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Systems modelling and simulation to guide targeted investments to reduce youth suicide and mental health problems in a low–middle-income country

Laura Ospina-Pinillos[1*], Adam Skinner[2], Mónica Natalí Sánchez-Nítola[1], Débora L. Shambo-Rodríguez[1], Alvaro A. Navarro-Mancilla[3,4], Salvador Camacho[5,6], Adriane Martin Hilber[5,6], Jose Miguel Uribe-Restrepo[1], Carlos Gomez-Restrepo[7,8], Ian B. Hickie[2] and Jo-an Occhipinti[2,9]

Abstract

Background Despite suicide's public health significance and global mental health awareness, current suicide prevention efforts show limited impact, posing a challenge for low- and middle-income countries. This study aimed to develop a dynamic simulation model that could be used to examine the potential effectiveness of alternative interventions for reducing youth mental health problems and suicidal behavior in Bogotá, Colombia.

Methods A system dynamics model was designed using a participatory approach involving three workshops conducted in 2021 and 2022. These workshops engaged 78 stakeholders from various health and social sectors to map key mental health outcomes and influential factors affecting them. A model was subsequently developed, tested, and presented to the participants for interactive feedback, guided by a moderator. Simulation analyses were conducted to compare projected mental health outcomes for a range of intervention scenarios with projections for a reference scenario corresponding to business-as-usual.

Results A total of 6670 suicide attempts and 347 suicides are projected among 7 – 17-year-olds from January 1, 2023, to early 2031 under the business-as-usual scenario. Mental health issues among 12 – 17-year-olds are projected to increase from 18.9% (2023) to 27.8% (2031), and substance use issues from 2.29 to 2.49% over the same period. School-based suicide prevention and gatekeeper training are the most effective strategies, reducing total numbers of suicide attempts and suicides by more than 20% (i.e., compared to business-as-usual). However, discontinuous funding significantly hinders these effective suicide prevention efforts.

Conclusions Systems modelling is an important tool for understanding where the best strategic financial and political investments lie for improving youth mental health in resource-constrained settings.

Keywords Strategic planning, Decision analysis, Systems modelling, Simulation, Suicide prevention, Mental health, Young people, Participatory research, Low- and middle-income countries, Colombia

*Correspondence:
Laura Ospina-Pinillos
laura.ospina@javeriana.edu.co
Full list of author information is available at the end of the article

Background

There is wide recognition of the global burden and disability related to common mental health (MH) and substance misuse problems [1]. Reducing suicidality in young people (YP) is a significant public health concern worldwide [1]. This issue is particularly alarming in low- and middle-income countries (LMICs), where 77% of all suicides occur [1]. Mental health problems and suicide are considered multifactorial issues influenced by a complex network of interacting individual, political, social, cultural, economic, and environmental factors [2]. The complex nature of these interactions means that effective interventions and policies have to consider the social determinants of health, as well as contextual and governmental factors such as accessibility, affordability and quality of care, MH literacy, and stigma [3]. Despite the importance of suicide as a public health concern and the increased awareness of intervening effectively to reduce the burden of MH conditions, emerging evidence suggests that current interventions are not yielding substantial impacts [4, 5], as trends are continuously on the rise [6–8]. These problems represent a significant challenge for LMICs, which are in a constant struggle to increase their mental capital through rapid implementation of interventions that are effective in reducing MH problems at a population level while also making the best use of limited resources [9].

To guide policy development, international agencies and academic institutions have issued a strong recommendation for governments to adopt systematic evidence-informed decision-making (EIDM) strategies [10, 11]. These approaches consider critical factors, including social determinants, resource availability, political commitment, and the regional social context, as essential components for achieving successful outcomes. Furthermore, EIDM places significant emphasis on the necessity of equipping stakeholders with comprehensive evidence, while also considering public opinion, effectiveness, sustainability, affordability, and acceptability as pivotal factors when crafting policies. Given the complexities inherent in reconciling conflicting evidence related to various interventions and their applicability in diverse populations [10, 12], EIDM serves as a reliable framework to provide guidance and assurance in the decision-making process.

Effective decision-making in public policy necessitates transparent, reliable governance that can adeptly respond to changing circumstances while ensuring equity across the population [13]. For an LMIC like Colombia, which is currently ranked 2nd as the most unequal country in the region, EIDM strategies are of particular importance. Furthermore, the country aims to transition from isolated interventions to comprehensive care and prevention programs [14] and has produced a strong MH legal framework to ensure the right to MH is fully exercised, advocating for prevention, promotion, treatment and rehabilitation across various settings [15–17]. However, substantial documented deficiencies in decision-making processes have led to the characterization of those processes as arbitrary, occasionally contradictory, and often unrealistic. Decision-making in these instances is often influenced by short-term needs or anecdotal evidence and frequently aligns with personal interests, ultimately undermining the overall quality and impact of implemented programs and policies [12, 13, 18]. This subjective decision-making approach not only carries the potential for negative impacts on population health outcomes, resulting in unintended harm, but also leads to the unnecessary waste of resources. Addressing these issues is vital for enhancing the effectiveness and sustainability of public policies in Colombia and other LMICs [1, 10, 12, 19, 20].

As effective decision-making becomes a more challenging task that requires consideration of multiple interacting determinants in a changing world, systems modelling and simulation emerge as a valuable tool in tackling these decision-making challenges. It provides a means of capturing the dynamics of a set of interconnected variables over time, as well as forecasting the effects of different interventions directly affecting one or more of those variables [4]. This approach provides the opportunity to thoroughly map and quantify the complex causal mechanisms that drive MH and suicide outcomes [4]. As a quantitative method within the realm of complex systems science, it can capture population and demographic changes, fluctuations in economic and social drivers, workforce dynamics, and, most notably, the potentially non-additive effects resulting from combinations of interventions [4]. This tool allows informed decisions about the most effective allocation of limited resources [4]. Used widely in other fields, including infectious disease epidemiology [21], its application in global MH could prove especially useful in LMICs such as Colombia, countering the short-term trial and error decisions usually adopted in these countries whilst also addressing the need for local and contextual interventions leading to effective change.

