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Adolescent marriage, maternity, and limited access to education in 106 countries: Bayesian analysis of prevalence, trend, and prediction

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Effectively addressing issues related to adolescent children being out of school and vulnerable to harmful practices is essential for advancing SDG 3—5. This study aimed to assess the prevalence, trends, and future projections of adolescent child vulnerability. We analyzed data from 386 datasets spanning 106 countries, encompassing 1,292,258 adolescent girls year 1990— 2023. Bayesian methods were employed to estimate prevalence, trends, and future projections. Sub-Saharan Africa and Latin America & the Caribbean showed a high prevalence of child marriage and early childbirth. Overall, these indicators decreased from 1990 to 2023, but recent years have seen increases in some countries. Projections for 2025 to 2030 suggest that changes in rates will occur in some countries, while most are expected to remain stable. The disparities are in underscore ongoing public health challenges. These issues risk derailing progress towards SDG targets of eliminating harmful practices and ensuring universal access to quality education. Addressing these challenges demands coordinated efforts from countries and the global community to implement effective interventions and strategies.

Keywords Adolescent vulnerabilities, Child marriage, Early childbirth, School dropout rates, Bayesian methods, Sustainable development goals

Adolescence marks a crucial period in a young girl's life, characterized by profound physical and emotional changes[1,2]. It's a time of heightened vulnerability, greatly impacting her future potential[3]. This period signifies pivotal transitions: from girlhood to womanhood, from primary to secondary education, and education to the realms of work and family. It involves navigating through various challenges and opportunities along the way[4]. When these transitions go awry, girls may face being excluded from school, early marriage, early childbirth, violence, abuse, HIV infection, and elevated maternal mortality rates[5]. Additionally, they may become the "missing generation" in terms of development[6–8].

In adolescence, girls' adherence to traditional gender roles intensifies, and gender bias becomes more pronounced. In numerous nations, adolescent girls find themselves confined to domestic duties, with their freedom of movement diminishing and their workload increasing[9,10].

When girls are empowered through education and shielded from harmful traditions, they gain the capacity to support their families, enrich their communities, and participate in the construction of robust nations. This paves the way for a sustainable future, ensuring a successful transition into adulthood. If a girl is not in school, she may be coerced into marriage or face pregnancy before she is prepared to become a mother. In such circumstances, her rights are compromised, hindering her from reaching her full potential and exposing her to increased risks and various hazards. Nevertheless, with more education, she is more inclined to marry at a later age, have fewer but healthier children, and earn an income that she can invest in her family, thereby safeguarding maternal health and reducing the risks of pregnancy-related complications[11–13].

Early marriage and pregnancy effectively truncate a girl's childhood, thrusting her prematurely into the roles of adulthood and motherhood before she is physically and mentally prepared, and before she completes her education[14]. This severely restricts her future opportunities, depriving her of the chance to fulfill her full potential. Married adolescent girls face significant vulnerability, often experiencing social isolation, early initiation into childbearing, susceptibility to sexually transmitted infections, and an elevated risk of intimate partner violence, including forced sexual intercourse with their husbands[15–17].

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Globally, in 2021, approximately 4.2% of births were to girls aged 15 to 19 years old[18]. According to the United Nations Educational, Scientific and Cultural Organization (UNESCO), the number of out-of-school children and youth increased by 6 million between 2021 and 2023[18,19].

The Global Programme was formulated as part of the 15-year (2016—2030) Sustainable Development Goals (SDGs), focusing particularly on SDG no. 3, which aims to ensure universal access to sexual and reproductive health-care services, including information and education; SDG no. 4, which seeks to ensure inclusive and equitable quality education and promote lifelong learning opportunities; and SDG no. 5, which targets the elimination of violence against women and all harmful practices, such as child marriage, by 2030. Additionally, SDG no. 5 emphasizes the objective of ensuring universal access to sexual and reproductive health and reproductive rights[20,21].

Indeed, adolescent girls represent a crucial demographic group to prioritize to effectively dismantle the intergenerational transmission of various barriers that impede development and hinder the achievement of different SDGs. This assessment underscores the significance of focusing on adolescent girls across the three pillar areas of global development. These areas serve as focal points for scaling up efforts aimed at improving educational attainment, preventing early marriage, and delaying early childbearing among adolescent girls.

Focusing on these three fundamental outcomes is essential for several reasons. Firstly, it is believed that changing these outcomes can have enduring impacts on an individual's well-being, as well as on the well-being of others, including families, communities, and entire countries[22]. Secondly, these outcomes have long-lasting effects on the lifetime well-being of both the current generation and the next generation. Thirdly, they significantly influence or shape all aspects of life for today's girls and tomorrow's women. Fourthly, addressing these outcomes helps reduce the gap in disproportionately high risks faced by adolescent girls compared to all other demographic groups[23–25].

The objective of this study is to analyze global trends and provide future projections for three critical indicators affecting adolescent girls: child marriage, teenage or early motherhood and school drop-out profiles. Worldwide the study will employ data from the Demographic and Health Surveys (DHS) and Multiple Indicator Cluster Surveys (MICS) to estimate prevalence of these indicators, analyze trends from 1990 to 2023 and forecast trends to 2025 and 2030. This paper aims at using Bayesian modeling to present a reductionist analysis of these issues, and provides guidance on designing specific socio-economic and cultural interventions for enhancing adolescent health globally.

Results

At the national level, the rates of adolescent child marriage, defined as marriage before the age of 18, varied greatly across countries. For instance, in Bangladesh, the prevalence was 55.55% (with a 95% CrI of 54.33— 56.76%), whereas in Tunisia, it was much lower at 0.46% (with a CrI of 0.17— 0.98%). Similarly, the incidence of early childbirth, occurring before the age of 19, also showed significant diversity among countries. Rates ranged from 34.3% (with a CrI of 32.9— 35.72%) in the Central African Republic to 1.02% (with a CrI of 0.77—1.32%) in Algeria. Moreover, the percentage of adolescents who were not enrolled in education during the year of data collection varied widely, ranging from 59.18% (with a 95% CrI of 57.05— 61.29%) in Zimbabwe to 0.28% (with a CrI of 0.21— 0.36%) in Colombia. These differences were accompanied by a noticeable skew in precision or signal-to-noise ratio (SNR) favoring higher values, suggesting high precision in the data (Fig. 1 & Supplementary Table 1).

