



Can we predict adolescent cannabis use? A Bayesian semi-parametric approach to project future trends

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ABSTRACT

Despite its decrease in many Western countries, cannabis remains the most used illicit substance among adolescents. This study aims to summarize cannabis consumption during the last two decades and project trends among 15-year-olds in the 2021–22 HBSC survey. A Bayesian semi-parametric hierarchical model was adopted to estimate the trend of cannabis consumption using data of about 287,000 adolescents from the 2001/2002 to the 2017/2018 HBSC wave and the 38 countries that met the inclusion criteria. Data show an overall decline in most countries for both boys and girls. However, in 22 countries of 38 cannabis use is expected to increase again in our projection. The discussion of these findings should take into account cultural, policy, social factors and unpredictable events such as the Covid-19 pandemic, that can significantly impact future trends leading to discrepancies between the projected and observed values. However, these discrepancies can provide insight into understanding the potential impact of preventive strategies and the underlying processes responsible for changes in cannabis use over time.

1. Introduction

Cannabis is the most commonly used illicit psychoactive substance among European and North American adolescents. The 2017/2018 Health Behaviour in School-aged Children (HBSC) study (Inchley et al., 2018) showed that the lifetime prevalence of cannabis use among 15-year-old school students ranged from about 2 % in Azerbaijan and Kazakhstan to 25 % in Bulgaria, with a 43-country average of about 13 % (Jo et al., 2017). Evidence indicates that early and frequent cannabis use can be harmful to health and mental health (Volkow et al., 2014; Albaugh et al., 2021). Early, heavy, and accelerated use are related to problems such as impaired brain development, low height and weight, short-term memory loss, and other cognitive disorders (Van Ours & Williams, 2009), deterioration of school performance and dropout (Bachman et al., 2007), risk taking, aggression and delinquency (Griffith-Lending et al., 2011), depression and anxiety (Griffith-Lending

et al., 2011), and the development of the so-called lack of motivation syndrome (Ding et al., 2014). Its use can also trigger psychosis among those who are vulnerable to this disorder (Casadio et al., 2011). Cannabis use is often part of a more extensive pattern of risk behaviors: it goes hand in hand with, among others, more smoking, (binge) drinking, and drunkenness (Charrier et al., 2019).

In the first decade of 2000, decreases in cannabis use were observed across many Western countries; however, this downward trend has come to a halt in most countries. The overall prevalence of lifetime and last 30-day use of cannabis among secondary school students has remained stable in Europe and Canada between 2014 and 2018 (Jo et al., 2017; Inchley et al., 2016). Stable trends in cannabis use but increases in some regions – South Europe and the Balkans – were also found in studies of the European School Survey Project on Alcohol and Other Drugs (ESPAD) (Kraus et al., 2018).

Consumption may have declined or stabilized in most regions of the

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Western world, but cannabis is still a widely used illicit drug, with a substantial minority of young people consuming it on a regular basis, from an early age on. Furthermore, population surveys show that the perception of the risk of cannabis has declined significantly (Harel-Fisch et al., 2015), and in many Western countries its use is “normalized” (Sznitman et al., 2015). Other studies suggested that cannabis use has “trickled down” from richer to poorer countries, and within these countries, from adolescents with higher family affluence to peers with lower family affluence (ter Bogt et al., 2014).

From a public health perspective, monitoring trends in adolescent substance use is essential. Health surveys have been shown to be a valuable tool to evaluate trajectories of continuity or change in health outcomes and are crucial for the (early) detection of changes over time. Not only monitoring but also predicting trends can have great value in shaping substance use interventions and policies. Comparing the actual data collected (and used for forecasting) with the forecast data can provide insight into the effectiveness of current policies and health promotion interventions. Pullum (2022) noticed that earlier rounds of a specific survey can be used to predict the levels of health outcomes in later rounds of the same survey. Indeed, predictions are built on the notion of continuity of underlying processes, and changes in expected values of an outcome may be indicative of modifications of health determinants.