Bogotá, the capital city of Colombia (48 M inhabitants), is experiencing significant growth in its population, currently adding up to 8 M inhabitants [22, 23]. With an expanding urban demographic, the city faces heightened risks of mental disorders, exacerbated by increased contextual complexities specific to the Colombian context. With one of the world's longest-lasting internal conflicts, exposure to violence is a compelling issue. According to the latest National Mental Health Survey (NMHS) from the Ministry of Health and Social Protection [24],

12.2% of Colombian adolescents and 9.6% of Colombian adults grapple with MH problems. The lifetime prevalence of MH disorders stands at 7.2% in the adolescent group and 9.1% in adults. In relation to substance use, in the 12–17 age group, the last-month prevalence of binge drinking was 12.1%. Additionally, 2.5% of all adolescents (12–17 years old) who were surveyed reported using illegal substances in the previous year [25]. In the 18–24 age group, 8.90% are at risk of or already misusing alcohol, and 7.47% have used illegal drugs in the last year. In terms of suicide, the reported suicide rate was 5.7 per 100,000 in 2021, with rates of 6.5 per 100,000 for YP aged 15–17 and 9.2 per 100,000 for those aged 18–19, with 72.3% of cases occurring in urban areas.

These complexities thus encompass social, family, educational, and vocational aspects, creating a growing burden on MH particularly affecting YP [26, 27]. A third [8] of Bogota's population is under 25 years of age and most of the population does not identify with any ethnic group [26, 28]. The city reported the highest number of Venezuelan migrants in the country [29] and faces significant levels of unemployment, homelessness, violence, drug trafficking, criminality, homicide, and internal displacement related to Colombia's armed conflict [7, 30–32].

The aim of this project is to use a participatory approach to develop a system dynamics model capturing this complexity to be used as a decision-support tool for strategic planning and investments in youth MH and suicide prevention. This is an international collaborative endeavor between CSART (Computer Simulation and Advanced Research Technologies, international), The University of Sydney (Camperdown, Australia), Swiss Tropical and Public Health Institute (Allschwil, Switzerland), and Pontificia Universidad Javeriana (Bogotá, Colombia), in partnership with a broad range of in-country stakeholders who participated in the research study and represent a diversity of sectors related to youth MH.

Methods

Model development

A system dynamics model [33, 34] was developed through a participatory approach with three workshops which were conducted in 2021 and 2022. For recruitment, institutions in Bogota from the education, health department, insurance, child protection, non-governmental organizations, primary care, and health provision sectors, as well as policymakers, special interest groups, academics, and individuals with lived experience (youth) and/or their caregivers [35] were first identified. Once the list was compiled, invitations were extended, and interested stakeholders were asked to identify one or more delegates and register them through an online form. Information about the project was provided to representatives, doubts were resolved, and logistics were arranged to ensure smooth enrolment [35].

The aim of these workshops was to map the key pathways and the principal social and economic factors contributing to MH problems (such as employment, education, and family violence) and routes through the MH care system. This involved identifying system barriers, incentives, disincentives, bottlenecks, and hidden pathways to create a valid model of the MH system for young individuals in Bogotá.

During the first workshop, discussions related to key MH outcomes, and influential factors impacting these outcomes were mapped, including aspects such as care pathways, healthcare systems, and support services. Additionally, interventions related to MH and suicide prevention were discussed for potential inclusion in the model. The objective of the second workshop was to present a preliminary version of the model and gather feedback and recommendations on its various components and key model assumptions. Overall, recommendations were provided for the model, along with specific critiques regarding individual components. The directionality of causal relationships between certain model components received significant attention and participants identified missing or alternative data that could improve the model. Afterward, the interventions were discussed to identify each intervention's specific components, their direct effects within the model, and any unintended consequences. The third workshop presented a draft of the model including how stakeholder input was incorporated and how data and evidence were selected to inform model development. A brief demonstration of the model and its key preliminary insights took place, after which participants could interact with it under the guidance of a moderator. Participants provided feedback and recommendations on the overall user interface, data sources informing the model, and specific suggestions regarding components.

Model structure, calibration, and outputs

The system dynamics model used for the simulation analyses presented here consists of a set of interconnected sub-models, or sectors, that includes (1) a population sector, capturing changes in population size and structure resulting from births, migration, aging, and mortality; (2) a sector modelling changes in the prevalence of MH problems; (3) a developmental vulnerability sector, capturing exposure to adverse experiences in childhood that increase the risk of MH problems in adolescence and adulthood (parental MH and substance use problems, poverty, family violence, internal displacement); (4) an education sector, modelling secondary and post-secondary education and vocational

training enrolment and completion rates; (5) an unemployment and poverty sector, capturing economic participation, unemployment, and informal employment and poverty; (6) a substance use sector, capturing changes in the prevalence of substance use problems; (7) a sector modelling exposure to family violence and violent crime; (8) an internal displacement sector, capturing the socioeconomic and MH effects of forced displacement resulting from conflict-related violence; (9) a health services sector, modelling access to MH services (community-based and hospital) and treatment-dependent recovery; and (10) a suicidal behavior sector, capturing initial and repeat suicide attempts and suicide deaths. Figure 1 presents a high-level map of the core model showing the (causal) connections among sectors. Detailed descriptions of all sectors, are provided in Additional file 1: Model structure. Model construction and analysis were performed with Stella Architect® version 2.1.5 ((isee systems, Lebanon, NH, USA; see https://www.iseesystems.com/).

