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Assessing Child Health in India: Development and Validation of a Comprehensive Child Health Index

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Abstract

While developing a child health index is of interest, it is particularly important in the Indian context, because of a high burden of poor child health, the disparities in child health between different social, economic, and geographical regions and the absence of such a comprehensive index. This paper focuses on the development and validation of a Child Health Index (CHI) for India. Using publicly available data at the district level and principal component analysis, this index is composed of 16 variables representing six domains namely socio-cultural, child health status, determinants of child health (both risk and protective factors), household environment and health system and policy. Several statistical tests were conducted to provide internal and external validation. The application to predict child mortality confirmed its validation. This study thus provides a new tool for characterising child health and detecting child health inequalities at a district level in India. Consequently, it can be used by policymakers, health service providers and other stakeholders involved in child welfare to monitor and improve child health over time and space.

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Highlights

- The existing Indian health indices need a social determinant framework and inclusion of different stages of life.
- Proposed Child Health Index (CHI) is based on 16 indicators measuring parameters impacting birth, infancy, and childhood.
- CHI has a strong theory-base, uses reliable indicators representing various complexity of child health, at small geographical level, it is computed using a robust statistical methodology.
- CHI provides ranking for all districts of India. Based on the ranking policy makers can prioritize geographical areas for action and focus on indicators that falter in the area.

Keywords Child health · Health indicators · Index · Health determinants · India

1 Introduction

Recent development in the measurement of population health involves the creation of composite health indices which, as the name suggests, are composed of multiple indicators. These composite indicators provide a more holistic understanding of population health than measuring health based on individual indicators, such as mortality and morbidity rates. Many health indices have been created mainly in the developed countries (See Ashraf et al., 2019; Kaltenthaler et al., 2004; WHO, 2018 for a review of literature on health indices), leaving the global South, and especially India, without the benefit of such fine-grained measures. In India too, some attempts have been made to develop health indices targeted for India as whole and for different target groups (Sehgal et al., 2023).

Protecting and improving the health of children is vital not only for the long-term effects on their own health but also for the whole population and the health of the next generation (Rigby, 2005). It becomes additionally important because of their inability to 'act as self-advocates' (Rigby et al., 2003). It is well documented that child health is influenced by multiple factors. These factors include social determinants of health (e.g. socioeconomic conditions), health outcomes (e.g., infectious diseases) and health system characteristics (e.g., access to care) (Spencer, 2018; Tarazi et al., 2016; Marmot, 2005). A composite child health index developed from multiple indicators can help identify potential health disparities, pinpoint areas that need improvement, and set priorities for interventions. Additionally, this index can be used to monitor the effectiveness of interventions, track changes in health over time, and enable policy makers to make informed decisions based on accurate data.

While developing a child health index is of interest, it is particularly important in the Indian context, mainly because of the high burden of poor child health and the disparities in child health between different social, economic, and geographical regions. In addition, the bulk of research in this area has been carried out on European and US data (Köhler, 2016; Köhler & Eriksson, 2018; Rigby, 2005; Rigby et al., 2003; Moore et al., 2007). A composite child health index developed for use in a developed country may not be suitable for use in a developing country such as India due to the different factors that affect child health. In developing countries, access to healthcare and nutrition can be more limited, and poverty and inequality more prevalent, meaning that the factors that influence child health are more complex and varied (Balarajan et al., 2011; Goli & Arokiasamy, 2014; Goli et al., 2013; Kumar et al., 2013; Reddy, 2012; Pathak et al., 2010). The limited attempt in India has used a complex methodology and state level data (Satyanarayana et al., 1995). This may, in part, be due to the challenge of (1) collecting information at a smaller administrative unit such as the district level and (2) translating various child health domains into characteristics that can be measured. Thus, there is a paucity of examples that replicate the international experience of comprehensive indexes in the Indian context. Therefore, policy makers in India (and elsewhere) have an inadequate knowledgebase to draw on to make informed decisions.

In India, Satyanarayana et al. (1995) developed a comprehensive index, the Index of Child Mortality. The Index was designed for monitoring the health status of children for longitudinal assessment and comparison between states. Using data on five indicators (under-five mortality rate, infant mortality rate, neonatal mortality rate, perinatal mortality rate, and stillbirth rate) obtained from the Sample Registration System, and factor analysis, the index that provided a comprehensive picture of child mortality. While this was a good start in the development of an index for cross-sectional comparison across states and longitudinal monitoring of trends in child health status, many other indicators such as age-appropriate health morbidities (e.g., diarrhoea, acute respiratory illness), gender-based health inequities (e.g., immunisation), and accessing health service for children (e.g., post-natal care) were not included. Moreover, the tedious statistical computations prohibited the widespread use of this comprehensive index of child mortality.

Critical steps in the creation of any index is to: articulate why one indicator was chosen, a rationale articulating the link between indicators and the broader concepts they represent, the basis of those choices, and a consideration of the ease of computation (Köhler, 2016; McQuinn et al., 2020). Availability and accuracy of data is one of many considerations, but that must be embedded within a theoretical justification. In case of a child health index, the indicators should also represent 'different stages of early child development' (Kåks & Målqvist, 2021). Acknowledging the importance of local geography for public policy (Kim et al., 2019), it is important to measure the child health index at a low administrative unit such as districts. In India, any index based on an administrative unit above district level risks masking areas of disparity and diversity of need. It is equally important to measure the indicators using the same data set so that inferences can be drawn with confidence without ascribing the results to the differences in data quality and methods.

Using the latest round of nationally representative survey the National Family Health Survey (NFHS 5) in 2015-16, this paper presents the development and validation for a child health index for India (International Institute for Population Sciences, 2021). We examine the geographical variation in the Indian Child Health Index across 707 districts of India. Our choice of indicators was based on previous research on the child health and child health indices (Kåks & Målqvist, 2021; Köhler, 2016; Köhler & Eriksson, 2018; Rigby, 2005; Rigby et al., 2003;

Satyanarayana et al., 1995; Selmani et al., 2021; Moore et al., 2007; WHO, 2014a). While selecting the individual indicators, we also chose variables that we could measure and interpret objectively with a well-defined hypothetical relationship (either positive or negative) with the child health index.

2 Data and Methods

2.1 Data

This study involved analysis of district level information corresponding to households from the latest round of the NFHS-5. The district was chosen as a unit of analysis because of the large intra-state differences in child health across India (IIPS, 2017; Singh et al., 2011). Additionally, in India policies are implemented by the deputy commissioner in collaboration with the local Member of the State Legislative Assembly (Swaminathan et al., 2019) making the district level even more important for assessing the need for and impacts of health interventions.