Recent evidence showed that relatively simple methods for predicting future trends in health issues can be highly accurate. For example, in an HBSC-study, alcohol use was predicted based on observed trends from past data, showing consistent patterns between estimated and actual prevalences across countries (Charrier et al., 2022).

The HBSC study serves as an important source for several indicators of cannabis use, relevant to both regional and cross-country assessments of health-related behaviors among adolescents. The present study aims to summarize HBSC cannabis consumption data from the past two decades and project trends among 15-year-olds in the HBSC 2021/2022 survey sample (data still under embargo). Moreover, since between the last two HBSC waves (2017/2018 and 2021/2022) the COVID-19 pandemic has heavily influenced adolescents’ lives and probably also their risk behaviors, including cannabis use, the discrepancies between the predicted and observed data in 2022 could help generate hypotheses about the effect of the pandemic and the measures taken to contain it. In fact, the studies to date have failed to uniquely capture this aspect, presenting mixed results.

2. Methods

2.1. Materials and methods

2.1.1. Participants

The HBSC surveillance is a collaborative cross-national study of the World Health Organization (WHO) that monitors adolescent health and well-being every four years in more than 50 European and North American countries and regions. It is a school-based survey that uses a self-report questionnaire administered in school classes. Data from each country are collected according to the HBSC research protocol, to ensure consistency in survey instruments, data collection, and processing procedures. Samples are designed to be nationally representative of students aged 11, 13 and 15 years. The youngest age group is not asked questions about drug use in the HBSC survey, and among 13-year-olds, cannabis use is still rare. Therefore, this study only analyzed data from 15-year-olds.

We used HBSC data collected in the 38 countries that participated in the 2017/2018 survey and in at least three out of five survey waves from 2001/2002 to 2017/2018, using the same item to assess cannabis use.

2.1.2. Cannabis use

Cannabis use was assessed with the question “Have you ever taken cannabis in your lifetime?”. For each item, response options were “1 =

never”, “2 = 1–2 days”, “3 = 3–5 days”, “4 = 6–9 days”, “5 = 10–19 days”, “6 = 20–29 days” and “7 = 30 days or more”. The variable was dichotomized into “no cannabis use” (response option 1) and “at least 1 day of cannabis use” (response options from 2 to 7).

Until the 2009/2010 survey, the response categories were indicated as “times”, in 2013/2014 the response categories changed from “times” to “days”. In 2017/2018, “life” was replaced with “lifetime”.

2.1.3. Statistical analyses

A Bayesian semi-parametric hierarchical model was adopted to estimate the trend of cannabis consumption in each of the 38 countries included. We adapted the model introduced by Paddock for the analysis of longitudinal data to estimate non-linear trends accounting for country-level variation (Paddock & Savitsky, 2013). Potential non-linear trajectory over time is modelled using polynomial functions that capture the overall trend and any deviations from the trend. The model includes random effects at the country level to account for differences between countries.

To be as flexible as possible in modelling the trend, we adopted the Dirichlet Process (DP) framework (Escobar & West, 1995). The DP is a stochastic process that generates probability distributions. Under the DP framework, we assume that the random effects are generated from an unknown distribution F , which we treat as the latent generating distribution for the random effects, whose properties are inferred from the available data. The DP is defined by two parameters: a base distribution, from which F is drawn, and a concentration parameter that determines the degree of confidence in the base distribution as the true generating distribution for F . Moreover, the DP allows for a positive probability of potential ties among the values of the random effects. The set of unique values among the random effects allows for borrowing strength in trend estimation from countries who share the same random effects. Specifically, countries with similar trends will have higher probabilities of co-clustering.

Finally, we made projections using the predictive posterior distribution of the model parameters. See Charrier et al., 2022 for more details about the model specification and the MCMC simulations run to obtain the model parameters posterior estimates (Charrier et al., 2022).

All analyses were performed using R version 4.1.2 (R Core Team, 2021).

3. Results

The overall sample size contained 286,995 15-year-old adolescents from the 2001/2002 to the 2017/2018 HBSC wave and the 38 countries that met the inclusion criteria; 51.8 % were girls.

