of children under 5 in the western region. The differences might be also related to the large disparities in the natural environment and the level of socio-economic development between the eastern, central, and western regions [34]. For example, first of all, China has a vast territory, with great differences in environmental climate, natural resources, living habits, concept consciousness [35], and physical quality in the eastern, central, and western regions. Thus, the applicability of the current toilet improvement scheme varies from region to region, resulting in differences in the effect of toilet improvement in different regions [26]. For another, the economic development level in the eastern region is high—thus, reconstruction work starts early, and the toilet renovation project has taken a long time to implement [36]. The access to sanitary toilets is restricted by the law of diminishing marginal benefit—the higher the access to sanitary toilets, the lower the marginal benefit, and the less significant the effect of the toilet improvement project. The level of toilet reform in the western region is low and the popularization rate is low; thus, the project in this area is in the stage where it can have a remarkable effect.

6. Conclusion

As shown above, the findings of this study can be summarized briefly as follows: (1) the increased rate of access to sanitary toilets has effectively reduced the incidence of hepatitis A and dysentery; (2) the impact of sanitary toilet access on perinatal mortality, infant mortality, and the mortality rate of children under 5 is minimal or even insignificant; (3) there are regional differences in the influence of the rate of access to sanitary toilets on the incidence and mortality of intestinal infectious diseases, among which the popularization of sanitary toilets in the central and western regions has had a significant effect on reducing the incidence of infectious diseases, but the effect of the rate of access to sanitary toilets in the eastern region is not obvious—furthermore, the effect of the rate of access to sanitary toilets on mortality is obvious in the western region but not in the eastern and central regions; and (4) the per capita GDP, the urbanization rate, the medical technical personnel in health care institutions in rural areas, and the proportion of government expenditure on health play a clear role in reducing the incidence of intestinal infectious diseases.

The findings of this project suggests the following policy implications: (1) the government should increase the financial subsidies, especially paying attention to the trends in the Chinese central and western regions, improve the enthusiasm of farmers to change their toilets, and continue to improve the rate of access to sanitary toilets; (2) according to local conditions and according to the level of economic development, natural environment and other differences, a sub-regional approach should be adopted to promote the rural toilet improvement project to ensure its quality; (3) it is necessary to explore the establishment of the socialized and market-oriented service mechanism of rural sanitary toilets, strengthen the management and protection after the renovation of toilets, implement the harmless treatment of feces, and improve the living environment in rural areas; (4) sanitary toilet hand-washing facilities should be improved and rural residents guided to wash their hands after visiting the toilet, reducing bacterial infection, to improve the health effect of "toilet renovation"; (5) we should promote the popularization of health knowledge in rural areas, especially in old-fashioned areas, and train rural residents to wash their hands frequently through educational guidance; and (6) at present, many developing countries in the world have poor health infrastructure in rural areas, and open defecation is widespread. In the context of the new coronavirus disease (COVID-19), which is prevalent around the world, it is of great practical significance for countries to strengthen the transformation and popularization of sanitary toilets to prevent the spread of infectious diseases such as intestinal infectious diseases. We can learn from China's successful toilet improvement experience in rural areas and strive to improve the living environment in rural areas and reduce the channels for the spread of infectious diseases.

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Conflict of interest

The authors declare there is no conflicts of interest.

References

1. D. Coffey, A. Gupta, P. Hathi, D. Khurana, D. Spears, N. Srivastav, et al., Revealed preference for open defecation—Evidence from a new survey in rural North India, *Econ. Polit. Wkly.*, **38** (2014), 43–55.
2. M. Odagiri, A. Schriewer, E. Daniels-Miles, S. Wuertz, W. A. Smith, T. Clasen, et al., Human fecal and pathogen exposure pathways in rural Indian villages and the effect of increased latrine coverage, *Water Res.*, **100** (2016), 232–244.
3. K. Santosh, V. Sebastian, Does improved sanitation reduce diarrhea in children in rural India? *Health Econ.*, **22** (2013), 410–427.
4. V. Shyama, T. F. Ramani, D. Arijita, On Diarrhoea in adolescents and school toilets: Insights from an Indian village school study, *J. Dev. Stud.*, **53** (2017), 1899–1914.
5. U. F. Ekpo, S. N. Odoemene, C. F. Mafiana, S. O. Sam-Wobo, Helminthiasis and hygiene conditions of schools in Ikenne, Ogun State, Nigeria, *PLoS Negl. Trop Dis.*, **2** (2008), 1–6.
6. D. T. Trang, K. Mølbak, P. D. Cam, A. Dalsgaard, Helminth infections among people using wastewater and human excreta in peri-urban agriculture and aquaculture in Hanoi, Vietnam, *Trop Med. Int. Health.*, **12** (2007), 82–90.
7. L. Andrés, B. Briceño, C. Chase, J. A. Echenique, Sanitation and externalities: Evidence from

early childhood health in rural India, *J. Water Sanit Hyg Dev.*, **7** (2017), 272–289.

