Regulation of highly hazardous pesticides in India - implications for suicide prevention

CURRENT STATUS: ACCEPTED

BMC Public Health  BMCMajors

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DOI:
10.21203/rs.2.15477/v1

SUBJECT AREAS
Health Policy

KEYWORDS
India, suicide, poisoning, pesticides, prevention
Abstract
Background: Pesticide self-poisoning is a common means of suicide in India. Banning highly hazardous pesticides from agricultural use has been successful in reducing total suicide numbers in several South Asian countries without affecting agricultural output. Here, we describe national and state-level regulation of highly hazardous pesticides and relate them to suicide rates across India.

Methods: Information on pesticide regulation was collated from agriculture departments of central and state governments. National and state-level data on suicides for 1995 until 2015 was obtained from the National Crime Records Bureau (NCRB). We used joinpoint analysis and negative binomial regression to investigate the possible effects of pesticide bans on trends in suicide rates.

Results: As of August 2019, 314 pesticides were registered for use in India, of which 18 were extremely (Class Ia) or highly (Class Ib) hazardous according to World Health Organization toxicity criteria. Despite many highly hazardous pesticides still being available, a number of bans have been implemented during the period studied. In our quantitative analyses we focussed on the permanent bans in Kerala in 2005 (of endosulfan) and 2011 (of 14 other pesticides); and nationally in 2011 (of endosulfan). NCRB data indicate that pesticides were used in 441,918 reported suicides in India from 1995-2015, 90.3% of which occurred in 11 of the 29 states. Time series analysis demonstrated statistical evidence of lower than expected rates of pesticide suicides and total suicides nationally after the 2011 endosulfan ban. In Kerala, there was a lower than expected rate of pesticide suicides but no change to the already decreasing trend in total suicides after both the 2005 ban of endosulfan and the 2011 ban of 14 pesticides.

Discussion: Highly hazardous pesticides continue to be used in India, and pesticide suicide remains a serious public health problem. However, some bans of pesticides do appear to have impacted previous trends in the rates of both pesticide suicides and all suicides. Comprehensive national bans of highly hazardous pesticides could lead to a reduction in suicides across India, in addition to reduced occupational poisoning, with minimal effects on agricultural yield.

Introduction
Self-poisoning with pesticides accounts for 14–20% of global suicides, an estimated 110,000–168,000
deaths each year [1], down from an estimated 371,000 in the late 1990s [2]. The problem is most severe in rural Asian communities, where a wide range of agricultural highly hazardous pesticides (HHPs) are easily available within the home and from shops [3–6]. They are often used impulsively for suicide attempts in times of acute stress [7], frequently with less than 30 minutes of planning [5]. Surviving an act of pesticide self-poisoning allows people to receive support from their family, community, and medical and psychosocial services, and most non-fatal suicide attempts are not repeated [8–11].

HHPs have a high case fatality rate in poisoning compared to other agents commonly used for self-poisoning such as analgesics and sedatives [12]. Those who do choose another poison in the absence of HHPs are likely to choose a method of lower lethality that offers a higher chance of survival after what is often a transient episode of suicidal intent. This is one example of how means restriction can reduce not only the burden of suicide from that particular method, but also the overall burden of suicide [13–17].

HHPs of World Health Organization (WHO) toxicity classes Ia, Ib and II - such as the organophosphorus insecticides monocrotophos, phorate, and methyl parathion or the herbicide paraquat [18] - have been responsible for most pesticide suicides worldwide over the last five decades [17, 19, 20]. Pesticide suicide prevention will require a combination of improved medical management, improved community use of pesticides, and government regulation to remove HHPs from agricultural practice [12]. However, medical treatment of pesticide poisoned patients is challenging, particularly in remote areas, where patients commonly present late to poorly-resourced hospitals with limited critical care facilities [21, 22]. A large cluster-randomised controlled trial has demonstrated that improved HHP storage is unlikely to substantially reduce the number of deaths [23, 24]. In contrast, national bans of HHP in several countries have produced major reductions in the number of pesticide suicides and in the total number of suicides where pesticide self-poisoning is a common means of suicide [25].

Pesticides are regulated in India under the Insecticides Act, 1968 [26], and the Insecticide Rules, 1971 [27]. Replacement Pesticide Management Bills proposed in 2008 and 2017 have not been passed [28–30]. The Central Insecticide Board (CIB) advises the Ministry of Agriculture and Farmers’ Welfare on
pesticide safety [31]. Its mandate includes reviewing matters relating to (a) the risk to human beings or animals involved in the use of insecticides and the safety measures necessary to prevent such risk, and (b) the manufacture, sale, storage, transport and distribution of insecticides with a view to ensuring safety for human beings or animals (Insecticides Act, 4 (2)). Despite its name, the CIB also advises the government on other pesticides such as herbicides and fungicides. The Registration Committee of the CIB is responsible for deciding which individual pesticide compounds can be registered for production and sale, domestically and for export. The Insecticides Act does not provide for regular review of registered pesticides, suggesting that registration is currently permanent. Other expert committees occasionally reassess specific registered pesticides if a problem arises, recommending restrictions or bans [32].