Parameter values that could not be derived directly from available data or published research were estimated via constrained optimization, using historical time series data for a wide range of sociodemographic and health-related outcomes (see Additional file 1: Table S2). Powell's method was used to obtain the set of (optimal) parameter values minimizing the mean of the absolute differences between the observed time series values and the corresponding model outputs, where each difference was expressed as a percentage of the observed value (i.e., the mean absolute percent error was used as the objective function for the optimization analysis) [33]. Primary model outputs include total (cumulative) numbers of suicide attempts and suicide deaths for children and adolescents aged 7 – 17 years, numbers of child and adolescent suicide attempts and

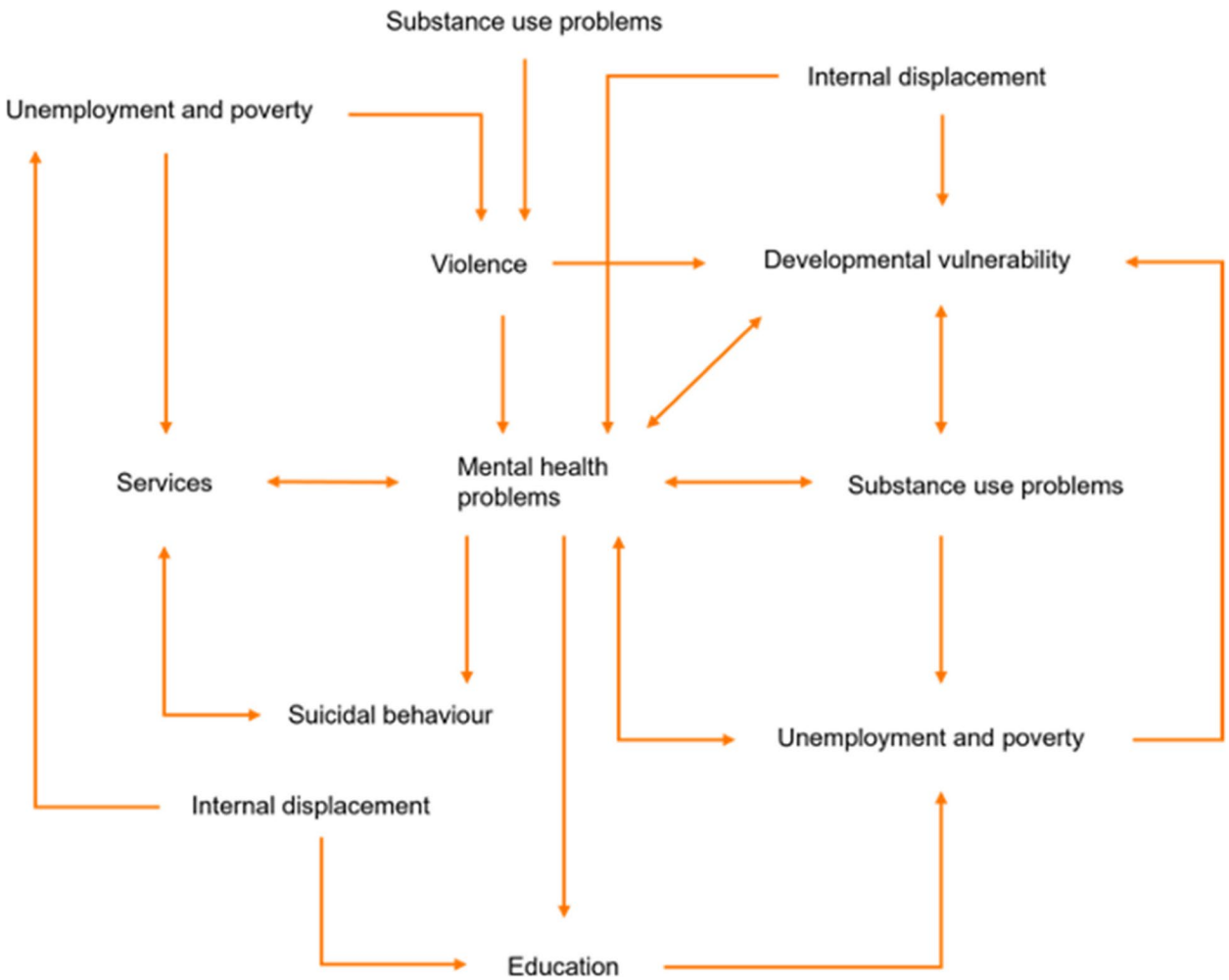

Fig. 1 High-level map of the core system dynamics model showing the causal connections among model sectors. Single-headed arrows indicate unidirectional causal connections; bidirectional causal connections are shown as double-headed arrows

suicides per year, and the proportions of children and adolescents aged 12 – 17 years with MH problems and substance use problems. All outputs are calculated every 0.0625 years (about 3 and a half weeks) over a period of 21 years, starting from 1 January 2010, so that the impacts of health services and community interventions were modeled from the time of implementation (1 January 2023) to the start of 2031 (we ran simulations from the start of 2010 to permit comparisons of model outputs with past system behavior; see Additional file 1: Figure S8, S10, S12, S14, S16, S18, and S20).

Policy testing and sensitivity analyses

We modeled the effects on child and adolescent MH and suicidal behavior of six health services and community interventions prioritized by stakeholders in the participatory modeling workshops: school-based suicide prevention programs, anti-bullying programs, gatekeeper suicide prevention training, increased access to suicide helplines, general practitioner MH training, and community connectedness programs (Table 1). Additionally, we considered the effects of cyclical (as opposed to continuous) program funding, in which selected interventions were discontinued and restarted midway through 2026 and 2030 (we assumed a 4-year funding cycle aligned with, although not necessarily attributable to, government periods). A total of 10 alternative intervention scenarios were compared with a baseline (business as usual) scenario in which existing policies and programs remain in place and the current growth in community-based MH services capacity is maintained until the end of the simulation.

Sensitivity analyses were performed to assess the impact of uncertainty in estimates of the direct intervention effects on the simulation results. Latin hypercube sampling was employed to generate 200 sets of values for all model parameters determining the direct effects of the interventions on MH, suicidal behavior, substance use, and engagement with MH services from a relatively broad (joint) distribution of values (see Table S3). Differences in the projected total number of suicide attempts, suicide mortality, and the prevalence of MH and substance use problems between the baseline and intervention scenarios were calculated for each set of parameter values and summarized using simple descriptive statistics (means, medians, and 95% intervals). All intervals reported in this paper are derived from the distributions of model outputs calculated in the sensitivity analyses; they provide a measure of the impact of uncertainty in the intervention effect estimates but should not be interpreted as confidence intervals.

