Chapter 8
A 4D Indicator System of Count, P Rate, G Rate and PG Rate for Epidemiology and Global Health

Xinguang Chen, Bin Yu, and (Din) Ding-Geng Chen

Abstract How to end the HIV/AIDS epidemic is a typical global health question since the impact of HIV/AIDS is global and it cannot be ended without collaborative global effort. In this chapter, a new measurement system is introduced to inform HIV/AIDS control cross the globe. All countries with data available on area size, total population and total number of persons living with HIV (PLWH) were included, yielding a sample of 148 countries. Four indicators, including the *total count*, population-based *p rate*, geographic area-based *g rate* and population and geographic area-based *pg rate* were used as a 4D system to describe the global HIV epidemic. The total PLWH count provided data informing resource allocation for individual countries to improve HIV/AIDS care; and the top five countries with highest PLWH count were South Africa, Nigeria, India, Kenya, and Mozambique. Information from the remaining three indicators provided a global risk profile of the HIV epidemic, supporting HIV/AIDS prevention programming strategies. Five countries with highest p rates were Swaziland, Botswana, Lesotho, South Africa, and Zimbabwe; five countries with highest g rates were Swaziland, Malawi, Lesotho, Rwanda, and Uganda; and five countries with highest pg rates were Barbados, Swaziland, Lesotho, Malta, and Mauritius. According to pg rates, two HIV hotspots (south and middle Africa and Caribbean region) and one HIV belt across Euro-Asian were identified. In addition to HIV/AIDS, the 4D measurement

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X. Chen, (Din) D.-G. Chen (eds.), *Statistical Methods for Global Health and Epidemiology*, ICSA Book Series in Statistics,
https://doi.org/10.1007/978-3-030-35260-8_8

system can be used to describe morbidity and mortality for many diseases across the globe. We recommend the use of this measurement system in research to address significant global health and epidemiologic issues.

Keywords Global health research · HIV/AIDS epidemic · Geographic area-based g rate · Geographic and population-based pg rate · Global mapping

8.1 Introduction

One fundamental task for epidemiology, particularly global health epidemiology is to provide good tools to extract information from data for accurate understanding of the level, risk factors of a disease and its impact on population health (Rothman, Greenland, & Lash, 2008; Szklo & Nieto, 2018). In addition to the disease epidemiology, such information is essential for public health planning and strategic decision-making, prevention intervention programming and program evaluation (Bayer & Galea, 2015; Chen & Wang, 2017; Khoury, Iademarco, & Riley, 2016). Since the beginning of epidemiology and public health, two indicators most commonly used in research have been (1) the total count that informs us about the total number of persons who suffer from or died of a disease; and (2) rate that reflects the risk of a person suffering from or being died of a disease.

During early stages when a disease has just started to appear, the number of new cases is counted periodical (i.e., daily, weekly, or monthly); the counts are then accumulated to show the progress of the disease epidemic in a population, such as SARS (Wikipedia, 2019), Ebola (Meltzer et al., 2014), and bird flu (Ferguson, Fraser, Donnelly, Ghani, & Anderson, 2004) as being commonly practiced today. When a disease becomes an epidemic and lasts for long time to affect more and more people in a population, annual count of persons who suffered from or died of the disease is used to monitor the epidemic, such as the number of persons living with HIV/AIDS or died from AIDS each years (WHO, 2018). In vital statistics, the number of persons suffered from or died of different causes of diseases is documented on an annual or biannual basis as shown in many statistical yearbooks.

The headcount of a disease as an epidemiologic measure provides information very useful for decision-making at the population level. It is the basic data used in planning and decision-making to allocate resource for disease treatment and prevention (Bautista-Arredondo, Gadsden, Harris, & Bertozzi, 2008). For example, if a total of 1200 persons are diagnosed with cancer. Assuming that the government expenditure for treating one cancer patient per year on average is \$15,000, a total of \$18 million (\$15,000$_*$1200) every year must be allocated in the country's budget for treating all the cancer patients. In the United States, the Centers for Disease Control and Prevention uses this method to plan its Healthy People 2030 for resource allocation for all public health programs, and more details can be found at the URL: https://www.healthypeople.gov/.

Despite the usefulness, information provided by headcount is inadequate for measuring and comparing risks of a disease across regions and jurisdictions with a country and across countries in the world. This is because given the same level of likelihood for a disease to spread, the head count of a disease will differ for countries and regions with different population sizes. A country or region with a larger population will have more people at risk of suffering from a disease than a country or region with a smaller population given the same risk level. Epidemiologists have overcome the limitation of headcount data by using the indicator rate. Methodologically, a rate is a measure that adjusts the impact of population size in assessing disease risk (Chen, 2017; Chen & Wang, 2017). Disease rates therefore provide a measure more informative than disease count for comparison across regions within a country, and across countries in the world.