The Insecticides Act gives state governments limited powers to regulate pesticides. They may issue licences to companies to manufacture, sell, stock or exhibit for sale or distribute pesticides through application licensing officers. The Act permits states to ban pesticides for 60 days if a safety concern arises, with 30-day extensions in some cases. The states of Punjab, Kerala and Sikkim have developed additional state-level legislation for pesticide regulation beyond the Insecticides Act and have restricted HHP use through this route [33–36].

The purpose of this study is to summarise the pesticide bans and restrictions that have been implemented to date by the central and state governments in India, and to relate those regulations to changes in rates of both pesticide suicides and suicides from all methods.

Methods
Data was collected on the number of pesticides recorded in India, national and state pesticide regulatory actions, and the incidence of suicides nationally and by state from 1995–2015. Twenty-nine states were included. Telangana officially separated from Andhra Pradesh in 2014 but was treated as part of Andhra Pradesh for this analysis. The Union Territories were excluded due to the comparatively small numbers of pesticide suicides (<0.3% of the total over the 20 years studied) and a lack of official population estimates for 2015 meaning that interpolated suicide rates for the years after the 2011 census could not be calculated. Additional data was collected on agricultural yields
over the study period from the Ministry of Statistics and Programme Implementation [37].

**Pesticide toxicity**

A list of pesticides registered in India was obtained from the website of the CIB, Ministry of Agriculture & Farmer’s Welfare [38]. The pesticides were then grouped according to the WHO toxicity classification (Ia: extremely hazardous; 1b: highly hazardous; II: moderately hazardous; III: slightly hazardous; and U: unlikely to cause acute hazards) [18]. Of note, the WHO classify pesticides according to their 50% lethal dose (LD50) in mg/kg via both dermal and oral routes in rats as a comparable and reproducible value. This classification does not always translate to case fatality rates in human self-poisoning, with some Class II pesticides such as paraquat and endosulfan having very high case fatality after ingestion [39].

**Pesticide regulatory actions**

Information on pesticide regulatory actions was obtained for the national level from the CIB website [38]. For regulations at the state level, the official websites of every state’s Agriculture Department were searched using the term “pesticide”, as more specific search terms excluded some relevant documents. Regulatory actions not found through the initial search were identified through media reports. In these cases, targeted searching with the name of the pesticide and the date of the ban was subsequently used to locate the original government notification pertaining to the ban or restriction. Some compounds had their registration announced but were later omitted from lists of registered pesticides. These omissions were assumed to be errors and the pesticide to be still registered unless there was a government notification specifically announcing a ban on that compound. Permanent bans, temporary bans and partial restrictions were all included but only permanent bans were used in the time series analysis due to concerns about the continuing availability of pesticides under the less strict regulations.

**Pesticide usage**

Data on pesticide usage by metric tonne was obtained from the Department of Chemicals and Petrochemicals’ website for financial years 2001/2002 to 2015/2016 [40–42]. This provided consumption data for several individual compounds at the national level, and data for overall pesticide consumption at the state level. However, data on consumption of individual compounds at
the state level was not available so we were unable to assess if state-wide bans reduced consumption within that state. Pesticide use was estimated by the Department of Chemicals and Petrochemicals by subtracting the quantity exported and adding the quantity imported to the quantity produced domestically. This methodology does not adjust for differences in stockpiling from year-to-year or any inaccuracies in reports from importing or manufacturing firms.

Suicides
Suicide data were obtained from the National Crime Records Bureau (NCRB), a central government body. It produces annual reports on Accidental Deaths and Suicides, from which data was extracted for the years 1981 to 2015 [43]. A suicide is defined by the NCRB as an unnatural and deliberate termination of life, when the desire to die originates within the individual and there is a reason for ending that life. Suicides are recorded by police officers and reported to this central body. Methods used in recorded suicides are classified into 12 categories: insecticides, other poisons, drowning, self-immolation, firearms, hanging, overdose of sleeping pills, self-inflicting injury, jumping (from height or from moving vehicles/trains), being hit by vehicles/trains, touching electric wire, and other means. It is unclear whether the insecticide class includes all forms of agricultural pesticides, including herbicides, as the document also refers to “insecticides/pesticides”; we assumed that deaths recorded as insecticide self-poisoning also included other pesticides. The NCRB statistical reports do not provide detail on how the data on means of suicide are gathered. Prior to 1995, pesticides did not have their own category as a means of suicide, being included in a ‘poisons’ category. Data for all forms of poisoning (including pesticide) suicides were therefore extracted for 1981-2015 to identify longer-term trends.

