

Supplementary Materials for “Assessing global preparedness for the next pandemic: development and application of an epidemic preparedness index”

1. Methods

The Epidemic Preparedness Index (EPI) is composed of five sub-indices, which are comprised of a weighted combination of underlying indicators. Indicator data for the EPI were derived from publicly-accessible datasets produced by international organizations including the World Bank, the World Health Organization, United Nations specialized agencies, non-governmental organizations, and local administrative sources (detailed in Supplementary Table 1). Missing data were replaced with estimates from alternate sources with similar indicator designs and estimation methodologies, as required, and are posted along with replication materials.

Supplementary Table 1. Indicators included in the Epidemic Preparedness Index, by Sub-Index

Sub-index 1: Public Health Infrastructure			
Indicator	Concept	Source(s)	Link
Surveillance	Capacity for early detection and identification of emerging pathogens or epidemic outbreaks	World Health Organization, International Health Regulations Core Capacities Score	http://apps.who.int/gho/data/view.main.IHRCTRY03v?lang=en
Intra-governmental coordination	Effective coordination across government agencies responsible for outbreak identification and response	World Health Organization, International Health Regulations Core Capacities Score	http://apps.who.int/gho//data/view.main.IHRREG02v?lang=en
Immunization	Proxy for ability of public health agencies to access and provide health services to population	World Health Organization / UNICEF joint estimates	http://apps.who.int/immunization_monitoring/globalsummary/timeseries/tswucoveragedtp1.html
Density of skilled medical personnel	Density of public health workforce	World Health Organization Survey of Global Health Workforce	http://apps.who.int/gho/data/node.main.HWFGROUPS?lang=en
Hospital beds per capita	Capacity to manage rapid increase in clinical cases	CIA World Factbook	https://www.cia.gov/Library/publications/the-world-factbook/fields/print_2227.html

Sub-index 2: Physical and communications infrastructure

Indicator	Concept	Source(s)	Link
Road quality	Quality of transportation infrastructure	World Road Statistics (WRS), World Bank World Development Indicators	http://www.nationsencyclopedia.com/WorldStats/WDI-transport-roads-paved.html
Mobile phone access (mobile phone users per 100)	Capacity to coordinate and disseminate information	World Bank World Development Indicators	http://data.worldbank.org/indicator/IT.CEL.SETS.P2
Internet access (internet users per 100)	Capacity to coordinate and disseminate information	World Bank World Development Indicators	http://data.worldbank.org/indicator/IT.NET.USER.P2
Logistical capacity	Capacity to efficiently process, transport, and track vital supplies	Logistics Performance Index, World Bank	http://data.worldbank.org/indicator/LP.LPI.OVRL.XQ
% population with access to an improved water source	Density of preventive sanitary infrastructure	WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation	http://data.worldbank.org/indicator/SH.H2O.SAFE.ZS
% population with access to an improved sanitation facilities source	Density of preventive sanitary infrastructure	WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation	http://data.worldbank.org/indicator/SH.STA.ACSN

Sub-index 3: Institutional capacity			
Indicator	Concept	Source(s)	Link
Corruption	Public sector corruption and leakage of resources	Transparency International, World Bank Worldwide Governance Indicators	https://www.transparency.org/cpi2014 http://info.worldbank.org/governance/wgi/index.aspx#reports
Vital registration	Knowledge of population distribution, accuracy of demographic and population data	United Nations Statistics Division, Civil Registration and Vital Statistics (CRVS) coverage estimates	http://unstats.un.org/unsd/demographic/CRVS/CR_coverage.htm
Bureaucratic capacity	Quality and efficiency of civil service and public sector management	World Bank Country Policy and Institutional Assessment, public sector management and institutions cluster	http://databank.worldbank.org/data/reports.aspx?source=country-policy-and-institutional-assessment
Political stability	Government stability and capacity to function under periods of institutional and political stress	World Bank Worldwide Governance Indicators political stability and absence of violence indicator	http://info.worldbank.org/governance/wgi/index.aspx#home
Armed conflict	Government control, capacity to access territory to conduct public health operations. Inverse value is taken, to penalize more violent states.	Uppsala Conflict Data Program	http://www.pcr.uu.se/research/ucdp/datasets/