The two epidemiologic indicators, headcount and disease rate described above have been used almost everywhere from research to practice, including the World Health Organization, governmental and nongovernmental agencies; researchers and students in institutes and universities; and public health workers in communities and neighborhoods. While appreciating the value and utility of the two epidemiologic indicators, we cannot overlook their limitations. Although measures of disease rate are more informative than measures of headcount with regard to informing levels of risk of a disease at the population level, both headcount and disease rate cannot address another key factor–the size of geographic areas people reside (Chen, 2017; Chen & Wang, 2017). To fill in this methodology gap, in this chapter, we will introduce a new measurement system by incorporating geographic area size into measurement. We illustrate the new measurement system using the global HIV epidemic as an example.

8.2 Ending the HIV/AIDS Epidemic by 2030

The epidemic of the human immunodeficiency virus (HIV) and the acquired immunodeficiency syndrome (AIDS) is a typical global health problem (Chen, 2014; Merson, Black, & Mills, 2012). Worldwide, the number of persons living with HIV (PLWH) has totaled 36.9 million (WHO, 2018). The impact of HIV/AIDS on human health is global; therefore, effective HIV/AIDS control and prevention requires collaborative and global efforts (Deeks et al., 2016; International Aids Society Scientific Working Group on H I V Cure et al., 2012). No one individual country is immune to HIV infection and no one individual country alone can get rid of the HIV epidemic without involving other countries and agencies in the world.

In fighting the HIV/AIDS epidemic, two strategies are widely used: (1) Antiretroviral therapy (ART) and (2) prevention intervention programs. The first strategy is designated for treating persons living with HIV (PLWH) whose viral load has not been suppressed and this strategies has been widely implemented across the globe (Tanser, Barnighausen, Grapsa, Zaidi, & Newell, 2013; UNAIDS, 2017a). In addition to treading the infected, appropriate implementation of ART, such as treatment as prevention (TasP) can help PLWH to achieve viral suppression, reducing the number of infected persons who can infect others (Cohen, 2011; Granich et al., 2010).

The second strategy of prevention is for all persons who are at risk for HIV infection, including the PLWH who can be re-infected (Lyles et al., 2007). These programs include school- or community-based interventions for general population and venue-based high-risk population intervention (e.g., drug users, men who have sex with men, sex workers). To develop and implant either an ART program or a prevention intervention strategy, adequate data are always needed for strategic planning, evidence-based decision-making, and objective program evaluation (Courtenay-Quirk, Spindler, Leidich, & Bachanas, 2016; H. I. V. Modelling Consortium Treatment as Prevention Editorial Writing Group, 2012; Marsh & Farrell, 2015).

Based on the epidemic of HIV/AIDS and success in treatment and prevention, the Jointed United Nations Program on HIV/AIDS sets the goal to End the AIDS Epidemic by 2030 (UNAIDS, 2014b). To achieve the goal, the UNAIDS further asked that by 2020, 90% of PLWH know their HIV status, 90% of diagnosed PLWH receive sustained ART and 90% who receive ART have their blood viral load suppressed (90-90-90 strategy) (UNAIDS, 2017a). Pursuing these goals requires collaborative efforts to plan and deliver patient-centered ART and population-centered (both the general and at-risk population) prevention programs to reduce the risk of HIV transmission by all possible venues, including sexual contact, needle sharing and vertical maternal-child transition (AVERT, 2017; CDC, 2018b; National Health and Family Planning Commission of PRC, 2015; WHO, 2017).

8.3 Four-Dimensional Measurement System

8.3.1 Two Conventional Measure of Headcount and P Rate

From a precision public health perspective (Chen & Wang, 2017; Khoury et al., 2016), relevant and sufficient information is essential to plan and implement HIV/AIDS treatment and prevention strategies to achieve the goal of ending the HIV/AIDS epidemic by 2030. For example, the number of PLWH by country is needed for resource allocation to achieve the 90-90-90 proposed by UNAIDS. If it costs on average $1000 to treat one PLWH per year, a total of $39 billion will be needed to treat all the 39 million PLWH in the world. There were 850,000 PLWH in China in 2015, which meant China needs $850 million per year to treat these infected persons.

Despite great significance, information conveyed by the number of PLWH for individual countries provides limited information about between-country differences in the risk of HIV transition because of population size (Chen, 2017; Chen & Wang, 2017). In addition to risk factors, the total number of PLWH in a country is directly related to the population size. For example, in 2015, there were 850,000 PLWH in China and 830,000 in Brazil (see Appendix to this chapter for detailed data). If larger number of PLWH meant higher risk of HIV transmission, people in China may face a higher risk than people in Brazil. However, the population of

Brazil was 208 million, only about 15% of 1.4 billion, the total population in China. We cannot determine whether the risk of HIV transmission is higher in China or in Brazil using only the measure of total headcount of PLWH.