Suicide rates were calculated using census population records for the years 2001 and 2011, and using official estimates for each state for 2015 [44–46]. Official state-wise population records from the 1991 census were implausibly low and did not correspond to national population records so were not used. Official population estimates for 2015 were only available for the 20 largest states. Populations for intervening years were estimated using interpolation. Suicides in NCRB records were not stratified by age for each individual state, so crude mortality rates were used. Both pesticide suicides and total
suicides (including all methods of suicide) were included. The results were displayed in map format using mapchart.net under a Creative Commons Attribution-Share Alike 4.0 International licence [47]. This study did not investigate gender as a factor influencing suicide rates, although previous studies using the NCRB and other sources have noted that suicide rates amongst Indian women have fallen by 22–26% over the past 20 years, while rates in Indian males have remained stable [48, 49].

Statistical analysis
We used Joinpoint regression analysis [50] to identify periods of stable trends in suicide rates and the timing of changes in trends (i.e. “join points”) between 1995 and 2014. We analysed trends in suicides by all methods and pesticide suicides in the geographical area affected by each permanent ban. We fitted log-linear regression models to detect the number and location of the join points, and further analysed permanent bans associated with changes to trends in suicide rates. There was statistical evidence of over-dispersion in the Poisson regression models, and therefore we used negative binominal regression to compare suicide rates after these bans with those predicted based on pre-ban trends. We calculated rate ratios for each year after each ban compared with predicted rates based on extrapolated trends before each ban. 2015 was excluded from our primary analysis due to a possibly artefactual sudden increase in rate of pesticide suicide from 2014. A sensitivity analysis was also conducted including the year 2015. Stata version 15 [51] was used for the regression analysis.

Results
Three hundred and fourteen pesticides were registered in India as of August 2019 (table 1), twelve with some restrictions on their use (table 2) [52, 53]. Four of these pesticides are WHO toxicity class Ia (extremely hazardous) compounds (bromadiolone, captafol, phorate, phosphamidon) while fourteen are WHO toxicity class Ib (highly hazardous) compounds (beta-cyfluthrin, carbofuran, coumatetralyl, cyfluthrin, dichlorvos, edifenphos, methomyl, monocrotophos, oxydemeton-methyl, propetamphos, sodium cyanide, tefluthrin, triazophos and zinc phosphide). Many of these compounds are used within India at rates of several thousand tonnes annually [40], indicating widespread availability of pesticides with high acute toxicity.

Ninety-five WHO toxicity class II pesticides are also registered, some of which are highly toxic after
ingestion [21], with case fatalities often greater than 10% as shown by a large prospective secondary hospital case series from Sri Lanka [39] (paraquat 42.7%, dimethoate 20.6%, quinalphos 12.1%, alachlor 11.1%, profenofos 11.0%, propanil 10.9%, and carbosulfan 10.7%) [39]. Thirty-one class III (slightly hazardous) pesticides and 47 class U (unlikely to present acute hazard) pesticides are registered in India.

Three fumigants are registered for use in India—aluminium phosphide, DD mixture (dichloropropene and dichloropropane), and methyl bromide. Although not classified by the WHO, aluminium phosphide is extremely toxic after self-poisoning, with a case fatality often exceeding 50% after ingestion of the previously common 56% 3 gram tablets [54-59].

An additional 116 non-fumigant pesticides registered for use in India are not yet classified by the WHO for toxicity, and five pesticides listed by the WHO as obsolete are also registered for use. None of these compounds have their consumption reported by the Department of Chemicals and Petrochemicals [40], which could indicate that they do not constitute a large part of the market.

National regulatory actions
Thirty-nine pesticides have been banned nationally since 1989 (table 3) [60-64], including ten HHPs (bold in table 2) identified in previous studies as being important for suicide in South Asia [21, 39, 65-69]. An additional 26 pesticides have been refused registration or withdrawn from the market (table 3, footnote) [52, 60, 70-73].

In 2015, the Indian government set up the Anupam Verma Committee to review the continued use of 66 pesticides that have been banned or restricted for farming use in other countries [32]. In 2016, it recommended a ban on 13 pesticides, phasing out of 6 pesticides by 2020, and further review of 27 pesticides in 2018 [74, 75]. The Ministry of Agriculture partially implemented the recommendations in August 2018, banning 10 pesticides, placing restrictions on 2, and scheduling six bans for 2020 including several WHO Class Ia HHPs (table 2). Two pesticides had been recommended for a complete ban but were only restricted: sodium cyanide was banned for insecticidal use while trifluralin was restricted to use on wheat. DDT was not banned and its sole permitted use by the Ministry of Health was maintained.
Endosulfan was banned by the Supreme Court of India in May 2011, with the final stocks disposed of or exported by January 2017 [60]. According to the Department of Chemicals and Petrochemicals, no more endosulfan was produced domestically after the ban [41].

Overall, these regulatory actions have included national bans of ten HHPs that are relevant to pesticide suicides (table 2). Another eleven have been restricted in their use, for example ‘not to be used on vegetables’, or are only available in certain formulations (table 3). However, effective enforcement of these partial restrictions has proven difficult [76–78]. Monocrotophos, for example, despite being banned for use on food crops, is still widely used by farmers on vegetables as well as on its main permitted use for cotton [78, 79], as demonstrated by the Ministry of Agriculture’s “Monitoring of Pesticide Residues at National Level” scheme frequently identifying monocrotophos at above the maximum residue limit in samples of vegetables from markets and at the farm gate [75, 80].

