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Convergence Analysis of the Sanitation Index for 158 Countries

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Abstract

Since 1990, 2.1 billion people in the world gained access to improved sanitation by 2015. However, 2.4 billion people still did not use a basic toilet. We examined whether the country differences in the sanitation index existing in 1990 had narrowed. We deployed convergence methodology to answer the questions for 158 countries. Results of our analysis indicate that the sanitation indexes for 158 countries were converging toward a rapid reduction of dispersion and a moderate catch-up. The speed of dispersion reduction was led by the upper middle income group, together with the South Asia region. The speed of catch-up was led by the low income group and the Sub-Saharan African region.

The policy implication from this study is that individual countries should be guided by the speeds of catch-up and dispersion reduction estimated from the appropriate subgroup where they belong for evaluating their future progress.

1 Introduction

Access to improved sanitation has been recognized as a vital issue to health, growth, and well-being of all people throughout the world (Van Minh and Hung, 2011; Whittington, 2015; Osei, et al., 2015; United Nations Children's Fund and World Health Organization, 2015; Hutton and Chase, 2016, 2017; Abubakar, 2017; Garn, et al., 2017; Armah, et al., 2018). More recently, access to sanitation is viewed as one of the critical human rights issues. (Obani, 2018; UNICEF, 2016).

In response, the United Nations (UN) in its Millennium Development Goals (MDGS) called for halving the global proportion of the population without sustainable access to basic sanitation between 1990 and 2015 (UN, 2008). Since sanitation index measures the proportion of the people using improved sanitation facilities, this meant that the 2015 goal of sanitation index was established at 77 percent of global population from 54 percent which existed in 1990.

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Extending the works of MDG, the United Nations have established even more ambitious Sustainable Development Goals (SDGs) (UN,2017). SDG 6.2 aims to achieve by 2030, access to adequate and equitable sanitation and hygiene for all, and end open defecation, paying special attention to the needs of women and girls. The actual global sanitation index improved by 14 percentage to 68 percent by 2015 missing the MDP target by 9 percentage and about 700 million people. Therefore, 2.4 billion people still do not use a basic toilet lacking access to improved sanitation.

In addition, large disparities in access by regions and countries still exist. For example, developed regions with 1.27 billion people in 2015 showed the highest sanitation index of 96 percent, while developing regions with 6 billion people recorded a lower index of 62 percent. Least developing regions with 940 million people showed a much lower sanitation index of 38 percent in 2015 from the 1990 index of only 20 percent (WHO-UNICEF, 2015).

Disparities in access were even greater among individual countries. For example, there were 17 countries who achieved a complete access for all their people with the sanitation index or 100 percent in 2015. At the lowest access group, there were 7 countries whose 2015 sanitation index ranged from 11 percent to 19 percent with an averaged ratio of only 14.1 percent (WHO-UNICEF, 2015).

These examples clearly demonstrate that sanitation gap is real and wide dividing the regions and countries with high sanitation index from very low sanitation index. Whenever, such a wide sanitation gap exists, narrowing the dispersion of country differences for sanitation index may become as important as that of improving the mean value of sanitation ratio for the whole group of countries. In fact, narrowing the dispersion of country differences is required in order to meet the SDG Goal 6.2 in which access to adequate sanitation is mandated for all, meaning people in all countries and in all regions.

When an increase in the mean value of sanitation ratio for a group of countries is being evaluated together with changing dispersion of country differences of sanitation ratio, three different results can occur. First, an increase in the mean value of outcomes can be accompanied with a decreasing dispersion. Second, an increase in the mean value may bring about a constant dispersion. Third, an increase in the mean value may be accompanied by an increasing dispersion.

The first type of outcome would be viewed as most desirable because reduction of dispersion indicates that country differences of sanitation service have been narrowed. At the same time, the average sanitation service level for all countries in the group has also improved. The second type of result would be viewed as less desirable than the first type, but by more desirable than the third type of outcome.

The third type of outcome would be viewed as least desirable because an increase of dispersion indicates that country differences of sanitation service have been widened even though the average sanitation service for the group has improved. In this case, some countries with lower sanitation service may not have participated in the overall improving trend, thus contributing toward widening differences between those countries with higher versus lower level of sanitation service. On the other hand, improvement of sanitation may have occurred more among countries with higher sanitation ratio.

In fact, there can be a variety of improvement patterns of sanitation displaying different degree of trade-offs between mean value and dispersion of country differences. Thus, the use of convergence analysis is quite useful in analyzing the dispersion pattern of country differences of sanitation.

By the use of convergence analysis, this paper attempts to examine two basic questions related to country differences of sanitation index: First, do countries with initially poor sanitation index improve faster than countries with superior sanitation measures to catch-up and how rapid is the speed of catch-up. Second, does spread of sanitation index of multiple countries decrease over time and how fast is the reduction of dispersion? We will examine these questions for all 158 countries with complete record of sanitation index during 1990 to 2015. In addition, we will examine the same questions in the context of subgroups of countries defined by income levels as well as by regional category.

To our best knowledge, such a comprehensive convergence analysis of global sanitation index involving multiple countries has not yet been published. Thus, this article may represent a now contribution in the literature.

After this introduction, the paper is structured in the following four additional sections. A simple modified convergence method to measure the speed of catch-up and dispersion reduction will be explained in the second section. The third section explains sanitation index structure and data sources that we used.

Analysis of results will be presented next in the fourth section. Finally, the fifth section summarizes the key findings and discusses relevant policy implications and limitations of this research.

2 Convergence methodology

The convergence analysis attempts to examine two basis questions. First, do countries initially lagging in such performance measures sanitation index tend to improve faster so that they catch-up to the performance of leading countries over time? Second, does dispersion of sanitation index among countries get reduced over time?

Traditionally, β convergence is used to examine the first question, while σ convergence is used to analyze the second question. The so-called Barro β convergence method (Barro, 1991) regress the rate of improvement during a period on the initial value of the performance measure for respective countries. If the value of coefficient of slope is negative and statistically significant, then the catch-up process is demonstrated (Barro, 1991; Barro and Sala-i-Martin, 1992).