To more accurately assess the risk of HIV transition, a population-based measure has devised by dividing the number of PLWH with total population. In our 4D measurement system, this population-based measure is termed as *p rate* (Chen & Wang, 2017). Epidemiologically, a p rate is more accurate than a headcount to assess between-country differences in risk of HIV transmission because it quantitatively adjusts the differences in population sizes. Following the same example in the previous paragraph, the p rate for Brazil was 3.993/1000 population, 6.4 times higher than 0.630/1000, the p rate for China. Therefore, based on the p rates, we can conclude that the risk of HIV transmission is 6.4 times higher in Brazil than in China.

8.3.2 Two New Measures of G Rate and P Rate

P rate has been one of the most commonly used measures in epidemiology and global health. Despite its advantage in controlling for population size, p rates for different countries are confounded by the geographic area size of a country. Again using PLWH as examples: the total number of PLWH in 2015 was about 220,000 in two countries: Swaziland and Mexico; however, the total area was 172,000 km^2 for Swaziland, much smaller than 19,440,000 km^2, the geographic area size of Mexico. If people from the two countries reside on a same size of a geographic area (say, like Swaziland), the risk of HIV transmission would be 113 times (19,440,000/172,000) higher in Swaziland than in Mexico. To consider difference in geographic area size like the p rate for population size, *a new and geographic area-based measure has been developed and named as g rate* (Chen, 2017; Chen & Wang, 2017).

G rate of a country/place was defined as the ratio of total events over the total geographic area size of the country/place. G rate can be defined for many medical and health events. For example, g rate can be defined and estimated for new infections of a disease to evaluate the risk of disease transmission; g rate can also be defined and estimated for total deaths by country to assess risk of mortality; and certainly g rate can be used to measure PLWH and compare between-country differences in the risk of HIV transmission. While a p rate provides a measure that has epidemiologically adjusted the confounding from different population sizes; a g rate provides another measure that has epidemiologically controlled the confounding from the different geographic area sizes. With a g rate, the significance of geographic areas in disease epidemiology (Sattenspiel, 2009) can be assessed quantitatively.

Inspired by p rate and g rate, a natural extension would be to consider both population size and geographic area to assess the morbidity and mortality of any health conditions. It is based on this line of thought, another new measurement – pg rate has been developed (Chen & Wang, 2017). As the name suggests, a pg rate of a health event for a country is defined as the ratio of total count of the event over both the total population and the total geographic area of the country. Since the confounding effect from both population and geographic areas are adjusted, pg rate provides a measure better than p rate and g rate alone to assess the epidemiology of any medical and health event across countries in the world.

The four epidemiological measures of headcount, p rate, g rate and pg rate consist of a new 4D measurement system. This 4D assessment system extends the conventional measures and can be used in assessing many medical and health conditions to advance both research and practice in global health and epidemiology.

8.4 An Example of Global HIV Epidemic

To demonstrate the 4D measurement System and its application, we analyzed data for PLWH in 2015. The method can be used for study any other diseases.

8.4.1 Materials and Method

Persons living with HIV (PLWH). These data were limited to 2015 and were derived from multi-sources, including the UNAIDS, government websites and different governmental reports. Data for a total of 148 countries with data available on PLWH were included. Of these countries, data for 107 countries were derived from the UNAIDS, and three from the government report or HIV/AIDS data hub, including the United Kingdom, China and Laos (UNAIDS, 2016, 2017b). For the remaining countries with no data in 2015, data for most closed years were used. For example, 2014 data were used for Canada, Fiji, Montenegro, Netherlands, New Zealand, and Singapore were derived from the Progress Report by Country (UNAIDS, 2014a); 2014 data for Estonia were derived from the Evaluation Report of the World Health Organization (WHO Regional Office for Europe, 2014); data for the United States in 2013 were from the Centers for Diseases Control and Prevention (CDC, 2018a); and data for Guinea-Bissau in 2012 were derived from the UNICEF (UNICEF, 2013).

Geographic area size by country. Data for the size of geographic area (km^2) of individual countries are extracted from the World Bank Data Depot (World Bank, 2015a). This is a great official source of geographic data for countries in the world, and has been globally accepted. Data from this source are also widely used in statistical analysis and visualization to address global issues (Redding & Venables, 2004).

Population data by country. The population data by country were also derived from the World Bank Data Depot (World Bank, 2015b). The data stored are compiled by the United Nations Population Division, and the population data in this source are based on multi-official sources, including census reports and other statistical publications, the population and vital statistic report by census bureau of various countries in the world.