State regulatory actions
Kerala, Punjab and Sikkim have passed separate laws permanently banning some pesticides, whilst Karnataka and Maharashtra have implemented temporary bans.

Kerala permanently banned endosulfan in October 2005 [81] and 14 other pesticides, many relevant for suicide, in January 2011—two WHO class Ia, four class Ib, five class II, two class III and one listed by the WHO as obsolete (table 2) [33, 82]. Bans for some of these pesticides have now been announced by the Central Government: methoxy ethyl mercuric chloride and methyl parathion in 2018 and phorate and triazophos in 2020. However, nine pesticides banned in Kerala remain in use nationally with no plans for regulatory action (anilofos, atrazine, carbofuran, edifenphos, monocrotophos, paraquat dichloride, profenofos, thiobencarb and tricyclazole).

Punjab, using the provision of the Insecticides Act that allows states to refuse renewal of pesticide licenses once they expire, decided not to renew licenses of 20 pesticides in 2018, including the HHPs carbosulfan, endosulfan, fenitrothion, methomyl, monocrotophos, phorate and phosphamidon (table 2) [28, 34, 83]. Sikkim banned all inorganic agricultural inputs, including HHP, in 2014 under the Sikkim Agricultural, Horticultural Input and Livestock Feed Regulatory Act [36]. Pesticides were
withdrawn from agricultural use in the state by 2016 [35].

Temporary bans have taken place in Maharashtra and Karnataka (table 2). In November 2017, Maharashtra state requested that the Central Government ban five pesticides inhaled by victims of an accidental mass poisoning in Yavatmal district. The state also banned five formulations of these compounds for 60 days, including acephate 75% and monocrotophos 36% (table 2). The ban only applied to five districts and other formulations were still permitted [84]. Karnataka banned endosulfan in February 2011 for 60 days [85], shortly before the Supreme Court banned the compound nationally in May of that year [60]. Kerala was thus the only state that applied permanent pesticide bans within the period studied, and was, therefore, the only state for which we performed time series analysis to assess the effects of those bans.

Suicides
The NCRB recorded 133,623 deaths from suicide in 2015 [43], of which 23,930 (17.9%) were due to pesticides. From 1995 to 2015, 441,918 pesticide suicides and 2,451,410 suicides from all methods were recorded in India. Suicide rates from all methods, all poisons, pesticides and other poisons are shown in figure 1. Also presented in this figure is data on combined agricultural yield in kg/hectare of rice, wheat, cotton and 26 other important crops, as compiled by the Ministry of Statistics and Programme Implementation. This data is indexed to the yield recorded in the year 2001 and shows an increasing trend despite the pesticide bans that have taken place.

The majority of pesticide suicides (90.3%) occurred in eleven of the 29 states: Maharashtra, Andhra Pradesh, Madhya Pradesh, Tamil Nadu, West Bengal, Kerala, Telangana, Karnataka, Gujarat, Odisha and Chhattisgarh (figure 2). These states account for approximately 54.1% of the total population of India [45], and 84.2% of suicides by all methods in India. Maharashtra had the largest number of pesticide suicide deaths from 1995–2015 with 84,194 (19.2% of total), followed by Andhra Pradesh with 77,394 (17.6% of total) (figure 3).

Throughout most of the study period the pesticide suicide rate was highest in Andhra Pradesh and Telangana. Annual pesticide suicide rates for the eleven states with the highest numbers of pesticide suicides are plotted in figure 4 and the change in pesticide suicide rates for all states in map format in
figure 5. Equivalent data for suicides by all methods is displayed in figures 6 and 7, where Kerala had the highest rate for most of the study period before being superseded by Chhattisgarh.

The national total and pesticide suicide rates were lower than expected, based on previous trends, for each year after the 2011 national ban on endosulfan (table 4). The reduction was larger for pesticide suicide (48% [95% CI 46 to 51%] less than expected by 2014) than total suicides (10% [95% CI 7 to 13%] less than expected by 2014).

In Kerala, after the 2011 ban on 14 other pesticides, the rate of pesticide suicides fell further than expected based on previous trends (55% [95% CI 51–58%] lower than expected in 2014), but there was no evidence of a change to the pre-existing downward trend in total suicides (table 4). The 2005 ban on endosulfan similarly did not appear to affect the trend in total suicides, but there was statistical evidence of a reduction in pesticide suicides rates compared to pre-ban trends (1999–2005) (table 5).

The large increase in pesticide suicides in 2015 was mostly due to increased numbers in Karnataka (increase of 2,818, or 501.4%), Tamil Nadu (increase of 1,591, or 92.9%) and Andhra Pradesh (increase of 1,830, or 55.1%) (figure 2). However, all three of these states saw large decreases in suicides coded as “consuming other poison” over the same period—2,138 for Karnataka, 1,142 for Tamil Nadu and 1,168 for Andhra Pradesh. These are nearly as large as the increases in pesticide suicides, suggesting that changes in coding may have contributed to the rise. Inclusion of the year 2015 in our time series analysis changed one of our conclusions—there was evidence of a decline of total suicide rate as well as pesticide suicide rate in Kerala during that year relative to 2011. The increase in the national pesticide suicide rate in that year was not large enough to change our conclusions about the trend since 2011 (table 6).