The NFHS-5, the most recent wave in the NFHS series, is a nationally representative survey. It was conducted in all States and Union Territories using a format very similar to that of the Demographic and Health Surveys (DHS), modified to meet Indian conditions and the needs of policy makers and programme planners (International Institute for Population Sciences, 2021). The NFHS-5 covers all 707 districts as per the 2011 census of India and provides high-quality, up-to-date information on all the key variables. The survey covered a representative sample of 636,699 households, 724,115 women, and 101,839 men. This is a reliable data source, has been recently collected, and is used for planning and policy making by the government at the state and national level (International Institute for Population Sciences, 2021).

The survey was conducted by a non-government, independent institution. Hence, the reported data are less likely to be influenced by state administration or community level influences. Further details regarding the survey are available from National Family Health Survey, India (International Institute for Population Sciences, 2021).

2.2 Measures

We drew on the work done in Europe (Kåks & Målqvist, 2021; Köhler, 2016; Köhler & Eriksson, 2018; Rigby, 2005; Rigby et al., 2003), India (Satyanarayana et al., 1995) and recommendations from WHO (2014a) to incorporate some India specific indicators to reflect its developing country status (Table 1). While we retained all four domains (health outcomes, risk factors, protective factors, access and utilisation of care and support) with indicators specific to India from the European index, we included an additional domain (household environment). The main criteria for inclusion of indicators were: availability of data at the district level from the same data source to avoid quality bias, relevance for child health in the Indian context and repetition of the analysis over time to track changes

Table 1 Domains, selected indicators from NFHS 5, and corresponding life stages used for developing CHI for districts of India

Domains / Indicator	Description	Hypothesized direction of relationship with child health	Life stage		
			Birth	Infancy (0–1 month)	Early childhood (1–5 years)
Socio-Cultural					
Women's education	Women with 10 or more years of schooling (%)	+	×	×	×
Sex ratio	Sex ratio at birth for children born in the last five years (females per 1,000 males)	-	×		
Child health status					
Diarrhoea	Prevalence of diarrhoea in the 2 weeks preceding the survey (%)[a]	-		×	×
Acute respiratory infection (ARI)	Prevalence of symptoms of acute respiratory infection (ARI) in the 2 weeks preceding the survey (%)[a]	-		×	×
Health determinants- Risk factors					
Stunting	Percentage of children under 5 years who are stunted (%)	-		×	×
Wasting	Percentage of children under 5 years who are wasted (%)	-		×	×
Underweight	Percentage of children under 5 years who are underweight (%)	-		×	
Anaemic	Percentage of children aged 6–59 months who are anaemic (%)	-		×	×
Health determinants- Protective factors					
Breastfeeding	Children under age 3 years breastfed within one hour of birth (%)	+	×	×	×
Immunisation	Percentage of children aged 12–23 months fully immunised (%)	+	×	×	×
Household environment					
Drinking water	Percentage of household with an improved drinking water source[b] (%)	+	×	×	×
Toilet facility	Percentage of households with improved sanitation facility[c] (%)	+	×	×	×
Cooking fuel	Percentage of households using clean fuel for cooking[d] (%)	+	×	×	×
Child health system and policy					
Health insurance	Households with any usual member covered under a health insurance/financing scheme (%)	+		×	×

Table 1 (continued)

Domains / Indicator	Description	Hypothesized direction of relationship with child health	Life stage		
			Birth	Infancy (0–1 month)	Early childhood (1–5 years)
Postnatal care	Children who received postnatal care from a doctor/nurse/LHV/ANM/midwife/ other health personnel within 2 days of delivery (%)	+		×	×
Institutional births	Births taking place in institutions (%)	+	×		

[a]Limitation: indicator is affected by season of data collection

[b]Piped water into dwelling/yard/plot, public tap/standpipe, tube well or borehole, protected dug well, protected spring, rainwater, community RO plant

[c]Flush to piped sewer system, flush to septic tank, flush to pit latrine, ventilated improved pit (VIP)/biogas latrine, pit latrine with slab, twin pit/composting toilet, which is not shared with any other household

[d]Electricity, LPG/natural gas, biogas

in child health. Following Kåks and Målqvist (2021), we included indicators to represent different stages of child development, i.e., birth, infancy (1–12 months) and early childhood (1–5 years).

The six domains broadly capture a wide range of variables relating to socio-cultural, child health status, both protective and risk factors affecting child health, household environment and health system and services. Table 1 provides description of each indicator included in the index as well as the hypothesized direction of their association with the overall child health.

The first domain, *Socio-cultural*, includes variables which are proxies of socio-economic factors. There is empirical evidence indicating the importance of socioeconomic factors and material well-being for child health and in relation to accessing health services as well (Karlsson et al., 2020; Goli & Arokiasamy, 2014; Goli et al., 2013).

The second domain, *Child health*, includes the percentage of children with diarrhoea and with acute respiratory infection (ARIs). Childhood diarrhoea and acute respiratory infections are a major public health concern worldwide, leading to high mortality and morbidity in children under five (WHO, 2015). For example, globally, childhood diarrhoea is the second leading cause of mortality in children under five (WHO, 2018), while ARI constitutes 20% of under-five mortality (Pinzón-Rondón et al., 2016). Both diarrhoeal disease and ARI among children are also associated with many health outcomes including malnutrition in children (WHO, 2013, 2018). While India has made considerable progress in reducing infant and child mortality over the past 20 years, episodes of preventable diseases like diarrhoea and pneumonia remain high (IIPS, 2017).

The third domain, *Child health determinants*, includes the risk factors such as stunting, wasting, underweight, anaemia and protective factors such as percentage of children breastfed at 4 months and percentage of children fully immunised. Anthropometric measures of nutrition are considered important indicators of child health (Striessnig & Bora, 2020) as they are causally linked not only to infant mortality (Liu et al., 2016) but also are shown to be the underlying causes of child mortality due to diarrhoea, pneumonia, malaria or measles occurring in the developing world (Caulfield et al., 2004). Similarly, Child immunization (Hasan et al., 2020) and breastfed at 4 months are important indicators of child nutritional status and form the fourth domain, *Health determinants- Protective factors*.