Results

Workshop participants

A total of 78 stakeholders participated in the workshops, 57 in the first workshop, 42 in the second workshop, and 54 in the last workshop (Table 2). Three were in the 18–24 age group, 19 in the 25–34 age group, 25 in the 35–44 age group, 12 in the 45–54 age group, 18 in the 55–65 age group and 1 was above 65 years old.

Suicide attempts and suicide mortality

Modelled baseline numbers of suicide attempts and suicides per year for 7 – 17-year-olds are presented in Fig. 2. A total of 6670 suicide attempts and 347 suicides are projected from 1 January 2023 (the default starting date for all interventions) to the beginning of 2031 (i.e., assuming the status quo), with the suicide attempt rate increasing from 772 to 898 suicide attempts per year (67.6 to 84.0 suicide attempts per 10^5 population per year) and suicide mortality increasing from 40 to 47 suicides per year (3.51 to 4.36 suicides per 10^5 population per year) over this period (see Fig. 2). School-based suicide prevention programs and gatekeeper suicide prevention training are substantially more effective than the remaining interventions in preventing suicidal behavior (where each intervention is implemented alone; Fig. 3), reducing the total number of suicide attempts by 28.0% (95% interval, 23.8 – 31.9%) and 22.6% (95% interval, 13.6 – 30.7%), respectively, and total suicide mortality by 27.7% (95% interval, 23.5 – 31.5%) and 22.5% (95% interval, 13.4 – 30.5%), respectively. Anti-bullying programs and increased access to suicide helpline services reduce total numbers of suicide attempts and suicides by 3.8% and 3.5% respectively, while the effectiveness of community connectedness programs and general practitioner MH training on suicidal behavior is more limited (see Fig. 3). Nearly half of all suicide attempts and suicides projected under the baseline scenario are prevented when school-based suicide prevention programs are combined with gatekeeper suicide prevention training, anti-bullying programs, and increased access to suicide helplines (Fig. 3).

MH and substance use problems

Under the baseline scenario, the prevalence of MH problems among 12 – 17-year-olds is projected to increase from 18.9% at the beginning of 2023 to 27.8% at the start of 2031, while the proportion of 12 – 17-year-olds with a substance use problem is projected to increase from 2.29 to 2.49% (i.e., over the same period; see Fig. 4). Programs that act to directly increase community connectedness reduce the projected prevalence of MH problems and substance use problems in 2031 by 2.12 percentage points (95% interval, 1.38 – 2.75 percentage points) and 0·78 percentage points (95% interval, 0.62 – 0.92 percentage

Table 1 Community and health services interventions examined in the analyses

Intervention	Description	Direct effect(s)	Reference(s)
a. School-based suicide prevention programs	Curriculum-embedded MH education aimed at increasing awareness of suicide and brief screening for depression and other risk factors associated with suicidal behavior	Reduces the incidence of suicide attempts and substance use problems, and increases the per capita rates at which adolescents perceive a need for care and engage with MH services	[36–38]
b. Anti-bullying programs	School-based programs aimed at reducing exposure to bullying and cyberbullying	Reduces the incidence of significant MH problems	[39]
c. Gatekeeper suicide prevention training	Programs providing suicide prevention training to community gatekeepers (educators, community mothers, young leaders, etc.) with the aim of reducing suicidal behavior among children and adolescents (aged 7 – 17 years)	Reduces the incidence of suicide attempts	[40]
d. Suicide helplines	Increased investment in helpline services for people experiencing suicidal crisis	Reduces the incidence of suicide attempts	[41]
e. GP MH training	Programs and policies aimed at enhancing the capability of general practitioners (GPs) and other health professionals to provide effective clinical support to patients with mental disorders, including (1) comprehensive MH training programs for primary care providers; (2) improving the quality of MH education in undergraduate medical curricula; and (3) providing incentives to encourage specialization in psychiatry	Increases total MH services capacity (i.e., the total number of MH-related consultations that can be provided per year)	[42]
f. Community connectedness programs	Community programs and services for adolescents (aged 12 – 17 years) that increase social connectedness, reducing isolation and enhancing resilience in the face of adversity	Reduces the incidence of significant MH problems and substance use problems	[43]

Note: Details of all interventions are provided in Additional file 1: Table S1

Table 2 Stakeholder categories per participatory workshop

Role	Workshop 1 *n*	Workshop 2 *n*	Workshop 3 *n*
Child protection	6	5	2
Consumers/people with lived experience/carers	6	5	5
Education sector/education department/counselors	3	2	2
Health department/policy makers/policy officers/local health district reps	9	8	15
Health providers	8	7	8
Insurance reps/health benefit plan management companies	2	1	1
Mental health clinicians	3	2	4
NGO	3	0	1
Primary care/GPs/nurse managers/allied health	5	2	7
Representatives from special interest groups	2	1	1
Youth mental health academics/epidemiologists/social scientists	10	9	8
Total	57	42	54