Discussion

According to Indian police data, over 20,000 Indians died in 2015 from pesticide self-poisoning. After a steady rise in suicides from 1981, there have only been relatively small changes in the overall suicide or pesticide suicide rates nationally since 2001. This stands in contrast to neighbouring Sri Lanka and Bangladesh, where both total and pesticide suicide rates have fallen dramatically after
pesticide regulation removed most HHPs from national agricultural practice [86, 87]. Our analysis does suggest an impact of pesticide restrictions in India—the 2011 endosulfan ban was associated with a small but significant decrease in total suicide rates and a larger decline in pesticide suicide rates. However, since many other highly hazardous pesticides remained available allowing switching to another highly lethal means of suicide was easy, the impact of this ban will have been attenuated compared to the effects seen in other countries.

The marked fall in total suicides in Sri Lanka followed removal of all Class I pesticides from agriculture. This left only comparatively lower toxicity pesticides accessible to people in a suicidal crisis. The incidence of non-fatal self-poisoning actually increased [88], but the use of less lethal pesticides caused the national total suicide rate to decline [15]. Additionally, most people who survived a first attempt do not repeat their act [8, 11].

The fall in total suicide deaths for all India noted from 2011 to 2014 (3,919) was smaller than the fall in pesticide suicide deaths (7,463). This suggests that there was some means substitution occurring, but not enough to negate the large drop in pesticide suicides.

Both pesticide suicides and total suicides were already falling in Kerala by the time the 2005 endosulfan ban and the 2011 ban of 14 pesticides were implemented. Our analysis does suggest an acceleration in the rate of decline in pesticide suicides after the 2011 ban, but there was no evidence of impact on the overall rate of suicide. One possible contributory factor to the decline in pesticide suicide in Kerala is the state’s comparatively rapid urbanisation [45, 89] leading to fewer households having direct access to agricultural pesticides even before the bans were implemented, an effect also seen in Taiwan [90]. As with the national trend, there was also some means substitution, attenuating the fall in overall suicides.

The year 2015 saw a concerning increase in recorded pesticide suicides in nearly all Indian states, with the largest increases in Karnataka, Tamil Nadu, and Andhra Pradesh. This may explain the contrast with recent publications that have reported reductions in the incidence of all poisoning suicides from 2001 to 2010 [91] and of pesticide suicides from 2010 to 2014 [92]. Whether the increase in 2015 reflects differences in reporting rates or coding accuracy is unclear without publicly
available methodology for the NCRB reports from each year and comparison with long-term epidemiological studies. It will be important to determine whether this increase is real and sustained. If 2015 is included in our time series analysis, one key conclusion is altered—there is evidence of a lower than expected rate of total suicides as well as pesticide suicides in Kerala after the 2011 bans, but the delay casts some doubt on whether the pesticide regulations were the most important factor in this.

Although there has been regulatory activity in India over the last 20 years at both national and state level, HHPs continue to be widely used in agriculture and responsible for tens of thousands of suicides each year. In August 2018, a few key HHPs were banned nationally; a further six including three pivotal suicide HHPs (dichlorvos, phorate and phosphamidon) are scheduled for bans in 2020. New regulations will need to be effectively and rapidly enforced—there have been reports of smuggling of banned pesticides across state borders [93, 94] which would reduce the effectiveness of the bans. This problem would, however, be insignificant for national bans, particularly with chemicals such as monocrotophos which are not manufactured in significant quantities outside of India. There is also a risk that future bans could be circumvented by manufacturers within the country. Inspections, and strict sanctions for firms failing to comply, are likely to be needed, together with ensuring that cost-effective and safe alternatives are widely available to farmers.

Sikkim has banned all pesticides from agricultural use, but the ban only came into effect in 2016, a year after the data available for this analysis. The effects of the fairly extensive 2018 bans in Punjab and nationally will likewise require further research.

