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A global indicator of wastewater treatment to inform the Sustainable Development Goals (SDGs)

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ABSTRACT

This paper assessed an effort to create an indicator of global wastewater treatment performance to inform environmental performance and sustainable development. We compiled wastewater treatment statistics for 183 countries and constructed a first-of-its-kind global indicator for wastewater treatment performance. Although reporting definitions are inconsistent across countries, we preliminarily concluded that wastewater performance trends vary globally, regionally, and by income. Overall, the lack of consistent definitions, reporting protocols, and a central custodian for wastewater treatment data are main reasons for many challenges we confronted in constructing comparable performance measures. We suggest a standardized definition of wastewater treatment aimed at the utility level, which could be normalized and aggregated to reflect national performance. U.N. negotiators, who are designing a Sustainable Development Goal (SDG) for water that includes a metric on wastewater treatment, must consider these issues if countries are to be successful in managing wastewater and ultimately, water quality.

1. Introduction

Wastewater management has a long history in urban societies. Some of the earliest cities in Eurasia made use of building and engineering methods to conduct waste from households. During the Minoan Civilization around the second century BCE, major cities were built with both sewer and storm water drainage systems that sometimes led to irrigation channels and allowed for human waste to be used as fertilizer (Angelakis et al., 2005). The Indus Valley civilization, active in the third century BCE, was also known for its advanced sewage systems in which household waste was transported through covered conduits under city streets, sometimes with systems of holding tanks (Deleur, 2003).

Today, wastewater is a major factor for freshwater quality and human health. Wastewater is defined as water that has been used by households, industries, and commercial establishments that, unless treated, no longer serves a useful purpose and may contain contaminants (Raschid-Sally and Jayakody, 2008; UNSD, 2012, p. 196). It is comprised of water from household sinks, washing machines, and kitchen

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appliances, as well as water flushed from toilets, and therefore contains a combination of nutrients and chemicals. Industrial contributions include carbon, nitrogen, and phosphorous nutrients, as well as pesticides and other chemicals depending on the specific industry (US EPA, 2004).

When left untreated, these nutrients and chemicals enter natural water systems where they cause harm to the environment and human health (Corcoran et al., 2010). A host of bacterial, viral, and protozoan organisms can survive in human waste and fecal matter, including *Escherichia coli* that can be present in pathogenic form in wastewater (WHO, 2011). In ecosystems, nutrient pollution can lead to algal blooms and eutrophication, due to excess nutrients allowing aquatic microorganisms to proliferate and consume all available oxygen. Eutrophication in turn can lead to fish die-offs from anoxic conditions (Corcoran et al., 2010). Humans are also at risk of shellfish poisoning from the accumulation of biological contaminants in filter-feeding organisms (Baum et al., 2013; Shuval, 2003). Other effects such as the emerging issue of endocrine disruption in organisms can occur in part due to the presence of pharmaceutical products or chemicals in waterways (Corcoran et al., 2010).

Wastewater is typically collected through sewage pipes in municipal areas. Treatment of wastewater entails a step-wise process that occurs in primary, secondary, and tertiary stages. Primary treatment involves basic screening and filtration processes to remove suspended solid waste and reduce its biochemical oxygen demand (BOD), which is an indicator to monitor water quality that assesses the amount of oxygen microorganisms must consume to break down the organic material present in wastewater (US EPA, 2012). Primary treatment can reduce BOD by up to 30% (Flörke, 2013). Secondary treatment uses biological processes to break down the dissolved organic matter remaining after primary treatment. Secondary treatment can remove up to 90% of BOD and total suspended solids (US EPA, 2004). Any additional step in wastewater treatment is considered tertiary treatment (or "advanced treatment"), which includes any purification process that continues beyond the previous steps and may require more complex technology such as ion exchange and reverse osmosis to further remove contaminants or phosphorous and nitrogen (World Bank, 2013b; US EPA, 2004).

Environmental problems occur when wastewater treatment plants do not have the capacity to treat all of the wastewater that they collect, or when they fail to adequately treat wastewater. In many cities located in developing countries, existing infrastructure may not be sufficient to treat all the wastewater it receives. This may occur when the growth of a city's population outpaces the construction of treatment facilities or when a city lacks the funds to properly maintain or upgrade existing plants over time (Mateo-Sagasta and Salian, 2012). As a result, wastewater treatment facilities may discharge partially or completely untreated wastewater directly into the environment (Corcoran et al., 2010). In Accra, the capital of Ghana, for instance, existing treatment plants were reported not operational in 2013 due to issues of capacity, therefore leading to illegal dumping wherein the waste is diverted directly into the ocean (Muspratt and Bäuerl, 2013; Murray and Drechsel, 2011). Although wastewater treatment is widely recognized as a major factor for water quality (US EPA, 2004), the UN Environment Programme (UNEP) estimates that 90% of the developing world does not treat any of its wastewater before it is released directly back into the environment (UNEP, 2010). Our study aims to provide the kind of support needed to understand such region specific characterizations.

Because of the salience of water resources to human and ecosystem health, United Nations negotiators are considering a Sustainable Development Goal (SDG) for water (Fig. 1). The SDGs are a set of goals applicable to all countries, developing and developed alike, that are set to succeed the Millennium Development Goals (MDGs) when they expire in 2015. The SDGs must be "aspirational, universal, communicable, and measurable", and they must set countries on a path toward reaching global targets between 2015 and 2030. The SDGs aim to help the world transition to a more sustainable system by presenting balanced environmental objectives and poverty reduction goals (Sachs, 2012). To that end, the Open Working Group of the UN General Assembly is facilitating high-level discussions of specific environmental themes throughout 2014, including the proposed SDG on water with a sub-goal for improved water quality through wastewater management (UN DESA, 2013; Bjørnsen, 2013). As of this winter, the OWG has passed their recommendations on to the General Assembly, which will consider them in its next session in September 2015.

While the proposed sub-goal for improved water quality and wastewater management includes a goal to "reduce both the urban population with untreated wastewater and untreated industrial wastewater flows", there are currently no globally comparable data on the percentage of wastewater treatment at the national scale to aid in the assessment of this effort (Sato et al., 2013; Baum et al., 2013). Sato et al. (2013) found that information on the quantity of wastewater generated, treated, and used at the national scale is often "unavailable, limited, or outdated". It is for this reason that the baseline percentage of wastewater treatment at the global level has been poorly understood.

To address the gap in available, comparable national wastewater treatment data, this paper presents the first-ever dataset of a country-level wastewater treatment indicator at the global scale. Our immediate goal was to develop an indicator of water quality to include in the 2014 edition of the Environmental Performance Index (EPI), a biennial global ranking of country performance on a range of environmental issues (Hsu et al., 2014). A secondary objective was to evaluate the global availability of national data to assess wastewater treatment to inform current proposals for a wastewater treatment indicator in the UN SDG process. Last, we aimed to analyze global trends in wastewater treatment to inform baseline and target measurements for that process.