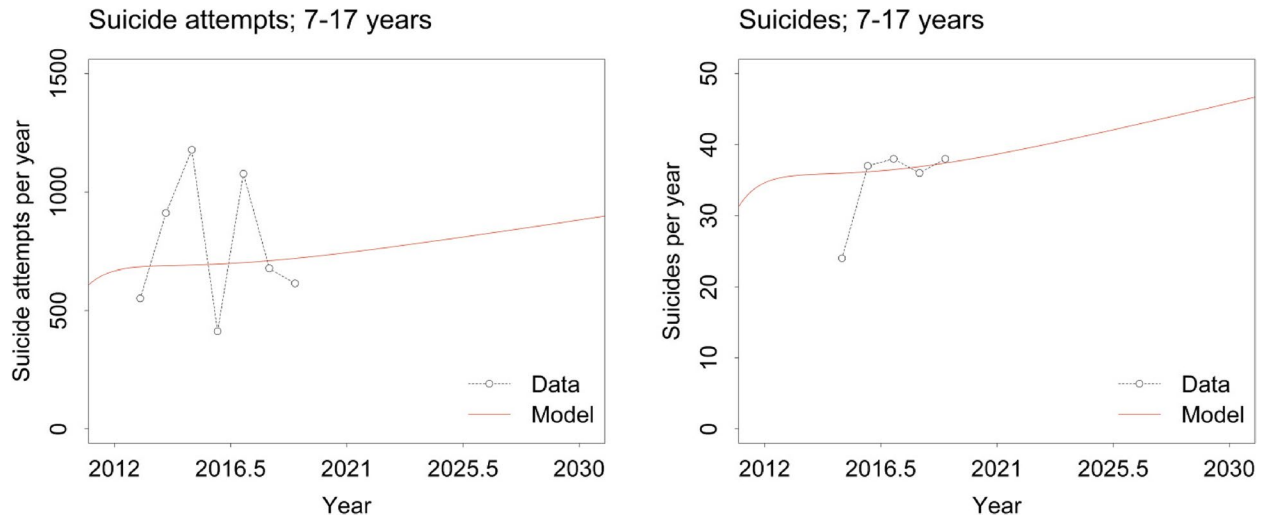

Fig. 2 Projected numbers of suicide attempts and suicides per year for children and adolescents (7 – 17 years) in Bogotá, Colombia under the baseline scenario. Data for suicide attempts and suicides are from the Suicidal Behaviour Epidemiological Surveillance Subsystem (SISVECOS) and the National Institute of Legal Medicine and Forensic Sciences (INMLCF), respectively

points), respectively. More substantial reductions are achieved when community connectedness programs are combined with school-based suicide prevention programs (which are assumed to cover both substance use prevention and suicide prevention) and anti-bullying programs; under this scenario, the prevalence of MH problems increases to 21.6% in 2031 (a 6.2 percentage point reduction relative to the baseline projection), while the prevalence of substance use problems declines to 1.39% (a 1.1 percentage point reduction; see Fig. 4). The most effective combination of four interventions for preventing suicidal behavior (school-based suicide prevention programs + gatekeeper suicide prevention training + increased access to suicide helplines + anti-bullying programs; scenario g in Fig. 3) reduces the prevalence of MH problems and substance use problems in 2031 by 4.55 percentage points (95% interval, 3.55 – 5.53 percentage points) and 0. 50 percentage points (95% interval, 0.35 – 0.64 percentage points), respectively (see Fig. 4).

Discontinuous program funding

Discontinuous (or cyclical) funding restricts the projected impacts of effective suicide prevention interventions considerably (see Fig. 5). Percentage reductions in total numbers of suicide attempts and suicides for 7 – 17-year-olds achieved with a combination of school-based suicide prevention programs, gatekeeper