Table 1 and Fig. 1 report the time trends in cannabis consumption, for both boys and girls. Data show different starting levels in cannabis use in the first survey in 2001/2002. Among girls, the lowest last year prevalence was found in the Republic of Macedonia (2 %) and the highest in Greenland (47 %), the lowest prevalence for boys, again, in the Republic of Macedonia (4 %) and the highest in Switzerland (49 %). Regarding the period between 2001/2002 and 2017/2018, a general decline can be observed in most countries for both boys and girls. In some countries, the overall decrease was modest but still considerable after high levels of cannabis use in the intermediate period, for example in Estonia. In others the overall decrease was substantial or even dramatic, and more linear (for example, Belgium, Canada, Switzerland, Czechia, Denmark, Spain, France, England, Scotland, Greenland, Ireland, Netherlands, Portugal, Russian Federation, Slovenia, Slovakia, and Ukraine, for both girls and boys). However, the use of cannabis has increased among both boys and girls in Bulgaria, Greece, Lithuania, Latvia, Republic of Macedonia, Malta, and Romania; among boys in Finland, Israel, and Sweden; among girls in Estonia, Italy, and Poland.

Fig. 1 shows the forecast of cannabis consumption in the 2021/2022 survey wave, stratified by gender (last circle and triangle in each country trend). The estimation is also shown in Table 1 (2022 column) and its

Table 1
Observed prevalence of cannabis consumption from 2002 to 2018 and projected predicted value on 2022 using the from trend model.

Region	Males						Females					
	Observed prevalence					Projection	Observed prevalence					Projection
	2002	2006	2010	2014	2018	2022	2002	2006	2010	2014	2018	2022
AT	15	13	14	12	14	14	13	13	13	7	9	9
BE-VLG	27	25	23	18	16	18	23	17	17	14	7	12
BE-FR	31	26	23	26	18	18	22	21	18	18	14	15
BG		20		23	25	20		18		23	24	16
CA	48	35	34	25	24	20	42	34	33	26	26	18
CH	49	36	35	29	27	21	40	28	24	19	16	13
CZ	35	27	31	23	20	18	27	22	30	23	17	13
DE	28	18	14	18	22	19	20	14	9	15	16	14
DK	26	20	16	21	16	18	21	13	14	12	5	10
EE	23	31	27	29	20	19	12	19	18	19	14	15
ES	36	31	30	20	21	18	33	30	25	18	18	13
FI	11	10	11	13	13	14	10	5	8	7	7	9
FR	34	29	30	30	16	18	26	25	24	26	13	13
GB-ENG	43	26	21	19	25	18	38	23	22	19	16	13
GB-SCT	39	29	22	20	20	18	35	27	15	13	13	12
GB-WLS	36	30	22	18	22	18	32	32	20	18	21	13
GL	44	23	21		10	13	47	16	15		10	13
GR	8	6	11		11	14	3	2	3		7	9
HR	19	17	16	19	17	17	14	11	11	11	12	11
HU	17	14	18	12	15	15	11	10	11	14	10	10
IE	27	26	18	12	15	16	15	21	12	9	11	12
IL	8	6	8	11	14	15	4	2	3	3	4	9
IS		11	12	7	10	13		9	5	5	6	9
IT	26	25	23	27	24	20	18	17	16	17	20	16
LT	11	20	29	19	21	20	4	10	13	10	14	10
LU		25	22	18	17	18		21	15	18	13	14
LV	16	28	30	23	21	20	9	16	21	19	17	16
MK	4	4	4	4	7	13	2	3	1	3	3	9
MT	9	14		15	11	15	4	11		11	6	9
NL	29	26	23	17	18	18	23	22	18	15	12	14
PL	25	24	24	26	15	18	12	13	14	22	14	15
PT	25	12	15	13	10	13	15	7	9	10	7	9
RO		5	12	10	8	12		2	5	6	5	8
RU	19	17	11	11	5	12	9	13	6	7	3	8
SE	7			7	8	13	7			5	6	9
SI	31	21	27	24	22	19	26	14	19	19	20	16
SK		21	21	20	16	17		14	13	14	10	12
UA	33	23	18	9	9	7	15	10	5	6	4	8