The paper is organized as follows: Section 2 provides an overview of the methods used to research and compile national statistics on wastewater treatment. Section 3 then discusses global dataset results, with analysis of performance and factors related to data availability and coverage. Section 4 identifies major gaps with respect to existing data to assess wastewater treatment performance, including recommendations for an ideal indicator and standardized definitions that can help facilitate future data collection efforts.

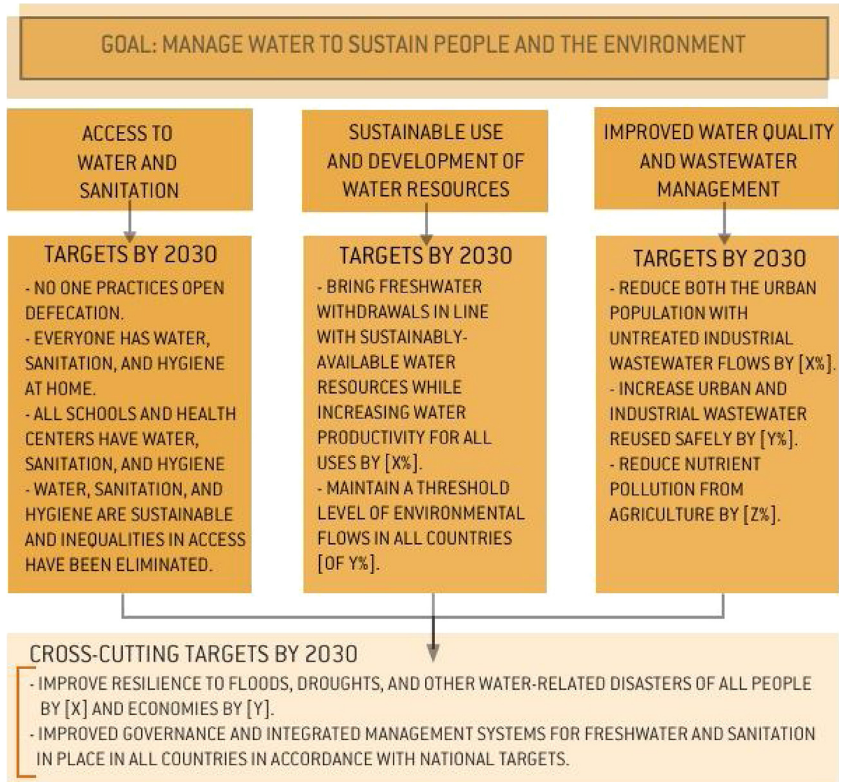

Fig. 1 – The proposed Sustainable Development Goal for water has three components: (1) access to water supply and sanitation; (2) sustainable use and development of water resources; and (3) improved water quality and wastewater management.
Source: Bjørnsen (2013) and UN-Water (2014).

2. Materials and methods

2.1. *Compiling the global database*

We sought to collect data that primarily assessed two variables: wastewater treatment and sewerage connection rate. We defined wastewater treatment as the amount of wastewater that is treated within a country relative to the amount of wastewater that is collected, generated, or produced. Connection rate we specified as the population connected to municipal sewerage systems relative to the population living in that country.

We used data for wastewater treatment and sewerage connection rates from the *Pinsent Masons Water Yearbook* (2013), United Nations Statistics Division (2011), Organisation for Economic Cooperation and Development (OECD) (2013), and the Food and Agriculture Organization of the United Nations (FAO) (2013) as a starting point for our global database (Box 1). After analyzing the country and time-series coverage (Table 1) for each of these datasets, we researched additional publicly available data to fill in any remaining gaps, aiming to develop as complete of a dataset across time and space.

We first searched for national-level country statistics in reports and on national statistics websites. We primarily used State of the Environment reports, National Bureaus of Statistics databases, Ministries of Environment reports, and other national statistical offices databases. For example, Benin's statistical database was available online from the Benin Institute of Statistics and Economic Analysis (Benin Institute of Statistics and Economic Analysis, 2013); the Government of Bermuda's Ministry of Public Works provided their country's statistics (2013); the New Zealand Ministry of Environment published their country's numbers (Ministry of Environment, 2012).

If no country-level or national statistics were available, we searched statistical reports for major cities to find subnational data. We selected the largest cities according to population using WolframAlpha's search tool (Wolfram Alpha LLC, 2013). In most cases, the only city-level data available online were from a country's capital city or major cities. For example, in Namibia, we only found available data for the capital, Windhoek (Lahnsteiner and Lempert, 2007). For Rwanda, data were derived from the capital city of Kigali (Umuoza Mbateye et al., 2010). Pakistan's value was derived from Karachi, which, while not the capital, is the largest city in the country for which data were available (UNEP, 2004). While we acknowledge that the consideration of major cities excludes possible wastewater treatment occurring in rural areas (through, e.g., septic tank treatment), the availability of data limited our search to primarily urban areas because we could not find rural statistics of wastewater treatment for many countries.

Box 1. Existing datasets for variables relating to wastewater treatment

1. UN Statistics Division (2011)

The UNSD dataset provides data for 82 countries. It includes two variables: "Population connected to wastewater collecting system" and "Population connected to wastewater treatment". "Population connected to wastewater treatment" is defined as "the percentage of a population whose wastewater is treated at wastewater treatment plants" (UNSD, 2011). Data sources include UNSD/UNEP biennial surveys, Eurostat, and OECD.

2. Organisation for Economic Cooperation (2013)

The OECD dataset provides data for 31 out of the 34 OECD countries (2013). The variable used in this analysis was "Connected to wastewater treatment plant without treatment". It provides percentages of the populations connected to public sewerage networks, based on the amount of installed water management equipment. The metadata describes where each country has different calculation methods in terms of years excluded and data gaps such as various amounts and urban versus rural coverage.

3. Pinsent Masons Water Yearbook (2013)

The *Pinsent Masons Water Yearbook* is published by Pinsent Masons, LLP and Global Water Intelligence based in the United Kingdom. The 2013 dataset covers 157 countries, but it includes estimations that cannot always be verified through public sources because many estimates are derived in consultation with water infrastructure experts (Owen, 2013). The year 2011 was assumed to be the reporting year for all data points used from the *Yearbook*, although these compendium values may have been derived from earlier years.

4. The Food and Agriculture Organization of the United Nations (FAO), Aquastat (2013)

The FAO dataset provides global water use information for a large number of variables. Variables relevant for wastewater treatment were extracted for the desired numerator ("Volume Wastewater Treated") and denominator ("Volume of Wastewater Collected" or "Volume of Wastewater Produced") allow for statistical wastewater treatment calculations for 30 countries.