The number of suicides reported by the NCRB is likely to be a substantial underestimate of the actual number of suicides in India due to under-reporting [95–97]. The legal status of attempted suicide remains ambiguous. It is a crime according to Section 309 of the Indian Penal Code (IPC) [98]. The Mental Healthcare Act 2017 [99] decriminalized suicide, affirming a “presumption of severe stress in cases of attempt to commit suicide”, but the IPC was not amended and Section 309 remains in place. Significant social stigma also continues to surround the issue of suicide in India [100]. There is currently no specific national suicide prevention strategy in India, which many, including the
WHO, have called for [101, 102], but reducing access to highly hazardous pesticides should be a key part of further efforts to prevent suicide. Some specific HHPs not currently listed for bans stand out as being of highest priority for further regulations [103]. All WHO class Ia and Ib pesticides are frequently lethal in self-poisoning and should have no place in routine agricultural practice in small-scale farms without the resources to store or use them safely [104]. Monocrotophos (class Ib) has been highlighted by the WHO as being particularly damaging to India’s health [79] and, as one of the most widely used pesticides [40, 78, 105], a total ban could have a large effect in reducing access to the means of suicide. Monocrotophos also illustrates the problem of just restricting pesticides to certain uses - it is banned for use on vegetables [60] to protect consumers from residues in their food [106], but its widespread use in cotton production means it is still easily available in shops for illegal use in vegetable production. Easily avoided regulations mean that people with suicidal thoughts still have easy access to highly lethal agents for self-poisoning. Other pesticides with high case fatality rates in self-poisoning for which bans should be considered to reduce suicides include WHO toxicity class II HHPs paraquat, profenofos, quinalphos, dimethoate, and carbosulfan, as well as the extremely toxic fumigant aluminium phosphide, which is still used in a large number of self-poisoning deaths, primarily in the north of the country [54–59]. A promising change to aluminium phosphide regulation was noted in a 2008 paper from Chandigarh, where case fatality ratios for acute poisoning from the compound dropped after 2000, possibly due to restrictions on the sale of tablets of aluminium in favour of loose powder sachets [107].

An argument often given in favour of limiting restrictions on pesticides is that inexpensive pesticides are necessary to maintain agricultural productivity [108, 109]. However, this claim does not specifically apply to HHPs, as integrated pest management (IPM) and less hazardous but still inexpensive pesticides are available as effective alternatives [110, 111]. Yields increased over the time period of this study despite the pesticide bans that have taken place. In other Asian countries that have banned some or all HHPs, such as Sri Lanka, Bangladesh, and South Korea, no effect on agricultural output has been seen [15, 16, 86, 110, 112]. The economic status of farmers and their families is also negatively affected by HHPs - occupational exposure and self-poisoning lead to
expensive medical bills even for those who survive [22], as well as reduced family income and increased debt burden due to death or disability [113].

Since the passing of the Insecticides Act 60 years ago, understanding of pesticide management and the harms associated with their use has improved, and international guidance has changed [103, 114]. The Act does not currently enable state governments to ban pesticides long-term. The 2017 Draft Bill aimed to extend the duration of a state ban from 90 to 240 days [30]. However, to address the harm done by pesticides on their territories, states should probably be able to permanently ban pesticides that are locally problematic. Temporary bans seem to have little effect on the availability of HHPs for agricultural use or for suicides, as normal use and sale is reinstated once the ban is over and there is no provision within the Insecticides Act for the recall of existing stocks [26]. Pesticide registration could be reviewed regularly, with registration routinely valid for perhaps five years. A more precautionary approach to registering new pesticides, taking into account the likely toxicity in self-poisoning, in addition to that from inadvertent exposure, would reduce the chances of banned pesticides being replaced by similarly lethal new pesticides. Effective enforcement of regulations is also needed. The actions of the government of Kerala are an example to other regional governments in Asia. Its Agricultural Development Policy acknowledges the harms inflicted on farmers and society by the use of HHPs. A key objective of the policy is to minimise the use of HHPs by ensuring that farmers can access chemicals of biological origin, reducing the quantities of pesticides used, and imposing continuous restrictions on the use of HHP [115]. Sikkim has been recognised by the United Nations for being a world leader in organic agricultural production, banning all pesticides [35], although data analysed in this study did not extend to 2016 so we could not assess the effects of this ban.

The Standing Committee on Agriculture, in a report to the Lok Sabha (the lower house of India’s Parliament) has acknowledged that excessive use of pesticides has led to high levels of pesticide residues in food and animal feed, accumulation of dangerous persistent organic pollutants, possible increased rates of cancer, increased input costs of agriculture [116] and farmers suffering a wide variety of adverse health effects from occupational exposure to pesticides [117]. However, relatively
little attention has been focused on the link between HHPs and suicide in India. Other countries have demonstrated that pesticide regulation is probably the most effective approach to suicide reduction in places where pesticides are an important means of suicide [25]. HHP bans may also result in marked reductions in the incidence of occupational and unintentional pesticide poisoning [118, 119]. Additionally, banning all HHPs could support India’s efforts to meet, among others, target 3.4 of the United Nations’ Sustainable Development Goals [120] - to reduce by one third premature mortality from non-communicable diseases. Suicide mortality is a key indicator of this; bans of HHPs are likely to be highly effective at reducing the suicide rate [25].

Limitations
This quasi-experimental study can provide an estimate of the effect of bans but cannot confirm a causal link between pesticide regulations and suicide. Importantly, we did not control for potential confounding factors such as age, gender, economic conditions, urbanisation, quantity of pesticides sold annually, unemployment and prevalence of mental health disorders. The NCRB reported suicides within each state stratified by gender, but not age, meaning that multivariable time series modelling would omit one of the most important factors in suicide. This, combined with the concerns about the reliability of NCRB data, meant that we deemed simple time series analysis to be the most appropriate initial method of using this data.