When the regression includes only the initial value as independent variable, it models "unconditional" or "absolute" β convergence in which all countries are assumed to move toward a common destination. Since such a restrictive assumption is rarely satisfied in practice, the resulting estimate may contain a significant bias. For that reason, the regression often includes multiple variables relating to the characteristics of countries such as productivity, quality of education, etc. Then, it represents a model of "conditional" β convergence or club convergence.

The use of "Barro regression" for both unconditional and conditional β convergence was criticized to yield biased estimates (Friedman, 1992) due to Galton Fallacy relating to the tendency of regression to mean. Instead, Friedman (1992) suggests that β convergence can be more appropriately measured by tracking the inter-temporal change in the coefficient of variations of the distribution of performance measures for given countries. This method is known as σ convergence. If the trend is statistically significant and declining, σ convergence is confirmed. In addition, σ convergence method is simple to use.

Another criticism of β convergence (Quah, 1996) is that the method does not provide us with the inter-temporal intra-distribution mobility of countries with respect to performance measures. Therefore, Quah (1993) suggests a method which is capable of capturing the full dynamics of evolving cross-country distribution using Markov Chain analysis. A simple approximation to Quah's methodology was proposed by Boyle and McCarthy (1997) where they use Kendall's index of rank concordance (Siegel, 1956) to measure changes in the ordinal ranking of countries over time. They label their method as γ convergence. By using γ convergence with simple measure of σ convergence, they suggest that one can identify the nature of β convergence and also a sense of the dynamics of the cross-country distribution of performance measures.

Since then, a large number of studies using γ convergence methodology have been published in such areas as energy, economic growth, inflation, employment, and healthcare (Agovino and Rapposelli, 2017; Bhattacharya et al., 2018; Carrasco and Ferreiro, 2014; Ferrara and Nistico, 2015; Huang et al., 2018; Jaunky and Zhang, 2016; Kallioras and Tsiapa, 2015; Yu and Zhang, 2015; Zumaquero and Rivero, 2016).

For our methodology, we use γ convergence (Boyle and McCarthy, 1997) and σ convergence (Friedman, 1992). Common measures of dispersion include the standard deviation and coefficient of variation (Heckelman, 2015). For σ convergence, we have selected to use coefficient of variation (CV). CV is measured by dividing standard deviation by the sample average. Using CV which is dimensionless ratio enables us to compare the degree of dispersion for performance measures with different units. We then measure the inter-temporal changes by normalizing CV in subsequent years to CV at the initial year of 1990. Therefore, CV in 1990 is always 1.0. If the values of normalized CVs in the subsequent years are less than the CV in the initial year, then, the normalized CV in subsequent years will be less than 1.0. If the values of normalized CVs in the subsequent years continue to decrease, and the differences between CVs are statistically significant, the result is viewed as evidence of σ convergence or reduction of dispersion. We use two sample t test for CV (http://www.real- statistics.com/students-t-distribution/coefficient-of-variation-testing/). This test works best when the sample sizes are at least 10. Sime our sample sizes are much larger than 10, this test should work well.

For γ convergence model, Boyle and McCarthy (1997) suggested the use of Kendall's index of rank concordance which measures mobility of the individual countries over time within the cross country distribution of a particular performance measure (Liddle, 2012; Chang et al., 2019). In other words, γ convergence measures the degree of changing ranking order of countries between a given year and the initial year. The γ- convergence we use is Kendall's binary index version and is defined as follows:

$$\gamma_t = \left[\frac{var\ (AR\ (Y)_{it} + AR\ (Y)_{io})}{var\ (2 * AR\ (Y)_{io})}\right] \tag{1}$$

Where, *AR* (*Y*) = the actual rank of country i's performance measure in year t
AR (0) = the actual rank of country I's performance measure in year 0
γ_t = Binary Gamma Index in year t

The γ index has the advantage of being of single number traced over time in two- dimension, analogous to the σ convergence index. The value of rank concordance ranges from zero to unity. If no change in rank order takes place, the rank concordance becomes unity. If a catch-up process is present, which result in change of rank order the index will be less than unity. The statistic is distributed as chi-square and we test the null hypothesis that γ convergence shows no difference between ranks of different years (Siegel, 1956).

According to Real Statistics Using Excel (http://www.real-statistics.com/reliability/kendalls-w/), the proper use of X^2 test to test statistical difference between Kendall's coefficients of concordance (W) on yearly γ indexes requires that the number of countries involved should be equal to 5 or more. Or the number of years being compared should be more than 15 years. In our case, the number of countries involved will be much larger than 5 countries. Therefore, we can use this X^2 test to validate the null hypothesis that W=0 or that there is no agreement between the years being compared.

How do we use σ and γ index together to evaluate reduction of dispersion as well as catch-up process? There are four different cases that can occur. The simplest case is when both σ and γ index are increasing in values. Under the circumstance, neither reduction of dispersion nor catch-up may be taking place. The second case is that both σ and γ indexes are decreasing which indicates that both reduction of dispersion and catch-up process are taking place. The third case occurs where σ convergence measure is constant, while γ convergence value is in decline. Since β convergence is a necessary but not sufficient condition for σ convergence, this indicates that catch-up process is taking place, while reduction of dispersion is not. The fourth case occurs where γ index is constant while a substantial decline occurred with σ index. This indicates that country differences in performance measures remain so that no rank change among countries takes place. However, performance differences among countries have reduced considerably, which indicates conditional β convergence. Put it another way, catch-up process may be taking place within subgroups of countries.

3 Data & data sources

Improved sanitation facilities for a given country are measured as % of population with access to improved sanitation facilities which refers to the percentage of the population actually using improved sanitation facilities. Improved sanitation fatalities are likely to ensure hygienic separation of human excretes from human contact. The data source is WHO / UNICEF Joint Monitoring Program (JMP) for water supply and sanitation (wasinfo.org). We downloaded yearly data from 1990 to 2015 from the World Bank's World Development indicators (https://data.worldbank.org/indicator/SH.STA.ACSN)

From the initial list of 264 Countries, we have selected 158 Countries with complete yearly data for our analysis. The total group of 158 Countries is divided into 4 Subgroups of high, upper middle, lower middle, and low income following the World Bank Categorization of gross national income per capita, calculated using the World Bank Altas method.