When no country- or city-level statistics were available, we searched for utility-reported data for wastewater treatment plants. For example, in the case of Cape Verde, we used data reported by Electra Water and Electricity – a major utility company in the capital city of Praia. This represented wastewater treatment value for the whole country due to lack of any other relevant data (Electra, 2009). Utility-reported data for Palau and other small-island countries were derived from a regional report from the Wastewater Utilities Benchmarking Report (Pacific Water and Wastes Association, 2012).

We searched peer-reviewed literature for relevant wastewater treatment statistics as a final step to fill in remaining gaps. In a handful of cases, we directly contacted experts and government officials to estimate treatment or connection values. For example, we contacted researchers in Ghana who could use expert knowledge to estimate values for the capital city Accra, which was then used to represent the country in the database (Muspratt and Bäuerl, 2013; see Supplementary Materials).

2.2. *Recording metadata*

For each data point, we recorded the geographic scope (national or city-level), demographic scale (urban or total population), variable definition (e.g., population connection rate, number of treatment plants), units (volume, number), whether or not wastewater treatment percentage was calculated from volumes treated divided by volumes collected, year, and data source (see Supplementary Materials). We recorded the most recent year available where possible. If a year was not reported, we estimated the year based on the given date of the report from which the statistic was found. If there was a range of reported or referenced years, we chose less recent years to account for a generalized lag in reporting activity. For instance, in the two-year range of "2011–2012" from *Pinsent Masons* 12th Ed., the earlier of the two years was recorded, and in FAO, the median year was recorded (e.g., 2009 for "2008–2010"). We did not accept values for future dates or projected estimates.

2.3. *Estimations and manual corrections*

In some cases, we had to estimate values when anecdotal descriptions were provided. For example, a number of sources reported qualitative information by stating that "little" or "no wastewater treatment" occurs in the country of interest, which led us to record a value of "0%" in our database. For example, the main utility in Guyana's capital, Georgetown, reported that "there are no treatment processes" in the city (Guyana Water Incorporated, 2013). In a similar example, we interpreted the assertion that none of the five cities examined in Burundi had any wastewater treatment (UN-Habitat, 2007) as meaning that there was "0%" treatment. In other cases we

Table 1 – The availability of wastewater treatment and connection rate data varies between different datasets.

Dataset	Number of countries (wastewater treatment)	Years covered	Number of countries (connection rate)	Years covered
EPI (primary dataset)	83	1990–2013	68	1995–2013
OECD	31	1990–2011	NA	NA
UNSD	82	1990–2009	95	1990–2009
Pinsent-Masons	157	2011	157	2011
FAO	30	1962–2012	NA	NA
Combined datasets	183	1990–2013	183	1990–2013

manually calculated estimated values based on reported volumes of wastewater generated or collected in a country and the amount of wastewater treated.

The complete database of wastewater treatment data we compiled is available in Supplementary Materials.

2.4. Calculating the EPI indicator for wastewater treatment

We designed our indicator to assess national wastewater treatment percentage normalized by the population connected to municipal sewerage systems (i.e., ''wastewater treatment level'' multiplied by ''connection rate'' in calculations). We used our original database of compiled statistics from publicly available national data described above as the starting point, and then supplemented with data from the OECD (2013), the UN Statistics Division (2011), the *Pinsent Masons* Water Yearbook (2013); and finally the FAO Aquastat database (2013). For the connection rate data, we used a similar process, but in this case used UNSD as the baseline dataset due to its relatively complete country coverage at 95 countries. This was supplemented with data from *Pinsent Masons*, which has 157 countries in total in its 2013 dataset.

When we found conflicting values for the same country and year, we examined each such observation with supplemental desk research to determine whether preference should be given to one observation over the other. Decisions were made based on whether the statistics fit in with the trend or whether one data source was more timely and credible. If both conflicting observations were of equal merit, the two values were averaged. For example, in the case of Peru, we used the average of two values from the same source for the year 2000 (UNEP, 2002), one of which was the national total value of wastewater treatment (17%), while another source reported the urban treatment level (39%). Due to these conflicting values, we took the average of the two values (28%) for the year 2000. Steps were taken for conflicting data points on a case-by-case basis in this manner (see Supplementary Materials).

To address the challenge of inconsistent time series, we created decadal averages from available data from 2000 to 2013 to derive single summary values of wastewater treatment and connection rate. If there were no values available for a country for 2000 through 2013, we used an average of available values for 1990 through 2000 to represent the summary wastewater treatment or connection rate value of that country. As a final step, we multiplied the final wastewater treatment and connection rate values for each country to calculate determine the final indicator for the 2014 EPI. This final value was used to rank countries in the 2014 EPI.

3. Results

The discussion of results is divided into two parts: (1) an exploration with respect to data availability for assessing national wastewater treatment performance, and (2) an analysis of the wastewater treatment and connection rate data globally, regionally, and by income group.

3.1. General data availability

Patterns emerged in the scope of the type of data found. Wastewater data were often reported at the city or municipal level, limiting the study to predominantly urban areas. The metadata of the supplementary datasets (e.g., wastewater treatment variables in UNSD, 2011) and the footnotes of regional reports (e.g., UNEP, 2004) often indicated that city-level data were being used to represent an entire country.

There was also a lack of information given on the type of wastewater treatment (i.e., primary, secondary, tertiary treatment) occurring in a reference. For this reason we assumed ''at least primary treatment'' for all countries. An exception was OECD countries, for which information was disaggregated by stages of treatment (OECD, 2013).

The data were also sparsely reported though time, and it was not possible for us to develop a time-series but rather a single-year average based on the available data observations.

3.1.1. Variable definitions

We found a range of reported variable descriptions related to wastewater treatment and connection rates. By and large, most of the variables reported fell into two types: ''wastewater treatment percentage'' and ''population connection rate''. While there was inconsistency in reporting definitions (Fig. 2), the most commonly reported statistics were ''Treatment Level'' and ''Population Connection Rate''. For the purposes of this paper, we use the term ''Treatment Level'' to mean ''wastewater treatment percentage'' rather than primary, secondary, or tertiary treatment.

3.1.2. Availability of data by region, time, and source

We found inconsistency in reporting frequency across regions. Fig. 3 illustrates the global landscape of reporting ''recentness'', in which countries that lack wastewater treatment data after 2005, according to our survey, are highlighted. We could not find data after 2005 for 96 countries. Latin America and the Caribbean lacked the most recent data (82.2% of countries), followed by East Asia and the Pacific (70.5%), and Eastern Europe and Central Asia (64.7%). Europe reported the most recent data (only 31.7% of countries missing), although France, as an example of an exception, only had data from 2004 (OECD, 2013).

Finding values for both wastewater treatment and connection rate for sub-Saharan African countries was particularly challenging. Specifically, we had difficulty finding data for Botswana, Comoros, Djibouti, Equatorial Guinea, Guinea-Bissau, Mauritania, Tanzania, The Gambia, Somalia, and Zambia. In many of these cases, we used city-level data and data from the *Pinsent Masons Water Yearbook* (Pinsent Masons, 2013). In North Africa and the Middle East, we had difficulty verifying nationally reported data for Libya, Bahrain, Kuwait, Oman; values were taken from a combination of FAO (2013), UNSD (2011), and *Pinsent Masons* (2013).

