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Strengthening health security through routine vaccination policy: A comprehensive analysis of childhood vaccination laws across 194 countries

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ABSTRACT

Background: Vaccine preventable diseases (VPD) present a resurgent threat to global health security and jeopardize decades of advancements in public health and economic development. Since 1974, childhood vaccinations are estimated to have prevented 154 million deaths from VPD, yet recent declines in routine vaccination rates highlight the global population's growing vulnerability to these diseases. When paired with appropriate access to healthcare and trusted information, evidence informed enforceable policies have demonstrably improved childhood vaccination rates in countries that have recently implemented more stringent laws on routine vaccination. Here we comprehensively map and describe the current legal environment for childhood vaccination.

Methods: We conducted a comprehensive analysis of the childhood vaccination-related policies in 194 countries. Policies were systematically identified, collated, and categorized into a publicly available tool.

Results: A total of 106 countries have legally-enforceable policies requiring vaccination for at least one disease. We found that vaccines against diphtheria, measles, and tetanus were the most universally mandated, while vaccines against COVID-19 and Japanese Encephalitis were mandated by the fewest countries. In 91 countries, childhood vaccination requirements are enforced through either legal sanctions, such as monetary fines or incarceration, through exclusion from congregate settings, or through some combination of the two.

Conclusion: Analyses of the efficacy of childhood vaccination laws are predicated upon a comprehensive mapping of the current legal landscape related to routine immunization. Public health officials and researchers with an interest in increasing routine childhood vaccination rates in their country must know what characteristics of policy have been effective across various contexts. Our mapping of legally-enforceable childhood vaccination policies is foundational for assessing current vulnerabilities to vaccine-preventable diseases and future policy analyses.

1. Background

Vaccine preventable diseases (VPD) present a resurgent threat to global health security and jeopardize decades of advancements in public health and economic development. Since 1974, an estimated 154 million lives have been saved globally due to routine childhood vaccinations, a significant proportion of those in children under the age of 5 [1]. In the United States alone, since 1994, nine routine childhood vaccinations have prevented a predicted 508 million lifetime cases of VPD, and averted over 1 million premature deaths [2]. These vaccinations also generated significant economic benefits, directly saving over $780 billion USD and nearly $3 trillion USD in societal costs, such as lost wages resulting from vaccine-preventable disease (VPD)-related morbidity and mortality [2]. The substantial direct and indirect cost savings have rendered routine childhood vaccination one of the most cost-effective public health interventions implemented in the United States [2–4].

Despite the demonstrable benefits of routine vaccination, regional variation in vaccine uptake trends have highlighted ongoing challenges to ensuring adequate global childhood vaccination coverage over the past decade. Between 2010 and 2019, significant increases in vaccine coverage were reported in Sub-Saharan Africa and India driven by improved access to routine vaccinations. Despite these gains, the majority of children that have never received a vaccine are clustered within 10 countries in the world, including in the highly populated nations of Nigeria, Brazil, and the Philippines [5]. In most of these countries, the

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proportion of unvaccinated children has increased since 2010 [5]. During this time period, significant decreases in vaccine uptake were also observed in Europe, Central and South America, and the Western Pacific. These negative trends are likely context-dependent, stemming from factors such as limited access to vaccines, logistical supply challenges, or parental vaccine hesitancy fueled by misinformation or distrust [6–11].

The COVID-19 pandemic exacerbated the factors contributing to diminished childhood vaccination coverage. While routine childhood vaccination rates dropped globally by an average of 1–3 % between 2019 and 2022, low-and middle-income countries (LMICs) experienced the most significant decreases, with some experiencing year over year vaccination coverage rates dropping by 7–10 % [12]. Based on these trends, it is likely that supply-side factors such as a lack of access to routine vaccines due to quarantine measures and the international focus on COVID-19 vaccinations, coupled with demand-side factors, such as decreased vaccine confidence driven by mis- and disinformation, hindered childhood vaccination coverage during the pandemic.

Declining vaccination rates threaten both individual and societal health. In addition to protecting individuals, routine childhood vaccinations generate positive externalities, such as herd immunity, which protects individuals who cannot be vaccinated for medical reasons by reducing the spread of infection within the community [13]. In 2019, more than 200,000 people died from measles, and nearly 870,000 cases were reported. This marked a 50 % increase in measles-related mortality since 2016 and the highest number of cases reported to the WHO since 1996, driven primarily by declining vaccination coverage [14–16]. These outbreaks of VPD, which are fueled by inadequate routine vaccination rates, highlight the need for interventions to restore high vaccination coverage.