And then, the total group is divided into six subgroups of East Asia and Pacific (EAP), Europe, Central Asia and North America (ECA&NA), Latin America and Caribbean (LAC), Middle East North Africa (MENA), South Asia (SA), and Sub- Saharan African (SSA) regions following the World Bank's seven regional classifications. We merged North American region to Europe and Central Asia region because only 3 countries were included in the North America.

4 Analysis of results

The sanitation ratio for the total group of 158 countries has improved from 66.75% in 1990 to 75.99% in 2015 at the compounded annual growth rate (CAGR) of 0.52% as shown in Table 1. The high income subgroup of 58 countries shows the lowest CAGR of 0.07% due to the high initial sanitation ratio of 95.74% in 1990 which has improved further to 97.39% by 2015. The low income group of 23 Countries has the highest CAGR of 2.16% which has increased the 1990 sanitation ratio of 15.69% to 26.75% by 2015. The low middle income group of 34 Countries shows the second highest CAGR of 1.27%, whereas the upper middle income group of 43 Countries has the CAGR of 0.65%. The 2015 sanitation ratios are 85.03% for the upper middle income group and 61.33% for the low middle income group. Figure 1 display continuous improvement patterns for each and all 5 groups of nations.

Table 1 Averaged sanitation ratios for total and four subgroups of countries (1990~2015)

Sanitation Ratio	Total (158)	High (58)	Upper Middle (43)	Lower Middle (34)	Low (23)
1990	66.75	95.74	72.32	44.78	15.69
1991	67.08	95.81	72.87	45.27	16.04
1992	67.40	95.88	73.40	45.75	16.40
1993	67.77	95.96	73.93	46.39	16.78
1994	68.16	96.02	74.51	47.11	17.16
1995	68.59	96.11	75.15	47.85	17.58
1996	69.01	96.19	75.77	48.59	18.00
1997	69.44	96.27	76.40	49.34	18.50
1998	69.86	96.34	77.00	50.07	18.96
1999	70.28	96.42	77.61	50.81	19.42
2000	70.70	96.51	78.21	51.56	19.91
2001	71.12	96.58	78.81	52.30	20.38
2002	71.54	96.66	79.41	53.04	20.85
2003	71.96	96.74	80.01	53.77	21.33
2004	72.38	96.82	80.58	54.52	21.80
2005	72.79	96.90	81.14	55.25	22.28
2006	73.18	96.98	81.65	55.98	22.75
2007	73.56	97.04	82.15	56.71	23.22
2008	73.94	97.11	82.62	57.42	23.70
2009	74.30	97.17	83.09	58.10	24.17
2010	74.66	97.22	83.55	58.77	24.64
2011	75.00	97.27	83.98	59.41	25.12
2012	75.33	97.32	84.33	60.09	25.58
2013	75.62	97.35	84.67	60.63	26.03
2014	75.84	97.37	84.89	61.06	26.46
2015	75.99	97.39	85.03	61.33	26.78
CAGR (%)	0.52%	0.07%	0.65%	1.27%	2.16%

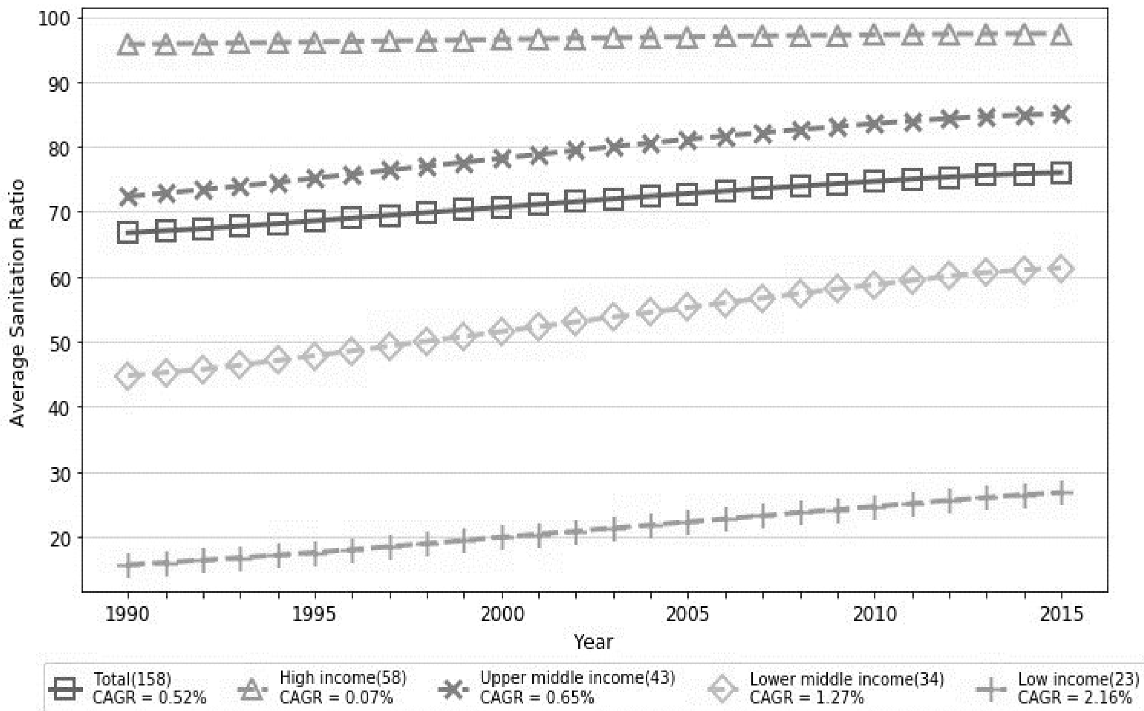

Fig. 1 Averaged Sanitation Indexes for Total and Four Subgroups of Countries (1990~2015)

Next, historical normalized yearly σ and γ indexes for the total group of 158 countries are listed in Table 2 and displayed in Figure 2. Both σ and γ indexes display declining patterns during the period of 1990-2015 indicating that convergence of sanitation indexes has taken place. However, the rates of decline between the two indexes are very different.