Countries in Asia where we could not find statistics first-hand were Sri Lanka, Nepal, and Afghanistan. Data for small-island countries were difficult to locate, except those mentioned in the Pacific Water and Wastes Association (2012) report. We could not find data for Togo, Mauritius, São Tomé and Principe, Saint Kitts and Nevis, Saint Pierre, Saint Lucia, and the Turks and Caicos Islands. Many Latin American countries

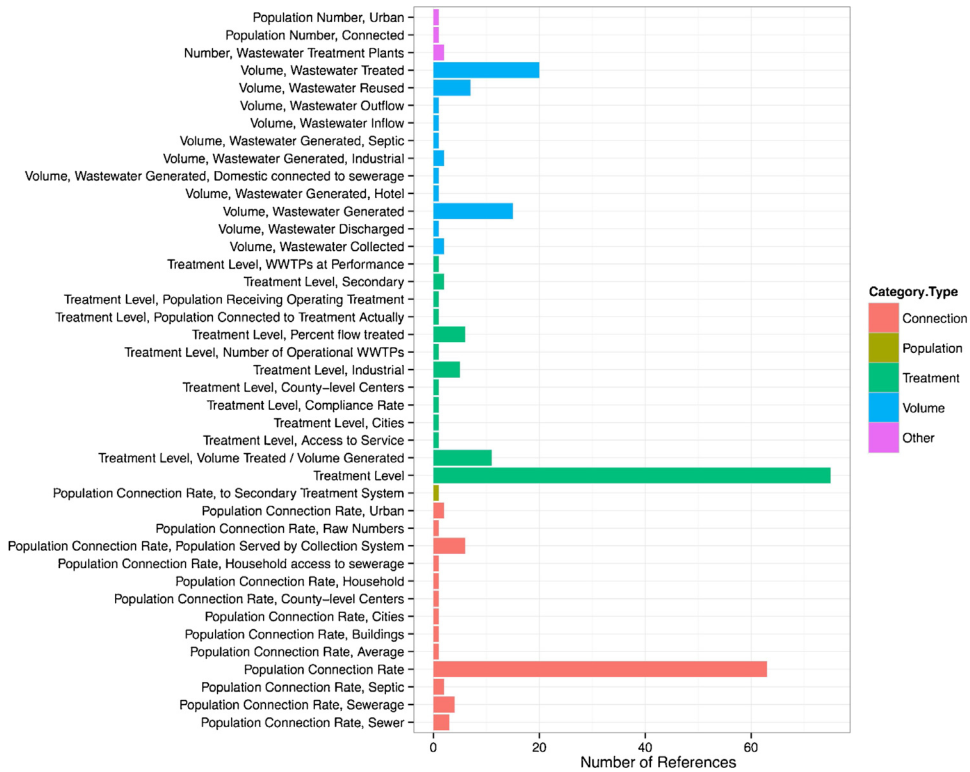

Fig. 2 – Availability of variables related to wastewater treatment levels and connection rates show most data points described treatment levels and the population connected to wastewater treatment.

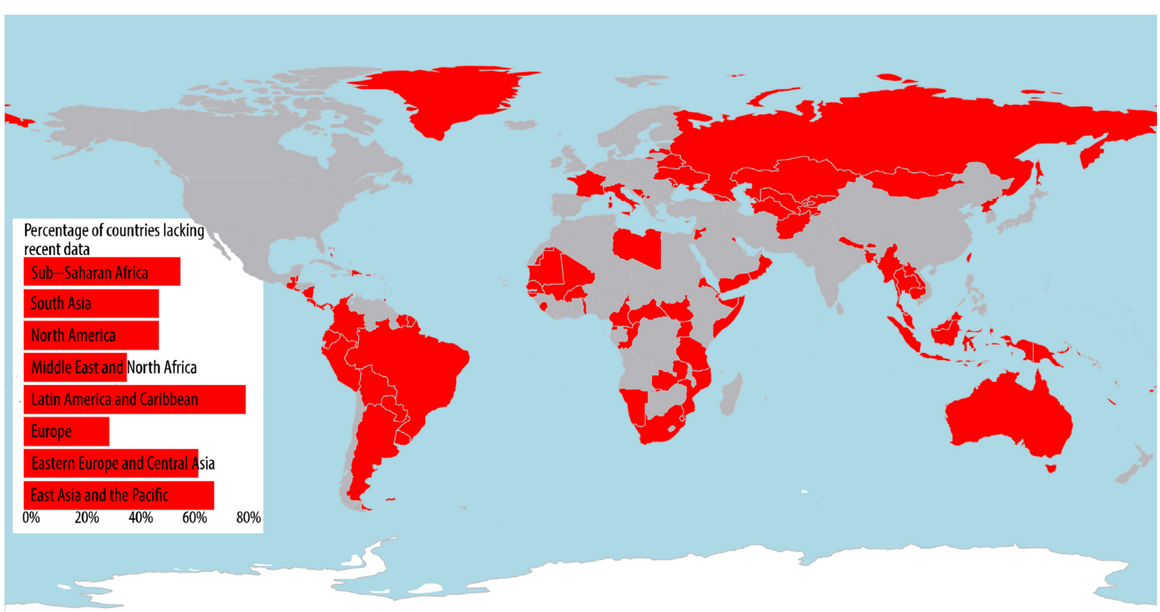

Fig. 3 – The availability of recently (defined as "after 2005") reported wastewater data lags the most in Latin America and the Caribbean region. Countries whose reported data (if available) was not recent (defined as "after 2005") are shaded in red, while countries whose data (if available) were recent are shaded in gray. An absence of reported data was gauged as "not recent" and "zero treatment" was counted as reported data. (For interpretation of the references to color in this text, the reader is referred to the web version of the article.)

tended to have data from the early 2000s, which are classified here as "non-recent (i.e., reported prior to 2005)". Most Latin American data were reported to UNSD (2011) or included in a report on stormwater management (UNEP, 2002).

Some OECD countries were missing reported data in the OECD (2013) database. For example, Australia's wastewater treatment data were missing from OECD (2013), which necessitated the use of its 2011 value from the *Pinsent Masons Water Yearbook* (2013). Virtually no information was available for Russia at the national scale, so we derived its wastewater treatment value from *Pinsent Masons* (2013).

3.1.3. *Compiled dataset results*

In the end, we found 106 observations for wastewater treatment, which resulted in wastewater treatment values for a final 83 countries (some of the 106 primary observations were duplicate values for a single country; see Section 2 for further details on how duplicate values were averaged). Supplementing our database with other datasets (i.e., OECD, 2013; UNSD, 2011; Pinsent Masons, 2013; FAO, 2013, respectively, in that order) subsequently added 100 more countries for a total of 183 countries (Table 1). Specifically, the OECD (2013) dataset added 26 countries, UNSD (2011) added 31, and *Pinsent Masons* (2013) added an additional 43. No data from FAO (2013) were supplemented to our compiled database.