When paired with appropriate access to healthcare and trusted information, evidence-informed enforceable policy has demonstrably improved vaccination rates in countries that have recently implemented more stringent policies on routine vaccination [17]. For example, after facing outbreaks of VPD in 2017 and 2018, the Italian and French governments bolstered existing laws mandating routine vaccination for children entering schools by increasing the number of required vaccines. Within two years, rates of vaccination against measles, a disease for which vaccination had been made mandatory by the Italian and French legal reforms, had risen nearly 6 % in Italy, and 3–4 % in France. These results suggest that the changes to these laws played a role in the increased vaccination uptake [18–20]. However, coercive measures will likely vary in success across different socio-political and cultural contexts. Moreover, in some instances, their usage may foment vaccine hesitancy and exemption-seeking behavior, suggesting that such policies must take into account relevant contextual and cultural factors [10,11].

When permissive nonmedical exemption (NME) provisions are included in vaccination laws - allowing parents to opt out of routine vaccination for ideological reasons - the enforcement mechanisms in these mandates may be made irrelevant. These provisions offer vaccine-hesitant individuals a legal means to remain unvaccinated without facing consequences [21]. California's decision to abolish new NMEs to vaccination decreased exemptions granted by 2.5 % within one year. Since exemptions and vaccination rates are inversely related, these findings suggest that removing the NME provision would have led to a corresponding 2.5 % increase in vaccination rates [22].

Here, we present our efforts to comprehensively map and characterize the current legal environment surrounding routine childhood vaccinations globally. We describe patterns in which vaccinations are legally mandated, how such mandates are enforced, and where exemptions are permitted. Such descriptive data lays the foundation for future analyses of which legal frameworks are most effective, and under what circumstances, in enhancing vaccination coverage and bolstering health security by mitigating the spread of vaccine-preventable diseases.

2. Methods

2.1. Project scoping and nation inclusion

We analyzed routine childhood and emergency vaccination policies for 192 of the United Nations (UN) Member States [23], as well as the Holy See (Vatican City) and Taiwan. Previous analyses of vaccination policies focused on mandates within individual countries or geographical regions. This project represents the most comprehensive mapping of legally-enforceable childhood and emergency immunization policy to date.

The vaccination datasets described here are just one facet of the Analysis and Mapping of Policies for Emerging Infectious Diseases (AMP-EID) research effort, which created a novel, open-access database of policies across various topics with implications for international health security [24]. Across the project, we employed a standardized operating procedure (SOP) for data collection. The SOP included a literature review to develop appropriate search terms for the topic's policy collection protocol. After the completion of the childhood and emergency vaccine literature reviews, we conducted a proof-of-concept study of ten geopolitically and economically diverse countries to test the methodology and determine a final series of query terms to be employed across each of the two dataset collection efforts. After proof-of-concept, we reviewed and resolved gaps in the policy collection protocols and coding methodology. We then created the customized data taxonomy (**Supplementary Fig. 1**).

2.2. Definitions

Only legally-enforceable policies were included in the study. To capture the diversity of ways in which countries codify their rules and regulations, policy was conceptualized broadly to describe a legally-binding document produced by a competent governing authority to control the conduct of individuals and entities within their jurisdiction (**Supplementary Table 1**). For this work, we categorized legally-binding policies as those that included specific enforcement mechanisms in the document or associated with a penal code that could be used to require parties within the jurisdiction to comply with the document contents.

Conceptualizations of vaccination mandates vary significantly across nations and regions. However, this work required a standardized definition for systematic application across all contexts included in this analysis. We therefore defined mandatory vaccination policy as a legally-enforceable rule by which individuals are mandated to be vaccinated or to have their dependents vaccinated against one or more diseases.

For this research, we included only policies that were legally-enforceable, meaning they were both valid and capable of being enforced, either through criminal or civil actions. Separately, we evaluated enforcement mechanisms, which we defined as language included in a policy or associated penal code outlining a consequence specifically designed to punish noncompliance with vaccine mandates. Thus, legally-enforceable policy is a prerequisite for an enforcement mechanism, however specific provisions within an enforceable policy can lack a clear mechanism for enforcement.

We distinguished between routine childhood vaccination and emergency vaccination. Routine childhood vaccination refers to immunizing individuals legally classified as children at regular intervals for specific diseases, following internationally recognized best practices [25]. In contrast, emergency vaccination refers to immunization efforts initiated in response to an acute threat, such as conflict, natural disasters, or high-risk disease outbreaks, and may target the entire population rather than a specific demographic group.

Policies solely designed to mandate emergency COVID-19 vaccination have been previously documented and were beyond the scope of this work [26,27]. However, if COVID-19 vaccine requirements had

been incorporated into routine childhood vaccination mandates at the time of data collection, those requirements were captured. Similarly, some policies apply exclusively to certain professional groups, such as healthcare workers or military personnel. Due to their limited focus, mandates targeting only these groups or exclusively addressing COVID-19 are not included in our database.