8.4.2 Estimation of P Rate, G Rate and PG Rate

P rate, g rate and pg rate for the 148 countries included in this example were computed respectively using the following three equations:

$$p\ rate = \frac{N}{P}\ \text{(per 1000 population)} \tag{8.1}$$

$$g\ rate = \frac{N}{A}\left(\text{per } 100\ \text{km}^2\right) \tag{8.2}$$

$$pg\ rate = \frac{N}{P \times A}\left(\text{per million population} \cdot 100\ \text{km}^2\right) \tag{8.3}$$

Where N represents the number of PLWH, P represents the number of population, and A represents geographic area size.

The total population and geographic area, the total counts of PLWH, and the calculated p rates, g rates, and pg rates for individual countries were included in Appendix.

8.4.3 Geographic Mapping

The four epidemiologic indicators by country each were mapped globally, including the headcount of PLWH, and the calculated p rates, g rates and pg rates using the software R. Three R packages for mapping were used, including the “maps”, “mapproj” and “ggplot2”. A dataset “worlddata” was thus created by extracting geographic information of individual countries (country name, longitude, latitude) from the “maps” and merged with the derived data of the population size, geographic area, count of PLWH, calculated p rate, g rate and pg rate by country.

After data preparation, we created a world map using the dataset “worlddata”. Following the National Standard Map Services, we used the “ggplot2” with “rectangular” option and orientation (latitude = 90, longitude = 150, rotation = 0) and “mapproj” to create the world map. A color scale was used to represent different levels of each PLWH indicators by *five* percentiles. Greenland located in the far north was not included in the mapping because of the lack of HIV data. R codes for the geographic mapping are available from the author Bin Yu upon request.

8.5 Results

With data from the 148 countries included in this analysis, worldwide an estimate of 35,426,911 persons who were infected and lived with the virus at the time around 2015. The global prevalence rate was 0.51 PLWH per 1000 population.

8.5.1 *The Global HIV Epidemic Measured by Headcounts of PLWH*

Table 8.1 lists the 15 countries with the largest number of PLWH. Of these 15 countries, the top five were South Africa, Nigeria, India, Kenya and Mozambique with a total of 15,600,000 PLWH, accounting for 44% of that of the total 148 countries included in the analysis.

Figure 8.1 presents the total counts of PLWH by country. Countries with the largest number of PLWH (dark-red) were located, from left to right, in south and middle Africa, Ukraine, India, China and most other Southeast Asian countries, the United States, and Brazil. Overall, the number of PLWH in these countries ranged from 200,000 to 7000,000.

The total number of PLWH provides the information needed for estimating ART cost. One research in South Africa estimates that it costs $119 to maintain ART per

Table 8.1 Top 15 countries with the largest number of persons living with HIV (PLWH) in the world, 2013–2015

Name of the country	Continent	PLWH (in 1000)	Rank
South Africa	Africa	7000	1
Nigeria	Africa	3500	2
India	Asia	2100	3
Kenya	Africa	1500	4
Mozambique	Africa	1500	5
Uganda	Africa	1500	6
Tanzania	Africa	1400	7
Zimbabwe	Africa	1400	8
USA	North America	1242	9
Zambia	Africa	1200	10
Malawi	Africa	980	11
China	Asia	850	12
Brazil	South America	830	13
Ethiopia	Africa	794	14
Indonesia	Asia	690	15
World total	–	35,427	–

PLWH Persons living with HIV

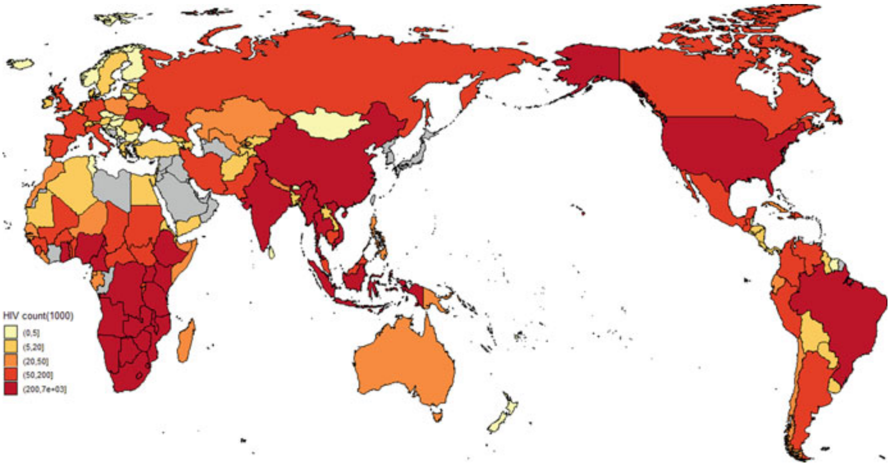

Fig. 8.1 The Global HIV epidemic measured by headcount of PLWH (1000), 2013–2015. Note: *Grey area* data not available

