

Evidence of the influence of wastewater treatment on improved public health

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ABSTRACT

This paper analyzes the influence of wastewater treatment access of a region and the effect on public health improvement independent of its economy. The sample set is derived from 39 different nations. The study employs health, economic and environmental indicators such as gross national income, human development index; disease mortality due to diarrheal diseases, tuberculosis and malaria, access to sanitation, wastewater treatment and collection. It is necessary to extricate the impact of increased wastewater treatment access on disease mortality from that of increased national income and health care. Hence we observed this influence for very small ranges of human development. It was concluded that an increase in wastewater treatment availability reduces disease mortality, independent of an increase in income or sanitation. Trends in the lack of wastewater treatment with the logarithm of disease mortality had correlation coefficients (r^2) of 0.35–0.5 at a high significance ($P < 0.001$). Previous studies have emphasized the relation between improved sanitation and public health. This study reasserts the necessity for wastewater treatment in order to mitigate disease burden and mortality.

Key words | disease, human development, public health, sanitation, wastewater

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INTRODUCTION

Sanitation and wastewater treatment protect human health by conveying wastewaters away from populated areas and converting them to less hazardous or less infective forms. Public sanitation has benefited from early laws and regulations that often addressed other water-based issues. For instance, in the USA the earliest water laws protected navigation by preventing the introduction of solid wastes into navigable waters (Viessman Jr. *et al.* 2009).

The history of public sanitation laws in the USA illustrates how regulations have evolved from protecting navigation and public health to protecting the environment. From 1912, when the Public Health Service Act provided a section on the removal of waterborne diseases, to the formation of the Environmental Protection Agency (EPA) in 1970, and the passing of Clean Water Act in 1972 to protect water quality for the environment, water regulations had adapted to technological advancement (Viessman Jr. *et al.* 2009). Yet, the primary objective of protecting human health cannot be neglected, despite the increasing focus on environment protection.

Lately, increased industrial development has introduced many pollutants such as endocrine disrupters, explosives and heavy metals to surface and ground waters (Benotti *et al.* 2009). Wastewater treatment can reduce such pollutants, thus eliminating the necessity for an excessively sophisticated and expensive drinking water treatment system (Leu 2012). Also, as waterborne diseases stem from source water contamination, protecting source water is necessary to reduce disease burden via direct contact or vector breeding. Balancing an efficient drinking water supply and wastewater treatment is the key to eliminating waterborne diseases.

Sanitation is usually considered to be a more fundamental community need relative to wastewater treatment (Handbook of Public Water Systems 2001). Our study demonstrates that many nations that have complete sanitation but low wastewater treatment also have high disease mortality. The aim of the paper is to establish that increased wastewater-treatment access reduces waterborne disease mortality. As increased national income implies improved health care services, the effect of wastewater treatment on disease mortality is verified independent of that of economy.

Literature review

Previous studies have analyzed the relationship between sanitation or water supply and disease mortality or burden extensively by employing various methodologies, sampled data and disease indicators. Table 1 reviews previous work based on the relationship of water and public health. A few relevant studies might have been omitted inadvertently.

METHODS

Indicators

There are three indicators in this study: health, environmental and economic. Based on previously encountered methodological problems, the availability and suitability of data, parameters have been chosen for these indicators. The indicators, the bases for their selection and the parent database are described in Table 2 and the following section in detail.

The Gross National Income (GNI) per capita, an economic indicator, quantifies the net capita income of a population. It impacts health care, infrastructure and hygiene (UN Statistics Division 2010). For the human development index (HDI), another economic indicator, the calculations have been described in detail in the Human Development Report (UN Development Program 2010). Disease mortality was more reliable than disease burden as a health indicator. Disease burden data, measuring number of cases, was inconsistent and possibly improbable for the low-income countries where health care might receive lesser priority (WHO Statistical Information System 2010). The data are based on tuberculosis, diarrheal diseases and malaria as they differ in geographic susceptibility and are consistently reported. Parasitic diseases were not considered due to inadequate data. Due to the unavailability of data for some countries, they have been excluded from the analysis for collection of wastewater. Water quality was not used as an indicator as a means to avoid complexity.