Figure 1A depicts six countries across diverse regions: the Central African Republic, Mali, and Niger in Sub-Saharan Africa (SSA), and one from Central and South Asia (Bangladesh). These countries exhibit significant proportions of adolescent child marriage, with at least 40% marrying before reaching the age of 18 (Fig. 1A).

25% of adolescents from eleven countries experience early childbirth before their 18th birthday. Eight of these countries are located in Sub-Saharan Africa, such as Angola, Mali, Congo, and others (Fig. 1B). Figure 1C shows four countries from different parts of the world: three in Sub-Saharan Africa (Zimbabwe, Mali, and Niger) and Yemen. Each of these countries has at least 50% of adolescents not attending school (Fig. 1C).

In 33, 19, and 45 countries, there are instances where at least 20% of adolescent children are married before reaching 18, give birth before turning 19, and do not attend school, respectively. Among these countries, 17, 15, and 21 are located in Sub-Saharan Africa (SSA), respectively. Nearly all the mentioned countries exhibit high data accuracy, with a Signal-to-Noise Ratio (SNR) greater than one (Fig. 1 & Supplementary Fig. 1).

Out of more than 800 subnational administrative areas across 106 countries, 25 (approximately 3%) experienced the phenomenon where at least half of their adolescent children were married before the age of 18. Of these areas, 18 (72%) were situated in Sub-Saharan Africa (SSA), with the remaining distributed across Bangladesh. Additionally, over 82 (about 10%) of these regions reported that more than a quarter of adolescent children gave birth before reaching 19. The majority of these adolescent births (about 85%) occurred in SSA, while the remainder were reported in Honduras, Guyana, and Bangladesh. About 86 (around 10%) of the regions had at least half of their adolescent children out of school, with a significant number of them located in SSA and reported with high data accuracy. (Fig. 2 & Supplementary Fig. 2).

Overall, the highest prevalence rates for all cases were mainly concentrated in Sub-Saharan Africa (SSA), particularly in Western and Central Africa (Fig. 2). These regions consistently showed elevated prevalence rates across multiple indicators. Importantly, all regions with high prevalence rates had precise data, with a Signal-to-Noise Ratio (SNR) greater than one (Supplementary Fig. 2).

In Central and South Asia, along with most countries in East and Southeast Asia and West Asia & North Africa, there was a decline over time as shown in Fig. 3, but most of these countries still faced significant challenges from the pandemic across all indicators (Fig. 1). In Latin America and the Caribbean, most countries initially saw an increase over time, but in the most recent year, there was a decline across all indicators. In Sub-Saharan Africa (SSA), many countries made substantial progress in reducing all cases, although some