The fifth domain, *Household environment*, includes drinking water, sanitation facilities, and cooking fuel. There is research evidence that drinking water and sanitation facilities are associated with childhood diarrhoea (Lakshminarayanan & Jayalakshmy, 2015). Clean fuel for cooking avoids deaths by indoor air pollution which is a significant cause of pneumonia in LMICs (WHO, 2014b). The sixth and last domain relates to *Health system and services*. This last domain includes percentage of households with a health insurance/financing scheme, children who received postnatal care from a health personnel within 2 days of delivery and births taking place in institutions. These variables serve as proxies to access and utilisation of care and a viable health system. Coverage of health services is an important policy intervention for reducing inequities in maternal and child health (Victora et al., 2005). Some variables were reverse coded prior to PCA to ensure that a high score was positive. For example, a high score of wasting indicated poor health while a high score on not wasted indicated better health.

Some indicators in the six domains were reverse coded for analytical purpose to make the relationship of all the indicators with the Child Health Index operate in the same direction (higher score of all indicators reflect poorer health). For example, indicators such as high percentage of children who received postnatal care from a medical professional indicate better child health, but a high percentage of an indicator such as stunting indicates poor child health. For this purpose, the direction of 9 indicators was reversed by subtracting the percentage of the indicator from 100. The indicators that were reversed were: women's education, breastfeeding, immunisation, drinking water, toilet facility, cooking fuel, health insurance, postnatal care, and institutional births. Reverse coding of these indicators meant a higher score indicated poor health. Additionally, the indicator sex ratio at birth for children born in the last five years (females per 1,000 males) was reversed to males per 1000 females so that a higher sex ratio indicated poor child health.

2.3 Methods

Principal component analysis (PCA) was used to combine the indicators into a single health index. Thus, the index is derived using weight calculated by PCA according to the variability in the indicators. PCA is a useful technique which reduces the large number of dimensions, referred to as the principal components. These principal components are less in number than the original dimensions and explain most of the variation in the data set. The higher the collinearity between the indicators, the higher is the variance captured by the first principal components (Abdi & Williams, 2010; Jolliffe, 2002). PCA has been used to objectively compute the weights for indicators for developing country indices by Prinja et al. (2017) and Doke (2018). Preliminary examination of data was done to assess whether the underlying assumption for PCA have been met before constructing the index. These include the following:

2.4 Handling Missing Values: Missing Values of Indicator was Set to National mean

Assessing outliers, and linearity: Various procedures were used to check for outliers, and linearity of association between the variables. These included boxplots, histograms, and descriptive statistics (e.g., means and maximum and minimum values). See Supplementary Table 1. We also used log transformed data to address skewed data and to confirm normality.

Standardising the variables: The next step was to standardise the data to a common scale, so they have mean zero and standard deviation of one, hence a variance of one. Since different indicators had a variety of measurement units - such as number, percent, and ratio -standardisation was applied to remove the imbalance created in the contribution of variables due to unit difference. If the data were not standardised, then the variables with higher variance would have contributed more to identifying the principal components than those with lower variance.

2.5 Computing the Correlation Matrix, Eigenvalues and Eigenvectors

The correlation matrix was computed to observe the association between the variables. The results are presented in Supplementary Fig. 1. Once the correlation matrix is calculated, the eigenvectors and eigenvalues were computed. The eigenvectors inform the directions of the new data, while the eigenvalues represent the magnitude of these directions. Both eigenvector and eigenvalue go hand in hand with each eigenvector having an eigenvalue describing the magnitude. The eigenvector with the highest eigenvalue represents the direction of maximum variance. Eigenvectors give the weights to be used in the linear transformation of the original variables and eigenvalues tell how much variance is explained by those transformed variables. Supplementary Tables 2 and Supplementary Table 3 present the eigenvalues and eigenvectors respectively.

2.6 Selecting the Ideal Number of Principal Components

The next step was to determine the number of the principal components for dimensionality reduction. This was done by selecting the eigenvectors with the highest eigenvalues, as these represent the directions that explain the most variance in the dataset. Eigenvalue (the variance extracted by the components) (Supplementary Table 2) and the visual inspection of the scree plot (Supplementary Fig. 2) were used to decide the number of principal components to be retained for computing the Child Health Index. A score for each district was computed by multiplying the value of each principal component with proportion of weights (eigenvalue) explained (Supplementary Table 2) by that principal component.

Compute the Child Health Index: We used PCA to construct the Child Health Index by combining indicators into a single, composite index. Each column in Supplementary Table 3 represents the eigenvectors which give the weights to be used in the linear transformation. Thus, seven scores were created for each district-one for each principal component- by multiplying the respective standardized value of each indicator/variable with the proportion of the weights explained by each of the principal components. Seven scores were computed in this manner. The seven scores were summed to create one final score for each district. The final score for the district defines the CHI rank.

For example, Score1 = 0.39*standardized value of education + 0.00 * standardized value of sex ratio + 0.21* standardized value of diarrhea + 0.15* standardized value of ARI + 0.34* standardized value of stunting + 0.25* standardized value of wasting + 0.35* standardized value of underweight + 0.27* standardized value of anemia + 0.22* standardized value of breastfeeding + 0.11 * standardized value of immunization + 0.02* standardized value of drinking water + 0.35* standardized value of toilet facility + 0.26* standardized value of cooking fuel + 0.04* standardized value of health insurance + 0.24* standardized value of postnatal care + 0.30* standardized value of institutional births* (4.328/ (4.328 + 1.767 + 1.511 + 1.166 + 1 .162 + 0.937 + 0.883));

Final score = score1 + score2 + score3 + score4 + score5 + score6 + score7.

After creating the final score, the districts were classified into tertiles of three equal sized groups.

To quantify the extent of variability in child health within each state, Coefficient of Variation (CV) was computed for each state using district level Child Health Index rank. CV was calculated by dividing between-district standard deviation by the state's average Child Health Index rank and multiplying the fraction by 100. A large CV indicates greater dispersion around the mean Child Health Index.

2.7 Validity and Robustness

2.7.1 Internal Consistency of Constructed Child Health Index

The internal consistency of the Child Health Index was tested by Cronbach's alpha coefficient to judge the internal consistency of the variables. The closer the coefficient is to one, the better the verification that the variables were homogeneous. A Cronbach coefficient value of ≥ 0.70 is considered highly reliable (Nunnally & Bernstein, 1994).

2.7.2 External Validation of the Child Health Index

In the absence of any existing district level health index for all the districts of India, testing external validity was a challenge. Therefore, to assess the external validity of Child Health Index, Pearson's correlation coefficient between the constructed Child Health Index and under five child mortality for the same year at the state level was estimated. The state level rank was computed by calculating the arithmetic average of Child Health Index using the ranks of the district within each state. We used NFHS-5, state level data, to obtain under five child mortality (U5MR), presented in Fig. 1.