The following parameters were the environmental indicators. Access to sanitation comprises 'connections to public sewers, septic systems, pour-flush latrines, simple and ventilated improved pit latrines'. Population connected to wastewater collecting systems covers the percentage of population which 'may deliver wastewater via collecting systems either to treatment plants or discharge it directly to the environment'. 'The population connected to urban wastewater treatment denotes the percentage of the resident population whose wastewater is treated at wastewater treatment plants' (UN Environment Statistics 2010).

DATASET

Each point in the sample set corresponds to a country and the corresponding indicators. The dataset is given in Appendix 1 (available online at <http://www.iwaponline.com/wst/066/144.pdf>). Categorized based on HDI, the 'developed', 'moderately developed' and 'underdeveloped' country categories have almost an equal number of national statistics. Figure 1 shows a global variation of these indicators.

The overall disease rate is low in North America, Australia, Europe, Mexico and Argentina. Sanitation is mostly high or at least moderately developed globally except in India and Chad. Wastewater treatment access is more randomly distributed. Thus, barring a few extremes, disease mortality and wastewater treatment individually do not follow a prominent geographical pattern.

Our study resolves many previously encountered methodological problems. Table 3 describes those and our approach towards them.

RESULTS AND DISCUSSION

Interdependence

Figure 2 shows the effect of GNI on disease mortality, wastewater treatment and sanitation accessibility respectively. Disease mortality decreases with increased national income due to improvements in health care. Also, GNI indirectly affects disease mortality due to its effect on wastewater treatment. Thus, extricating the influence of wastewater treatment from that of GNI is necessary.

Wastewater and disease variation

The indicators being interdependent, analyzing the impact of wastewater treatment access on disease mortality at constant human development is necessary. We conducted a paired regression of disease mortality and lack of wastewater treatment access for small ranges of the HDI (range = 0.1) to approximate constant human development in those ranges. The parameter 'population not connected to wastewater treatment' was more suitable for a paired analysis with disease mortality. Figure 3 denotes the variation in disease mortality with lack of access of wastewater treatment in every small range of HDI.

Table 1 | Previous studies relating sanitation, wastewater treatment, water supply and public health