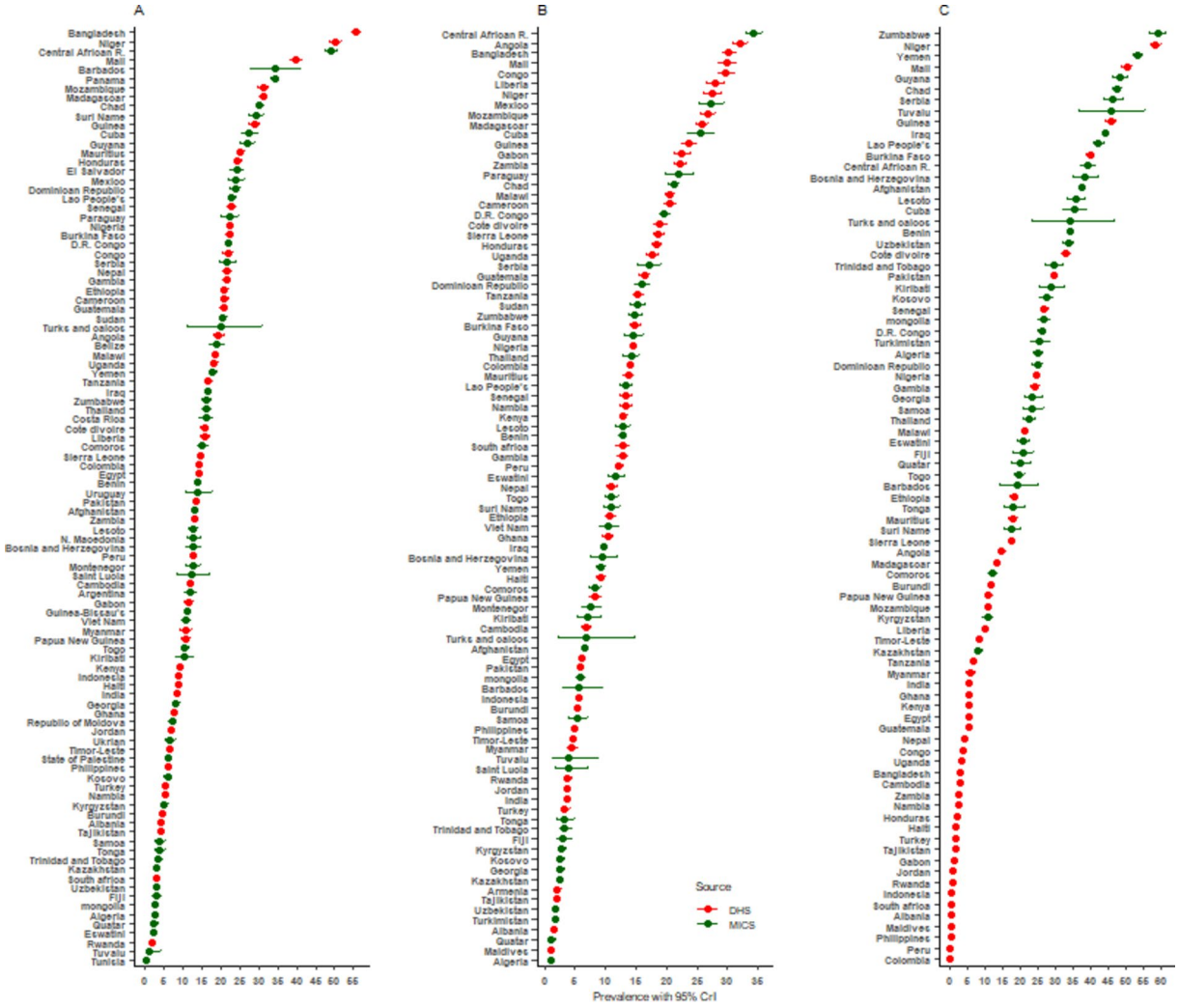

Fig. 1. Prevalence at the country levels with 95% credible intervals (CrI) of adolescent child marriage (**A**), early childbirth (**B**), and non-attendance in education (**C**). The colors denote the data source: red represents DHS data, while green signifies MICS data.

countries showed fluctuations; overall, the region still faced high prevalence across all indicators (Figs. 1 and 3). In general, some countries had high prevalence but the progress is remaining increased (ex. Madagascar, Congo, Kosovo …). Some countries with high prevalence showed a good reduction rate (ex. Bangladesh, Central Africa Republic, Mali …). Almost all lower prevalence of all pandemics showed declined over time (ex. Tunisia, Rwanda, Eswatini …) (Figs. 1 and 3).

Except specific regions such as East and Southeast Asia (including Cambodia, Philippines, and Thailand), Latin America and the Caribbean (including Colombia and the Dominican Republic), Europe (including Albania, Belarus, Bosnia and Herzegovina, and Macedonia), Sub-Saharan Africa (including Congo, Madagascar, and Zimbabwe), and West Asia and North Africa (including Algeria and Iraq), there is evidence of a decline over time in adolescent marriages before the age of 18 (Fig. 3A). Similarly, Cambodia, Colombia, Jordan, Peru, and Iraq show a decreasing trend over time in childbirth before the age of 19 (Fig. 3B). Likewise, except for Afghanistan, Macedonia, and Congo, most countries demonstrate a decline over time in the prevalence of children being out of school (Fig. 3C). Some countries showed declines over time but experienced increases in recent years (e.g., Namibia, State of Palestine…).

Overall, the decrease over time in out-of-school adolescent children was more favorable compared to other indicators, yet the prevalence remains notably high (Figs. 1 and 3). Figure 3A and B show that countries experiencing an increase in adolescent child marriage also tend to see increases in early childbirth, and vice versa (Fig. 3).

Child marriage and early childbirth are interconnected; efforts to address one often result in a reduction of the other, and vice versa. In contrast, the relationship between children being out of school and either early childbirth or marriage is more complex. In regions like Sub-Saharan Africa (SSA), all three issues show a clear interconnection, suggesting that addressing one problem can affect the prevalence of the others (see supplementary Fig. 3).

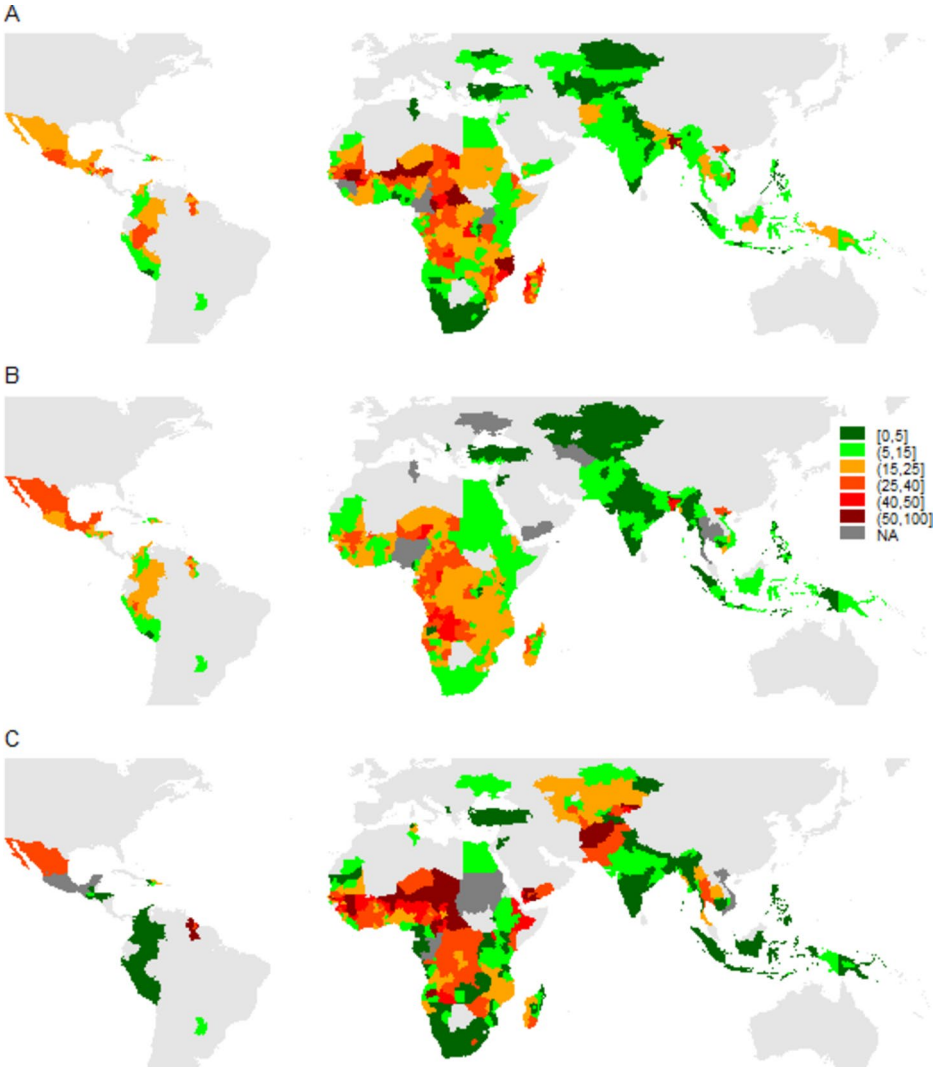

Fig. 2. Regional prevalence of adolescent marriage (**A**), early childbirth (**B**), and school dropout (**C**). The color indicates the severity of the respective cases, with bold red indicating the high prevalence and bold green indicating the lowest prevalence.