For all analyses statistical software, SAS release: 9.04.01M7P08062020 was used.

3 Results

3.1 Descriptive Statistics of Variables used in the Construction of Child Health Index in India

Descriptive statistics of the indicators included in the Child Health Index are provided in Supplementary Table 1. On average, 40% of women had 10 years or more of schooling. However, the indicator values varied greatly between districts. Sex ratio at birth for children born in the last five years (females per 1,000 males) was 944.

The overall prevalence of diarrhoeal disease and acute respiratory infection among children aged below 5 years was 6.5% and 2.5% respectively. Considering the nutritional statuses, 33.5%, 18.5%, 29.5% and 66.8% of children were identified to be stunted, wasted, underweight and anaemic, respectively. About 44.8% of children under age 3 were breastfed within 1 h of births while 44.8% children aged 12 to 23 years of age were fully immunised.

Most of the households had an improved source of drinking water (97.7%) and an improved toilet facility (68.2%). Around 54% of the houses used clean cooking fuel. Approximately 40.2% households had a member with health insurance. Most child births (78.9%) received care from trained medical professional within 48 h of delivery and a large proportion of deliveries (88.6%) took place in a health care providing institution.

Correlations between 16 indicators included in the Child Health Index are shown in Supplementary Fig. 1. A positive correlation implies that the magnitude in the variable pair increases and decreases together. On the other hand, a negative correlation indicates that the magnitude in a variable pair differs in opposite directions, i.e., increase (decrease) in magnitude in one variable tends to decrease (increase) the other variable. The correlation between the indicators is mainly weak or modest and in the expected direction. Wasting and stunting are highly correlated with underweight ($r^2 = 0.72$ and $r^2 = 0.70$ respectively). Women's education had a moderate negative correlation with stunting (r^2=-0.54), underweight ($r^2 = -0.53$), toilet facility ($r^2 = 0.58$), clean cooking fuel ($r^2 = 0.65$), and institutional delivery ($r^2 = 0.42$). At the other end of the scale, sex ratio, ARI, breastfeeding, immunisation, drinking water and health insurance were either not correlated significantly to any other indicator or weakly correlated with other indicators such as diarrhoea, toilet facility, and cooking fuel.

3.2 Principal Component Analysis (PCA) & Computing the Child Health Index

Using all 16 indicators, PCA was carried out to determine weights for each indicator and to summarize the indicators into a single score to compute the rank of the district. Supplementary Table 2 shows the eigenvalues of the first seven principal components. By inspecting the scree plot (Supplementary Fig. 2), we determined the point where the slope of the curve clearly levelled off (the 'elbow'), and by using the variance explained (at least 5% of variance explained) (Supplementary Table 2) we determined the number of components that should be retained by the analysis. After examining the scree plot, only seven components that had an eigenvalue of one or more, and explained at least 5% of the variance, were extracted for analysis. These seven principal components explain nearly 73% of the total variation in the data (Supplementary Table 2). For example, first principal component explains nearly 27% of the variation and the second principal component explains nearly 11% of variation. The third component explains nearly 9% of the variation. The fourth and fifth component accounted for 7% of the variance each, and the sixth and seventh principal component explained 5% of the variance each.

The Eigenvector matrix in Supplementary Table 3, presents Eigenvector/ weights assigned to each indicator in each of the principal component. A positive value of

Eigenvector/ weights indicates that a variable and a principal component are positively correlated, that is, an increase in one result signals an increase in the other. Negative value of the Eigenvector/ weight indicates a negative association. Large (either positive or negative) weight indicate that a variable has a strong effect on that principal component. The weights of each indicator vary on each principal component.

As shown in Supplementary Table 3, first principal component assigns large positive weights for the indicators: women's education, proportion of children with stunting, underweight, improved toilet facility.

The second principal component assigns large positive weights to: access to clean cooking fuel, postnatal care, institutional births; and negative weights to wasting, underweight, and anaemia.

The large positive weights were assigned by principal component third to prevalence of diarrhoea, ARI, and health insurance and negative weights to drinking water. Principal component fourth assigned large positive weights to health insurance and negative to sex ratio and immunization.

Principal component fifth assigned large positive weights to sex ratio, diarrhoea, ARI and improved drinking water and negative to breast feeding, and health insurance. Principal component sixth assigned largest weights to immunization. Principal component seventh assigned largest positive weights to sex ratio, and health insurance and negative to immunization.

After combining all the seven scores as described in the methodology, the districts were grouped into low, middle, and high tertiles based on the score created for each district. The three groups were Child Health Index < 235 rank, Child Health Index 235-470 rank, and Child Health Index > 470 rank denoting the states that lead, intermediate and lag. Thus, a lower value denotes better health and lower child health ranking. This approach is similar to HDI grouping countries in to four quartiles (United Nations Development Programme, 2022).

3.3 Internal Consistency

The computed Cronbach coefficient alpha was 0.7662, which suggested internal consistency and appropriateness of the PCA methodology, as the value of Cronbach coefficient alpha was greater than the suggested value of 0.70 given for comparison postulated by Nunnally and Bernstein (1994).

3.4 External Validation

In the absence of a district-level measure for validation of CHI, we used U5MR, a popular state-level indicator for measuring child health. Table 2 presents the Child Health Index rank, the U5MR, and the coefficient of variation of the CHI for each state. The CHI correlation with U5MR was 0.736. This figure indicates a positive relationship between CHI and U5MR, supporting an indication of construct validity. A scatter plot (Fig. 1) helps visualize this moderately strong positive relationship between the CHI and U5MR.