2.3. Identification of relevant policies

To collate a comprehensive dataset, we developed a standardized policy identification protocol to identify relevant policies across all countries. For each country, we began by running a review of peer-reviewed publication repositories by running a series of queries through the search function (**Supplementary Fig. 2**). All relevant articles were reviewed to identify policies related to childhood and/or emergency vaccination. The potentially-relevant policies referenced in these articles were then downloaded from the country's legal repository and included for further analysis. After review of available peer-reviewed literature for each country, we conducted a manual search in the Google search engine using an expanded set of query terms (**Supplementary Fig. 2**). To ensure comprehensive inclusion of potentially relevant policies, we finally undertook a manual search of the national government's legal database, where possible. If a legal database maintained on a country domain was available and open-access, all potentially relevant policies, identified by utilizing the query terms described above, were captured for further review.

Throughout policy identification, all searches were first conducted in English. For countries that conduct government in a language other than English, a machine translator was used to translate each query into the language primarily used by the central government in the target country. Once all potentially relevant policies from a country were identified, we used Google Translate to complete translation of policies in languages not spoken by any members of the research team. Where ambiguity in the meaning of a policy provision occurred, due either to the machine translation or to cultural interpretation of the policy, fluent speakers of these languages and subject matter experts were contacted to validate the translations.

In the case that no relevant policies were identified for a country during this standardized collection protocol, we coded that country under the general vaccination dataset as "No routine childhood vaccinations legally required" (**Supplementary Fig. 1**). Notably, although we identified all legally-enforceable policies in a country, we did not study the extent to which identified policies were implemented or enforced in that country. Therefore, it is likely that the execution of legally-enforceable policies may be inconsistent with their mandate.

2.4. Creation of the database and inclusion criteria

Potentially relevant policies identified through the standardized collection process were subject to a preliminary screening to eliminate documents that were not legally binding or were no longer enforceable. Therefore, strategies, plans, and other documents outlining future actions of the national government or suggesting criteria for the development of legally-binding policies were excluded from this research effort. Similarly, documents codifying country participation in the World Health Organization's Essential Programme on Immunization (EPI) [28] or other similar vaccination campaigns are not legally-binding for citizens and were therefore excluded from this database.

While the AMP-EID project has exclusively examined national level policies in the past, for this research effort, any country found to mandate childhood or emergency vaccinations universally at the subnational level was coded as having a legally-enforceable policy. This was verified through the identification of national-level policy devolving power over the specified sector to a subnational governing body. Countries in which enforceable vaccination mandates are not universally in place across subnational jurisdictions, were coded as having no relevant policy.

Policies that passed preliminary screening were reviewed in accordance with the standardized inclusion criteria (**Supplementary Table 2**). Policies that met the inclusion criteria were categorized into the customized data taxonomy and countries were assigned an applicable status for each subtopic (**Supplementary Fig. 1**). Policies were then downloaded as PDFs and collated in Airtable, a cloud-based platform for relational databases.

2.5. Data validation

Literature review, collection protocol, and inclusion criteria were reviewed by the entire research team and approved by the Principal Investigator. Policy collection and primary review by inclusion criteria were completed by a lead researcher. Once included in the database, a second member of the research team completed a secondary review of policies, assessing the primary researcher's coding. Any coding discrepancies that arose between researchers were deconflicted and reviewed by the Principal Investigator.

For quality assurance and control, after secondary review and reconciliation, we then used Perplexity AI, a generative artificial intelligence (GAI) chatbot powered by a large language model, to assess the concordance of the results. Any results that were nonconcordant between the research team's assessment and the GAI tool results were reviewed by the Principal Investigator and further reconciled based upon the available information and the inclusion criteria [29].

2.6. Policy analysis

All validated policies categorized according to the standardized data taxonomy were further sorted by policy type (**Supplementary Table 3**). Policy contents were reviewed for identification of the diseases for which children were required to be vaccinated. For legally-enforceable policies that require a government ministry to produce an annual vaccine schedule aligned with the law, we surfaced the latest publicly-available version of this document for analysis of required vaccinations. For the United States, which is the only country in which vaccinations are universally required at the subnational level, yet vary across jurisdiction, only those vaccines required in all 50 states for children were included as a nationally required vaccine.

3. Findings

We found that 54.1 % (105) of countries studied currently have legally-enforceable policies at the national level requiring childhood vaccination against at least one disease. One country, the United States, universally mandates routine vaccination of children for at least one disease across all subnational jurisdictions and was therefore included in our analysis as a nation with a nationally applicable vaccination requirement, bringing our total number of countries with a routine vaccine mandate to 106 (54.6 %) (Fig. 1**)**. While the majority of countries have a mandate for children to be routinely vaccinated, we identified significant variation in the types of policies used to mandate vaccination, the diseases for which vaccinations are required by law, and the characteristics of penalties associated with non-compliance with the law. Moreover, we found that the contents of the policies varied greatly between World Health Organization (WHO) regions, suggesting that cultural beliefs and socio-political factors are reflected in the policies themselves.