In 2025, a quarter of adolescent children in 23% of countries are projected to be married before the age of 18, decreasing to 17% by 2030. Additionally, 10% of countries are expected to see adolescents giving birth before age 19. Three out of five countries will experience both child marriage and early childbirth (e.g., Congo, Central African Republic, Niger…). Some countries, such as Guinea and Chad, are projected to reduce adolescent child marriage, early childbirth, and school dropout rates by more than 3% points. Most countries are anticipated to maintain stable rates across all indicators between 2025 and 2030 (Fig. 4).

None of the regions worldwide are expected to eliminate harmful practices by 2030, with Sub-Saharan Africa (SSA) projected to have the highest prevalence, followed by Central and South Asia (e.g., Congo, Bangladesh…) (Fig. 4).

By 2030, certain countries with currently high prevalence rates of adolescent issues—such as child marriage (e.g., Guyana, Suriname), early childbirth (e.g., Congo, Thailand, Vietnam), and being out of school (e.g., Guyana, Democratic Republic of Congo)—are expected to see increases of around 10%. Conversely, some countries with currently low prevalence rates are projected to shift to high prevalence in 2030 in terms of child marriage (e.g., Montenegro, North Macedonia), early childbirth (e.g., Thailand, Haiti), and school dropout rates (e.g., Kazakhstan, Kyrgyzstan) (Figs. 1 and 4).

Discussion

To the best of our knowledge, this study represents the first comprehensive assessment of child marriage, early childbirth, and children being out of school, and examining past, present, and future trends. Empowering girls through education and safeguarding them from harmful practices not only ensures stability in the present but also cultivates better opportunities for future generations.

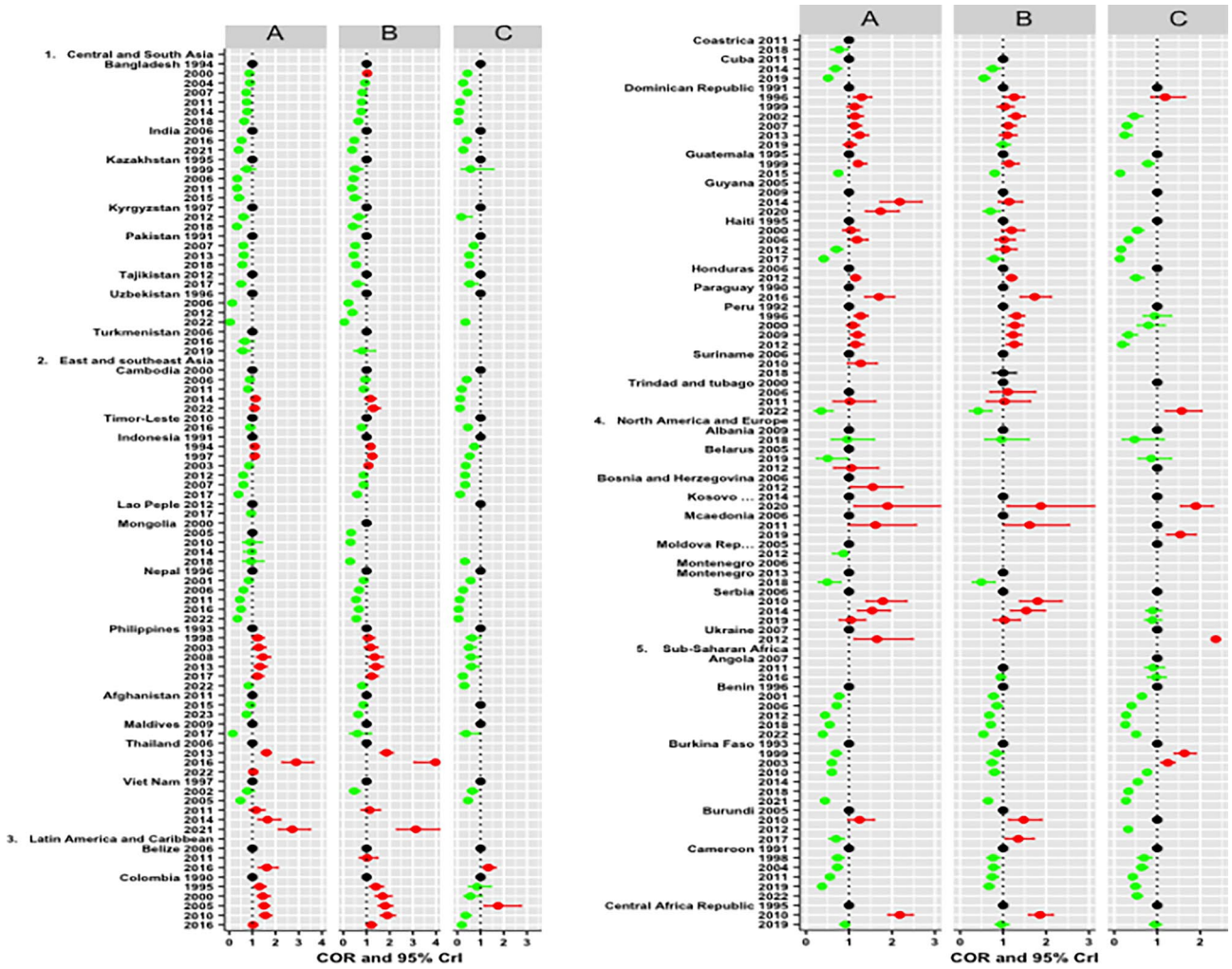

Fig. 3. Trend estimation using Crud Odds Ratio (COR) with 95% credible intervals (CrI) for adolescent child marriage (**A**), early childbirth (**B**), and school dropout (**C**). The colors represent trends over time: green indicates a decline, red indicates an increase in the corresponding cases, and black indicates no change or serves as the reference.