Regions: Austria (AT), Flemish Belgium (BE-VLG), French Belgium (BE-FR), Bulgaria (BG), Canada (CA), Switzerland (CH), Czechia (CZ), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), Finland (FI), France (FR), England (GB-ENG), Scotland (GB-SCT), Wales (GB-WLS), Greenland (GL), Greece (GR), Croatia (HR), Hungary (HU), Ireland (IE), Israel (IL), Iceland (IS), Italy (IT), Lithuania (LT), Luxembourg (LU), Latvia (LV), Republic of North Macedonia (MK), Malta (MT), The Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Russian Federation (RU), Sweden (SE), Slovenia (SI), Slovakia (SK), Ukraine (UA).

accuracy is presented in the supplementary [Table S1](#). Zooming in on a comparison between the data of the 2017/2018 survey and those estimated for 2021/2022, in about half of the countries a (further) decrease is expected, in others consumption has reached a low and is estimated to increase (again). Among both boys and girls, it is expected that cannabis use increases in Flemish Belgium, Denmark, Finland, Greenland, Greece, Ireland, Israel, Iceland, Luxembourg, Republic of Macedonia, Malta, Poland, Portugal, Romania, Russian Federation, Sweden, and Slovakia; among boys in France; among girls in French Belgium, Estonia, Netherlands, and Ukraine. In sum, in 17 countries out of 38 cannabis use is expected to increase among both boys and girls, in one among boys and in other four among girls, adding up to 22 countries in which cannabis use is rising in our projection.

4. Discussion

The current study aimed to summarize HBSC data on cannabis consumption among 15-year-olds from five consecutive surveys between 2001/2002 and 2017/2018, and to project trends in cannabis consumption in the 2021/2022 HBSC survey based on these data. The method employed a Bayesian semi-parametric hierarchical model, which allows for flexible modeling of non-linear trends, while incorporating country level variations through random effects. Moreover, the

model can capture shared trends among countries by employing a stochastic process and incorporating potential ties among random effects, which can reflect common consumption dynamics.

The model turned out to provide accurate estimates of cannabis consumption trends among 15-year-olds, as shown by the MAEs estimated on projections to 2018, which for most countries is within the error margin accepted for estimating a prevalence ($\pm 3\%$), based on the sample size ([Table S1](#)). The comparative approach facilitated by the hierarchical model allows for the comparison of trends across different countries. This analysis can help identify significant differences in consumption patterns in national contexts and potentially improve understanding of the factors that influence these variations. Regarding the period between 2001/2002 and 2017/2018, a general decline in cannabis use can be observed for both boys and girls. In some countries, the decrease is modest, but in others it is substantial. However, when considering the projected trend for the last round of the survey, it can be observed that the declining trend continues in some countries, but in 22 the use of cannabis is rising.

The observed trends further corroborate the general downward trends observed in other studies on substance use and risk behaviors in high-income countries. The findings are consistent with research conducted in Europe ([Kraus et al., 2016](#); [Leal-López et al., 2021](#)), USA ([Miech et al., 2019](#)), Australia ([Livingston et al., 2020](#)), New Zealand