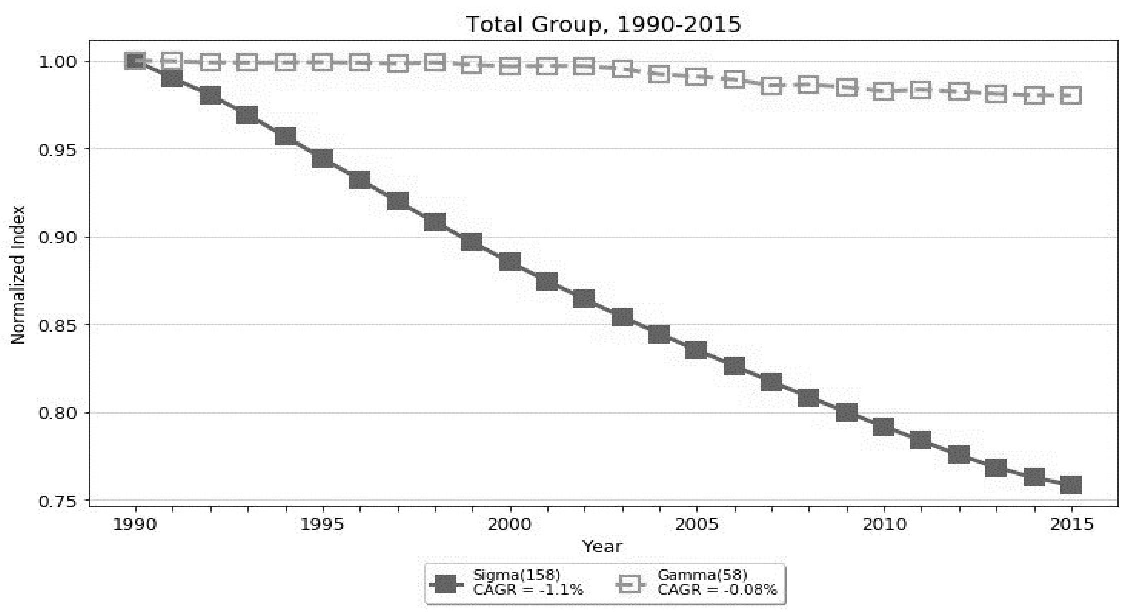

Fig. 2 Normalized Sigma and Gamma Sanitation Indexes for Total Group of 158 Countries (1990-2015)

Table 2 Normalized Sigma and Gamma Sanitation Indexes of Total Group of 158 Countries (1990-2015)

	All Countries (158)	
Year	Sigma	Gamma
1990	1.0000	1.0000
1991	0.9901	0.9997***

1992	0.9806	0.9990***
1993	0.9693	0.9988***
1994	0.9568	0.9989***
1995	0.9444	0.9991***
1996	0.9324	0.9988***
1997	0.9199	0.9988***
1998	0.9082	0.9989***
1999	0.8966	0.9977***
2000	0.8855	0.9968***
2001	0.8747	0.9971***
2002	0.8643	0.9970***
2003	0.8543*	0.9954***
2004	0.8446*	0.9922***
2005	0.8354*	0.9910***
2006	0.8263**	0.9892***
2007	0.8175**	0.9859***
2008	0.8086**	0.9864***
2009	0.8001**	0.9848***
2010	0.7918**	0.9827***
2011	0.7838***	0.9835***
2012	0.7757***	0.9824***
2013	0.7686***	0.9812***
2014	0.7628***	0.9804***
2015	0.7586***	0.9802***
CAGR(%)	-1.10%	-0.08%

*** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level

The rate of decline for γ index is moderate at the CAGR of -0.08%. The yearly γ index remained near 1.0 from 1990 through 2004 when its index was still 0.991. And then, from 2005 on, its index begins its decline to reach 0.9802 by 2015. However, differences of γ indexes between respective years to the beginning year of 1990 measured in X^2 test are statistically significant for every year at less than 0.1% level, as shown in Table 2.

The rate of decline for σ index during the period is about 13.7 times faster than that of γ index at the CAGR of -1.1%. Difference tests of C.V. between each following year to the beginning year of 1990 shows that statistically significant differences began to emerge from 2003 through 2015. Unlike γ index, the declining pattern of σ index is continuously smooth throughout the period, as shown in Figure 2. In short, there have been continuously rapid reduction of dispersion of sanitation measures among countries and a very moderate effects of lagging countries trying to catch up to the leading countries in sanitation indexes.

Next, the total group of 158 countries is divided into four subgroups of high, upper middle, lower middle, and low income and the results are listed again in Table 3 and displayed in Figures 3 and 4. As for σ indexes, the most rapid rate of reduction has occurred in the upper middle income subgroup with the CAGR of -2.02% which is nearly twice the rate for the total group. And then, lower middle and low income subgroups show more moderate declining rates of -1.45% and -1.42% respectively. The high income subgroup shows even more moderate rate of -1.27%. Difference tests of C.V. are statistically significant for more recent years such as 2009 or 2005 in cases of high, upper middle, and lower middle subgroups, but not in the case of low income subgroup. The declining patterns for these four income subgroups show, in general, continuously, smooth reduction, as shown in Figure 3.