This study examined country and sub-national prevalence, trends, and predictions regarding child marriage, early childbirth, and children being out of school. This approach allows for the identification of variations between regions and countries, changes over time, and future projections[26]. The findings reveal significant national and substantial within/between-country variations in the distribution of these phenomena, underscoring the importance of tailored programs and strategies in areas where education availability is low and harmful practices are prevalent[27]. The precision of the analyses was assessed using the SNR, ensuring the reliability and accuracy of the results.

The relationships between child marriages and early childbirth are depicted as linear or straightforward[27]. However, the relationship between children being out of school and child marriage or early childbirth is not linear. While the prevalence of child marriage, early childbirth, and children being out of school has been measured in numerous countries and regions, some countries have made significant progress while others continue to maintain unacceptably high rates of all these cases[26].

Early marriage and pregnancy can indeed serve as both the cause and consequence of dropping out of school[17,27,28]. While girls may leave or be withdrawn from school due to pregnancy or marriage, those who have already dropped out of school are more susceptible to early marriage and/or pregnancy[27,29–31]. Therefore, child marriage can be a consequence of pregnancy and dropping out of school, while being out of school can result from child marriage and early pregnancy[32–34]. These issues persist in many countries and present ongoing challenges that have yet to be effectively addressed[29,35].

Undoubtedly, prioritizing quality education for all and eradicating harmful practices are paramount goals. Both child education and protection from harmful practices are central targets of the SDGs. It's worth noting that approximately 200 countries worldwide have committed to ending harmful practices by 2030 as part of the SDGs agenda.

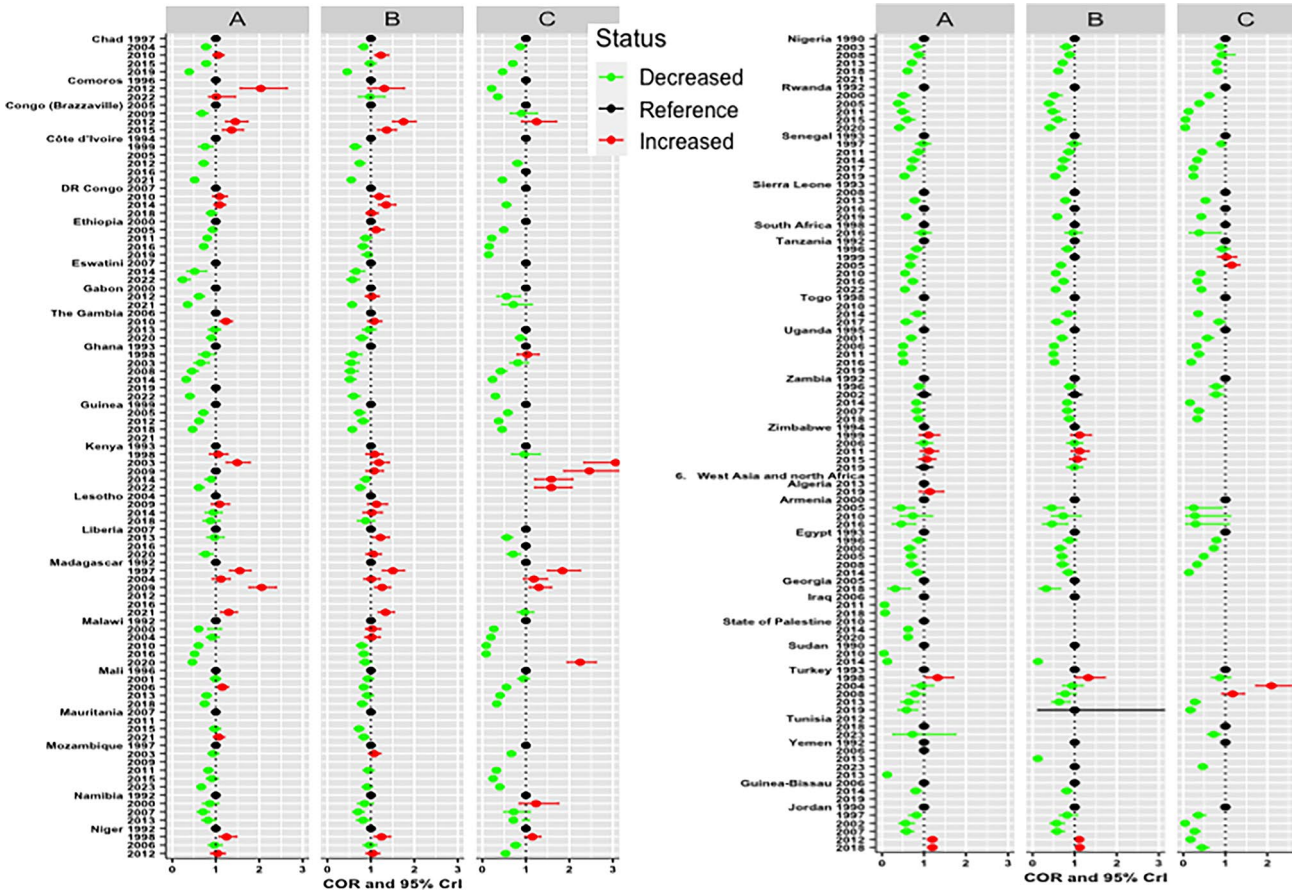

Figure 3. (continued)

These commitments must be translated into concrete actions. Given the historical progress in addressing these issues, achieving the 2030 goals poses a significant challenge. Time is of the essence, and there is no room for further delay. To realize the SDGs, it is imperative that every child is enrolled in school and that efforts are made to reduce child marriage before the age of 18. These actions are crucial steps toward mitigating early childbirth.