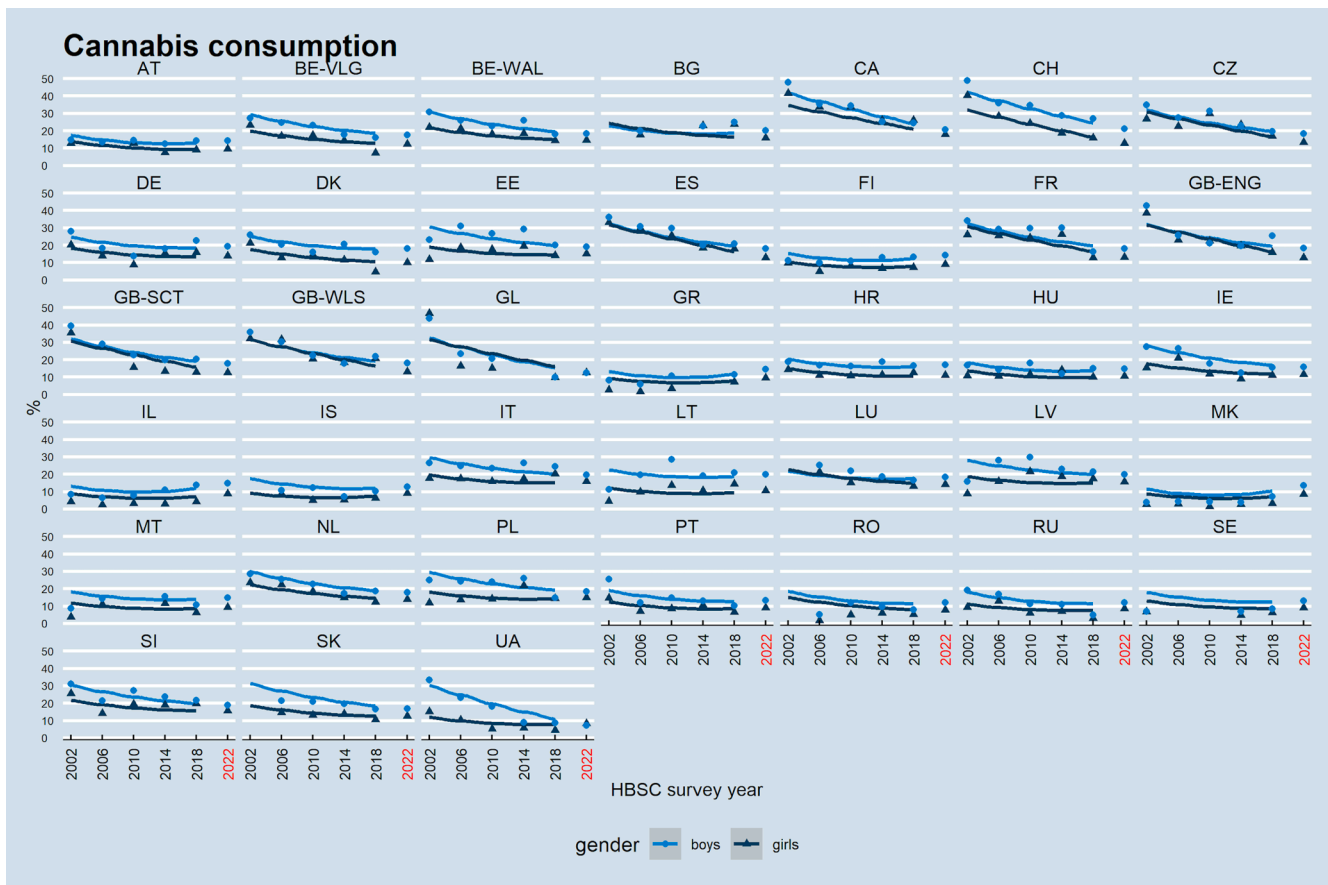


Fig. 1. Trends and estimated 2022 prevalence (%), by country, for boys (circles) and girls (triangles). Abbreviations: Austria (AT), Flemish Belgium (BE-VLG), French Belgium (BE-FR), Bulgaria (BG), Canada (CA), Switzerland (CH), Czechia (CZ), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), Finland (FI), France (FR), England (GB-ENG), Scotland (GB-SCT), Wales (GB-WLS), Greenland (GL), Greece (GR), Croatia (HR), Hungary (HU), Ireland (IE), Israel (IL), Iceland (IS), Italy (IT), Lithuania (LT), Luxembourg (LU), Latvia (LV), Republic of North Macedonia (MK), Malta (MT), The Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Russian Federation (RU), Sweden (SE), Slovenia (SI), Slovakia (SK), Ukraine (UA).