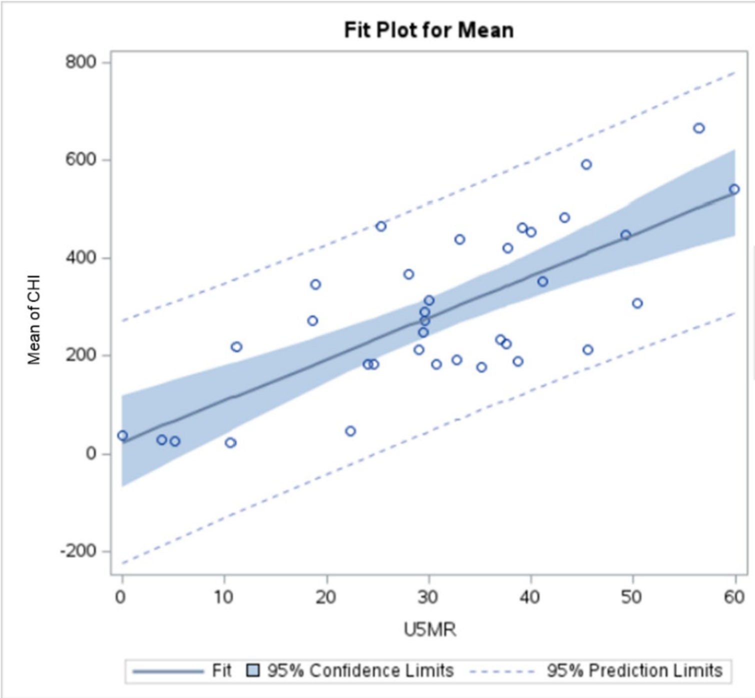

Fig. 1 Plot of mean CHI and U5MR for states/ UTs

3.5 Child Health Index: District and State Level Variations

The state level CHI rank showed wide differences between states (Table 2). Of all the states and union territories, Goa from the West and Kerala, Puducherry, Lakshadweep, and Tamil Nadu from the South depict the best Child health as indicated by their lower rank and lower score. Bihar, Jharkhand, Uttar Pradesh from the North, Tripura from the Northeast and West Bengal from the East depict the worst child health.

Wide variation in CHI between states and within several states (i.e. district level) can also be noted in the box plots in Fig. 2. In a box plot, the horizontal line drawn through the box is at the median. The whiskers start from each quartile to the minimum or maximum value of the CHI for each state, the length of the box shows the width of the range of CHI rank within the state. Analysing Table 2; Figs. 2 and 3 together shows that in states like Kerala and Tamil Nadu, districts exhibit low CHI ranks (ranging from 6 to 56 and 2 and 155 respectively), suggesting better health. However, both states display a moderately high coefficient of variation (CV) with Kerala at 55 and Tamil Nadu at 88, indicating significant inter-district variation. On the other hand, districts in states such as Bihar and Jharkhand have high CHI ranks, indicating poorer health, with ranks ranging from a minimum of 551 to a maximum of 707, and a low CV of 6 (Bihar) and 15 (Jharkhand), meaning all the districts are clustered together in the poor spectrum of health (Table 2; Fig. 3).

Table 2 State/UT CHI (arranged in ascending order state level CHI), and state level U5MR

State	Number of Districts	Range	Mean CHI	Rank by CHI	Minimum	Maximum	Std Dev	Coefficient of variation in CHI	U5MR	Rank by U5MR
Goa	2	40	24	1	4	44	28	118	11	3
Kerala	14	50	26	2	6	56	14	55	5	2
Puducherry	4	60	30	3	1	61	30	101	4	1
Lakshadweep	1	0	38	4	38	38	.	.	NA	
Tamil Nadu	32	153	46	5	2	155	41	88	22	7
Chandigarh	1	0	85	6	85	85	.	.	NA	
Andhra Pradesh	13	340	179	7	53	393	98	55	35	20
Mizoram	8	364	184	8	39	403	142	77	24	8
NCT of Delhi	11	173	184	9	93	266	52	28	31	17
Andaman & Nicobar	3	283	185	10	45	328	142	77	25	9
Haryana	22	577	190	11	46	623	127	67	39	24
Punjab	22	373	194	12	18	391	114	59	33	18
Himachal Pradesh	12	259	212	13	74	333	88	42	29	12
Uttarakhand	13	358	213	14	80	438	104	49	46	30
Sikkim	4	246	220	15	62	308	115	52	11	4
Rajasthan	33	410	225	16	49	459	96	43	38	22
Dadra Nagar Haveli	3	257	234	17	70	327	142	61	37	21
Telangana	31	505	250	18	47	552	119	48	29	13
Jammu & Kashmir	20	511	273	19	58	569	147	54	19	5
Karnataka	30	600	273	20	40	640	204	75	30	14
Ladakh	2	53	291	21	264	317	37	13	30	15
Chhattisgarh	27	654	310	22	8	662	176	57	50	32
Manipur	9	362	314	23	69	431	111	35	30	16

Table 2 (continued)

State	Number of Districts	Range	Mean CHI	Rank by CHI	Minimum	Maximum	Std Dev	Coefficient of variation in CHI	U5MR	Rank by U5MR
Arunachal Pradesh	20	384	347	24	115	499	112	32	19	6
Odisha	30	588	352	25	41	629	150	42	41	27
Maharashtra	36	641	369	26	48	689	192	52	28	11
Gujarat	33	610	423	27	60	670	167	40	38	23
Nagaland	11	430	440	28	196	626	136	31	33	19
Madhya Pradesh	51	572	448	29	100	672	148	33	49	31
Meghalaya	11	326	453	30	275	601	105	23	40	26
Assam	33	402	464	31	247	649	101	22	39	25
West Bengal	20	452	466	32	203	655	125		25	10
Tripura	8	410	484	33	222	632	117	24	43	28
Uttar Pradesh	75	476	540	34	225	701	107	20	60	34
Jharkhand	24	330	591	35	376	706	89	15	45	29
Bihar	38	156	666	36	551	707	40	6	56	33