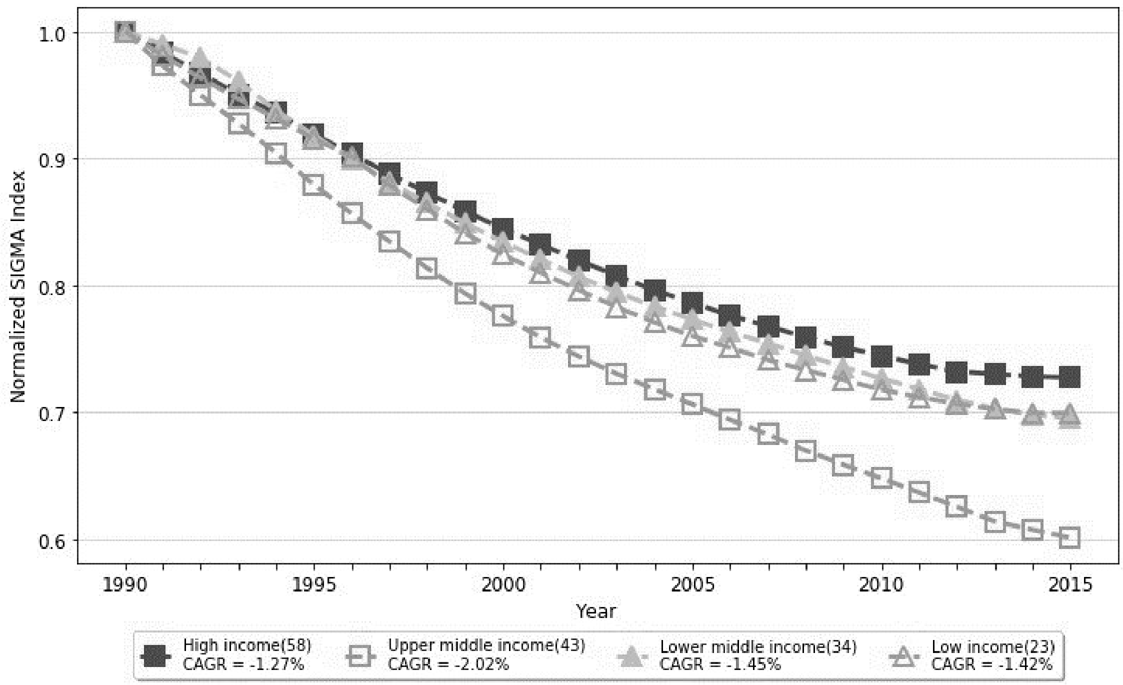

Fig. 3 Normalized Sigma Sanitation Indexes for Four Income Subgroups (1990-2015)

As for γ indexes, the variation of reduction rates among the 4 income subgroups is somewhat greater than σ indexes. The most rapid reduction is observed for the low income subgroups with its CAGR of -0.93%, which is about 11.6 times faster than that for the total group. In contrast, the upper middle and low middle income subgroups show the declining rate of -0.68% and -0.37% respectively. The high income subgroup shows the lowest declining rate at the CAGR of -0.17%.

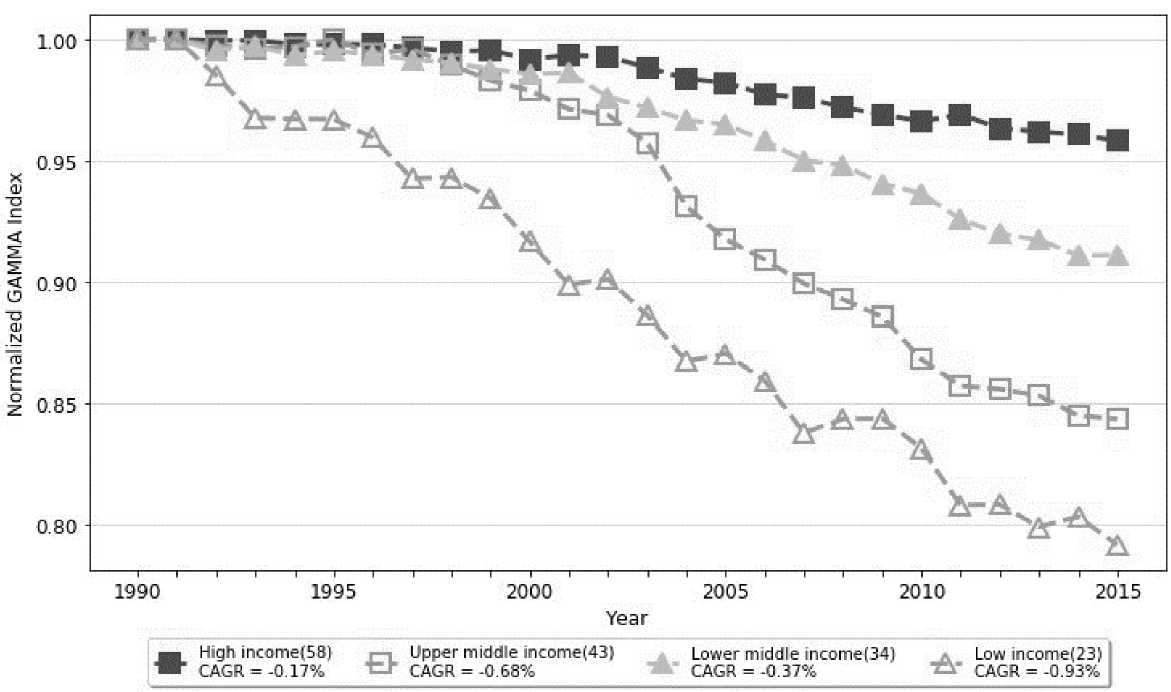

Fig. 4 Normalized Gamma Sanitation Indexes for Four Income Subgroups (1990-2015)

As for the γ convergence pattern, only the high income subgroup displays a similar pattern to that of the total group. Namely, very little reduction of γ index took place until about 2004 in high income subgroup. And then, a moderate decline has taken place through 2015. The other subgroups of upper middle, and lower middle also show somewhat similar stationary pattern through the late 1990's and then began their declining pattern of γ indexes thereafter. The low income subgroup, however, began its declining pattern of γ index much earlier in 1994 and then to continue its rapid decline through 2015, as shown in Figure 4. Difference test of X^2 show statistically valid results for all income subgroups.

In sum, the two-phase convergence patterns from 1990 to 2003 and from 2004 to 2015 for the total group are supported by all three income subgroups with an exception of low income subgroup. However, there is no corresponding match between declining rate of σ and γ indexes to the improvement rates of SI shown in Table 1. In other words, the rapid improvement rate for the averaged SI in the low income subgroup is not associated with high declining rates of σ and γ indexes in the low income subgroup. Similarly, the low improvement rate for the averaged SI for the high income subgroup is not associated with low declining rates of σ and γ indexes in the high income subgroup.