patient per month (Martinson et al., 2009). With this data, for treating one million of PLWH, it will cost $1.44 billion per year to cover the ART cost alone. It is estimated that there are 7000,000 PLWH in South Africa. To provide ART to them, it will cost the country approximately $1 trillion per year. To provide ART for the total 35.4 million of PLWH in the 148 countries, a total of $5+ trillion per year is needed. HIV is by far the one of most expensive diseases (Alistar, Owens, & Brandeau, 2011; CDC, 2017; Martinson et al., 2009).

8.5.2 The Global HIV Epidemic Measured by P Rates of PLWH

There were large variations in the population among the 148 countries varying from 284,000 for Barbados to 1.37 billion in China. The three countries with the smallest populations were Barbados (284,000), Iceland (319,000) and Belize (359,000); and the three countries with largest population were the United States (0.32 billion), India (1.31 billion) and China (1.37 billion). P rate provides a method to consider these between-country differences in population size for comparisons of the HIV epidemic among countries in the globe.

The 15 countries with highest p rates per 1000 population are listed in Table 8.2. Results in the table indicate that all the 15 countries were located in Africa, and with the total five being Swaziland (170.9/1000), Botswana (154.7/1000), Lesotho (145.2/1000), South Africa (127.4/1000) and Zimbabwe (89.7/1000). The p rate for Swaziland was 33.5 times the average rate of 5.1/1000 for the 148 countries.

Table 8.2 Top 15 countries with the highest p rates of PLWH, 2013–2015

Name of the country	Continent	P rate (PLWH/1000)	Rank
Swaziland	Africa	170.9	1
Botswana	Africa	154.7	2
Lesotho	Africa	145.2	3
South Africa	Africa	127.4	4
Zimbabwe	Africa	89.7	5
Namibia	Africa	85.4	6
Zambia	Africa	74.0	7
Malawi	Africa	56.9	8
Mozambique	Africa	53.6	9
Uganda	Africa	38.4	10
Kenya	Africa	32.6	11
Equatorial Guinea	Africa	32.0	12
Gabon	Africa	27.2	13
Cameroon	Africa	26.6	14
Tanzania	Africa	26.2	15
Worldwide	–	5.11	–

PLWH Persons living with HIV

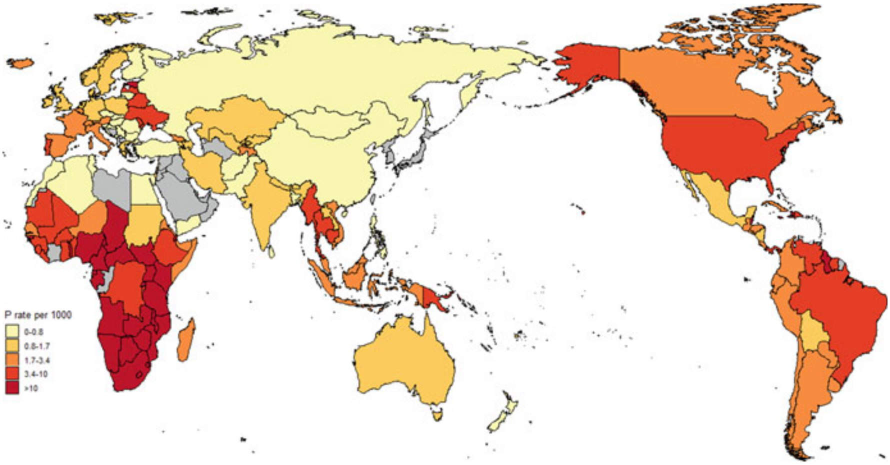

Fig. 8.2 The Global HIV epidemic measured by p rates of PLWH (per 1000 population), 2013–2015. Note: *Grey area* data not available

Figure 8.2 presents the p rate mapping of the global HIV epidemic with population size being adjusted. Thus, the map in this figure provides better data than that Fig. 8.1 (headcount) on the risk of HIV epidemic for cross-country comparison. Compared to Fig. 8.1, the first and most striking difference was that several countries with large population and top headcounts of PLWH were no longer on the top list, such as Brazil, China, India, Mexico, Russia, and USA.

Second, most African countries with highest headcounts of PLWH remained the highest with p rates (dark-red). This result suggests the risk of HIV transmission remained high in these countries after considering the population size. Interestingly, two from the lower PLWH-headcount countries moved to the 20% countries with highest p rates (dark-red): Guyana in South America and Estonia in East Europe. These two countries were rather small with regard to population size but the headcounts of PLWH were higher (see Appendix), resulting in high p rates.