The methodology used in Patel and colleagues’ paper [121] gives a more accurate point estimate of mortality rates from suicide, but does not show the change in rate over time in response to changing regulations. A recent paper by Arya et al [92] also uses the NCRB data and corrects for confounding factors, but analysed states in groups based on socio-demographic factors rather than regulatory status which often only affects one state.

The NCRB reports have several other limitations, including: minimal description of how the data is gathered each year (so reporting of suicides may have changed over time, perhaps explaining the increase in 2015); likely underreporting due to the data being gathered by police officers in the context of an illegal act; and no post-mortem laboratory confirmation of the poisoning agent used. Monthly data on suicides would enable improved accuracy of time series analysis. Unfortunately, the
NCRB reports for 2016, 2017 and 2018 have not yet been released.

Additional weaknesses of our study are that it does not consider lag effects; includes only three years post-intervention for the 2011 bans; and has not assessed the effects of bans announced after 2015. Suicide data from these years and later will need to be reviewed to consider the effectiveness of further pesticide regulations and measures to reduce the burden of suicide in India. Bans in Sri Lanka typically demonstrated initial effects within two years [25, 122].

Finally, our literature search for notifications of bans had some limitations. The nature of the various state and central government websites where the notifications are stored made systematic searching challenging, so a more opportunistic search strategy was necessary which may have omitted some regulations. Although English is an official language in India, most central government documents we used were also published in Hindi. One notification from Kerala was written in Malayalam [33], with only the names of pesticides being the same in English, although this ban was cross-referenced with another document from that state’s government describing the ban in English [82]. It is thus also possible that some documents concerning pesticide bans written in Hindi or other official state languages have been missed.

Conclusions
This study suggests that pesticide regulation in India may have had an effect on the rate of suicide nationally and in Kerala, corroborating the effect demonstrated by pesticide bans in other South Asian countries where pesticide self-poisoning has been a common method of suicide. Further research is required to assess the effects of restrictions after 2015, and better-quality data including further representative samples will be beneficial in assessing the effect of this and other interventions to reduce suicide. However, it is clear that HHP bans could be considered as part of a broader national suicide prevention strategy in India.

Abbreviations
NCRB—National Crime Records Bureau
HHP—highly hazardous pesticide
WHO—World Health Organization
CIB—Central Insecticides Board

LD50—median lethal dose (dose required to kill half the members of a tested population)

IPC—Indian Penal Code

Declarations

Ethics approval
Not applicable. All data were publicly available, so ethical approval was not sought.

Consent for publication
Not applicable.

Availability of data and materials
All data are available from public websites as reported in the paper.

Competing interests
The authors declare no conflicts of interest.

Funding
The Centre for Pesticide Suicide Prevention is funded by an incubation grant from the Open Philanthropy Project on the recommendation of GiveWell. The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the manuscript.

Author’s contributions
ME conceptualized the study. ME and TB designed the study, acquired the data and drafted and revised the manuscript. LU provided legal opinion and contributed to the writing of the manuscript. DG and DK performed the statistical analysis and contributed to the writing of the manuscript. All authors read and approved the final manuscript.

Acknowledgements
Not applicable

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Tables

Table 1: Pesticides registered for use in India in August 2019 [53] by WHO toxicity class[18]

| WHO class of pesticide          | Number of registered compounds |
|---------------------------------|-------------------------------|
| Ia                              | 4                             |
| Ib                              | 14                            |
| II                              | 95                            |
| III                             | 31                            |
| Unlikely to cause toxicity      | 47                            |
| Obsolete                        | 4                             |
| Fumigant                        | 3                             |
| Not classified by WHO           | 116                           |
| **Total**                       | **314**                       |
Table 2: Timeline of partial restrictions

| Date     | Territory | National restrictions                           |
|----------|-----------|-----------------------------------------------|
| 1999     | National  | methyl bromide ¹                             |
| 2001     | National  | aluminium phosphide ², captafol ³             |
| 2005     | National  | monocrotophos ⁴                              |
| 2007     | National  | fenitrothion ⁵                               |
| 2008     | National  | dazomet ⁶                                     |
| 2009     | National  | cypermethrin ¹                                |
| Before 2012 b | National | phosphamidon ⁷, carbofuran ⁷, methomyl ⁷ |
| 2018     | National  | sodium cyanide ⁸, trifluralin ⁹              |
Restrictions: 1: restricted to government use only; 2; use of tube packs with 10 or 20 tablets of aluminium phosphide 3 grams banned 3: use as spray banned, seed dresser permitted; 4: use on vegetables not permitted; 5: locust control in desert areas only; 6: use on tea not permitted; 7: only stronger formulations banned; 8: use as insecticide not permitted; 9: use permitted for wheat only.

The following 18 pesticides were refused registration upon application to the Registration Committee: EPN, mevinphos, disulfoton, azinphos-ethyl, azinphos-methyl, calcium arsenate, dicrotophos, lead arsenate, vamidothion, 2,4,5-T, fentin acetate, fentin hydroxide, ammonium sulfamate, chinomethionat, binapacryl, carbophenothon, leptophos, mephospholan.

b: information on when these pesticides were restricted is not available.