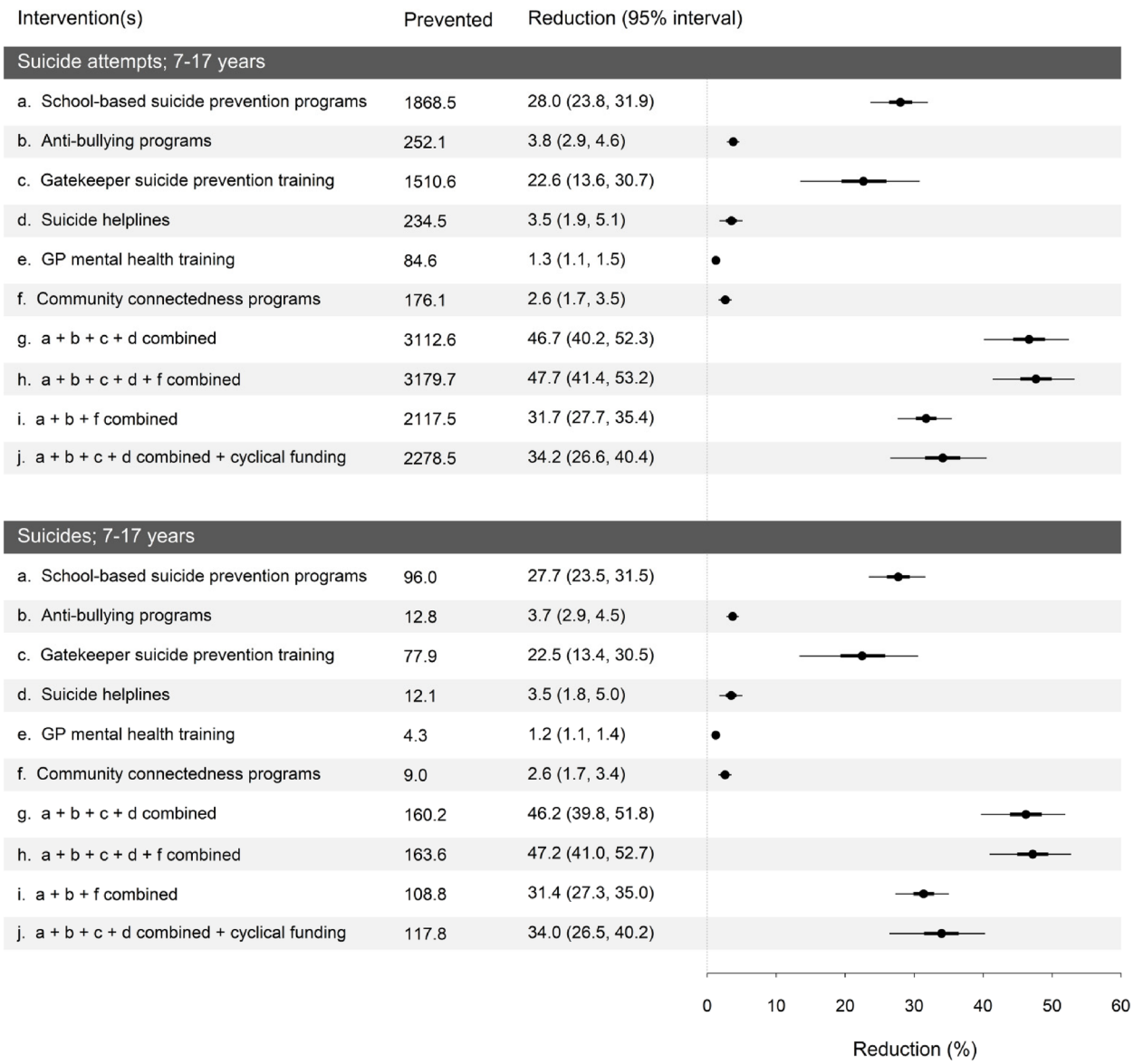

Fig. 3 Differences in total (cumulative) numbers of suicide attempts and suicide mortality between the baseline and intervention scenarios for children and adolescents (7 – 17 years) in Bogotá, Colombia over the period 2023 – 2031. Mean numbers of prevented suicide attempts and suicides (reported in the second column from the left) and mean percentage reductions and 95% intervals (in the rightmost column) were derived from the distributions of projected outcomes calculated in the sensitivity analyses. Note that the 95% intervals provide a measure of the impact of uncertainty in the assumed intervention effects but should not be interpreted as confidence intervals. The plot on the right shows the mean percentage reductions (closed circles) and 95% and 50% intervals (light and heavy lines, respectively)

suicide prevention training, increased access to suicide helplines, and anti-bullying programs fall from 46.7% (95% interval, 40.2 – 52.3%) and 46.2% (95% interval, 39.8 – 51.8%), respectively, to 34.2% (95% interval, 26.6–40.4%) and 34.0% (95% interval, 26.5–40.2%) [43], respectively, when interrupted funding results in all four interventions ending and recommencing midway through 2026 and again in mid-2030 (Fig. 3).

Discussion

System dynamics involves integrating all available evidence, including administrative data, previous research, expert opinions, and lived experiences, into a logically consistent, interactive "what-if" tool. This tool serves to enhance the understanding of potential impacts associated with proposed interventions before adoption, and it is particularly relevant when resources are limited [44]. This process involves interdisciplinary and collaborative

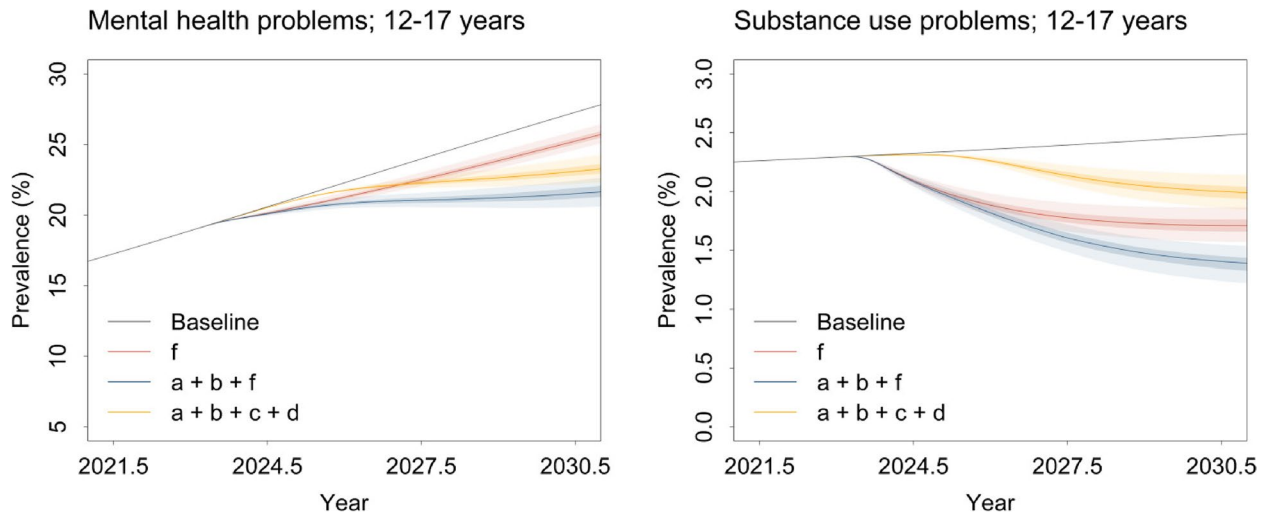

Fig. 4 Prevalence of child and adolescent MH problems and substance use problems (12 – 17 years) in Bogotá, Colombia under the baseline scenario and for selected intervention scenarios: f (red), community connectedness programs; a + b + f (blue), school-based suicide prevention programs + anti-bullying programs + community connectedness programs; a + b + c + d (yellow), school-based suicide prevention programs + anti-bullying programs + gatekeeper suicide prevention training + suicide helplines. Solid lines correspond to median values derived from the sensitivity analyses. Pointwise 95% and 50% intervals are indicated with light and dark shading, respectively