3.1. Policy characteristics

The vast majority of countries regulate childhood vaccination at the national level (105/109), with a few notable exceptions. In the United States, vaccinations are universally mandated by state level governments in all 50 states. By contrast, provincial governments in Pakistan

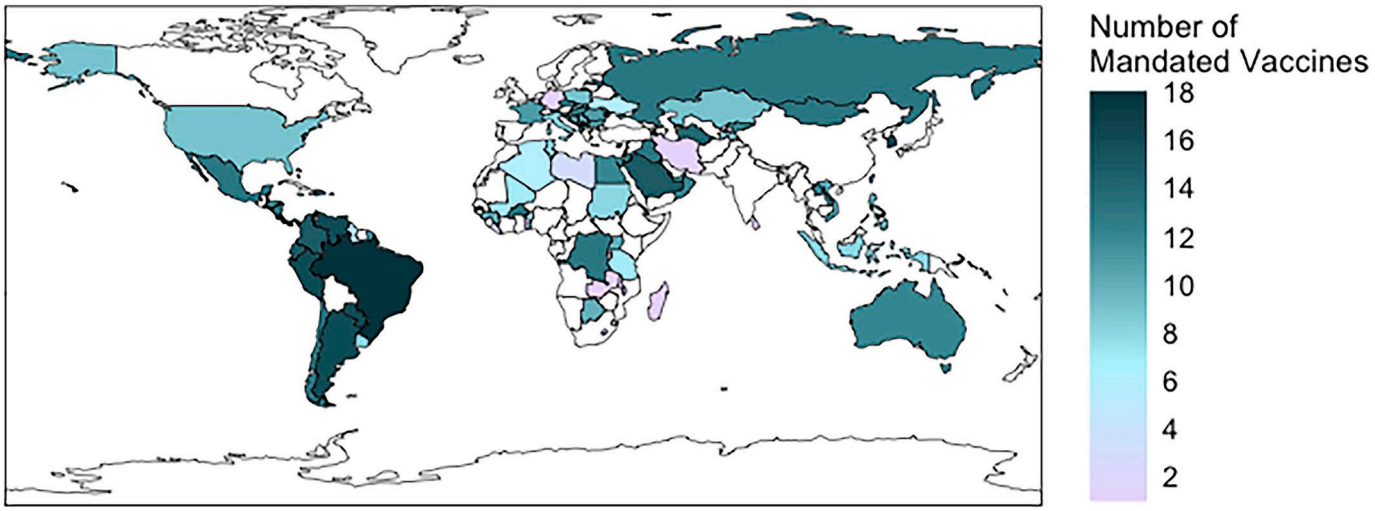

Fig. 1. World choropleth map of the number of diseases against which children must be vaccinated under legally enforceable policy. Vaccinations required against particular diseases were extracted by policy review. Diseases for which vaccinations are required were counted individually and therefore do not necessarily correspond to current vaccine formulations. Countries in white do not mandate routine childhood vaccination against one or more diseases in national policy, but may have subnational requirements that are not universally applied across the country.

and Canada are responsible for mandating vaccination, yet these subnational governing bodies have not universally adopted legally-enforceable vaccine policy. For example, Ontario, New Brunswick and Manitoba are the only Canadian provinces with vaccine requirements [30]. In Nigeria, while the 2003 Child Rights Act specified that children had a right to vaccination, the policy has not been universally adopted across all 36 states, and, as such, is not enforceable across all subnational jurisdictions [31].

For countries that have national routine childhood vaccination mandates, we found that general public health laws were the type of policy most often used to implement this requirement. General public health laws were used by 38.1 % (40/105) of countries with national routine vaccine mandates to document the requirement. 34.3 % (36/105) of countries employed national laws on vaccination to outline routine immunization mandates, while a further 23.8 % (25/105) used broader communicable disease laws. Less commonly, laws unrelated to health were used to document routine vaccination requirements. A total of 6 nations (5.7 %) used laws related to children's rights to document mandatory vaccinations. The majority of countries that include such mandates in children's right laws were clustered in the Eastern Mediterranean WHO region. Two countries (1.9 %), both located in the Caribbean, include childhood vaccination requirements in laws related to education, while one nation (0.95 %), Australia, includes routine vaccination mandates in the tax code.

3.2. Diseases for which routine vaccines are mandated

We found that the total number of routine childhood vaccinations required under legally-enforceable policy ranged from 18 in Brazil to just 1 in fourteen countries. Twelve countries require 15 or more routine vaccinations for children under the age of 18. Of these countries that mandate 15 or more vaccinations, 83.3 % (10/12) are in Central or South America. By contrast, those with one mandated vaccination tended to be located in Sub-Saharan Africa or the Caribbean (71.4 %; 10/14) (Fig. 1).

Diphtheria vaccination was the most universally mandated immunization, with 85 countries (80.2 %; 85/106) enforcing vaccination requirements for children. Routine immunizations against measles, tetanus, polio, and pertussis were also widely mandated, with enforcement rates ranging from 79.2 % (84/106) to 72.6 % (77/106) among countries with vaccination mandates (Fig. 2). Countries that had a mandate for children to be routinely vaccinated with at least one vaccine, yet did not include any of the five most universally required vaccines, tended to be clustered in Sub-Saharan Africa (5/12) and the Caribbean (5/12).