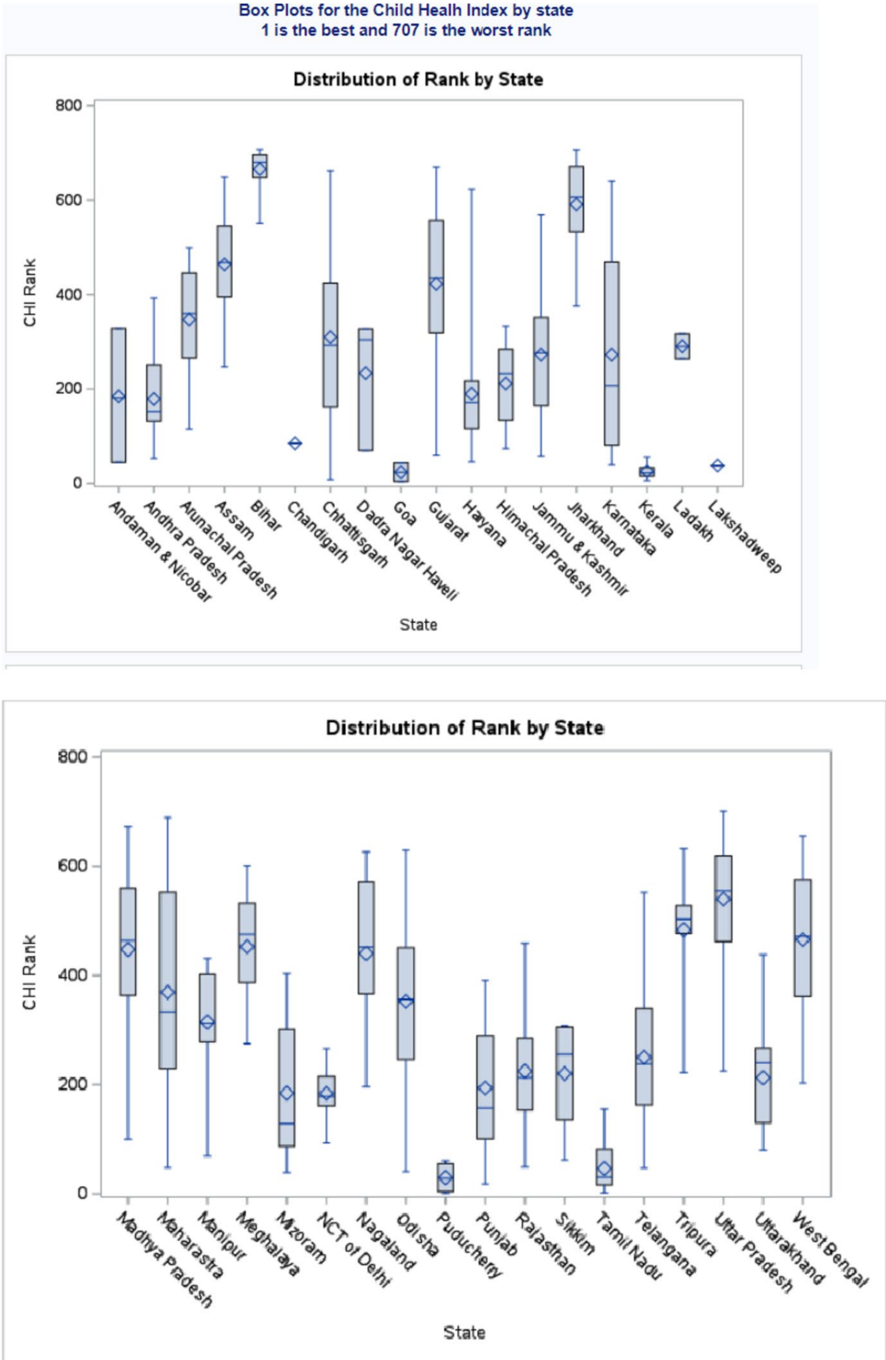

Fig. 2 Box plot showing variation in CHI between and within states/UTs

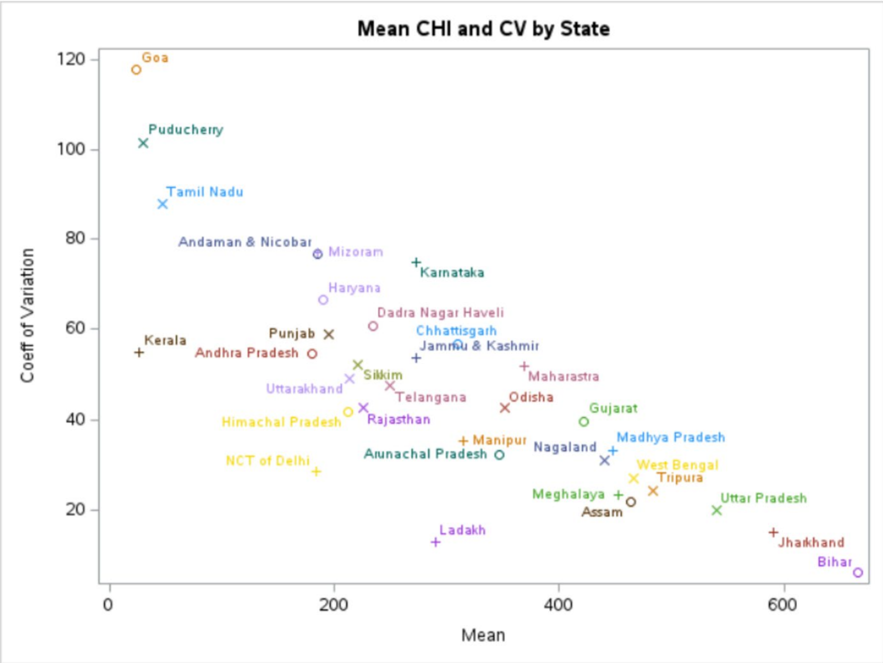

Fig. 3 Plot of mean CHI and Coefficient of Variation for states/ UTs

Table 3 provides a comparison of the States based on the number of districts into lead, intermediary, and lagged on CHI. This Table clearly demonstrates within-state disparities in child health. While 100% of districts in some states such as Kerala and Tamil Nadu fall under lead state (i.e., their CHI value is below 234), 100% in progressing states (e.g., Ladakh with a CHI value falling between 234 and 470), on the other extreme, 100% districts in some states such as Bihar are laggards (i.e., their CHI value is above 470). 56% of districts in the lead states come from Tamil Nadu (14%), Rajasthan (9%), Haryana (8%), Karnataka (7%), and Punjab, Kerala, and Telangana (with 9% each). On the other hand, Uttar Pradesh (24%), Bihar (16%), Madhya Pradesh (10%) and Jharkhand (9%) make up of approximately 60% of lagged states (Fig. 4).

3.6 Predicting the Child Health Index

The correlation matrix in Supplementary Table 4 shows the key indicators are positively related to CHI. Strong positive correlation of CHI was noted with a few indicators in each domain. From the health determining risk factor domain, stunting had moderately strong correlation (($r^2=0.69$) and underweight ($r^2=0.61$); from the health system and policy domains - prompt postnatal medical care and institutional delivery had strong correlation at around $r^2=0.68$ and $r^2=0.60$ respectively; likewise, women's education from the socio-cultural domain had $r^2=0.67$; from