For connection rate data, we derived 118 countries' values from UNSD (2011) and *Pinsent Masons* (2013). Our data search yielded new observations for an additional 68 countries, for a total of 183 values generated that matched the geographies of the wastewater level data-points.

3.2. *Analysis of results*

3.2.1. *Wastewater treatment performance – global snapshot*

In analyzing the wastewater treatment indicator (e.g., percentage of wastewater treated normalized by connection rate) developed for the 2014 EPI, we observe that wastewater treatment performance varies greatly by region (Fig. 4). Both the Northern and Southern hemispheres show heterogeneity of scores among countries, although patterns emerge at the regional level. The regions with the greatest average scores were Europe (66.14 ± 4.97), North America (50.32 ± 17.42), Middle East and North Africa (36.45 ± 6.33), East Asia and the Pacific (27.06 ± 6.91), Eastern Europe and Central Asia (18.34 ± 5.40), Latin America and the Caribbean (11.37 ± 2.51), Sub-Saharan Africa (3.96 ± 1.50), and South Asia (2.33 ± 1.34).

3.3. *Wastewater treatment performance by region*

The regions with the highest levels of treatment were Europe (79.19 ± 4.89), North America (68.10 ± 21.96), Middle East and North Africa (46.78 ± 6.79), East Asia and the Pacific (44.59 ± 8.57), Eastern Europe and Central Asia (26.96 ± 6.50), Latin America and the Caribbean (22.45 ± 3.19), Sub-Saharan Africa (12.57 ± 3.33), and South Asia (5.41 ± 3.88).

The regions with the greatest levels of connection rate were Europe (80.24 ± 3.10), Middle East and North Africa (65.08 ± 6.00), Eastern Europe and Central Asia (62.64 ± 4.03), North America (58.29 ± 18.99), Latin America and the Caribbean (42.41 ± 4.48), East Asia and the Pacific (41.45 ± 6.50), South Asia (28.23 ± 10.92), and Sub-Saharan Africa (13.97 ± 2.38).

In all cases for wastewater treatment as well as connection rate, Europe had the highest average values and Sub-Saharan Africa and South Asia had the lowest averages, meaning they were the lowest-performing regions. North America was the second-highest performer in treatment level following Europe, and performed better in treatment level than connection rate. In connection rate the Middle East and North Africa and Eastern Europe and Central Asia were the second and the third highest, respectively, outperforming

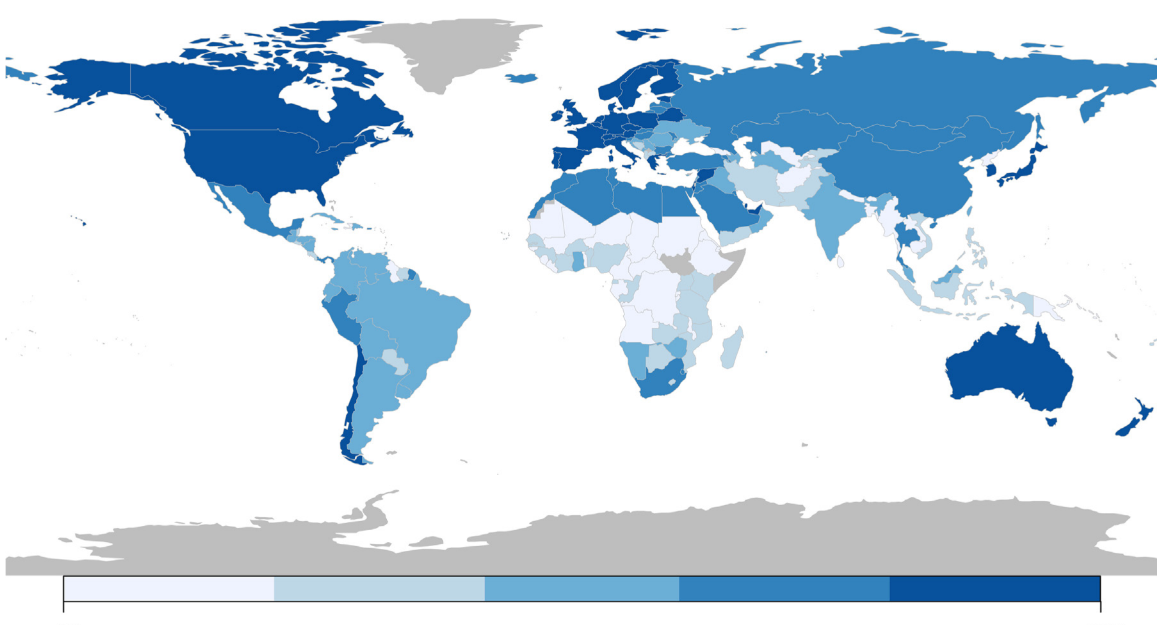

Fig. 4 – The level of wastewater treatment normalized by connection rate was used to calculate a proximity-to-target indicator for the 2014 EPI.

North America. In all cases, Middle East and North Africa performed better than East Asia and the Pacific, Eastern Europe and Central America, and Latin America and the Caribbean (Fig. 5).

3.4. *Wastewater treatment performance - by income group*

Performance also varied according to income group. Fig. 7 displays results for wastewater treatment ("treatment"), connection rate ("connection"), and the 2014 EPI wastewater treatment indicator ("indicator") aggregated by income group, according to World Bank (2013a,b) classifications (Low income: $1035 or less; lower middle income: $1036–$4085; upper middle income: $4086–$12,615; high income: $12,616 or more). The high-income group had the highest levels of average wastewater treatment and connection rate (75.6 ± 4.1% and 77.3 ± 3.2%, respectively). The upper-middle income group had higher average connection rates (40.9 ± 3.5%) than average wastewater treatment rates (24.5 ± 3.9%), a trend that was also consistent among lower-middle income countries, which had an average connection rate of 31.2 ± 4.3% and a wastewater treatment rate of 18.5 ± 4.1%. Low-income countries had the lowest performance overall in terms of the indicator used for the 2014 EPI – wastewater connection multiplied by connection rate – with an average of 0.85 ± 0.5% (Fig. 6).

3.5. *Correlation between wastewater treatment and connection rate*

A positive relationship exists between wastewater treatment and connection rate ($r^2 = 0.517$, Fig. 7). Countries with low connection rates tend to have low treatment levels. Notable outliers where there are high treatment levels and low connection rates include Thailand (THAI), Cape Verde (CPV), Palau (PLW), American Samoa (ASM). Other countries had high connection rates and low treatment levels, including Maldives (MDV), Colombia (COL), and Georgia (GEO).