Vaccines against COVID-19, Japanese Encephalitis and meningococcal disease were required by law in at least one country, but were the least universally mandated (Fig. 2). Routine childhood vaccinations against COVID-19 were required in 3 countries (3 %), all of which were in the WHO Pan American Region, governed by the Pan American Health Organization (PAHO). The three nations that had included this requirement for COVID-19 vaccination utilized a change in the a legally-enforceable vaccine calendar set by the Ministry of Health annually, as opposed to changing an underlying law to include the new vaccination. Likewise, routine immunization against Japanese Encephalitis was mandated in 4 countries, all of which were in the Western Pacific or South-East Asian WHO regions.

Requirements for vaccinations against smallpox were found to remain in legally-enforceable laws of 15 nations. In 66.7 % of these countries (10/15), vaccination against smallpox was the only vaccine required by law.

We observed significant regional clustering in the mandates for vaccination for certain diseases. While requirements for measles, diphtheria and polio, all of which are vaccinated for using different vaccines, were evenly distributed across regions, countries with mandatory vaccination against tuberculosis and varicella varied geographically. Requirements for vaccination against Tuberculosis were concentrated in countries in Eastern Europe, Africa, and South and Central America. By contrast, countries that require vaccination against varicella (chickenpox) were highly concentrated in the Western Hemisphere (Fig. 3).

3.3. Enforcement mechanisms in vaccination policy

We found that 87.7 % (93/106) of countries with legally-enforceable routine vaccination policies include specific enforcement mechanisms to ensure compliance with immunization requirements, though there was significant diversity in enforcement mechanisms. The thirteen nations that have legally-enforceable vaccination laws, but do not outline specific penalties for failure to comply with mandatory vaccinations are not regionally clustered. However, all but one of these countries were classified as a Low-and-Middle Income Country (LMIC) by the World Bank.

Legal sanctions, which could include financial penalties and/or incarceration of parents that refuse to comply with vaccination