Table 3 Normalized Sigma and Gamma Sanitation Indexes of Four Income Subgroups, (1990-2015)

	High (58)		Upper Middle (43)		Lower Middle (34)		Low (23)	
year	Sigma	Gamma	Sigma	Gamma	Sigma	Gamma	Sigma	Gamma
1990	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1991	0.9834	1.0000***	0.9732	0.9998***	0.9900	0.9997***	0.9815	1.0000***
1992	0.9672	0.9996***	0.9500	0.9975***	0.9794	0.9956***	0.9635	0.9851***
1993	0.9503	0.9996***	0.9276	0.9962***	0.9610	0.9972***	0.9470	0.9677***
1994	0.9359	0.9979***	0.9042	0.9971***	0.9378	0.9934***	0.9315	0.9671***
1995	0.9191	0.9980***	0.8792	1.0001***	0.9183	0.9953***	0.9155	0.9671***
1996	0.9034	0.9979***	0.8564	0.9939***	0.8991	0.9937***	0.9013	0.9595***
1997	0.8877	0.9966***	0.8343	0.9960***	0.8814	0.9917***	0.8787	0.9426***
1998	0.8728	0.9950***	0.8135	0.9895***	0.8649	0.9904***	0.8597	0.9432***
1999	0.8584	0.9955***	0.7933	0.9830***	0.8489	0.9878***	0.8410	0.9345***
2000	0.8443	0.9918***	0.7757	0.9789***	0.8341	0.9858***	0.8243	0.9167***
2001	0.8322	0.9935***	0.7587*	0.9713***	0.8203	0.9862***	0.8097	0.8990***
2002	0.8194	0.9928***	0.7438*	0.9688***	0.8067	0.9763***	0.7961	0.9012***
2003	0.8076	0.9885***	0.7302*	0.9574***	0.7944	0.9719***	0.7828	0.8864***
2004	0.7960*	0.9838***	0.7180**	0.9312***	0.7830	0.9667***	0.7707	0.8673***
2005	0.7861*	0.9822***	0.7060**	0.9176***	0.7729	0.9650***	0.7599	0.8706***
2006	0.7761*	0.9774***	0.6939**	0.9094***	0.7631	0.9583***	0.7507	0.8594***
2007	0.7677**	0.9760***	0.6822**	0.8994***	0.7542	0.9502***	0.7410	0.8379***
2008	0.7590**	0.9720***	0.6696**	0.8929***	0.7446	0.9481***	0.7329	0.8436***
2009	0.7511**	0.9691***	0.6584**	0.8858***	0.7354	0.9406***	0.7254	0.8439***
2010	0.7443**	0.9662***	0.6476***	0.8682***	0.7264	0.9365***	0.7175	0.8315***
2011	0.7377**	0.9691***	0.6364***	0.8572***	0.7181	0.9259***	0.7117	0.8080***
2012	0.7318**	0.9633***	0.6251***	0.8559***	0.7094	0.9199***	0.7064	0.8083***
2013	0.7298**	0.9620***	0.6137***	0.8532***	0.7027	0.9173***	0.7021	0.7991***
2014	0.7280**	0.9608***	0.6070***	0.8450***	0.6979*	0.9110***	0.6992	0.8034***
2015	0.7270**	0.9583***	0.6007***	0.8437***	0.6947*	0.9112***	0.6991	0.7917***
CAGR(%)	-1.27%	-0.17%	-2.02%	-0.68%	-1.45%	-0.37%	-1.42%	-0.93%

*** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level

Next, results of convergence analysis for six regional subgroups are listed in Table 4 and displayed in Figures 5 and 6. The rates of decline for σ indexes for the six regions vary significantly from the high of -2.97% for SA region to the low of -0.76% for MENA region. In between, EAP and LAC regions show rapid reduction rates of -1.94% and -1.92%. SSA and ECA&NA show moderate rates of decline at -1.32% and -1.15% respectively, which are close to the reduction rate from the total group. Difference test of C.V. are statistically significant for more recent 7 to 11 years for the three regions of EAP, ECA&NA, and LAC, but not for the remaining three regions.

Table 4 Normalized Sigma and Gamma Sanitation Indexes for Six Regional Subgroups, (1990-2015)

	EAP (25)		ECA&NA (42)		LAC (32)	
year	Sigma	Gamma	Sigma	Gamma	Sigma	Gamma
1990	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1991	0.9835	0.9993***	0.9887	0.9973***	0.9765	0.9998***
1992	0.9679	0.9986***	0.9791	0.9984***	0.9547	0.9998***
1993	0.9448	0.9979***	0.9719	0.9971***	0.9322	0.9998***
1994	0.9201	0.9968***	0.9628	0.9967***	0.9104	0.9974***
1995	0.8974	0.9937***	0.9426	0.9943***	0.8903	0.9995***
1996	0.8756	0.9898***	0.9240	0.9912***	0.8705	0.9975***
1997	0.8543	0.9870***	0.9068	0.9954***	0.8510	0.9989***
1998	0.8346	0.9846***	0.8886	0.9910***	0.8334	0.9961***
1999	0.8153	0.9846***	0.8726	0.9935***	0.8153	0.9976***
2000	0.7977	0.9828***	0.8574	0.9940***	0.7991	0.9961***
2001	0.7804	0.9821***	0.8441	0.9946***	0.7820	0.9975***
2002	0.7648	0.9877***	0.8307	0.9926***	0.7660	0.9949***
2003	0.7499	0.9800***	0.8177	0.9861***	0.7508	1.0000***
2004	0.7365	0.9573***	0.8064	0.9882***	0.7356	0.9984***
2005	0.7233	0.9817***	0.7961	0.9830***	0.7212*	0.9972***
2006	0.7097	0.9737***	0.7906	0.9792***	0.7074*	0.9912***
2007	0.6965	0.9785***	0.7836	0.9541***	0.6948*	0.9881***
2008	0.6829	0.9784***	0.7767	0.9461***	0.6815**	0.9850***
2009	0.6696*	0.9784***	0.7703*	0.9400***	0.6698**	0.9830***
2010	0.6571*	0.9750***	0.7644*	0.9386***	0.6585**	0.9790***
2011	0.6453*	0.9708***	0.7598*	0.9408***	0.6481**	0.9649***
2012	0.6330*	0.9668***	0.7560*	0.9366***	0.6376**	0.9672***
2013	0.6253**	0.9689***	0.7525*	0.9335***	0.6272**	0.9619***
2014	0.6179**	0.9655***	0.7489*	0.9289***	0.6197**	0.9564***
2015	0.6123**	0.9634***	0.7496*	0.9314***	0.6159**	0.9635***
CAGR(%)	-1.94%	-0.15%	-1.15%	-0.28%	-1.92%	-0.15%

*** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level

[Continued] **Table 4** Normalized Sigma and Gamma Sanitation Indexes for Six Regional Subgroups, (1990-2015)

	MENA (17)		SA (7)		SSA (35)	
year	Sigma	Gamma	Sigma	Gamma	Sigma	Gamma
1990	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1991	0.9733	1.0046***	0.9778	1.0000**	0.9884	0.9922***
1992	0.9496	1.0046***	0.9500	1.0000**	0.9772	0.9919***
1993	0.9266	0.9989***	0.9148	1.0000**	0.9660	0.9879***
1994	0.8992	0.9989***	0.8709	1.0000**	0.9536	0.9900***
1995	0.8822	0.9989***	0.8381	1.0000**	0.9395	0.9918***
1996	0.8683	0.9989***	0.8087	1.0000**	0.9260	0.9870***
1997	0.8535	0.9989***	0.7801	1.0000**	0.9094	0.9806***
1998	0.8426	0.9978***	0.7539	1.0000**	0.8946	0.9856***
1999	0.8331	0.9967***	0.7300	1.0000**	0.8799	0.9806***
2000	0.8244	0.9945***	0.7064	1.0000**	0.8660	0.9735***
2001	0.8182	0.9945***	0.6858	1.0000**	0.8531	0.9749***
2002	0.8146	1.0001***	0.6667	0.9821**	0.8402	0.9729***
2003	0.8136	0.9878***	0.6483	0.9821**	0.8277	0.9683***
2004	0.8126	0.9713***	0.6302	0.9821**	0.8159	0.9605***
2005	0.8137	0.9756***	0.6136	0.9821**	0.8043	0.9611***
2006	0.8154	0.9958***	0.5989	0.9821**	0.7938	0.9556***
2007	0.8184	0.9958***	0.5837	0.9643**	0.7830	0.9467***
2008	0.8225	0.9924***	0.5697	0.9643**	0.7727	0.9481***
2009	0.8282	0.9901***	0.5558	0.9643**	0.7633	0.9440***
2010	0.8347	0.9824***	0.5430	0.9643**	0.7535	0.9410***
2011	0.8423	0.9858***	0.5273	0.9643**	0.7449	0.9334***
2012	0.8359	0.9858***	0.5110	0.9464**	0.7366	0.9335***
2013	0.8296	0.9858***	0.4979	0.9464**	0.7288	0.9286***
2014	0.8267	0.9858***	0.4824	0.9464**	0.7218	0.9310***
2015	0.8257	0.9858***	0.4705	0.9464**	0.7174	0.9283***
CAGR(%)	-0.76%	-0.06%	-2.97%	-0.22%	-1.32%	-0.30%

*** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level

The declining patterns shown in Figure 5 indicate that with the exception of MENA region, the remaining five regions display continuously smooth reduction. However, MENA region displays a moderate reduction pattern through the year 2000, followed by a moderate divergence thereafter.

As for γ indexes, more rapid speed are displayed by SSA, ECA&NA, and SA regions at -0.3%, -0.28% and -0.22% respectively, whereas the slowest rate is -0.06% for MENA region. As Figure 6 shows, the most striking sudden cliff has taken place for EAP where γ index of 0.98 in 2003 has plunged to 0.9573 in 2004, followed by a stationary movement through 2015. A somewhat similar cliff has taken place for MENA when its γ index dropped from 1.0001 in 2002 to 0.9713 by 2004, followed by another stationary movement thereafter.

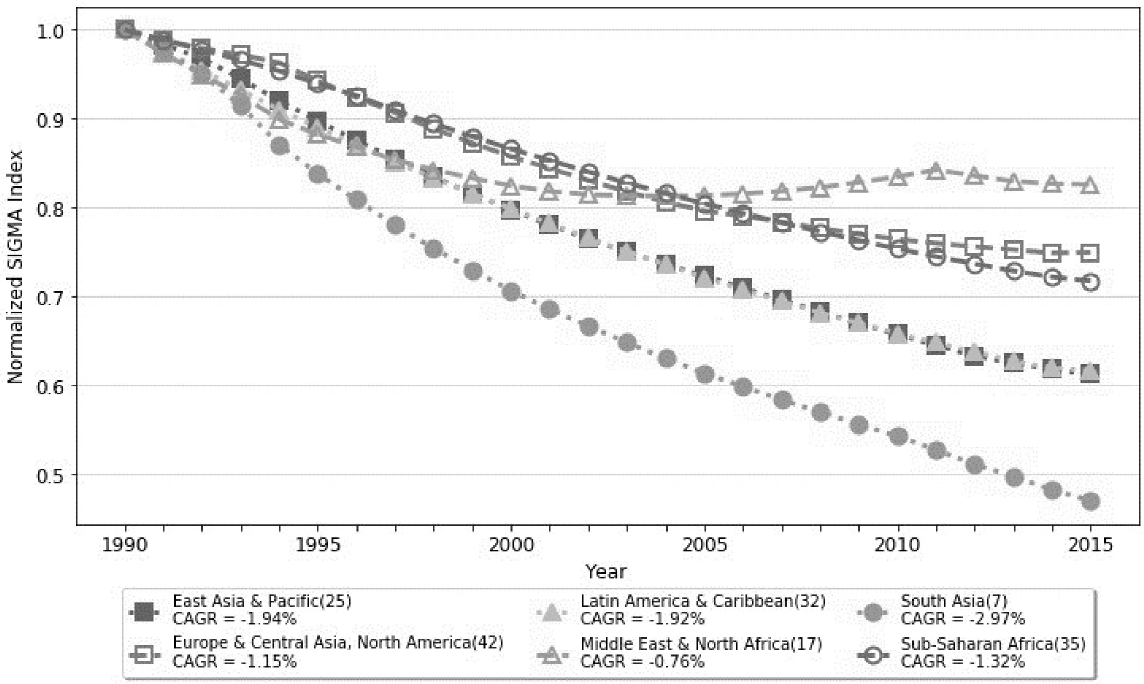

Fig. 5 Normalized Sigma Sanitation Indexes for Six Regional Subgroups (1990-2015)