Reference	Objective/Results	Summarized conclusions
Blum & Feacham (1983)	Reviewed previous studies and qualitatively examined methodological problems that can distort or hinder conclusive analyses from such studies	Methodological problems are listed as follows (elaborated in later sections): Inadequate control, One-to-one comparison, Complex variables, Health indicator recall, Health indicator definition, No analysis by age, Lack of facility usage record
Esrey <i>et al.</i> (1985)	- Studied pathogen dose–response relationship by also separating mild and severe diarrhea based on incidence rate - Formulated model relating improved water supply and excreta disposal with diarrhea incidence rate - Reviewed: 67 studies from 28 countries based on different infections or different health indicators and calculated median reduction based on different conditions	- Water supply or excreta disposal can reduce ingestion of pathogens by young children, which reduces diarrhea - With increased pathogen dosage mild diarrhea increases to a breakpoint after which severe diarrhea dominates - Significant reduction in both diarrheal morbidity (27%) and mortality observed (30%)
Soller <i>et al.</i> (2003)	Formulated hydraulic model on San Joaquin River, CA, USA integrated with a dynamic disease transmission model for diarrhea to assess incremental benefit associated with added tertiary treatment	- Continuous risk to individual with recreational water source - In winter, tertiary treatment lowers risk by 15–50%, though effluent pathogen count below EPA limit (site-specific results)
Fewtrell <i>et al.</i> (2005)	Reviewed 46 studies from peer-reviewed articles to pool data and conduct conclusive analysis by random effects test on disease mortality reduction due to interventions like improved water supply, sanitation and hygiene	- Relative risks (reduction in frequency of diarrhea) for: - Hygiene: 0.55 (0.52–0.77) 95% - Sanitation: 0.68 (0.53–0.87) 95% - Water supply: 0.75 (0.62–0.91) 95% - Water quality: 0.61 (0.46–0.81)
Haller <i>et al.</i> (2010)	Analyzed cost–effectiveness for increasing access to improved water supply and sanitation facilities, increasing access to in-house piped water and sewerage connection, and providing household water treatment, in ten continental WHO sub-regions	- Piped water supply and sewerage accomplished maximum health gains - Disinfection had lowest cost–benefit, but had high health improvements - The highest improvement was in low diarrheal mortality countries of the Eastern Mediterranean Region, the Americas, Europe and South-east Asia
Nelson & Murray (2008)	Reviewed current sanitation technologies with respect to long-term performance, user demands, expenses and capacity	- Existing facilities do not suffice in protecting human health and treating waste - Water quality standards should be the deciding factor in the design of sanitation and wastewater treatment infrastructure
Tsuzuki (2008)	Conducted a correlation analysis between Pollutant Discharges per Capita (PDC) and GNI, access to safe drinking water, domestic water usage amount, and integrated parameters of water, sanitation and economic indicators for eight international coastal zones and lakeside regions	- PDC-BOD is correlated with GNI per capita with a third-order regression - PDC-TP is correlated with the integrated parameters of water, sanitation, economy with 10% significance - A complex relationship suggested by multiple linear regression analyses between PDC-BOD and safe drinking water availability
Tsuzuki (2009)	Conducted linear and log regression analyses on PDC and gross domestic product per capita (GDPC) in seven international lakeside and coastal regions	PDC-BOD, PDC-TN (total nitrogen) and PDC-TP (total phosphorus) have different correlations with GDPC because of prioritizing nutrient removal after a certain economic development

(continued)

Table 1 | continued

Reference	Objective/Results	Summarized conclusions
Mara <i>et al.</i> (2010)	Reviewed and analyzed benefits and implementation of sanitation	• Inappropriate population target and lack of guidance to users • Situation-specific approach is necessary
Cairncross <i>et al.</i> (2010)	Analyzed inadequacy of sanitation and suggested tasks for organizations at different levels	• Tasks at various organizational levels: • Local Government: quick response to local needs, effective delivery and co-operation with local providers • Central Government: support local government by regulation and resourcing • External agencies: optimize financing sanitation and obtaining investment from users • Health sector: propagate importance of hygiene, sanitation, water supply and quality; establish by-laws; support at household and community levels

Table 2 | Nomenclature for Economic, Environmental and Health indicators

Indicator	Units	Range	Definition	Reference
Gross national income	US\$ per capita	Undefined	'Income of country' – aggregate balances of gross primary incomes for all sectors	United Nations Statistics Division (2010)
Human development index (HDI)	–	0–1	'Measure of human development' – based on health, education and standard of living	United Nations Development Program (2010)
Disease mortality	Numbers per million	Undefined	Number of deaths by cause	World Health Organization Statistical Information System (2010)
Access to wastewater treatment	Percent	0–100	Percent population connected to facilities	United Nations Environment Statistics (2010)
Access to sanitation	Percent	0–100	Percent population connected to facilities	United Nations Social Statistics (2010)
Access to collection	Percent	0–100	Percent population connected to facilities	United Nations Environment Statistics (2010)

The plots show that disease mortality increases with lack of access to wastewater treatment (both parameters of corresponding pairs appear close together). Though not a linear variation, more wastewater treatment access indicates low disease mortality and vice versa. The public health benefit can also be observed for all degrees of development and countries having 100% sanitation. Therefore, the relationship between disease and availability of wastewater treatment is independent of national income, development and sanitation. In the paired analysis, there were a greater

number of supporting pairs for diarrheal diseases than for malaria or tuberculosis (diarrhea: 28, tuberculosis: 27, malaria: 22).