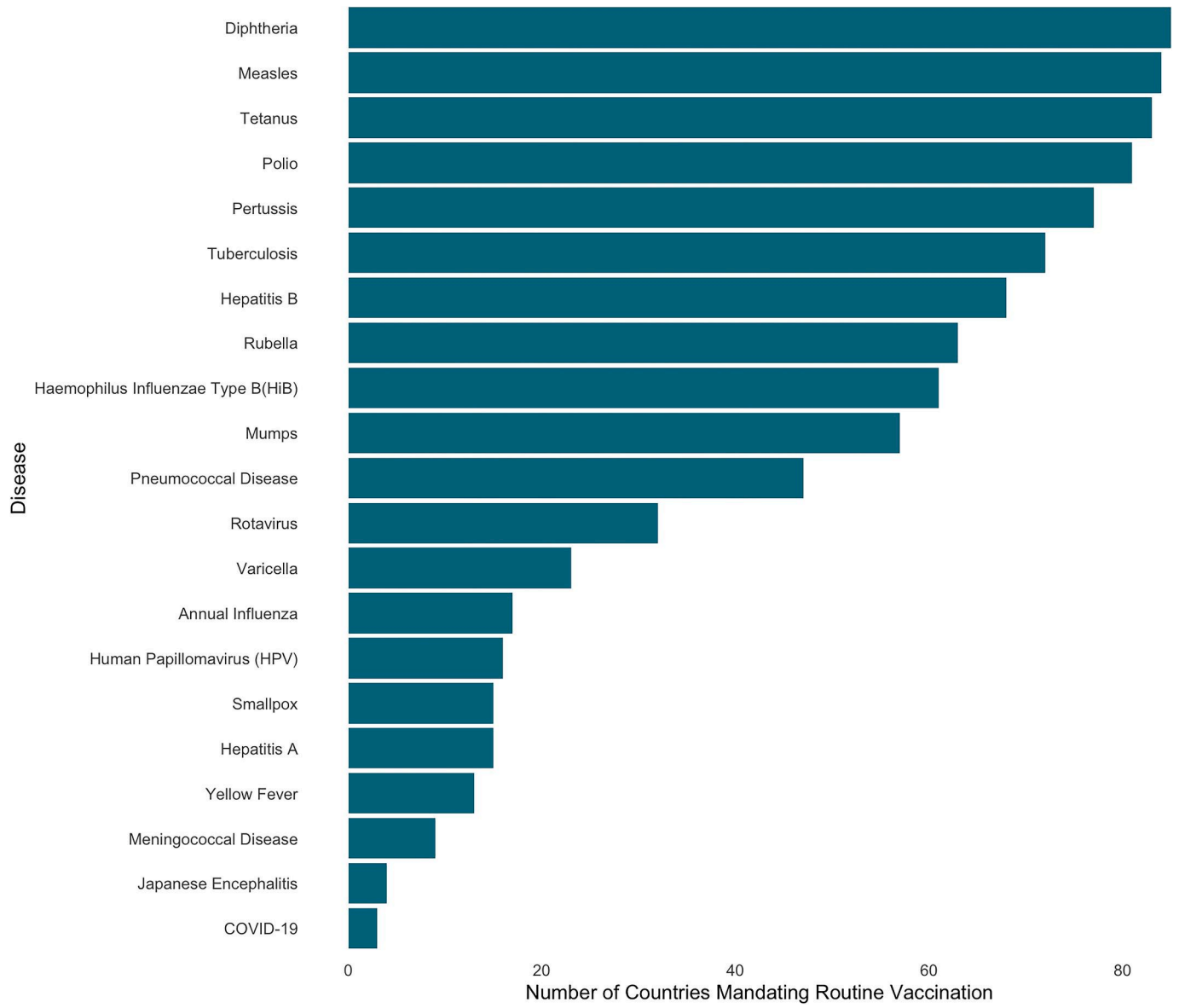

Fig. 2. Diseases for which routine childhood immunization is required under legally-enforceable national policy. Disease data were extracted manually from applicable policy by CMW and processed in R.

requirements, were the most used enforcement mechanisms in countries with childhood immunization mandates. In the 40 countries that utilize legal sanctions either independently or in concert with other enforcement mechanisms, 83.3 % (50/60) explicitly define the value of penalties associated with noncompliance. Maximum monetary penalties that may be assigned for failure to comply with vaccination mandates were found to range from $0.04 USD in Sri Lanka to $60,552 USD in Chile. Four countries listed monetary penalties in obsolete currency. Of the ten nations that did not explicitly assign monetary penalties for noncompliance, seven allowed the undefined fine to be decided on a case-by-case basis in the judicial system, while the remaining three nations allowed a child to be removed from parental care due to criminal negligence.

Social exclusion, which was defined as any enforcement mechanism that barred unvaccinated children from participating in communal activities or otherwise participating in societal processes, were found to be used in 48 countries with legally-enforceable childhood vaccination mandates. In all countries, social exclusion is used to preclude unvaccinated children from attending a congregate childcare center or an educational institution. In the case of Argentina, however, social exclusion is also used to bar unvaccinated individuals from receiving critical paperwork, including passports and driver's licenses.

One country solely employed enforcement mechanisms other than social exclusion or legal sanctions. Australia utilized financial levers to penalize the parents of unvaccinated children by stipulating in the tax law that families in which all children were not appropriately vaccinated would not receive the standard family tax subsidies. Argentina and Brazil similarly utilized tax subsidies to incentivize individuals to comply with vaccination mandates, in addition to social exclusion and legal sanctions.

We found that the remaining 19 countries used some combination of legal sanctions, social exclusion and/or some other method to enforce vaccine mandates. Moldovan law states that while unvaccinated children may be excluded from schools, in the case that the child transmits a VPD, the parents may be held financially responsible for the treatment of all individuals infected by the unvaccinated child. Finally, laws in Hungary, Mexico and Venezuela reserve the right for the government to forcibly vaccinate noncompliant individuals, in addition to other legal sanctions.