Homicide	Government control, capacity to access territory to conduct public health operations. Inverse value is taken, to penalize more violent states.	UN Office on Drugs and Crime, estimates of intentional homicides per 100,000	http://data.worldbank.org/indicator/VC.IHR.PSRC.P5
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Sub-index 4: Economic resources

Indicator	Concept	Source(s)	Link
Gross Domestic Product	Aggregate national resource base	World Bank World Development Indicators (GDP, current USD)	http://data.worldbank.org/indicator/NY.GDP.MKTP.CD
Health spending per capita	Investment in health infrastructure	Health Expenditure per capita (current USD), World Health Organization Global Health Expenditure database	http://data.worldbank.org/indicator/SH.XPD.PCAP/countries
GNI per capita	Aggregate national resource base	GNI per capita, purchasing power parity (current international \$), World Bank, International Comparison Program database.	http://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD/countries
Government revenue as a share of GDP	National capacity to generate domestic revenues and resources	World Bank, generated from estimates by the International Monetary Fund, Government Finance Statistics Yearbook and data files, and World Bank and OECD GDP estimates. Heritage Foundation Index of Economic Freedom, CIA World Factbook	http://data.worldbank.org/indicator/GC.TAX.TOTL.GD.ZS
Resource rents as share of GDP	Vulnerability of economy to commodity price shocks. (Inverse value is taken, to penalize more resource-dependent states.)	World Bank	http://data.worldbank.org/indicator/NY.GDP.TOTL.RT.ZS

Sub-index 5: Public health communications

Indicator	Concept	Source(s)	Link
Primary education completion rate	Public education and scientific literacy, and probability of understanding government risk communications	Primary completion rate, UNESCO Institute for Statistics.	http://data.worldbank.org/indicator/SE.PRM.CMPT.ZS
Risk communications	Government capacity to disseminate public health information to the public	World Health Organization International Health Regulations Core Capacities Score. Global Health Security Agenda capacity assessments	http://apps.who.int/gho/data/view.main.IHRCTRY06v

2. Delphi panel selection and composition

Defining appropriate expertise and sampling accordingly is critical for the reliability and validity of a Delphi process. Experts were recruited via a multi-stage process. First, a review of the literature on outbreak detection and response was conducted, in order to identify relevant types of expertise. These were determined to include clinical medicine, epidemiology, health system capacity building, outbreak or humanitarian response, and quantitative/statistical analysis. A second stage identified additional characteristics relevant to the development of a global index, which included research experience, and work experience in a diverse range of geographies and social contexts, notably within resource-constrained settings. In order to mitigate against disciplinary biases—specifically, the tendency to limit consideration of non-health system factors—experts were sampled within the strata identified above, in order to create a balanced panel. Key Delphi panel characteristics are presented in Table 2.

Supplementary Table 2. Characteristics of Delphi panel

Advanced degree	11/11 (100%)
PhD or DVM or MD	9/11 (81·8%)
Clinical medicine experience	4/11 (36·4%)
Experience in epidemiology	10/11 (90·9%)
Outbreak response experience	5/11 (45·5%)
Health system capacity building experience	7/11 (63·6%)
Work experience in developing countries	9/11 (81·8%)
Experience in statistical analysis	11/11 (100%)

3. Results

Countries and territories excluded from the EPI

Several types of countries and territories were excluded from the EPI, primarily because of sparse or unreliable data. Three types of areas were excluded: political dependencies of other sovereign states that hold responsibility for basic governance and public health functions, sovereign states with sparse statistical coverage, and territories with unsettled international status or borders.