While achieving the complete elimination of harmful practices and ensuring quality education within the next six years is ambitious, this endeavor holds the potential for significant positive impacts. The eradication of harmful practices can lead to improved health, safety, and well-being for adolescent girls, as well as broader benefits for families, communities, and nations worldwide.

Addressing quality education and ending harmful practices are fundamental to achieving eight of the SDGs. These include SDG 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health and well-being), SDG 4 (quality education), SDG 5 (gender equality), SDG 8 (decent work and economic growth), SDG 10 (reduced inequalities), and SDG 16 (peace, justice, and strong institutions). Moreover, these efforts align with human rights principles, as recognized in Article 16 of the 1948 United Nations Declaration of Human Rights, which identifies harmful practices as global human rights violations.

Within most countries or regions are, recognizing the complex interplay of social, cultural, economic, and health factors that contribute to these phenomena. Understanding and addressing these interconnected challenges is essential for promoting the rights and well-being of children and adolescents globally.

Child marriage, early childbirth, and children being out of school are not only interconnected but also represent critical health and human rights issues. Some research has delved into the nexus of early pregnancy[36], early marriage[37,38], and school dropout[39] within specific countries or regions, recognizing the complex interplay of social, cultural, economic, and health factors that contribute to these phenomena. Understanding and addressing these interconnected challenges is essential for promoting the rights and well-being of children and adolescents globally.

In the 35 years since 1990, significant progress has been achieved in reducing adolescent child marriage, early pregnancy, and school dropout rates in many countries, particularly in the earlier years. However, recent data suggests that some countries are experiencing some increment in these indicators. As a result, predictions indicate a slight increase in some countries from 2025 to 2030. Unfortunately, progress is not occurring rapidly enough to achieve the goal of quality education for all and the elimination of harmful practices by 2030. This highlights the urgent need for accelerated efforts to address these challenges and meet the targets set forth by global initiatives.

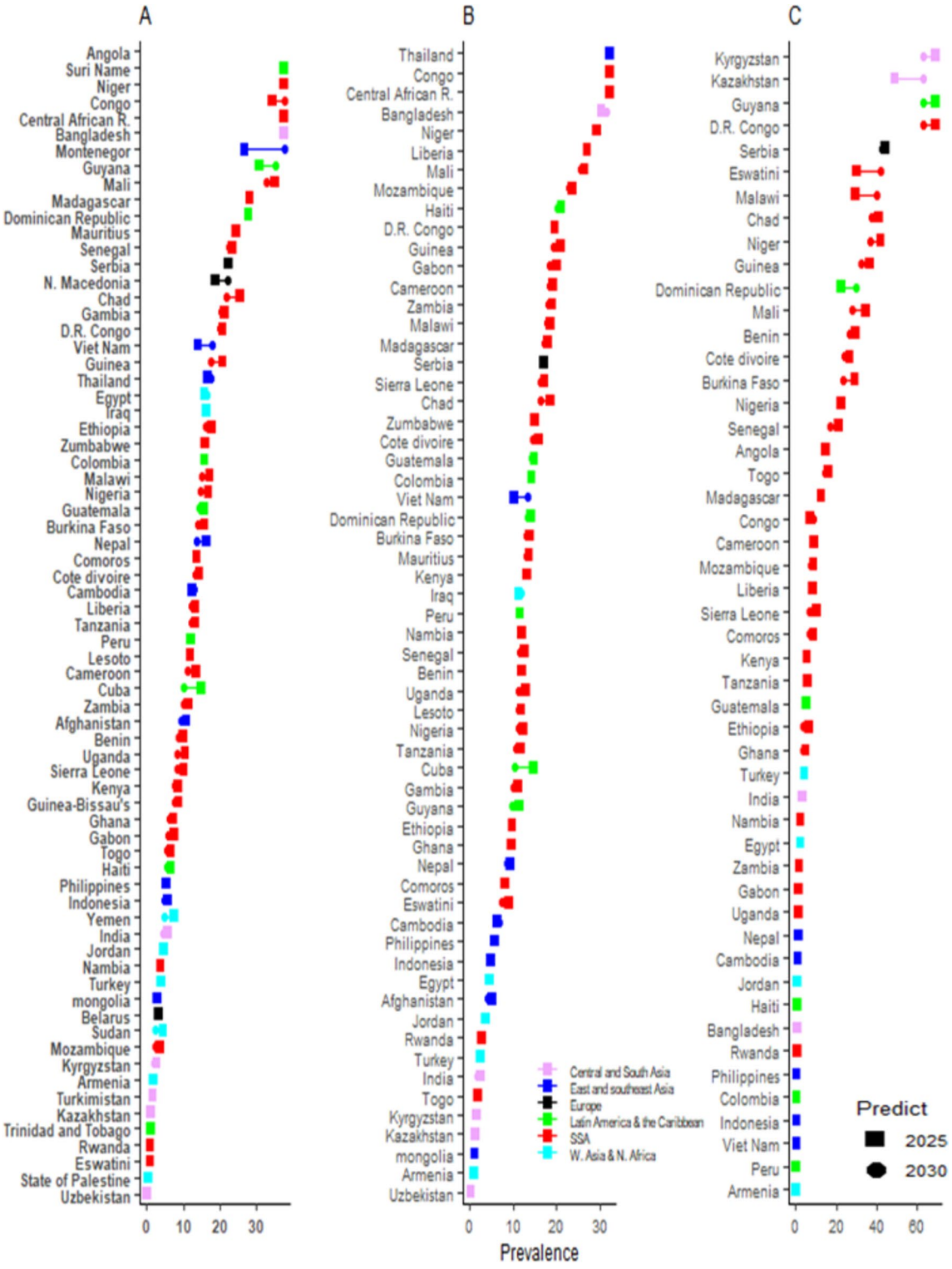

Fig. 4. Forecasting adolescent early childbirth (**A**), maternity (**B**), and school dropout (**C**) prevalence using Crud Odds Ratio (COR). Colors represent global regions (e.g., red indicates SSA countries), where rectangles indicate predicted prevalence values for 2025 and circles indicate predicted prevalence values for 2030.