Table 3: Timeline of national and state pesticide bans

| Date | Territory | National bans |
|------|-----------|---------------|
| 1974 | National  | parathion (ethyl parathion) |
| 1989 | National  | dibromochloropropane, pentachloronitrobenzene, toxaphene |
| 1990 | National  | endrin |
| 1996 | National  | aldrin, chlordane, heptachlor |
| 2001 | National  | aldicarb, chlorbenzilate, dieldrin, ethylene dibromide, maleic hydrazide, trichloroacetic acid |
| 2005 | National  | (dalapon, ferbam, formothion, nickel chloride, paradichlorobenzene, simazine, warfarin) |
| 2005 | Kerala    | benzene hexachloride, calcium cyanide, copper acetoarsenite, ethyl mercury |
| 2005 | National  | |
|      | National  | |

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Before 2007<sup>a</sup> chloride, menazon, nitrofen, **paraquat dimethyl sulphate**, pentachlorophenol, phenyl mercury acetate, sodium methane arsonate, tetradifon

| Year | State   | Pesticide(s)                      |
|------|---------|-----------------------------------|
| 2011 | Kerala  |                                   |
| 2011 | Karnataka | endosulfan                         |
| 2011 | National | chlorofenviphos, metoxuron            |

2007 to 2012<sup>a</sup> chlorofenviphos, metoxuron

| Year | State   | Pesticide(s)                      |
|------|---------|-----------------------------------|
| 2013 | National | lindane                             |
| 2014 | Sikkim  |                                   |
| 2014 | National | (sirmate)                           |
| 2017 | Maharashtra |                                   |
| 2018 | Punjab  |                                   |

2018 National benomyl, **carbaryl**, **diazinon**, fenarimol, **fenthion**, linuron, methoxy ethyl mercuric chloride, **methyl parathion**, thiometon, tridemorph

| Year | State   | Pesticide(s)                      |
|------|---------|-----------------------------------|
| 2020 | National | **alachlor**, **dichlorvos**, **phorate**, **phosphamidon**, triazophos, trichlorfon |

Key: HHPs frequently used for suicide are indicated in **bold**. Pesticides withdrawn from use until further information as requested by the Registration Committee is submitted are in (parentheses). Temporarily banned pesticides are in [square brackets]. Proposed future bans on pesticides are in *italics*.

<sup>a</sup>: information on which year these pesticides were banned is not available.
Table 4: Rate ratios for suicide after 2011 ban of endosulfan nationally and 14 pesticides in Kerala

| Post-ban years | National suicides | Kerala suicides<sup>c</sup> |
|----------------|-------------------|-----------------------------|
|                | Total<sup>a</sup> | Pesticide<sup>b</sup>       | Total            | Pesticide     |
| 2011           | 1.00 (0.98, 1.02) | 0.83 (0.81, 0.86)          | 0.99 (0.98, 1.01)| 0.85 (0.80, 0.9) |
| 2012           | 0.97 (0.95, 1.00) | 0.75 (0.72, 0.77)          | 1.01 (0.99, 1.03)| 0.73 (0.68, 0.7) |
| 2013           | 0.95 (0.92, 0.97) | 0.71 (0.69, 0.74)          | 1.04 (1.01, 1.06)| 0.51 (0.47, 0.5) |
| 2014           | 0.90 (0.87, 0.93) | 0.52 (0.49, 0.54)          | 1.02 (1.00, 1.05)| 0.45 (0.42, 0.4) |

Period of consistent linear trend prior to ban: <sup>a</sup>2003-2010; <sup>b</sup>1997-2010; <sup>c</sup>1999-2010

Table 5: Rate ratios for suicide after 2005 ban of endosulfan in Kerala

| Post-ban years | Kerala suicides* |
|----------------|------------------|
|                | Total            | Pesticide       |
| 2006           | 0.99 (0.96, 1.02)| 0.87 (0.77, 0.99) |
| 2007           | 0.99 (0.96, 1.02)| 0.77 (0.66, 0.89) |
| 2008           | 0.95 (0.92, 0.99)| 0.83 (0.70, 0.99) |
| 2008           | 0.98 (0.94, 1.03)| 0.83 (0.68, 1.01) |
| 2010           | 0.97 (0.93, 1.02)| 0.79 (0.64, 0.99) |

*Period of consistent linear trend prior to endosulfan ban 1999-2005

Figures
Figure 1
Annual incidence of ‘total suicides’, ‘insecticide suicides’, ‘other poisoning suicides’ and ‘suicides by other means’ from 1995 to 2015, with annual yield of principal crops from 2001 to 2014

Figure 2
Annual pesticide suicides by state from 1995 to 2015
Figure 3

Total pesticide suicides by state from 1995 to 2015
Figure 4

Incidence of pesticide suicide by state from 2001 to 2015
Figure 5

Map of change in pesticide suicide rate by state from 2001 to 2015
Figure 6

Incidence of all suicides by state from 2001 to 2015
Figure 7

Map of change in total suicide rate by state from 2001 to 2015