Legal sanctions were found to be most prevalent in policies from

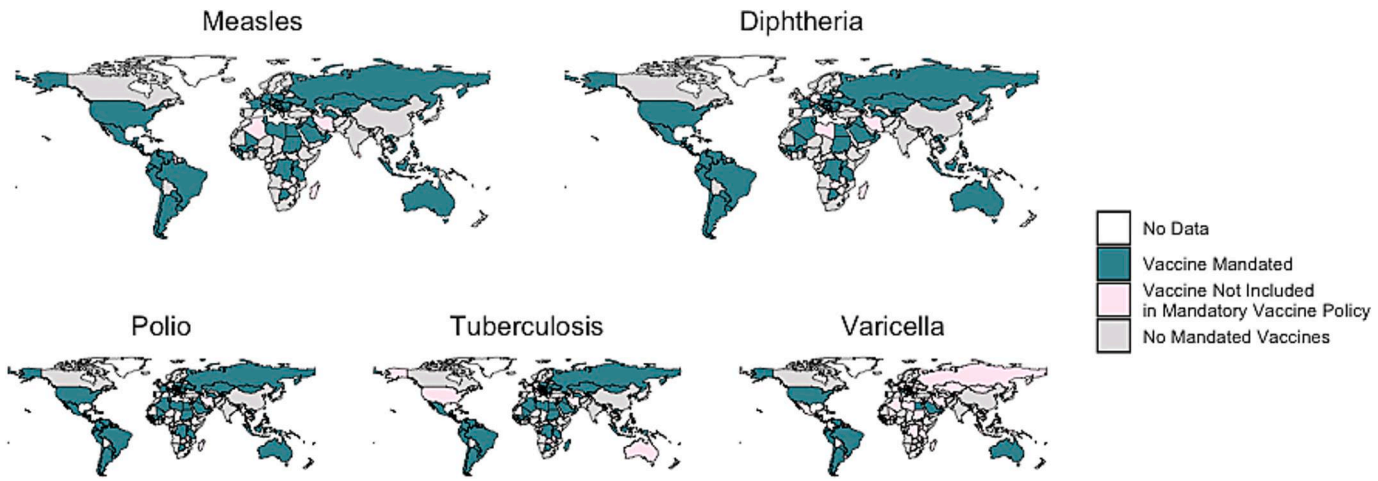

Fig. 3. Countries with vaccine mandates for specific diseases demonstrate geospatial clustering. Data processing and figure creation completed in R. Mapping layer utilized rnaturalearth package [32].

LMICs, while social exclusion tended to be more readily in laws from high income countries. There was not significant regional clustering found by enforcement mechanism (Fig. 4).

3.4. Exemptions

We found that 72 % of countries have explicitly included medical or nonmedical exemptions to vaccine requirements in legally-enforceable policy. The remaining 28 % of countries with vaccine mandates did not have exemptions codified in relevant law. Of the 76 countries that have codified exemptions, 85.5 % (65/76) allow only for medical exemptions, while 10 countries (13.2 %) have explicitly or implicitly codified access to nonmedical exemptions. In the United States, nonmedical exemptions are legally permitted in the majority of states, though are not universally available in all subnational jurisdictions.

4. Discussion

When paired with equitable access to healthcare and trusted information, enforceable policies provide an opportunity to increase vaccination rates and improve health security. We found that, currently, 106 countries (54.6 %) have universally applied routine childhood vaccination mandates. However, there was significant diversity in the diseases against which citizens are required to be immunized, the mechanisms of enforcement used to penalize noncompliance, and the presence of exemptions from requirements. We also found that diseases for which vaccinations were required did not necessarily correlate with available vaccines. For example, in Singapore, the national law requires only vaccination against measles and diphtheria [33]. However, immunizations against these two diseases are currently offered in Singapore only in combinations, such as the measles, mumps and rubella vaccine (MMR) [34]. As such, in some countries while there are only some diseases for which vaccinations are de jure required, there may be broader de facto vaccine requirements.

Diseases which have historically caused significant morbidity and mortality and for which vaccines have long been available, such as diphtheria, measles, and polio were the most universally included in legally-enforceable policy. By contrast, recently emergent diseases, such as COVID-19, and diseases endemic to limited geographical regions, such as Japanese Encephalitis, were the least commonly included by law. We also found regional clustering of diseases for which vaccination is required, which may be attributable both to geospatially varied burden of disease and cultural perceptions of disease. For example, countries that required vaccination against tuberculosis tended to be

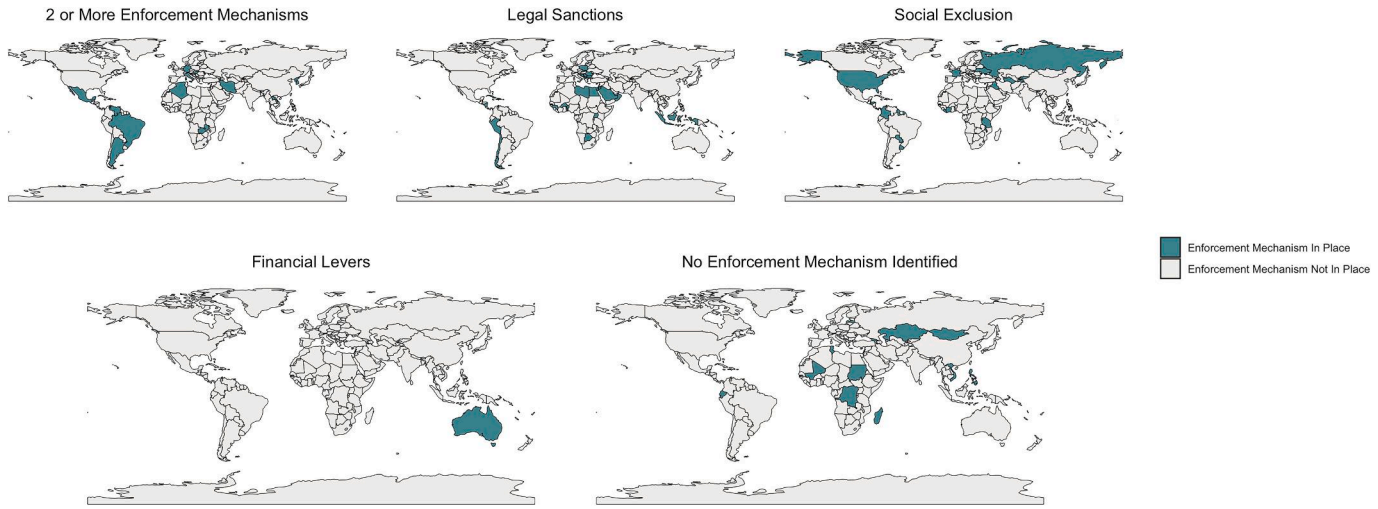

Fig. 4. Geographical distribution of enforcement mechanisms included in legally-enforceable vaccination policy. 2 or more enforcement mechanisms indicates that a country utilizes more than one category of enforcement mechanism to enforce the requirements of the policy. Data extracted by CMW and processed in R. mapping layer utilized rnaturalearth package [32].