4. Discussion

4.1. *Challenges*

We confronted several challenges in constructing a global dataset of country-level wastewater treatment. The greatest challenge was the variation in definitions for "wastewater treatment level", as a percentage, and "connection rate" across sources. A statistic of "wastewater treatment" could mean: (number of houses connected)/(number of houses in the city), (number of customers for utility)/(number of houses in the city), or (volume wastewater collected)/(volume wastewater produced). Clear definitions and disaggregated numerators and denominators for reported percentages would have

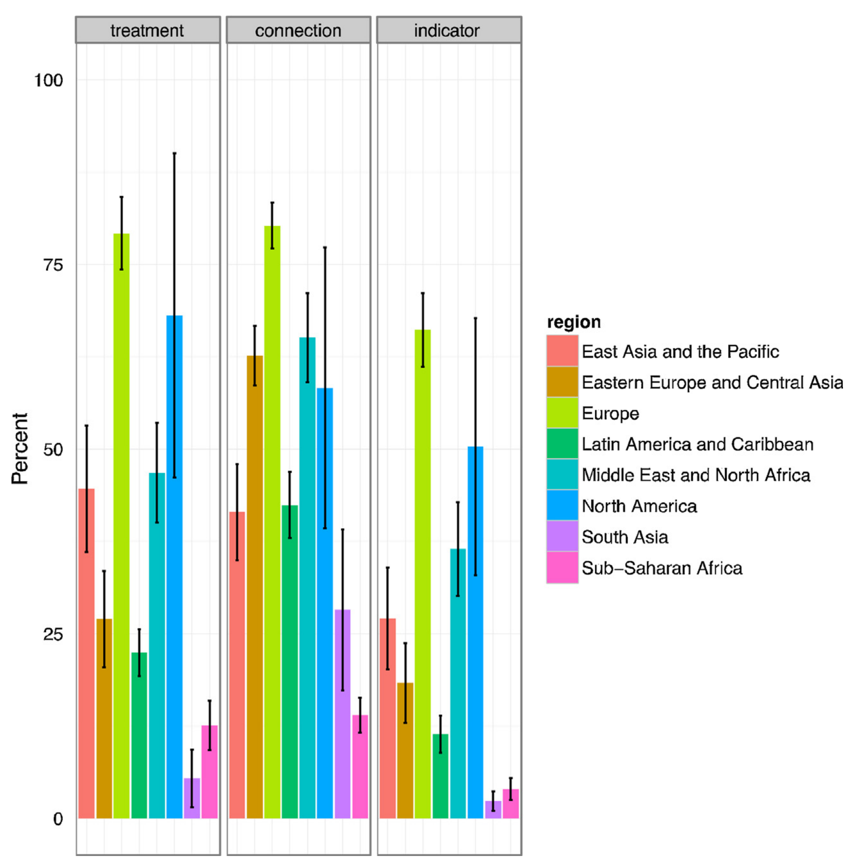

Fig. 5 – Average percentages of wastewater treatment and connection rate, by region, are higher in Europe than all other regions. Bars represent standard error.

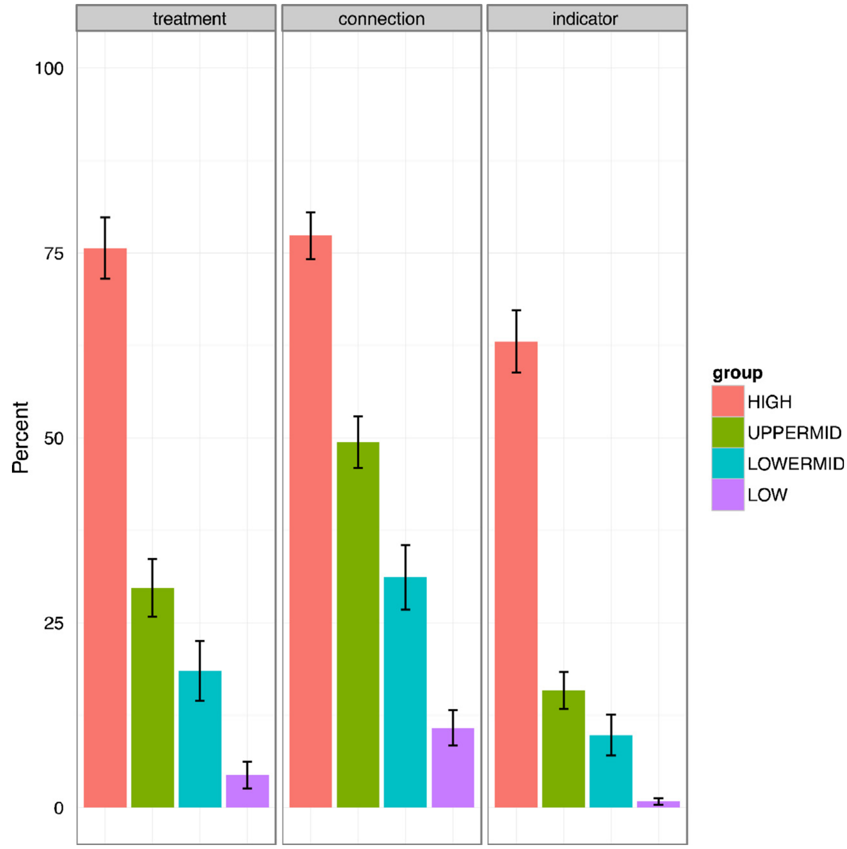

Fig. 6 – Wastewater treatment (treatment), connection rate (connection), and the EPI wastewater treatment indicator (indicator) vary by income group (GNI per capita). Low income: $1035 or less; lower middle income: $1036-$4085; upper middle income: $4086-$12,615; high income: $12,616 or more.

been useful in specifying amounts of wastewater collected and treated.

Further, many sources did not distinguish between sources of wastewater, whether industrial, municipal, or household waste. Reported statistics often included a combination of sources, so we assumed that reported statistics include all categories. Our methods were consistent with FAO's technique of combining several forms of waste into their "municipal wastewater treated" variable, which includes "domestic, commercial and industrial effluents, and storm water runoff, generated within urban areas" (Mateo-Sagasta and Salian, 2012). Assuming multiple sources of wastewater is also common among other practitioners of wastewater accounting (e.g., the Environmental-Economic Accounting for wastewater definitions (UNSD, 2011)). However, these assumptions of wastewater sources highlight the challenge and poor disaggregation of wastewater treatment data and its challenges.

Many sources also did not clarify whether the stage of treatment was primary, secondary, or tertiary, so again we were not able to classify data points or statistics in these terms. In the case of European countries, however, countries separately reported primary, secondary, and tertiary treatment. For example, Sweden reports to the OECD for the year 2010 that 0% of the population is "connected to wastewater treatment plant *without* treatment" [emphasis added], which is further broken down into: 0% receiving primary treatment, 4% receiving secondary treatment, and 83% receiving tertiary treatment. Almost all of Sweden's public treatment, therefore, is reported to be at the tertiary level (OECD, 2013). Ideally, other countries' statistics would include this level of detail to allow for more comparable analysis (e.g., primary treatment of one country versus primary treatment of another country).