Globally, the decline in those key indicators has been insufficient. Approximately a quarter of countries still have at least a third of their children out of school, while a third of countries have at least a fifth of children experiencing early marriage, and a fifth of countries have at least a fifth of children suffering in childbirth. Looking ahead to 2030, projections suggest that 24%, 17%, and 32% of countries will continue to have one in

every five adolescent children married, giving birth, and out of school, respectively. The uncontrolled distribution of these cases increases the likelihood of missing the 2030 SDG targets[40].

Girls who marry before the age of 18 are at a higher risk of experiencing early pregnancies and dropping out of school. Ending child marriage is crucial not only for improving the health and well-being of girls but also for the well-being of their future families and communities. Additionally, ending child marriage can help prevent early childbirth and school dropout[41].

The future of our world cannot be shaped for the better without significant changes for today's girls and tomorrow's women. The Global Fund for Women recognizes that girls possess their strengths, which are valuable not only for themselves but also for their families and communities. Adolescent girls play a fundamental role in every aspect of their communities and countries. They are essential for achieving systemic transformation that will create a world rooted in equity. However, the reality is that the potential of girls often remains untapped due to barriers such as limited access to education and exposure to harmful practices.

While most countries have agreed to work towards the elimination of harmful practices and ensuring quality education for all, progress has been declining over time[42]. However, it remains challenging to eliminate these issues in the next few years. The current situation highlights that only a few countries are making progress towards their goals, while the majority are falling behind. In normal circumstances, adolescent girls typically rely on their parents for support to continue their education. However, many girls end up dependent on their husbands, dropping out of school, and experiencing early childbirth. This cycle has persisted not only in the past and present but also threatens to continue. As they grow older, these women may become dependent on their children, perpetuating a harmful cycle. This approach is unsustainable; every woman deserves to be independent, in control of her destiny, educated, and self-reliant. Unfortunately, some girls lack these opportunities due to harmful practices and a lack of access to education.

In essence, people learn by observing others, and today's girls, who will become tomorrow's women, serve as practical teachers for their daughters. Focusing on empowering girls in education and eliminating harmful practices is not only investing in the current generation but also shaping the future. Efforts to support girls today will have a ripple effect, influencing the education and well-being of future generations. Bridging the gap between targets and practical achievements requires collective efforts and a holistic approach from all stakeholders towards building a sustainable world.

This analysis is subject to several limitations. Firstly, the use of secondary nationally representative surveys may lead to the underrepresentation or exclusion of certain marginalized populations, potentially resulting in biased estimates. Secondly, combining data from different survey years and countries can introduce inconsistencies in measurement methods, survey administration, and the socio-economic context of adolescents across periods and borders, affecting the comparability and reliability of trends and predictions. Thirdly, the accuracy and reliability of the secondary survey data rely on the quality of data collection, including sampling techniques, questionnaire design, and data processing, which, if erroneous or biased, could impact the validity of prevalence estimates and trend analyses. Furthermore, while the surveys cover a large number of countries and regions, the findings may not be universally applicable due to variations in cultural norms, social structures, and policy environments, potentially influencing adolescent outcomes differently across contexts. Additionally, insufficient data availability in some countries may limit the analysis and interpretation of trends and predictions, leading to gaps in understanding the dynamics of adolescent outcomes and hindering the formulation of targeted interventions. Moreover, the use of Bayesian estimation methods and prior distributions, such as Jeffrey's prior, is contingent on certain statistical assumptions about the data and underlying population parameters, violations of which could compromise the validity and robustness of inference. Lastly, while the analysis offers valuable insights into adolescent outcomes, interpreting the findings necessitates consideration of broader socio-economic, cultural, and policy contexts, given the complex interplay of factors influencing adolescent well-being beyond mere statistical associations.

The findings of this study have significant implications across several domains. In practice, there's a pressing need for customized interventions that tackle specific challenges faced by adolescent girls, such as early marriage, childbirth, and educational barriers. Early interventions focusing on education and empowerment can disrupt the cycle of early marriage and childbirth, offering girls better prospects for the future. Community engagement is crucial in challenging harmful traditions and promoting girls' education and well-being.

Policymakers must align their efforts with SDGs related to education, gender equality, health, and poverty eradication. This alignment can guide policy formulation aimed at eliminating harmful practices and ensuring universal access to quality education. Strengthening legislation and enforcement mechanisms against child marriage and enforcing compulsory education for girls can protect their rights and foster their development. Increased investment in education infrastructure and resources can enhance access to quality education for girls, reducing dropout rates due to early marriage or pregnancy.

Further studies are needed to understand the underlying factors contributing to early marriage, childbirth, and educational exclusion among adolescent girls. Evidence-based interventions and policy decisions can stem from such research. Advocacy efforts are crucial in raising awareness about the detrimental effects of early marriage and childbirth on girls' health and well-being, advocating for policy changes, and increasing investment in girls' education and empowerment.

In the realm of global initiatives, collaboration between governments, NGOs, and civil society is essential in addressing the multifaceted challenges faced by adolescent girls worldwide. Coordinated efforts can leverage resources and expertise to scale up interventions and achieve meaningful impact. Continuous monitoring and evaluation of progress towards SDG targets related to girls' education and the elimination of harmful practices are vital to identify gaps, measure intervention effectiveness, and guide adjustments as necessary.

Overall, this study underscores the urgency of prioritizing the needs of adolescent girls, particularly in addressing early marriage, childbirth, and educational barriers. Through targeted interventions, policy

alignment with global goals, further research, and international collaboration, stakeholders can work towards a world where every girl has the opportunity to thrive and fulfill her potential.