Correlation

A linear fit of wastewater treatment access with logarithm of disease mortality gives correlation coefficients (r^2) of 0.319 for diarrheal diseases, 0.436 for tuberculosis and 0.484 for malaria. The correlations are significant as

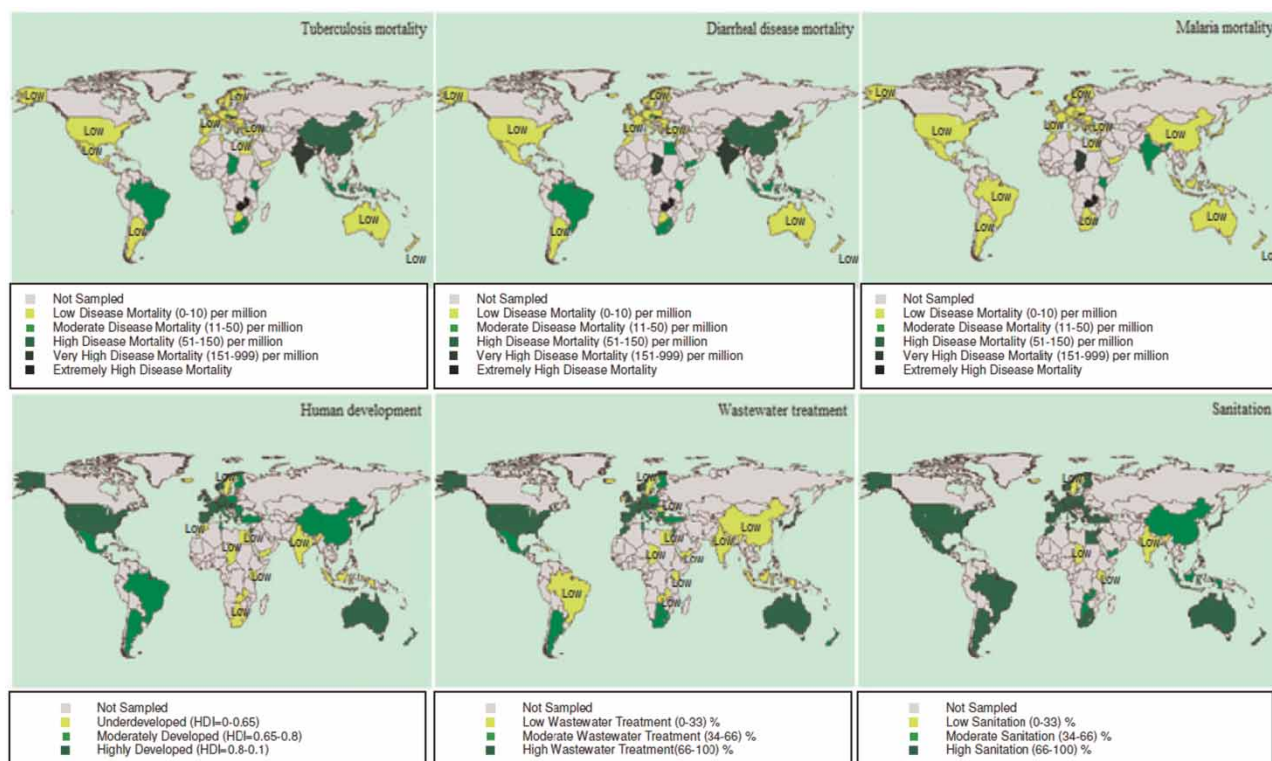


Figure 1 | Global variation of disease mortality, human development, and access to wastewater treatment and sanitation (UN Statistics Division 2010, UN Development Program 2010, WHO Statistical Information System 2010, UN Environment Statistics 2010).