In non-OECD cases, information on the stage of treatment was generally not available. We acknowledge that some statistics referring to advanced forms of treatment (e.g., secondary or tertiary) may have been reported in lieu of primary treatment. In some cases, a few countries that do conduct levels of wastewater treatment higher than primary may have received lower scores on the EPI indicator due to our definition of "at least primary treatment". However, it is acknowledged that reporting up to secondary treatment is adequate to reflect effective performance (EPA, 2004; Owen, 2013).

If countries were to report wastewater treatment disaggregated according to treatment stage, this would allow for the articulation of separate baselines and targets for each treatment stage. For countries that have achieved 100% or near complete levels of primary treatment, for example, separate targets could be established for secondary and

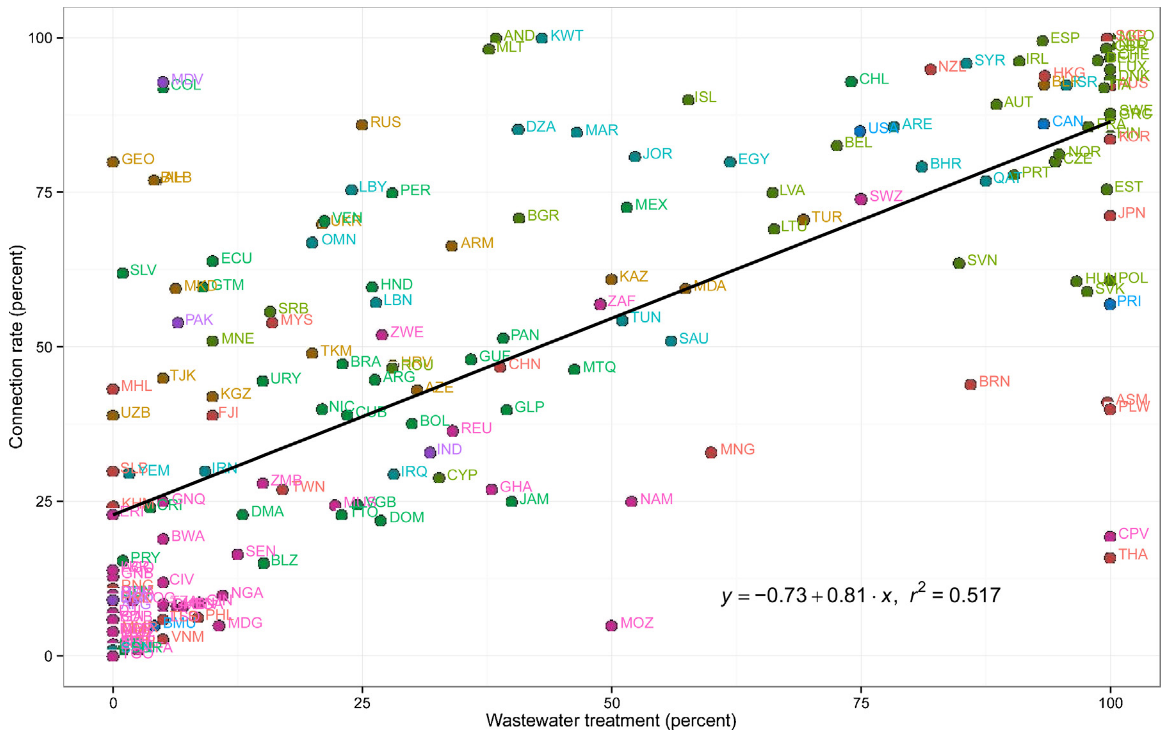

Fig. 7 – A significant positive relationship (r^2 = 0.517) is demonstrated between wastewater treatment (percent) and connection rate (percent) for the country data compiled in this study.

tertiary treatment. Specifying aspirational targets is especially important because further stages of treatment are more likely to remove phosphorous and nitrogen, which can cause ecosystem effects such as algal blooms and other toxic poisoning of ecosystems (Van Drecht et al., 2009).

In our database, we were unable to differentiate between generated wastewater and collected wastewater. Generated wastewater refers to the "volume of domestic, commercial and industrial effluents, and storm water runoff, generated within urban areas", according to FAO (Mateo-Sagasta and Salian, 2012). Meanwhile, collected wastewater refers to wastewater "collected by municipal wastewater sewers or other formal collection systems", which may include both wastewater that is "independently" managed, such as in pit latrines or septic tanks, that which is trucked to wastewater treatment plants (WWTPs), and that which is "collectively" managed through "planned municipal sewer systems" (FAO, 2013). Wastewater treated outside of the WWTPs, such as those being treated via a septic system, could then still count as receiving treatment in the broad term of the definition. However, because it is not possible to tease out which portion of municipal wastewater is from non-urban, non-sewerage sources, it is not possible to disaggregate the indicator into urban and rural percentages. We also found that in many more cases it was easier to find values for wastewater generated than wastewater collected, as demonstrated in Fig. 2. This finding is consistent with the FAO's datasets having more observations for "wastewater generated" than "wastewater collected". There are 199 observations for "generated", and 65 observations for "collected" (FAO, 2013).

Analysis of non-centralized wastewater treatment, such as septic systems in rural areas, might help to explain why North America, for instance, performed worse on connection rate than Middle East and North Africa, and Eastern Europe and Central Asia. In 2007, 20% of houses in the United States used septic systems, and 97% of those houses were outside of urban areas (US EPA, 2008). There has been a preference for decentralized systems in different periods of history in the United States (Burrian et al., 2000). Meanwhile, in arid regions of the Middle East and North Africa, wastewater is regarded as a useful resource, framing how both high-income and developing economies plan infrastructure (Qadir et al., 2009). In recent decades, centralized wastewater treatment systems have been the preferred choice of city-planners in the region (Bakir, 2001). The heterogeneity of Eastern Europe and Central Asia makes general assessments difficult, although countries attempting to join the European Union are required to direct efforts toward wastewater infrastructure as part of their accession agreements (Kundzewicz, 2001). Clearly, regions have different impetuses for their choice in waste management options. However, the difficulty of finding empirical data on decentralized systems for most countries makes urban-versus-rural performance assessments into estimations at best (Baum et al., 2013).

There is also a need to harmonize variable definitions. Reported statistics had to be parsed to determine whether they referred to populations served or volumes of water treated in order to convert them into wastewater treatment percentage values (Fig. 3). For instance, UNSD (2011) makes the distinction between population connected to sewerage system and population connected to wastewater treatment, and we interpreted the population connected to wastewater treatment to mean a value for treatment percentage for WWTPs. Similarly, the OECD (2013) database presents values separately for connection wastewater-treatment equipment and for the overall percentage of residents receiving or not receiving treatment services. In other cases, volumes were used to represent actual performance when compared to the volume of wastewater treated versus generated in a country for a particular year or range of years. We found data reported according to such volumes for a number of countries in the Middle East for which we managed to calculate values (see Supplementary Materials). In the unique case of South Africa, the definition of wastewater treatment was based on the "number of wastewater treatment plants at operational capacity" as defined by the Department of Water Affairs and Forestry in an internal government review (Snyman et al., 2006).