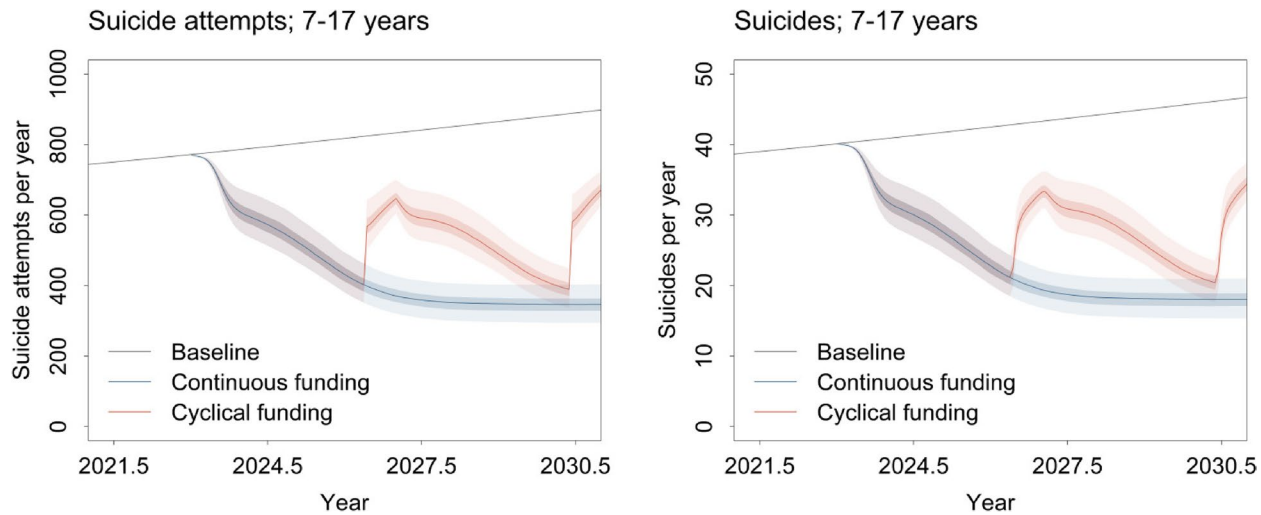

Fig. 5 Effect of cyclical program funding on reductions in suicidal behavior among children and adolescents (7 – 17 years) in Bogotá, Colombia. Continuous funding (blue): school-based suicide prevention programs + anti-bullying programs + gatekeeper suicide prevention training + suicide helplines (intervention scenario g in Fig. 3), continuously funded from 1 January 2023 until the end of the simulation. Cyclical funding (red): school-based suicide prevention programs + anti-bullying programs + gatekeeper suicide prevention training + suicide helplines, commencing in 2023 (as in the continuous funding simulation), but with discontinuous funding, so that all four interventions end and restart midway through 2026 and 2030 (we assumed a 4-year funding cycle aligned with, although not necessarily attributable to, presidential elections). Median values derived from the sensitivity analyses are plotted as solid lines. Pointwise 95% and 50% intervals are indicated with light and dark shading, respectively

work with stakeholders to understand mechanisms, proposed interventions, and possible outcomes within complex health systems [45, 46]. In Colombia, a nation with a history marked by persistent challenges, there are opportunities for improvement in areas such as civic participation, transparency, effective policy implementation, and robust monitoring mechanisms. Addressing issues related to resource allocation and enhancing governance practices will contribute to fostering positive change, so that employing system dynamics becomes

indispensable for navigating and addressing these intricate issues [47].

The Colombian governments (presidential, mayorship, and regional government) are elected for a 4-year term with no option for re-election. This essentially means that all public and political plans should ideally be designed, performed, and measured in a 4-year timeframe and be sufficiently transparent so that the next government can seamlessly continue its execution [48]. However, it has been documented that with the change of governments, the continuity of implementation is often jeopardized by political will, public opinion, and availability of resources, which become significant drivers in the new decision-making process [49] posing a risk to achieving significant public health outcomes. As such the incorporation of system dynamics offers a structured approach to assess and predict the potential impacts of policy changes, facilitating a more informed and sustainable decision-making process in Colombia's dynamic political landscape.

The objective of this project was to create a decision support tool based on national and regional data and best research evidence to examine the potential effectiveness of alternative interventions for reducing youth MH problems and suicidal behavior. Out of the intervention scenarios analyzed, school-based suicide prevention programs and gatekeeper suicide prevention training were the most effective interventions in reducing suicide attempts long term. The findings of our study are consistent with international literature. A recent meta-analysis analyzed the effect of suicide prevention programs for school-aged youth demonstrating small effects on suicidal behavior ($g=0{\cdot}17$, 95% CI [0·07–0·26], $p<0.01$) and psychological distress ($g=0.16$, 95% CI [0.10–0.23], $p<0.01$), but larger effects on suicide awareness and help-seeking [50]. Along the same line, European anti-bullying programs were reported to be moderately cost-effective when implemented for 6 years or longer, with an estimated reduction in bullying of 20% and an associated increase in quality-adjusted life years (QALYs) [51]. Furthermore, anti-bullying strategies have been shown to impact significantly on mental wellness [39]. The locally customized decision support tool provided through this action research has not only contributed to making a stronger case for investment in school-based suicide prevention programs and anti-bullying campaigns, but it has also provided this case in the context of its estimated impact over the next decade in an LMIC context compared to a suite of other commonly advocated strategies such as MH training for primary care providers, such as general practitioners.

At a community level, our findings are consistent with evidence suggesting that gatekeeper suicide prevention programs improve knowledge of and attitudes toward suicide [52–54], and can reduce suicide deaths and non-lethal suicide attempts [40, 55]. Culturally tailored gatekeeper training is also effective for specific groups; for example, research conducted with Indigenous communities in North America and other studies on military personnel have demonstrated positive results [56, 57]. Gatekeeper strategies can help to address MH care gaps in more disadvantaged countries. For instance, hairdressers in Togo, Africa were trained in MH counseling, due to the steep cost of therapy, and so far, this initiative has been well-received by the community [58]. Colombia has witnessed similar informal initiatives, including the "Puente de la Variante surveillance team" in Ibague City, which was established as a volunteer community vigilance group in response to a high number of suicides involving a local bridge. Mr. Victor Guerrero, a restaurant owner located close to the bridge, has prevented more than 300 deaths. Due to his efforts the initiative received private and public support in 2022 [59]. The impact of gatekeeper suicide prevention programs extends beyond individual awareness, shaping community perspectives on suicide; as such, community advocacy is needed to extend the delivery of this type of training to community settings where YP interact, as well as suicide hotspots.

While previous evidence from our research group showed that improving social connectedness is one of the most successful interventions [4], in this study, its impact was limited for suicide prevention but significant for reducing MH and substance use problems [20]. Colombian intrinsic factors like forced displacement, trauma (including transgenerational trauma), unemployment, migration challenges, domestic violence, homelessness, financial insecurity, and lack of green and blue spaces can further alter the social fabric [3]. As such, culturally and contextually appropriate social connectedness programs are needed to support positive environments and coexistence. Considering the wide diversity of contexts in the country, these strategies might need appropriate evidence to support effective implementation and replication among populations with similar characteristics, instead of scaling-up one size fits all programs. One of the most important findings in our study was the insight related to combining interventions that can have a greater than additive (synergistic) impact in our social context. Systems modeling offers a virtual space to examine the best mix, focus, timing, extent, frequency, and intensity of investments before they are implemented in the real world, saving time, resources, and potentially the lives of YP. Simulation, particularly in resource-constrained scenarios, has proved feasible and advantageous for evidence-based decision-making in LMIC contexts [44].