8. E. Duflo, M. Greenstone, R. P. Guiteras, T. Clasen, Toilets can work: Short and medium run health impacts of addressing complementarities and externalities in water and sanitation, Becker Friedman Institute for Research in Economics Working Paper No. 2654864, 2015. Available from: https://ssrn.com/abstract=2654864 or http://dx.doi.org/10.2139/ssrn.2654864.
9. D. Spears, how much international variation in child height can sanitation explain? World Bank Policy Research Working Paper. NO. 6351, 2013. Available from: https://documents1.worldbank.org/curated/en/449651468191643600/pdf/wps6351.pdf.
10. M. I. Smith, T. Yatsunenko, M. J. Manary, I. Trehan, R. Mkakosya, J. Cheng, et al., Gut microbiomes of Malawian twin pairs discordant for kwashiorkor, *Science*, **339** (2013), 548–554.
11. W. Checkley, G. Buckley, R. H. Gilman, A. M. Assis, R. L. Guerrant, S. S. Morris, et al., Multi-country analysis of the effects of diarrhoea on childhood stunting, *Int. J. Epidemiol.*, **37** (2008), 816–830.
12. J. H. Humphrey, Child undernutrition, tropical enteropathy, toilets, and handwashing, *Lancet*, **374** (2009), 1032–1035.
13. J. A. Fuller, E. Villamor, W. Cevallos, J. Trostle, J. N. Eisenberg, I get height with a little help from my friends: Herd protection from sanitation on child growth in rural Ecuador, *Int. J. Epidemiol.*, **45** (2016), 460–469.
14. A. Tarozzi, Growth reference charts and the nutritional status of Indian children, *Econ. Hum. Biol.*, **6** (2008), 455–468.
15. S. Jayachandran, R. Pande, Why are Indian children shorter than African. National Bureau of Economic Research: Cambridge, MA, USA, 2013. Available from: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.404.4791.
16. B. Augsburg, P. A. Rodríguez-Lesmes, Sanitation and child health in India, IFS Working Paper W15/32, 2015. Available from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.707.2958&rep=rep1&type=pdf.
17. C. Walker, I. K. Friberg, N. Binkin, M. Young, N. Walker, O. Fontaine, et al., Scaling up Diarrhea prevention and treatment interventions: A lives saved tool analysis, *PLoS Med.*, **8** (2011), 1–10.
18. C. Bozzoli, A. Deaton, C. Quintana-Domeque, Adult height and childhood disease, *Demography*, **46** (2009), 647–669.
19. J. Currie, D. Almond, Human capital development before age five, *Handb. Labor Econ.*, **4b** (2011), 1315–1486.
20. *World Health Organization*. Diarrhoeal Disease. Report of WHO, 2017. Available from: https://www.who.int/news-room/fact-sheets/detail/diarrhoeal-disease.
21. J. Hammer, D. Spears, Village sanitation and child health: Effects and external validity in a randomized field experiment in rural India, *J Health Econ.*, **48** (2016), 135–148.
22. M. Geruso, D. Spears, Neighborhood Sanitation and Infant Mortality, *Am. Econ. J.*, **10** (2018), 125–162.
23. K. Ezeh-Osita, E. Agho-Kingsley, M. J. Dibley, J. Hall, A. N. Page, The impact of water and sanitation on childhood mortality in Nigeria: Evidence from demographic and health surveys, 2003–2013, *Int. J. Environ. Res. Public Health.*, **11** (2014), 9256–9272.
24. A. Das, B. Das, Does sanitation affect health outcomes? Evidence from India, MPRA Paper. NO.63760, 2015. Available from: https://ideas.repec.org/p/pra/mprapa/63760.html.
25. H. Li, W. Yu, Effects of the Government’s Health Expenditure on the Health of Rural Residents

in China, *Soc. Sci. China (Chinese)*, **34** (2013), 41–60.
26. Z. Wen, Y. Yang, The Economic Benefit and Social Benefit of Improvident of Latrines in Countryside in Hunan Province, *Chinese Prim. Health Care (Chinese)*, **19** (2005), 76–78.
27. K. Y. Chay, M. Greenstone, The impact of air pollution on infant mortality: Evidence from geographic variation in pollution shocks induced by a recession, *Q. J. Econ.*, **118** (2003), 1121–1167.
28. J. H. You, P. M. Wei, D. G. Dong, Analysis on epidemiological characteristics of type A and B intestinal infectious diseases in Xinghua City from 1990 to 2019, *Chinese J. Disease Control Prevent. (Chinese)*, **24** (2020), 1348–1351.
29. C. P. Zhang, D. K. Sun, D. Z. Chen, S. M. Li, Q. Li, Performance evaluation of rural latrine renovation in Jinhu County from 2010 to 2014, *Int. J. Med. Parasit. Diseases (Chinese)*, **42** (2015), 323–327.
30. W. Song, M. Dong, L. S. Xu, Analysis on control effect of major intestinal infectious diseases after toilet improvement in rural areas, Tai'an city, 2013–2017, *Prevent. Med. Trib. (Chinese)*, **24** (2018), 933–935.
31. S. Wang, R. Zhang, Y. Tao, Burden of diarrheal in typical rural areas with water supply and latrines improvement, *J. Environ. Health (Chinese)*, **31** (2014), 159–162.
32. M. C. Freeman, J. V. Garn, G. D. Sclar, S. Boisson, K. Medlicott, K. T. Alexander, et al., The impact of sanitation on infectious disease and nutritional status: A systematic review and meta-analysis, *Int. J. Hyg Environ. Health*, **220** (2017), 928–949.
33. Q. L. Ni, Analysis of the Government's responsibilities in the "Toilet Revolution"—enlightenment of "Toilet Improvement" in Nantong City, Jiangsu Province, *Econom. Res. Guide (Chinese)*, **18** (2020), 39–40.
34. R. Parimita, S. Wolf-Peter, B. Sophie, C. Thomas, W. J. Marion, Socio-cultural and behavioral factors constraining latrine adoption in rural coastal Odisha: An exploratory qualitative study, *BMC Public Health*, **15** (2015), 1–19.
35. Y. H. Wang, X. P. Zeng, Y. Wang, Efficacy analysis of latrines improvement implementation on control of enteric infectious diseases, *Jiangsu J. Prevent. Med. (Chinese)*, **25** (2014), 20–22.
36. H. J. Hu，F. C. Fan, W. Yao, Y. F. Fu, Latrine improvement situation and influencing factors in rural areas of China, *J. Environ. Health (Chinese)*, **36** (2019), 1029–1032.