Materials & methods

Data sources

In this study, publicly available secondary data from the Demographic and Health Surveys (DHS)[43] and the Multiple Indicator Cluster Survey (MICS)[44] were analyzed. The DHS and MICS are nationally representative cross-sectional surveys, primarily conducted in low- and middle-income countries which encompass comprehensive information on adolescent education, marriage, and childbirth. These surveys utilize similar multi-stage cluster sampling techniques to select samples for inclusion, thereby rendering them highly comparable for global-based analyses of this nature. The analysis incorporated a total of 1,292,258 adolescent girls from 386 surveys conducted across 106 countries; spanning the years from 1990 to 2023 (See Supplementary Tables 1 & 2 for more sample details).

Dependent variable

Education status was assessed based on the adolescent child's status in the survey year (whether they attended education during that year or not). Child early marriage and childbirth were defined as a formal marriage or informal union where the girl is under the age of 18 and gives birth before the age of 19 (before her 18th birthday), respectively.

Data management

The DHS and MICS employ their standardized instruments with local adaptations, but some national surveys collect data differently. In cases where inconsistencies existed between surveys regarding question language, wording, coding, or response categories, a variable was coded to be broadly comparable to the data available in the DHS. These variables were then categorized into binary outcomes, such as whether the individual attended school in the current year or not, whether they were married before the age of 18 or not, and whether they gave birth before the age of 19 or not.

Statistical analysis

Every measure was condensed for each adolescent participant in every survey conducted. The estimates encompass adolescents aged 15 to 19 years worldwide.

Binary variables, representing non-case/case of certain characteristics, were summarized as proportions at both country (admin0) and regional (admin1) levels. Prevalence estimates were obtained using a Bayesian approach and reported with accompanying 95% Credible Intervals (CrI) for each country. Trend and prediction analysis were conducted using logistic regression models (Bayesian).

Prevalence estimation in administrative regions utilized either conjugate (where the prior distribution resembles the posterior distribution) or Jeffrey prior distributions. The likelihood comprised data from the most recent, while the prior consisted of data from the second most recent. However, due to insufficient data in some countries, employing a non-informative prior for some and a conjugate prior for others was considered inadequate. Utilizing Jeffrey's prior, which integrates data information through the Fisher information matrix, was found to offer more effective inference than non-informative priors. As a result, the Jeffrey prior was implemented in cases where only recent data was available for a country[45].

The rationale behind choosing the most recent data as likelihood and the second most recent as the prior (Conjugate prior) is as follows: the most recent data is expected to be the most pertinent and indicative of the present state of the population. Using the second most recent data as the prior achieves a balance by incorporating recent trends while also acknowledging longer-term patterns; it serves as a reliable benchmark with relatively high data quality and consistency, thus enhancing the stability of the estimation process. In essence, this approach to data selection aims to strike a balance between capturing current trends and upholding statistical reliability and consistency over time.

Trend analysis was conducted for each country by quantifying the change over time using binary logistic regression. The Odds Ratios (ORs) along with their 95% CrI were plotted. In this analysis, the oldest dataset for each country served as the reference point, and subsequent datasets were compared to the oldest. Non-informative priors were employed; countries with only one dataset available were excluded from trend analysis.

Countries with at least three different consecutive datasets were included as likelihood and no informative prior implemented in the prediction model. Logistic regression based on the individual status of each case was implemented for these countries.

To evaluate the impact and extent of measurement errors, a reliability coefficient was calculated, and its precision was assessed to ensure accurate measurements for safe and efficient outcomes in each case across all countries. The signal-to-noise ratio (SNR) was computed as part of this process to quantify the relationship between the desired signal and background noise. SNR serves as a metric for assessing the balance between pertinent information and extraneous or erroneous data, indicating the ratio of true information to false or irrelevant information. In this context, SNR was calculated based on the ratio of prevalence to standard error, providing insight into the quality and reliability of the measured data.

The approach that was used in this study has the following limitations regarding the choice of methods and materials. First, the use of some secondary data brings probable bias and a potential underestimation of the given population group. Third, data were collected using different methods from several years and countries and this could less directly compare the differences in trends over different regions. Despite the fact that the study involves 106 countries some countries are poorly represented or there is no recent and sufficient data on them, so the results of the study can only give an approximate picture of these areas and provide a rather

limited generalization at the global level. Not all factors related to adolescent marriage, childbearing and school dropout are well understood, and thus there is less ability to offer culturally, socially and economically sensitive recommendations. In addition, Bayesian methods are applied to the estimation of trends and forecast while the credibility of the projection largely depends on the quality and accessibility of the underlying data. Whenever there was sparse data, Jeffrey priors may not fully capture the dynamics of adolescents' experiences which would impact the projection and noted in the countries with lack of fresh data or inadequate data.

The final report includes Estimates of prevalence estimates along with their corresponding 95%CrI; change over time (COR) using binary logistic regression, accompanied by its 95% CrI, to depict trends over time; projections of prevalence estimates for the years 2025 and 2030; evaluation of the SNR to gauge the precision and reliability of the measurements, indicating the balance between relevant and irrelevant information.

The data management tasks were conducted using STATA (version 17), leveraging its robust features for data organization and manipulation. For the subsequent data analysis, R (version 4.3) was utilized, taking advantage of its extensive statistical capabilities. Specifically, rstan, a package within R, was employed for the calculation of the change over time and prediction using Bayesian inference methods. This combination of software tools ensured efficient and comprehensive handling of the data from management to analysis, facilitating rigorous and insightful research outcomes.

Data availability

The data are available from the corresponding author (Bayuh Asmamaw Hailu) upon reasonable request.

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Author contributions

B.A.H. designed the study, interpreted the results, drafted the article, and conducted the data analysis, and preparation of the manuscript and J.B. contributed to the choice and implementation of the statistical methods, interpretation of results, and critical review and editing. Both authors performed critical revisions for important intellectual content and read and approved the article.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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