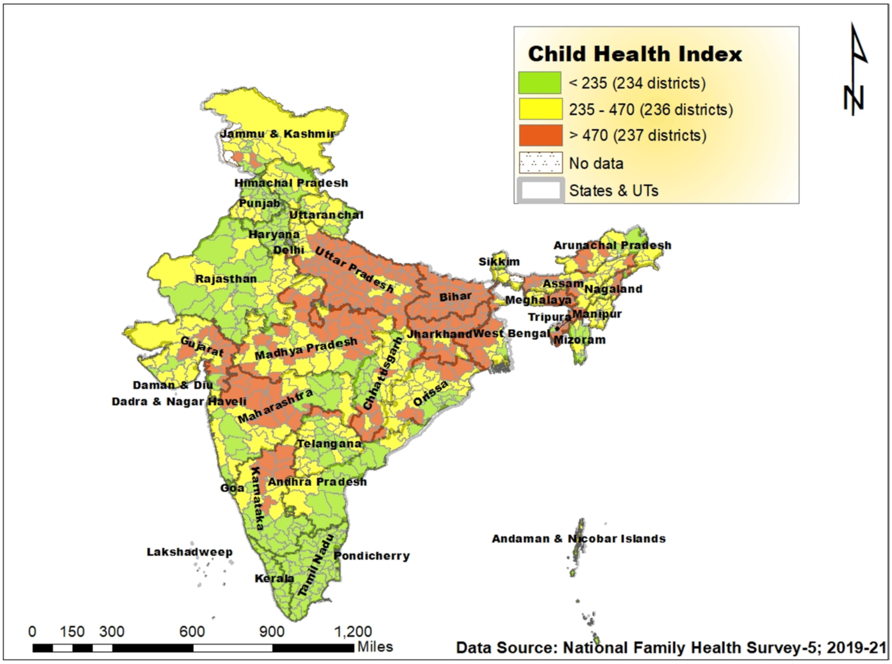

Fig. 4 Map showing districts of India classified by ranking of CHI

the health protective factors of household environment domain. The indicators of improved toilet facilities and clean cooking fuel had a moderate-strong correlation at 0.58 and 0.68 respectively, however, health status indicators of diarrhoea and ARI have weak correlation ($r^2 = 0.37$ and 0.31 respectively) with CHI.

4 Discussion

The aim of the paper was to develop and validate a comprehensive and multidimensional Child Health Index specifically tailored for assessing child health at the district level in India, using a Principal Component Analysis (PCA) framework. The motivation behind creating such an index was to provide a holistic and comprehensive tool that captures important aspects of a child's life, allowing service and policy organizations to monitor, improve and promote children's health and well-being at the district level. To achieve this goal, we focused on selecting indicators that were based on established research and evidence, ensuring their relevance and reliability in measuring various dimensions of child health. We used data from a single publicly available data source to ensure consistency and comparability across districts. The resulting CHI was comprehensive, covering a wide range of dimensions that influence child health, such as sociocultural dimensions, health determinants, the household environment, health system and policy.

Table 3 CHI ranking at district level grouped into leading, intermediate, and lagging category

		Rank			Districts
		Leading	Intermediate	3 Lagging	
		< 235	235–470	> 470	
States/UTs	N	234	236	237	707
Andaman & Nicobar	N	2	1	.	3
	Column Percent[a]	1	0	.	0
	Row Percent[a]	67	33	.	100
Andhra Pradesh	N	9	4	.	13
	Column Percent[a]	4	2	.	2
	Row Percent[a]	69	31	.	100
Arunachal Pradesh	N	4	12	4	20
	Column Percent[a]	2	5	2	3
	Row Percent[a]	20	60	20	100
Assam	N	.	17	16	33
	Column Percent[a]	.	7	7	5
	Row Percent[a]	.	52	48	100
Bihar	N	.	.	38	38
	Column Percent[a]	.	.	16	5
	Row Percent[a]	.	.	100	100
Chandigarh	N	1	.	.	1
	Column Percent[a]	0	.	.	0
	Row Percent[a]	100	.	.	100
Chhattisgarh	N	10	11	6	27
	Column Percent[a]	4	5	3	4
	Row Percent[a]	37	41	22	100
Dadra Nagar Haveli	N	1	2	.	3
	Column Percent[a]	0	1	.	0
	Row Percent[a]	33	67	.	100
Goa	N	2	.	.	2
	Column Percent[a]	1	.	.	0
	Row Percent[a]	100	.	.	100
Gujarat	N	4	16	13	33
	Column Percent[a]	2	7	5	5
	Row Percent[a]	12	48	39	100
Haryana	N	19	2	1	22
	Column Percent[a]	8	1	0	3
	Row Percent[a]	86	9	5	100
Himachal Pradesh	N	6	6	.	12
	Column Percent[a]	3	3	.	2
	Row Percent[a]	50	50	.	100

Table 3 (continued)

		Rank			Districts
		Leading	Intermediate	3 Lagging	
		< 235	235–470	> 470	
Jammu & Kashmir	N	8	9	3	20
	Column Percent[a]	3	4	1	3
	Row Percent[a]	40	45	15	100
Jharkhand	N	.	2	22	24
	Column Percent[a]	.	1	9	3
	Row Percent[a]	.	8	92	100
Karnataka	N	16	7	7	30
	Column Percent[a]	7	3	3	4
	Row Percent[a]	53	23	23	100
Kerala	N	14	.	.	14
	Column Percent[a]	6	.	.	2
	Row Percent[a]	100	.	.	100
Ladakh	N	.	2	.	2
	Column Percent[a]	.	1	.	0
	Row Percent[a]	.	100	.	100
Lakshadweep	N	1	.	.	1
	Column Percent[a]	0	.	.	0
	Row Percent[a]	100	.	.	100
Madhya Pradesh	N	5	22	24	51
	Column Percent[a]	2	9	10	7
	Row Percent[a]	10	43	47	100
Maharastra	N	11	13	12	36
	Column Percent	5	6	5	5
	Row Percent[a]	31	36	33	100
Manipur	N	1	8	.	9
	Column Percent[a]	0	3	.	1
	Row Percent[a]	11	89	.	100
Meghalaya	N	.	5	6	11
	Column Percent[a]	.	2	3	2
	Row Percent[a]	.	45	55	100
Mizoram	N	6	2	.	8
	Column Percent[a]	3	1	.	1
	Row Percent[a]	75	25	.	100
NCT of Delhi	N	9	2	.	11
	Column Percent[a]	4	1	.	2
	Row Percent[a]	82	18	.	100

Table 3 (continued)