located in Eastern Europe, Africa, and South and Central America, all regions that account for a significant burden of global tuberculosis cases. By contrast, vaccines for varicella (chickenpox) and the annual influenza vaccine were required almost exclusively in countries located in South and Central America and were notably excluded from vaccination mandates in Europe and Africa. These regional patterns may indicate differing cultural perceptions of the severity of disease in children caused by varicella and influenza.

Notably, variation in enforcement mechanisms was significant. Legal sanctions, including financial penalties and incarceration, as well as social exclusion, were the two most common enforcement mechanisms for individuals that violated childhood vaccination requirements. Occasionally, enforcement mechanisms were combined, suggesting that individuals in those societies would have greater incentive to comply with mandates in order to avoid penalization or that governments would have more opportunities to enforce the law.

Determining which enforcement mechanisms are the most effective requires determining how the strength of enforcement mechanisms differ across countries and which entities are required to enforce the policy. A standard financial penalty across countries will carry different weights across countries, particularly due to diversity in per-capita income, and may depreciate over time. In countries that have set the value of a monetary penalty at a certain point in time, the efficacy of this enforcement mechanism may diminish as inflation increases over time. Moreover, in all cases that employ monetary penalties to enforce vaccination, the government is responsible for carrying out enforcement actions and collecting funds from delinquent individuals, whereas the onus of enforcement of social exclusion provisions generally falls upon schools and nursery facilities. In both cases, while the majority of countries utilize the same categories of enforcement mechanisms, the effect of these penalties is likely dependent on government resources devoted to enforcement, incentives for schools to cooperate with enforcement requirements, and political will.

Despite the range of enforcement mechanisms included in policy, the number of policies that legally require vaccination against smallpox, a disease declared eradicated by the World Health Assembly in 1980, and that list financial penalties in obsolete currencies suggest a lack of enforcement or awareness of these policies in some nations. This may indicate a broader lack of enforcement of childhood vaccination laws, which has been demonstrated [21,35,36], particularly when there is little political will to penalize parents regarding this potentially fraught issue.

4.1. Limitations

Our work has important limitations. While we employed a standardized methodology, countries that do not have robust online policy repositories may not have been accurately represented in this study. Moreover, while we went to lengths to accurately translate identified policies, it is possible that interpretations of policies in foreign languages were inaccurate. This was particularly the case with disease names, as some languages do not differentiate between similar types of pathogens, such as poxviruses. Likewise, cultural understandings of 'mandate' may differ by nation. While we did not include childhood vaccination policies that suggested that parents *should* vaccinate their children, as is the case in Japan, we recognize that this may be interpreted as a requirement in certain contexts. Finally, this study has exclusively examined the legally-enforceable childhood vaccination policies in place globally, but implementation and enforcement of these policies, in practice, were not examined. For instance, while there are many nations with smallpox vaccination requirements, it is unlikely that such mandates continue to be enforced. Thus, in order for the completion of correlational or causal analyses between outbreaks of VPD or vaccination rates and legally-enforceable routine immunization policies, further exploration of policy implementation and enforcement is warranted.

5. Conclusion

VPD present a resurgent and growing threat to global health and action must be taken at the national level to mitigate this threat. Evidence-informed, legally-enforceable policy, paired with access to vaccination and trusted communication presents an option proven successful in some settings to bolster routine childhood vaccination rates. However, due to gaps in data availability, few studies have examined the effect of routine childhood vaccination laws in LMICs. In order to facilitate the analysis of such policies and inform their implementation, researchers and decision makers need to understand which policies currently exist across diverse geopolitical settings. Our global mapping of legally-enforceable policies related to routine childhood vaccination will serve as a foundation for further research on their effectiveness across settings.

CRediT authorship contribution statement

Ciara M. Weets: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rory Wilson:** Writing – review & editing, Validation. **Heather Swadley:** Writing – review & editing, Validation. **Rebecca Katz:** Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Rebecca Katz reports financial support was provided by The Rockefeller Foundation. RK is a member of the Technical Advisory Panel for the Pandemic Fund. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2025.127121.

Data availability

All datasets, reproducible code, and figures from this study are publicly available at https://github.com/cghss/Vaccination. This is expressed in the manuscript

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