By examining the results in Figs. 8.1 and 8.2 and Table 8.1 together, it can be seen first that a country with high PLWH count may not necessarily be the country with high risk of HIV transmission such as Brazil, China, India, Mexico, Russia, and USA. This is because the high counts of PLWH in these countries were primarily due to the large number of populations.

Second, countries with both high PLWH headcounts and high p rates have high risk of HIV transmission, such as most of the African countries with high ranks of both PLWH headcounts and p rates. With more total PLWH and PLWH per 1000 population in these countries, higher risk of HIV spreading is anticipated.

Last, people living in countries with high p rates are at high risk for HIV transmission regardless of PLWH headcounts, such as Guyana and Estonia.

8.5.3 The Global HIV Epidemic Measured by G Rates of PLWH

The size of geographic area of the 148 countries also varied dramatically from the smallest of 320 km^2 for Malta to the largest of 163,769,000 km^2 for Russia. The total area of the three smallest countries (Malta, Barbados and Singapore) accounted for only 0.001% of the world total; while the total are of the three largest countries (Russia, China and USA) accounts for 28%. Like the p rate for population, g rate provides a measure to gauge the HIV epidemic by adjusting these differences in geographic sizes for cross-country comparisons. This is one of the two new indicators we introduced in this chapter.

The world average and top 15 countries with highest g rates are listed in Table 8.3. The estimated g rate for Swaziland was 1279.1 PLWH/100km^2, 44.4 times that of the world average of 28.8. Of the top five countries, three with g rates greater than 1000 PLWH per unit geographic area of 10×10 km^2.

Figure 8.3 depicts the global HIV epidemic using the estimated g rates of PLWH. Similar to Fig. 8.2, the top 20% countries with highest g rates were colored in dark-red; and these countries were roughly located in three regions of the world. (1) Africa: including a strip of countries from Kenya in the north to South Africa in the south and a small group of countries in the East Africa (Nigeria, Equatorial Guinea, and Cameron); (2) several countries in Southeast Asia (Singapore, Thailand and Vietnam); and (3) several other countries in Caribbean (Costa Rica, Dominican, Hatti and Jamaica).

Table 8.3 Top 15 countries with the highest g rates of PLWH, 2013–2015

Name of the country	Continent	G rate (PLWH/100 km^2)	Rank
Swaziland	Africa	1279.1	1
Malawi	Africa	1039.5	2
Lesotho	Africa	1021.1	3
Rwanda	Africa	810.7	4
Uganda	Africa	748.1	5
Singapore	Asia	697.9	6
Barbados	Africa	604.7	7
South Africa	Africa	577.0	8
Haiti	Africa	471.7	9
Mauritius	Africa	403.9	10
Nigeria	Africa	384.3	11
Zimbabwe	Africa	361.9	12
Burundi	Africa	299.8	13
Jamaica	Gulf of Mexico	267.8	14
Kenya	Africa	263.6	15
Worldwide	–	28.8	–

PLWH Persons living with HIV

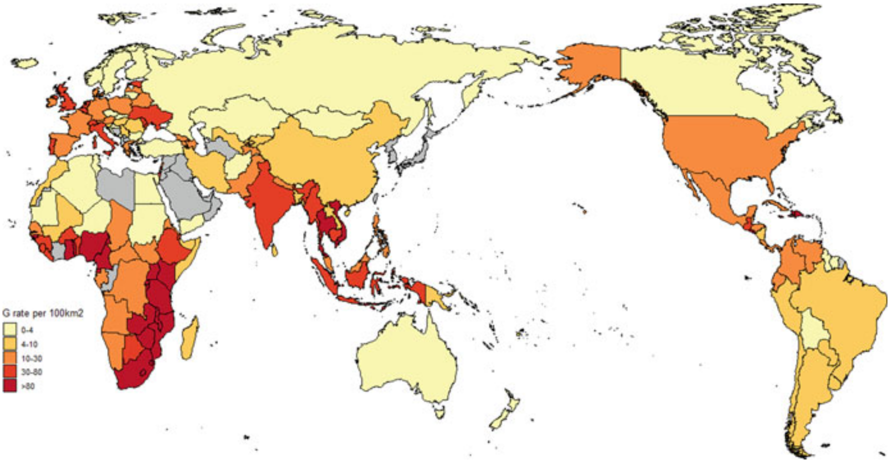

Fig. 8.3 The Global HIV epidemic measured by g rates (PLWH/per 100 km^2). Note: *Grey area* data not available

As expected, g rates were lower for countries with large area sizes even if its PLWH headcount was high, such as Brazil, Canada, China, Russian, and the United States. Given the same area size, higher g rate in a country indicates high risk of HIV transmission because of short distance for personal contact while lower g rate indicates low risk of HIV transmission because of long distance for personal contact.