		Rank			Districts
		Leading	Intermediate	3 Lagging	
		< 235	235–470	> 470	
Nagaland	N	1	6	4	11
	Column Percent[a]	0	3	2	2
	Row Percent[a]	9	55	36	100
Odisha	N	7	17	6	30
	Column Percent[a]	3	7	3	4
	Row Percent[a]	23	57	20	100
Puducherry	N	4	.	.	4
	Column Percent[a]	2	.	.	1
	Row Percent[a]	100	.	.	100
Punjab	N	15	7	.	22
	Column Percent[a]	6	3	.	3
	Row Percent[a]	68	32	.	100
Rajasthan	N	20	13	.	33
	Column Percent[a]	9	6	.	5
	Row Percent[a]	61	39	.	100
Sikkim	N	2	2	.	4
	Column Percent[a]	1	1	.	1
	Row Percent[a]	50	50	.	100
Tamil Nadu	N	32	.	.	32
	Column Percent[a]	14	.	.	5
	Row Percent[a]	100	.	.	100
Telangana	N	15	14	2	31
	Column Percent[a]	6	6	1	4
	Row Percent[a]	48	45	6	100
Tripura	N	1	.	7	8
	Column Percent[a]	0	.	3	1
	Row Percent[a]	13	.	88	100
Uttar Pradesh	N	1	18	56	75
	Column Percent[a]	0	8	24	11
	Row Percent[a]	1	24	75	100
Uttarakhand	N	6	7	.	13
	Column Percent[a]	3	3	.	2
	Row Percent[a]	46	54	.	100
West Bengal	N	1	9	10	20
	Column Percent[a]	0	4	4	3
	Row Percent[a]	5	45	50	100

[a] All percent are rounded to the nearest integral value

The Cronbach coefficient alpha (0.7662) suggested internal consistency and appropriateness of the PCA methodology. The external validity of the CHI was demonstrated by its association with U5MR (correlation of CHI with U5MR was 0.736). While under 5 mortality is a significant indicator of child health, it is important to recognize that under 5 mortality is not a comprehensive measure of child health per se but rather it adds another critical dimension to the assessment of child health. It primarily focuses on the outcome of health, which is mortality, within a specific age group. Given the global reduction in mortality and changing patterns of health outcomes, the Child Health Index offers an additional and valuable perspective. This approach goes beyond the traditional single indicator like under 5 mortality. Instead, it provides a more nuanced and holistic view of child health. The availability of representative data sub-nationally and over time through the National Family and Health Survey allows for the examination of spatial and temporal variations in the Child Health Index. Furthermore, the Indian Child Health Index could serve as a valuable reference tool for other Asian countries with comparable health challenges and sociocultural backgrounds. Given the availability of indicators used in computing the Child Health Index from Demographic and Health surveys (known as the National Family Health Survey in India), these countries can create their own indices by leveraging the experience and methodology used in developing the Indian Child health Index.

The use of the Child Health Index in India provides an opportunity to rank different districts based on their performance in child health for the first time. This ranking sheds light on significant geographical variations, inter-district disparities, and inequities in child health outcomes across the country. The findings from the index reveal that districts in the southern region such as Kerala and Tamil Nadu tend to show higher levels of child health, indicating relatively better health outcomes for children in those areas. In contrast, districts in the East regions, namely Bihar, Uttar Pradesh and Jharkhand depict worse child health. Even in states that are generally considered to have better overall child health, such as Kerala and Tamil Nadu, there are large differences in child health outcomes among districts. The high Coefficient of Variation (CV) values in these states (CV of 88 for Kerala and 55 for Tamil Nadu) emphasize the significant disparities that exist within leading states. On the other hand, states like Bihar, Jharkhand, and Uttar Pradesh exhibit less variation, but unfortunately, they are all placed in the "lagged" state category, indicating significant challenges in these regions. Although the creation of district-level health indices has been acknowledged in previous research (Prinja et al., 2017; Satyanarayana et al., 1995; Sekhar et al., 1991), a comprehensive ranking of health across all districts in India, including child health ranking at the All-India level, remains unavailable. Previous attempts to calculate district-level rankings in health have been limited, often focusing on only one or two states and considering restricted indicators, such as health performance (Sharma et al., 2019), universal health coverage (Prinja et al., 2017), or health infrastructure (Anand, 2014). As a result, it becomes challenging to compare our study's findings with those done by others.

The finding that all districts in Bihar fall under the "lagged" state category highlights the critical need for targeted interventions and resource allocation in this state to improve child health outcomes. The substantial inter-district variations in child health performance indicate that the quality of child health services and other determinants of child health can vary widely even within the same state. By identifying districts with better and worse child health outcomes, policymakers and health authorities can prioritize resources and implement strategies to address the specific challenges faced by different regions. Reducing inter-district and inter-state disparities in child health is essential for promoting equitable and sustainable improvements in the well-being of children across India. Therefore, the Child Health Index could facilitate a graded response, and enable the retargeting of resources even in such states where districts have very similar rankings.

Addressing inter-district variations in child health in India requires a multi-faceted and targeted approach. Policy measures should focus on addressing the underlying determinants of child health and providing comprehensive and accessible healthcare services. The results from our study show that stunting (both a cause and condition), should prompt postnatal care, institutional delivery, women's education, improved toilet facilities and clean cooking fuel. Implementing policies that address these social factors can have a positive ripple effect on child health.

While our study on Child Health Index in India offers a significant contribution to the field, it has some limitations that warrant consideration. First, the index provides only a relative measure of inequality between districts, but it does not offer information on absolute levels of health risk, health system performance, or health status. Hence, while the index allows for comparison and ranking of districts, it may not provide a clear picture of the specific health challenges faced by each district in absolute terms. Second, certain indicators, such as household-level crowding (as an indicator of poverty), percentage of children with low birth weight, and data segregated by gender, could provide valuable insights into the social determinants of child health and disparities between different population groups. The absence of such data limits the comprehensive understanding of child health issues and hinders the development of targeted interventions. Third, the study's reliance on data from the National Family Health Survey (NFHS-5) introduces potential limitations related to self-reported data and recall or reporting bias. These limitations might affect the accuracy and reliability of the indicators used in the index. Fourth, developing the index at the district level offers valuable insights into regional disparities. However, some districts in India are large and populous, potentially containing pockets of significantly different health outcomes. Creating the index at a smaller area level, such as the municipality or block level, could provide a more detailed understanding of local differences and better inform localized interventions. Finally, the study's findings are based on data from a specific time (NFHS-5), and child health outcomes may vary over time due to changes in policies, programs, and socioeconomic factors. Regular updates of the index using recent data are necessary to track progress and identify emerging health issues.

Despite the limitations, the development of the Child Health Index in India has several notable strengths that make it a valuable tool for addressing child health challenges in India. By using publicly available data, considering different life stages, and providing district-level comparisons, the index allows for a comprehensive assessment of child health across the country. Regular monitoring using the index, along with ongoing refinement and validation, can lead to evidence-based policies and targeted interventions to improve child health outcomes and promote equity in child health across India.

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