Table 3 | Previously encountered methodological problems and solutions (Blum & Feacham 1983)

Observed problem	Description	Approach in study
Lack of control group	No distinction between health improvements due to water supply/excreta disposal accessibility and that due to social or economic factors.	By dividing the dataset into very small increments of human development index, we approximated constant human development: observed disease trends were purely based on wastewater treatment access.
One-to-one comparison	Comparison of a single control community to a single intervention community: this would be just one data point as such interventions are a community-wide movement.	Thirty-nine different nations have been considered as data points. The degree of intervention changes in irregular increments.
Complex parameters	Controlling a number of intricate variables is complicated. Groups to be compared should be similar with respect to some variables.	In studying the trend between disease mortality and access to wastewater treatment, we analyzed groups which had approximately the same human development index.
Health indicator recall	Incomplete information on recurrence or family history of diarrhea.	This study uses disease mortality which is better recorded than disease burden.
Health indicator definition	Misinterpretation due to lack of definition of indicators.	In this study, all indicators used have been very well defined in Table 3.
Lack of facility usage record	Assumption that existence of a facility implies complete usage.	To denote wastewater treatment, sanitation or collection access, this study uses percent population connected to each of the facilities.

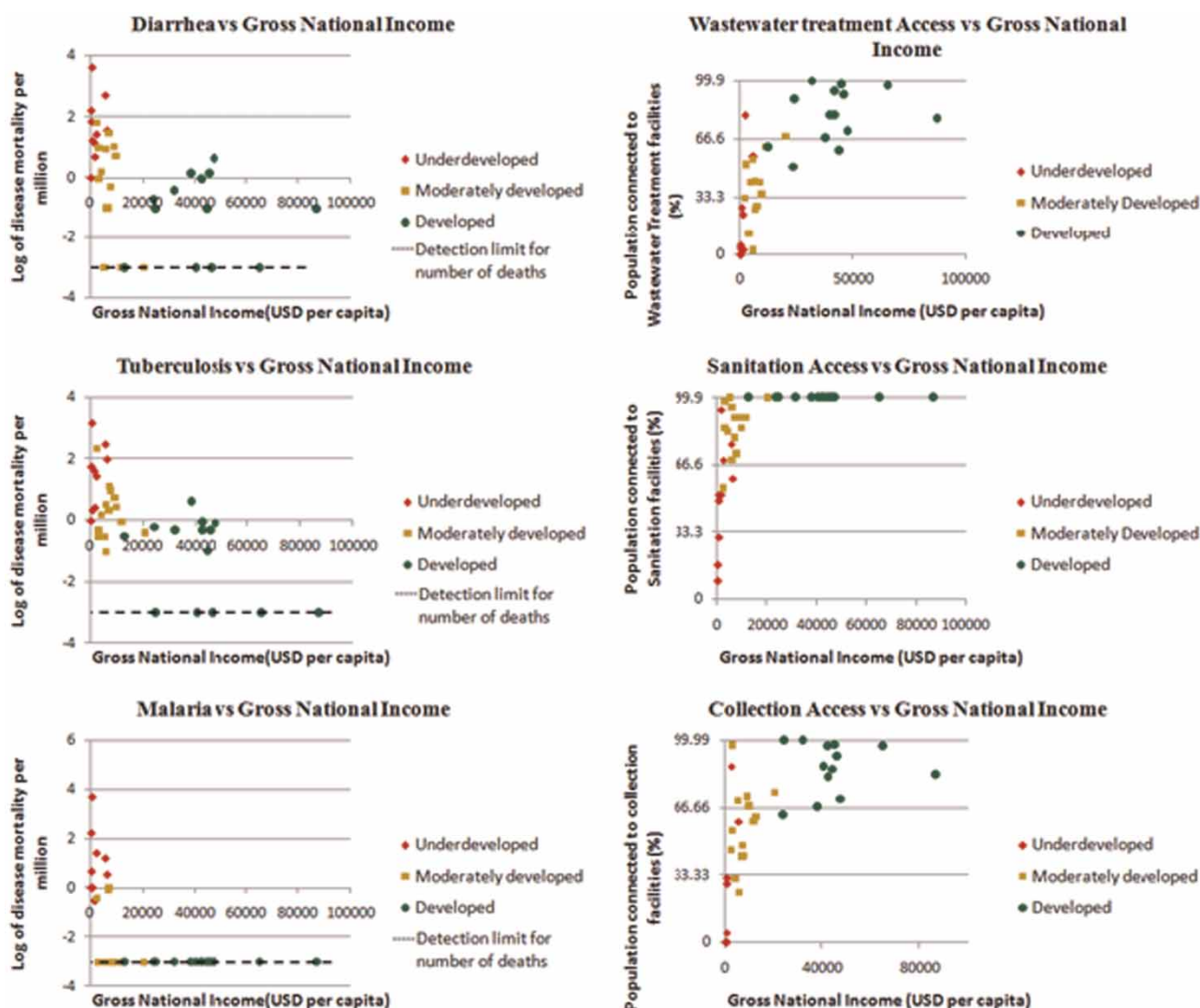


Figure 2 | Dependence of environmental and health indicators on Gross National Income (UN Statistics division 2010, UN Development Program 2010, WHO Statistical Information System 2010, UN Environment Statistics 2010, UN Social Statistics 2010).

they have a probability value of less than 0.001. Malaria has a higher correlation coefficient than tuberculosis and diarrheal diseases. This result was initially counter-intuitive to the authors' expected result of diarrheal diseases being more closely related to wastewater treatment. Upon reflection it was expected, as areas with more stagnant water accumulation have greater opportunity for waterborne diseases. Tuberculosis is an opportunistic disease more prominently affecting individuals with compromised immune systems due to diseases (e.g. diarrhea) (Winthrop 2006). The magnitude of these effects cannot be tested with the existing datasets, but provided are previously documented reasons for the correlations.

The low correlation coefficients can be explained by the possible nonlinearity of the relations. Also, the diarrheal disease data pertains to parasitic, viral or bacterial diarrhea. It is necessary to pursue a single diarrheal disease like cholera which is tracked exhaustively by organizations like the World Health Organization. In future studies, we would observe the variation of mortality due to cholera with wastewater treatment access.

Role of wastewater treatment in the human development index

Figure 4 shows the variation of HDI with the environmental indicators. HDI has individual dependence on