Table 8.4 Top 15 countries with the highest pg rates of PLWH (per million population per 100 km^2), 2013–2015

Name of the country	Continent	PG rate (/million pop. 100 km^2)	Rank
Barbados	Africa	2127.9	1
Swaziland	Africa	993.8	2
Lesotho	Africa	478.3	3
Malta	Africa	375.0	4
Mauritius	Africa	319.7	5
Bahamas	Caribbean	208.6	6
Trinidad and Tobago	Africa	157.7	7
Cape Verde	Africa	152.6	8
Singapore	Asia	126.9	9
Equatorial Guinea	Africa	113.9	10
Gambia	Africa	104.2	11
Jamaica	Caribbean	98.3	12
Guinea-Bissau	Africa	85.0	13
Luxembourg	Europe	74.5	14
Rwanda	Africa	69.8	15
Worldwide	n/a	0.005	n/a

PLWH Persons living with HIV

More details about individual countries can be found in Appendix to the end of this chapter.

8.5.4 The Global HIV Epidemic Measured by PG Rates of PLWH

PG rate is the second new indicator we introduced in this chapter to simultaneously adjust both population size and geographic area. For example, in Fig. 8.3, the United States was categorized into the top 40% countries with the risk of HIV spreading similar to many Caribbean countries, which may not be true, because population size was much large for the United States than for any Caribbean countries. The estimated pg rate indicated that worldwide, there were 0.005 PLWH/million population/100 km^2.

As usual, Table 8.4 lists the top 15 countries with highest pg rates. Barbados was now the country with the highest pg rate in the world with 2127.9 PLWH per million population per 100 km^2. This rate was 425,580 times that of the world average and 30 times that of Rwanda, the last one among the top 15. It was not surprise to see this result because of the small area of Rwanda (24,700 km^2) and population (11,610,000) and a large number of PLWH (an estimate of 200,000).

The global HIV epidemic depicted using pg rates is presented in Fig. 8.4. Results from this figure add addition data better than the headcount, p rate and g rate alone

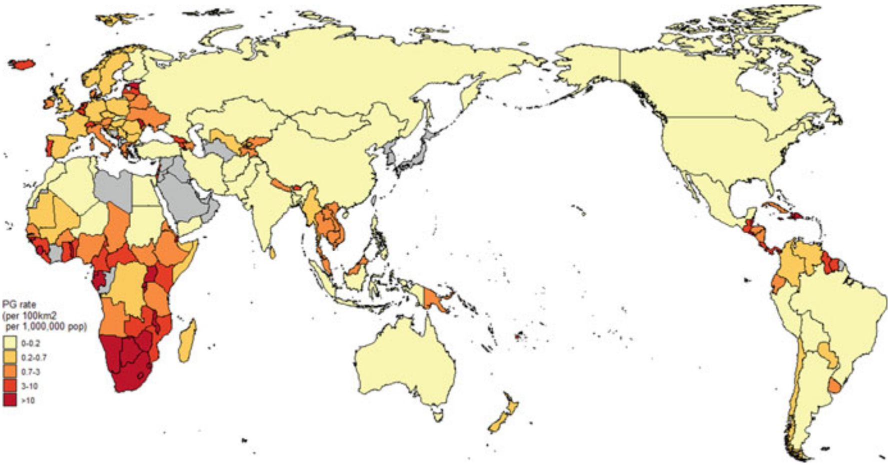

Fig. 8.4 The Global HIV/AIDS epidemic measured by pg rates of PLWH (per million persons per 100 km^2). Note: *Grey area* data not available

to reflect the global pattern of the risk for HIV transmission. Based on the top 40% (colored as dark and light red) with highest pg rates, countries with high threat of HIV epidemic were distributed along with One HIV Hot-Belt and Two HIV Hotspots.

The HIV Hot Belt: This belt comprises a list of countries scattered in a band region, the belt starts with Iceland on the top left of the world map, moves across the Euro-Asian, and ends at Papua New Guinea on the bottom right of the map. Other countries on this HIV Hot Belt region were Estonia, Latvia, Netherlands, Belgium, Luxembourg, Switzerland, Montenegro, Portugal, Moldova, Georgia, Armenia, Azerbaijan, Uzbekistan, Kyrgyzstan, Tajikistan, Nepal, Bhutan, Myanmar, Vietnam, Thailand, Laos, Cambodia, Malaysia, and Singapore.