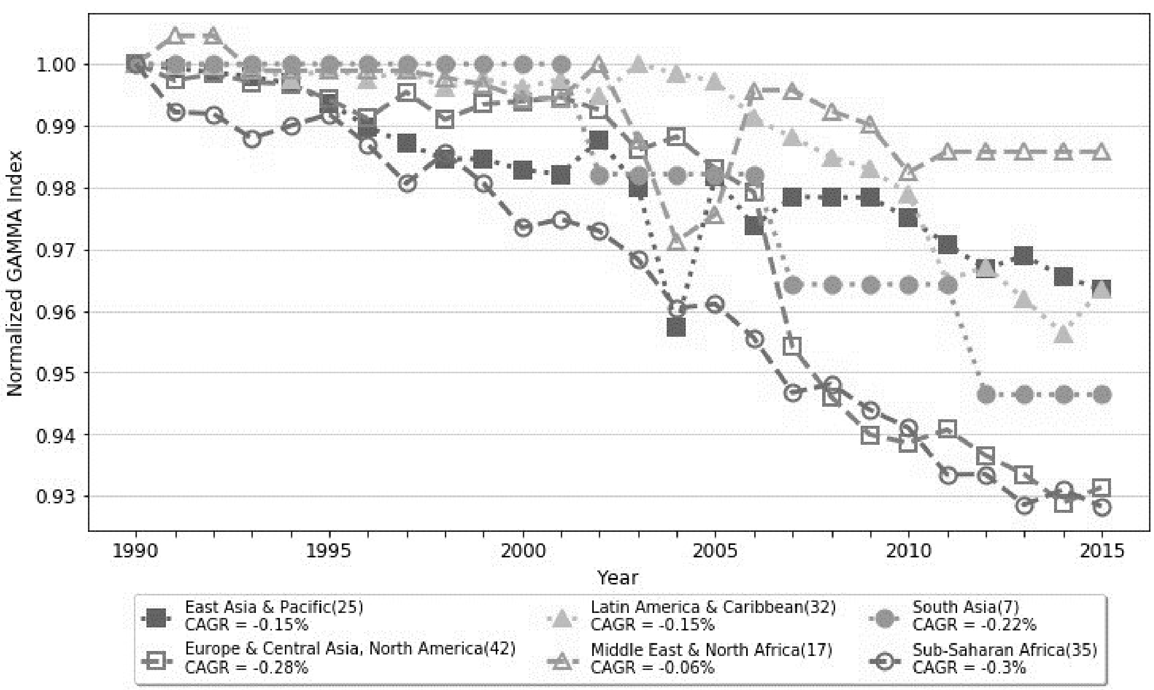

Fig. 6 Normalized Gamma Sanitation Indexes for Six Regional Subgroups (1990-2015)

5 Conclusions

The key findings from this research can be the summarized as follows. First, the averaged sanitation index for the total group of 158 countries shows a moderate improvement at the CAGR of 0.52%. As expected, the low income group shows the most rapid improvement which is about 2.5 times faster (2.16%) while the high income group shows almost no improvement (0.07%).

Second, the γ convergence analysis for the total group shows almost no catch-up from 1990 to 2002, which is followed by a moderate catch-up from 2003 to 2015. The σ index is declining about 10 times faster compared to the γ index, however. In other words, a much faster reduction rate of dispersion among countries is not accompanied by an equally rapid rate of catch-up effects.

Third, σ index for the upper middle group declines about 2 times faster than the total group. However, all the remaining three income groups decline at the rate similar to the total group of countries. The overall declining pattern is continuously smooth for all income groups. In contrast, γ index for the low income group shows the most rapid declining rate (-0.93%) which is almost 11.6 times faster than the total group (0.08%), as expected. The upper middle group also declines almost 8.5 times and the higher income group also declines almost 2 times faster than the total group. The decline for the high income group is most pronounced after 2005. In short, much more rapid catch-up effects have taken place for both low income as well as high income groups over the total group whereas reduction rate of dispersion among income subgroups tend to resemble the reduction rate of the total group.

Fourth, σ convergence for 6 regional groups indicates that SA region shows about 2.7 times faster declining rate followed by EAP and LAC regions declining at 1.8 times faster than the total group. As for γ index, two regions of SSA and ECA&NA show more rapid catch-up than the total group at more than 3.7 times each. The remaining 4 regions also show catch-up effect at the similar speed as the total group.

In summary, one of the most interesting finding is that catch-up effects become quite visible when countries are grouped by income and region. In particular, the low income group displays the most rapid catch-up effect, followed by the upper middle and even by the high income group. Also, SSA and ECA&NA regions also show the most active catch-up among the regional groups. Income and regional analysis of σ indexes also reveal somewhat different speed of decreasing dispersion, which are not shown in the analysis of total group.

What are some policy implications for individual countries trying to improve their sanitation access? How can they use the results from this research in evaluating their past progress and establishing future targets? The most relevant results from this research for individual countries are speed of catch-up and speed of dispersion reduction. Since these output measures vary so widely among different income and regional subgroups, individual countries should be guided by output measures estimated from the appropriate subgroup where they belong rather than from the total group of 158 countries. Since these output measures represent the average speed of convergence from a given subgroup, they should become the minimum targets to be achieved and exceeded by a particular country who is a member of that subgroup. Otherwise, that country may fall behind with respect to its peer countries belonging to the same subgroup. Going one step faster, individual country can conduct its convergence analysis to help narrowing its own disparities of sanitation levels existing within the country. For example, it is well-known that sanitation disparities exist between urban versus rural as well as between rich and poor populations in a majority of countries.

There are several limitations to this research. Further analysis by using additional relevant categories should yield even more interesting insights. The most obvious candidates for such analysis may include urban vs. rural (Satterthwaite, 2016), male vs female, age as well as such other environmental feature as weather, geographic terrain, population density, etc. Another limitation of this study is related to accuracy, relevancy and timeless of data used for this research. Continuous improvement in reporting methodology, however, should yield more useful data for analysis in the future (Bartram et al. 2014).

In spite of these limitations, knowing how to estimate the varying speed of convergence of both σ and γ indexes by income and regional subgroups may be useful in projecting the future improvement rate of sanitation indexes for respective subgroup or any other subgroups of countries. Furthermore, such knowledge should provide useful guideline for investing appropriate resources to better manage improvement efforts tailored to respective subgroups of countries (Cha et al. 2016).

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