Supplementary Table 3. Countries and territories excluded from the EPI

Reason for exclusion	Countries and territories excluded from the Index
Dependency or subnational area of a sovereign state	Aruba, Anguilla, Aland Islands, American Samoa, Bermuda, British Virgin Islands, Cayman Islands, Christmas Islands, Cocos (Keeling) Islands, Cook Islands, Curacao, Faeroe, Falkland Islands, French Guiana, Gibraltar, Guernsey, Greenland, Guadeloupe, Guam, Isle of Man, Jersey, Hong Kong, Macau, Martinique, Mayotte, Miquelon, Niue, Norfolk Island, Northern Mariana Islands, Puerto Rico, Reunion, St. Barthelemy, St Maarten, Svalbard Islands, Turks and Caicos, Virgin Islands (U.S.), Wallis and Futuna Islands
Limited coverage in cross-national statistics	Andorra, Cyprus (Northern), Democratic People’s Republic of Korea (North Korea), Kosovo, Kiribati, Liechtenstein, Marshall Islands, Montserrat, New Caledonia, Solomon Islands, Monaco, Nauru, Niue, Palau, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Republic of China (Taiwan), Timor-Leste (East Timor),
Territory or state with unsettled status or borders	Sahrawi Arab Democratic Republic (Western Sahara), Kosovo, Palestinian Territories (West Bank and Gaza Strip), Somaliland

Evaluation: Comparison to Existing Metrics

International Health Regulation (IHR) Scores

Data were queried on 06/27/2017 from the World Health Organization Global Health Observatory data repository (<http://www.who.int/gho/database/en/>), which maintains a repository of IHR core capacity scores from 2010-2016.

The latest data were extracted for all indicators. The full set of IHR core capacity indicators includes the following metrics:

- Legislation
- Coordination
- Surveillance
- Response
- Preparedness
- Risk Communication
- Human Resources
- Laboratory
- Zoonosis
- Food safety

Each country’s composite IHR score was estimated by taking the average (mean) of these indicators.

The median composite IHR score was 81.4 (Interquartile Range [IQR]: 67.7 – 93.6). Ten countries had perfect composite IHR scores.

Joint External Evaluation (JEE) Scores

Data were queried on 08/30/18 from Prevent Epidemics (<https://preventepidemics.org/about/>), which coded data from all completed and publicly available JEE mission reports, 66 of which were available in total (not including a subnational JEE assessment undertaken for Zanzibar, Tanzania) (<http://www.who.int/ihr/procedures/mission-reports/en/>). The mission reports which contain narrative analysis and scores for each JEE indicator. JEE indicator scores range between 1-5. A composite JEE score was computed in the same fashion as the IHR scores discussed above, by taking the mean of all indicators. The composite average JEE score was rescaled (multiplied by 20), yielding an indicator with a range of 0-100. This enables a direct comparison to the IHR and EPI scores, which also range between 0-100.

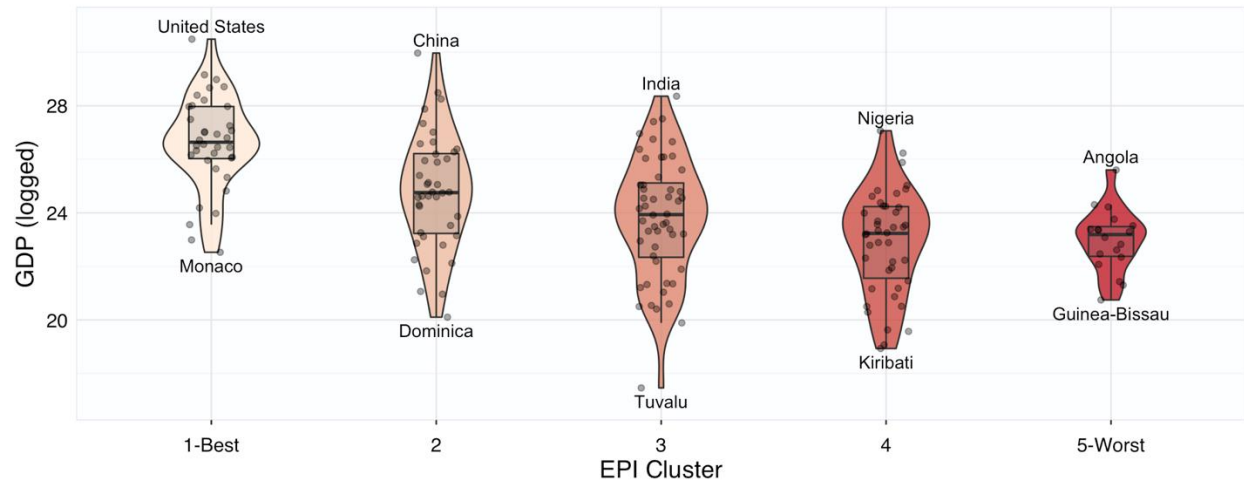
Supplementary Table 4. Correlation matrix of Epidemic Preparedness Index (EPI), International Health Regulation (IHR), and Joint External Evaluation (JEE) Scores