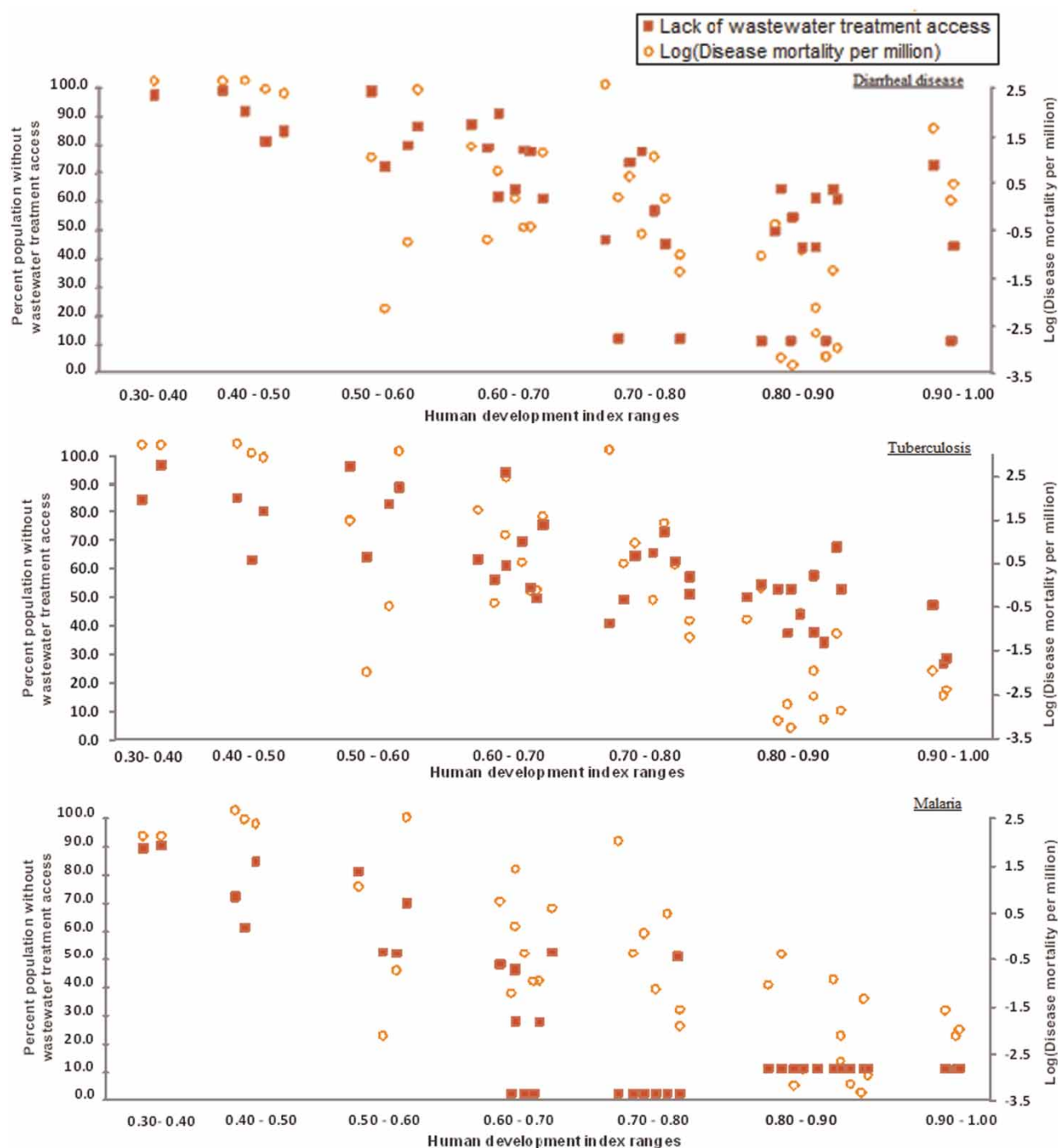


Figure 3 | Paired analysis for wastewater treatment and diarrheal disease, tuberculosis and malaria respectively at constant HDI (UN Development Program 2010, WHO Statistical Information System 2010, UN Environment Statistics 2010, UN Social Statistics 2010).

access to wastewater collection, treatment and sanitation. In the lower row of Figure 4, HDI does not correlate with the fraction of treated wastewater from collection systems and the fraction of collected wastewater from

sanitation facilities. We suggest that this facet of development be integrated in such a prominently used development index, to emphasize the need for wastewater treatment.