Limitations

While developing our model, a substantial challenge surfaced in the lack of unification among national information databases. Identifying 180 files (e.g., worksheets, dashboards, reports) from disconnected databases presented a significant hurdle, requiring a meticulous review and integration of these disparate databases into a cohesive framework. Lack of consensus among information-generating entities is apparent, as for instance, commonly used age breakdowns present limitations for studying the 10–24 age group in many official sources [60]. Regarding data in Colombia, the existence of multiple information sources, duplication, and lack of interoperability have been highlighted previously [60]. However, despite this fragmentation and the difficulty of identifying and collating available data, the quantity and quality of data available was sufficient for model development. For some indicators which might not have been publicly available, data donations from participants served to fill gaps, showing the complementary nature and value of participatory processes for systems modelling [15].

While better data is the cornerstone of decision-making and public policy [16], it is important to note that limited data availability, use of estimates, and other data deficiencies do not necessarily constitute a barrier to undertaking systems modelling projects in LMICs. Previous findings showcase that, in spite of uncertain baseline projections and even dramatically different projected impacts on outcomes of interest, best strategies remain highly consistent across alternative baseline scenarios [44]. For LMICs, there is hence a possibility of simultaneously developing improved decision-support tools and improving information systems, rather than doing so sequentially. In Colombia, comprehending the impact of implementation, especially of public initiatives; establishing an accurate feedback mechanism capable of monitoring the quality of the registered information; and researching the associations between MH problems and determinants such as poverty and migration remain important shortfalls to be addressed.

In addition, the collaborative nature of our approach enhances stakeholder familiarity with the software, ensuring user-friendliness and facilitating real-world impact exploration through feedback [15]. Nevertheless, the methodology's complexity extends development timelines, and training can pose challenges, given its applicability across diverse knowledge fields [15]. Moreover, the broader acceptability of these emerging decision support tools (beyond the stakeholders involved in model development) in the socio-economic context of an LMIC community remains uncertain.

Conclusions

Suicidality emerges as a pressing global health concern, significantly impacting societies and leaving enduring imprints on families and communities worldwide. The evidence underscores the imperative of prioritizing the well-being of our youth. Amidst diverse and challenging circumstances, advanced decision support tools offer indispensable insights, informing decision-making and shaping evidence-based programs with the potential for a lasting positive impact on individuals' lives. This relevance extends notably to addressing challenges encountered in LMICs, where factors such as budgetary constraints, limited human capital, intersectoral disconnection, and insufficient monitoring and evaluation processes contribute to the fragmentation and overall suboptimal quality and effectiveness of public health policies [15]. In the specific context of Colombia, where decision-making processes face challenges and concerns related to continuity, sustainability, and transparency, the routine application of participatory system dynamics modelling emerges as a strategic solution. This significance is particularly pronounced in a socio-political landscape marked by efforts to ensure project continuity across successive administrations [60]. Modelling stands out as a valuable tool, providing transparency and facilitating informed decision-making to guide future policy endeavors. Underscoring the value of effective decision-making in resource-constrained settings, this research not only emphasizes the relevance of systems modelling but also demonstrates its feasibility in developing sophisticated decision-support tools, even in contexts where a lack of sufficient data is often assumed.

Abbreviations

LMIC	Low–middle-income countries
YP	Young people
MH	Mental Health
EIDM	Evidence-informed decision-making
CSART	Computer Simulation and Advanced Research Technologies
NMHS	National Mental Health Survey
MSPS	Ministry of Health and Social Protection
QALYS	Quality-adjusted life years
GPs	General practitioners

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Authors' contributions

Manuscript concept and drafting: L.O.P, A.S, M.S.N, D.S. and J.O.; Model development: A.S.; Data analysis: A.S Critical revision of manuscript: S.C, A.M.M, A.N.M J.M.U.R, C.G.R, and I.B.H. All authors have read and approved the final version of the manuscript.

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Data availability
Detailed descriptions of all sectors, including specific databases, are provided in Additional File 1. National census data can be found at the National Administrative Department of Statistics website: https://www.dane.gov.co/index.php/en/. Data related to suicides and MH services can be requested to the Colombian Ministry of Health : sispro_bodega@minsalud.gov.co.

Declarations

Ethics approval and consent to participate
The study was approved by the Human Research Ethics Committee of the Pontificia Universidad Javeriana (Bogotá, Colombia) and the Hospital Universitario San Ignacio (protocol number FM-CIE-0103–21). All participants signed an informed consent. The study conformed to the principles of the Helsinki Declaration.

Consent for publication
Not applicable.

Competing interests
IBH is the Co-Director, Health and Policy at the Brain and Mind Centre (BMC) University of Sydney. He is the Chief Scientific Advisor to, and a 3.2% equity shareholder in InnoWell Pty Ltd. JO is both Head of Systems Modelling, Simulation & Data Science, and Co-Director of the Mental Wealth Initiative at the University of Sydney's Brain and Mind Centre. She is also Managing Director of Computer Simulation & Advanced Research Technologies (CSART) and acts as Advisor to the OECD Neuroscience-inspired Policy Initiative and the Brain Capital Alliance. The remaining authors declare no competing interests.

Author details
[1]Department of Psychiatry and Mental Health, Faculty of Medicine, Pontificia Universidad Javeriana, Bogota, Colombia. [2]Brain and Mind Centre, The University of Sydney, Camperdown, Australia. [3]Keralty Medical Centers, Bogota, Colombia. [4]Medicalnet SAS, Bogota, Colombia. [5]Swiss Tropical and Public Health Institute, Allschwil, Switzerland. [6]University of Basel, Basel, Switzerland. [7]Department of Clinical Epidemiology and Biostatistics and Department of Psychiatry and Mental Health, Pontificia Universidad Javeriana, Hospital Universitario San Ignacio, Bogotá, Colombia. [8]Hospital Universitario San Ignacio, Bogota, Colombia. [9]Computer Simulation & Advanced Research Technologies CSART, Sydney, Australia.

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