The HIV Hotspot 1-Africa: These hotspot comprises all countries in South and Middle Africa except Congo (DRC), Angola, and Tanzania. The majority of these countries was also considered as the places where HIV affects people the most using other three measures.

The HIF Hotspot 2-Caribbean: Countries in this hotspot were The Bahamas, Barbados, Belize, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Hatti, Honduras, Jamaica, Nicaragua, Panama, Trinidad and Tobago, Suriname, Venezuela.

8.6 Discussion and Conclusion Remarks

In this study, we took a 4D measurement system to describe the global HIV epidemic by adding two newly reported indicators of g rate and pg rate (Chen, 2017; Chen &

Wang, 2017), together with two conventionally used indicators of headcount and p rate. The count and p rate are widely used in research; and the g rate and pg rate add new information, forming a four-dimensional measurement system. We illustrated the utility of the 4D measurement system using HIV data from 148 countries in the world HIV epidemic.

The data about the number of PLWH confirm the conclusion from other studies that it will cost the world a big fortune to end the AIDS epidemic. Providing ART alone for 90% of 36.9 million PLWH in the world will cost $4.7 trillion per year, based on the estimated cost of $119 per month for ART in S. African. The estimated lifetime ART cost is $367,134 per PLWH in the United States (CDC, 2017), which means $1357 trillion, ~17 times of $80 trillion, annul GDP produced by all countries in the world. Of the 148 countries included in this study, financial burden will be the greatest for those with highest counts of PLWH, including South African (seven million), Nigeria (3.5million), and India (2.1 million).

Like the p rate to adjust for population size, g rate provides a measure of HIV risk without the influence of the size of a country's geographic area. High g rates suggest greater potentials for close contact between the HIV infected and uninfected persons. Therefore, given the same headcount and p rate, risk of HIV spreading will be higher in countries with high g rates. Singapore provides a best example. This country would be low at HIV transmission if the total number of PLWH (only 4900) and p rate (0.894/1000) were used; however, it became a high-risk country and ranked number 6 in the world when assessed using g rate (126.1 per 1000,000 population per 100 km^2).

On the contrary, g rates will be small for countries with large land area, such as Russia, Canada, Australia, Brazil, the United States and China. Given the same number of PLWH and the same p rate, the risk will be lower for HIV transmission in countries with smaller g rate since small g rate means longer distances for interpersonal contacts. This is consistent with the rural-urban differences in the HIV epidemic with more infections and quicker growths in urban areas where people crowd together than in rural areas where people reside sparsely (Mnyika et al., 1994). Data generated using g rates of PLWH provide direct evidence supporting the role of geographic area in disease epidemiology in general (Sattenspiel, 2009).

Another innovation is the use of pg rate controlling for both population size and the geographic area. It is an index of the number of PLWH in a given number of population and a geographic area. Thus, pg rates provide the most effective measure for cross-country comparison to assess the risk of transmission of HIV as well as many other infectious diseases. Based on the definition, pg rate will be high for countries with large number of headcount of persons suffering from or died of a disease, but a small population and small geographic area. For example, pg rate was 993.861 for Swaziland, which means roughly 1000 PLWH in every million population residing in an area of 100 km^2; while the corresponding pg rate was 0.007 for China, indicating much lower risk of HIV transmission. Given all other conditions the same, the likelihood for HIV (or any other infectious disease) to transmit from one to another in a place with small area and a large number of populations will be greater than in a place with large area and small number of populations.

With pg rate, countries in the region across Middle East and North Africa (MENA) were categorized low risk for HIV transmission. This is consistent with data from different sources (Gokengin, Doroudi, Tohme, Collins, & Madani, 2016) with different interpretations (Abu-Raddad et al., 2010; Gray, 2004). The advantage with our pg rate is that this MENA region looked much smoother and gradually expand to connect with other higher risk regions around, very different from the patterns shown by p rates or headcounts.

Based on pg rates, prevention of HIV transmission should pay particularly high attention to the three regions: One HIV Hot-Belt and two HIV Hotspots to better address the goal set by the UNAIDS to end the AIDS epidemic by 2030 (UNAIDS, 2014b). In general, countries in these high-risk belt and spots are relatively small in geographic area but with a large number of PLWH, in favor of HIV transmission from one to another.

In conclusion, this is the first time a 4D measurement system is formed and tested using the global HIV epidemic. More applications of the same method are highly recommended. For example, the same approach can be used to describe regional differences within a country; and to describe infectious diseases other than HIV. In addition to morbidity, the 4D approach can be used to describe mortality data. The utility of our 4D measurement system integrating headcount, p rate, g rate and pg rate together, providing the most comprehensive measure for researchers and decision makers to grasp the overall pattern of a disease in global health and epidemiology.

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