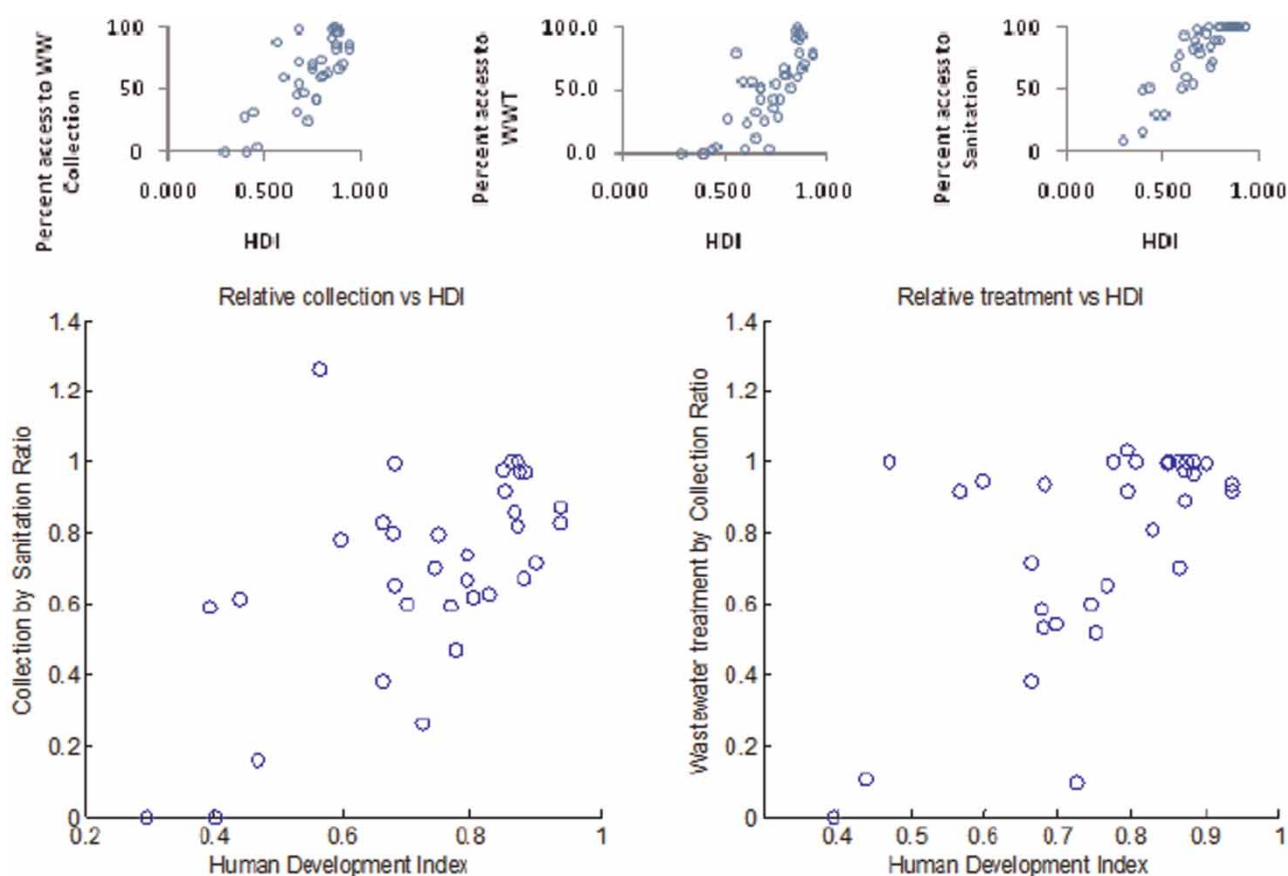


Figure 4 | Dependence of HDI on wastewater collection, sanitation and wastewater treatment and relative wastewater collection and relative wastewater treatment respectively (UN Development Program 2010, WHO Statistical Information System 2010, UN Environment Statistics 2010, UN Social Statistics 2010).

CONCLUSIONS

This study analyzes the influence of wastewater treatment access on public health independent of national economic growth or other development. Environmental, economic and health indicators corresponding to a set of 39 nations were used for this study. The availability of wastewater treatment significantly benefits public health, independent of increase in health care or national income. This variation is observed at all levels of human development and even conditions of complete sanitation. Also, a prominently used development indicator, the HDI, depends on access to wastewater treatment, collection and sanitation individually, but does not show dependence on their relationships. Overall, this study implies that wastewater treatment is not an extravagance for developed nations but a basic necessity for public health protection irrespective of the income of a nation. Hence it should be considered an integral part of planning the development of a nation. Future work would involve studying the impact of wastewater treatment

access on cholera mortality and age specific analysis owing to different age susceptibilities for all these diseases.

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