Because of these challenges, the database we compiled represents a crude estimation of wastewater treatment globally. The gaps identified in this paper point to the need for a global custodian to clearly specify definitions, protocols, and reporting mechanisms to make wastewater treatment data consistent. The World Health Organization (WHO) and UNICEF's Joint Monitoring Programme (JMP) is charged with the task of ensuring reliable collection of global, regional and national data on access to safe drinking water and basic sanitation as part of the MDGs. Similarly, an agency or institutions tasked with the goal to build capacity and interact with governments to ensure high-quality data collection on wastewater treatment will be needed if the SDG on water is to be successful and credible.

4.2. *Toward an ideal indicator*

Given the challenges in variable definitions and data gaps, we suggest an ideal measure of wastewater treatment performance to be defined as the weighted average of volumes of wastewater treated at all utilities in a country, normalized by the population served by a given utility. Measured at the site of the wastewater treatment plant, the underlying data for such variables would be the most direct measurement to approximate the pollution pressures of untreated wastewater on human health and freshwater ecosystems. This utility-level information can then be normalized and aggregated to the country level to compare national performance. The equation for this ideal indicator is illustrated in Box 2. Here it is assumed the volume of wastewater collected at the treatment plant equals the volume of wastewater generated in the municipality for the population connected to the system. It is also assumed that: (%wastewater treated) = (1 − (%wastewater not treated)). We assume that water that is not treated is discharged into the ecosystem as pollution.

UNEP (2004) attempted to approximate such an indicator in the early 2000s to be used in regional seas pollution reduction goals, but this failed due to data gaps. The OECD (2013) variable used in this study, "Connected to a wastewater treatment plant without treatment", includes a definition that most closely approximates the amount of untreated wastewater at the utility level, thus making it the best existing statistic out of those surveyed in this study.

A further idealized indicator would also include separate targets for primary, secondary, and tertiary treatment. Targets for wastewater reuse and recycling, noted as volumes out of the volume of treated wastewater, are also critical considerations. As water becomes a scarcer resource globally, wastewater reuse and recycling will inevitably become a more important way of framing the wastewater management issue (Salian, 2012). Cities in water-scarce regions, such as Windhoek, Namibia, have incorporated reuse into their water infrastructure (Lahnsteiner and Lempert, 2007). In the United States, the state of California has a Water Reuse Policy for promoting a sustainable water supply (Sato et al., 2013). The use of indicators has been integrated in wider management systems as well. In China, for instance, the government makes use of a "recycling rate of municipal wastewater" indicator for cities and provinces, and also has an "industrial wastewater recycling ratio" metric for industrial parks. These metrics are part of the national Circular Economy Evaluation Indicator System, which is part of a broader policy effort to steer toward a circular economy (Geng et al., 2011). Not all parts of the country are water scarce, however, and so the applicability of such indicators is useful to pollution control writ large and could gain traction in other countries.

4.3. *Recommendations for the post-2015 Development Agenda*

The post-2015 Development Agenda should include specific targets for wastewater and water quality as part of a proposed goal on water. This indicator should take into account the factors of both wastewater treatment and sewerage connection rates, in some measure, in order to gain a complete picture of global wastewater performance.

One major potential outcome of such a benchmarking process will be to ensure consistency of reporting for definitions of "treatment". As this study demonstrates, existing definitions of wastewater have been developed on an ad-hoc basis, and the attempts at quantifying the available

Box 2. Recommended ideal indicator of wastewater treatment

$$\text{Percent treated}_{\text{countyry}} = \frac{\sum_{i=1}^{n}(\text{volume treated in plant}_i/\text{volume collected by plant}_i) \times \text{population served by plant}_i}{\sum_{i=1}^{n}\text{percentage of population served by plant}_i}$$

An ideal indicator would represent the weighted average of volumes of wastewater treated at all utilities in a country, normalized by the population served by a given utility.

data to set targets (e.g., UNEP, 2004) have likewise been ad hoc. Establishing requirements within the SDG process for better data collection and reporting will reduce variation in wastewater treatment definitions, making data (Fig. 2) globally comparable. In this way, agreed-upon reporting of definitions, metrics, and best practices can be established between countries.

One proposed set of water targets could include: ensuring that a target amount of wastewater gets treated for an urban population; aiming to increase water reuse rates and safe disposal rates and ensuring that a target number of water bodies are in compliance with water quality standards. Each of these targets would require specific indicators. The SDGs and national governments policies should also include an incentive for municipal utilities to report their indicator efforts to national offices so that aggregations can occur at the country level. For example, Brazil may have recent data from WWTPs for large cities that are more up to date than the country-level statistics reported to the last update of the UNSD (2011) dataset, which only includes data from 2006. An incentive to share that data could make it more useful to the international development community.

Although there are still gaps in data available to assess water quality, the 2014 EPI's indicator of wastewater treatment is an effort to link present reporting capacities with future policy desires. It provides a rough baseline of where countries stand on an end-goal to which countries can aspire. Already, the dataset and resulting wastewater treatment indicator is being used to inform policy and point to gaps and future measurement needs. The United Nations Environment Programme (UNEP) is using the dataset and indicator of this study in the Rivers Assessment component of the indicator-based Transboundary Water Assessment Programme, (UNEP, in press, 2015). The experience of the WHO-UNICEF JMP efforts to harmonize data collection on clean drinking water and sanitation access is a clear example of how progress can be made with a specified data guardian and clear targets. However, while much progress has been made to improve access to sanitation and drinking water worldwide, there are still millions of individuals that lack access to clean water and sanitation (UNGA RES/64/292). It is important to raise the bar for measurements of well-being.

5. Conclusion

This paper evaluated the global availability of national statistics on wastewater treatment to create an indicator of environmental performance and to inform the Sustainable Development Goals (SDGs). In the end, we compiled wastewater treatment statistics for 183 countries and constructed a first-of-its-kind indicator of wastewater treatment normalized by sewerage connection rates. Although reporting definitions are inconsistent between countries, we preliminarily assessed wastewater performance trends that vary globally, regionally, and by income. Overall, there is room for improvement for all regions and countries. We found that the lack of consistent definitions, reporting protocols, and a central custodian for wastewater treatment data are reasons for many challenges confronted in constructing comparable performance measures. We suggest a standardized definition of wastewater treatment aimed at the utility level, which could be normalized and aggregated to reflect national performance. At minimum, UN negotiators for the SDGs must consider these issues if countries are to be successful in managing wastewater and ultimately, water quality.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2015.01.005.

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