	EPI	IHR	JEE
EPI	1		
IHR	0.7326	1	
JEE	0.8516	0.6216	1

Gross Domestic Product (GDP)

Because economic resources are often used as a proxy for epidemic preparedness, we first assessed the association between EPI and Gross Domestic Product (GDP). As the high level of dispersion in Supplementary Figure 1 indicates, there is substantial variation in GDP within EPI clusters. We find that GDP dispersion overlaps across all EPI clusters, indicating that performance in epidemic preparedness cannot be inferred from economic resources alone.

Supplementary Figure 1. Epidemic Preparedness Index (EPI) cluster by log of gross domestic product.



Evaluation of the Epidemic Preparedness Index

In the context of epidemics and pandemics, preparedness can be evaluated by assessing a country's ability to detect, communicate about, and respond to infectious disease threats. Therefore, the association between EPI cluster and preparedness was evaluated by the speed of outbreak reporting and the percent of population vaccinated during the 2009 influenza pandemic. All statistical analyses were conducted using the R statistical software.

Detection: Outbreak Report Timeliness

We collected and analyzed publicly-accessible World Health Organization records of Disease Outbreak News (WHO DON) reports based on WHO-confirmed outbreaks occurring between 1996 and 2016. WHO DON reports are widely regarded as one of the primary international sources for reporting of high profile events across that time period. The outcome of interest was time elapsed between the "initial event date", defined as the earliest of either first case onset or case detection, to the date of first WHO report issued for each country/outbreak. This metric captures country reporting capacity, because DONs are issued on the basis of reporting from Ministries of Health. Similar to previous studies, we excluded outbreaks based upon the following criteria: outbreaks missing dates of discovery, outbreaks where date reported was equal to the date of earliest case detection, single or no cases, and outbreaks falling within the categories of toxin/chemical/seasonal/foodborne/unknown pathogens.

To evaluate the association between EPI cluster and outbreak reporting timeliness, we performed exploratory data analysis on the median time until outbreak report. In addition, we constructed a multivariate Cox proportional hazards regression model with the time until outbreak reporting as the outcome, EPI cluster values as dummy variable predictors (in reference to the most-prepared EPI cluster) and the year the event started as a covariate, to control for unobserved, time-variant factors which might influence reporting dynamics.

Public Health Response: Vaccination during the 2009 Influenza Pandemic

One important aspect of public health response corresponds to the ability to acquire, distribute, and administer vaccines during epidemics and pandemics. To evaluate a country's ability to administer vaccines during a pandemic, we performed exploratory data analysis and created a linear regression model predicting a country's percent of population vaccinated as a function of EPI cluster compared to the best performing EPI cluster. The three datasets used correspond to the final vaccine vaccinated proportion of the population as reported by national health authorities (see references 23–25). Vaccine uptake was measured as the number of administered doses as percent of population during the 2009-2010 influenza pandemic.