(Clark et al., 2013), and Japan (Osaki et al., 2009), all indicating a pattern of declining use of illegal and legal substances in adolescents since the beginning of the 21st century. In some cases, more than half of countries showed reductions of about 50 %, reflecting a massive cultural change in a relatively short period. In their review, Ball et al. conclude that unstructured face-to-face time with friends, which is always positively linked to substance use and risky behaviors, has declined in these countries (Ball et al., 2023). In addition to this general underlying driver, evidence suggests that both country-level and behavior-specific factors are involved in the decreasing of substance use. It is plausible that country-level factors, such as differences in cannabis policies, play a role in explaining the different projected prevalence of cannabis use (Gabri et al., 2022; Benedetti et al., 2021); however, attributing these differences to a specific country policy is problematic. Indeed, a growing number of studies argue that a complex interplay of country-level and individual factors contribute to influencing adolescent cannabis use (Kotlaja & Carson, 2019; Shi et al., 2015; Stevens, 2019). The availability of tobacco and alcohol is now more controlled in most high-income countries. Smoking disapproval is more apparent among adolescents, and parents may be more restrictive in allowing their children to drink. It is hypothesized that this set of factors, related to tobacco and alcohol, could be responsible for the suppression of adolescent cannabis use as well. Our study shows that this trend is indeed present in most of the countries under study, but certainly not all, with 22 out of 38 HBSC countries where bottom levels of cannabis use have been reached in the period between 2001/2002 and 2017/2018, but is expected to increase again after 2017/2018. Notably, it appears that gender gap in the

prevalence of cannabis use is narrowing (gender convergence hypothesis), implying that adolescent girls are now as likely as boys to initiate cannabis use, consistent with previous studies on alcohol consumption and binge drinking (Cosma et al., 2022; Kuntsche et al., 2011). This could be due to the decline of traditional gender roles, especially in Western countries (Seedat et al., 2009).

Developing strategies to predict adolescent cannabis use has important public health implications. Projection of future prevalence based on earlier data can shed light on the efficacy of existing policies and prevention strategies within a country or region. Moreover, reliably anticipating a phenomenon's evolution over time allows planning and implementing tailored approaches to prevention (for example, by combining demographic characteristics and expected trends). Such tailored strategies have demonstrated their superiority over generic, one-size-fits-all campaigns (Donaldson et al., 2021). Developing timely interventions has the potential to enhance their effectiveness by directing preventive efforts where cannabis use is expected to increase. However, the proposed approach faces several limitations. The assumptions and simplifications made in the model may introduce some level of uncertainty in the estimates. Furthermore, disparities in data availability and coverage across countries and survey waves can affect the representativeness of the results. While the projections assume the continuity of past consumption patterns, it is crucial to acknowledge that cultural, policy, and societal factors, like the unprecedented impact of COVID-19, can significantly influence future trends. These external influences may contribute to discrepancies between projected values and the actual observed data on cannabis consumption. Our projections

for 2022 do not take into account the potential impact of the COVID-19 pandemic on the pattern of cannabis use among adolescents, as the latest available survey data are from the 2017/18 HBSC wave. Therefore, comparing the projections with the observed data of the 2021/22 HBSC wave (still under embargo) will allow us to generate hypotheses about whether and how the pandemic has affected this phenomenon.

5. Conclusion

Continuous monitoring of substance use is one of the effective and recommended interventions to prevent and discourage licit and illicit substance use among adolescents, which is associated with negative health, behavioral, economic, and social outcomes. Studies that have analyzed the effect of the COVID-19 pandemic on substance use among adolescents have reported mixed results. In this context, the findings of our study, based on an approach that has been shown to be accurate, may be useful for assessing the effectiveness of current prevention interventions among youth, for planning and implementing new ones, and for shedding light on how the pandemic has affected cannabis use among adolescents, contributing to the existing literature.

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CRedit authorship contribution statement

Lorena Charrier: Conceptualization, Data curation, Methodology, Project administration. **Alessio Vieno:** Conceptualization, Project administration, Supervision. **Natale Canale:** Investigation, Visualization. **Tom ter Bogt:** Investigation, Methodology, Visualization. **Rosanna Irene Comoretto:** Data curation, Investigation, Visualization. **Emanuele Koumantakis:** Investigation, Visualization. **Michela Lenzi:** Investigation, Visualization. **Paola Berchiarella:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.addbeh.2024.108009>.

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