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A Bayesian Analysis of Accidental Dwelling Fire Incidence, Injury, and Fatality in the Greater Manchester Area

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ABSTRACT

The relationship between accidental dwelling fire incidence and fire injury and fatality was examined using a Bayesian model to estimate the probability of a fire injury or fatality resulting from an accidental dwelling fire incidence under different circumstances of fire incidence (type of accidental dwelling fire, dwelling occupancy type, impairment due to suspected alcohol or drugs, and level of deprivation). Accidental dwelling fire incidence and fire injury and fatality data recorded by Greater Manchester Fire and Rescue Service between 2013/14 and 2023/24 were used to develop the Bayesian model. Overall, impairment due to suspected alcohol or drugs consumption appeared to increase the probability of fire injury across the different types of accidental dwelling fire, and the probability of fire injury and fatality resulting from an accidental dwelling fire was highest for candle and smoking-related fires.

1 | Introduction

The research reported in this article concerns the use of Bayesian analysis to examine the probability of fire injury and fatality resulting from an accidental dwelling fire incident based upon the type of accidental dwelling fire (cooking, smoking, heating fire, etc.); the dwelling occupancy type; impairment due to suspected alcohol or drugs; and the level of deprivation of the area in which the accidental fire incident occurred. The data used in the analysis was recorded in the UK Fire Incident Recording System [1] by Greater Manchester Fire and Rescue Service in the UK over the period 2013/14 to 2023/24. Greater Manchester covers 1276 km^2 in Northwest England and mainly includes urban areas.

The Bayesian modelling approach utilised existing knowledge of accidental dwelling fire injuries and fatalities (the prior probabilities) and updated that knowledge through the analysis of relevant accidental dwelling fire incident data. This analysis aimed to examine the posterior probabilities, the likelihood of fire injury or fatality following an accidental dwelling fire considering factors such as the type of accidental dwelling fire, the dwelling occupancy type, impairment due to suspected alcohol or drugs, and the level of deprivation in which the fire incidence occurred. Bayesian analysis can help improve our understanding of the outcomes from the different circumstances of accidental dwelling fires in terms of statistical significance and practical significance of the likelihood of fire injury and fatality. Bayesian analysis is a useful approach for modelling accidental dwelling fire injury and fatality risks since Bayesian statistics can be used with smaller sample sizes and discrete data. Artificial intelligence (machine learning) approaches are typically concerned with classification, prediction, or clustering and are more difficult to use with smaller sample sizes and discrete data. Machine learning models typically require large datasets for effective training and may be less effective with limited amounts of data, leading to issues such as overfitting and poor generalization. Bayesian analysis concerns the estimation of probabilities and can offer clear insights into the likelihood of fire injury and fatality for specific sets of fire incidence circumstances. By utilising prior knowledge, in this case the circumstances of accidental dwelling fires, Bayesian statistics can provide a deeper understanding of the likelihood of fire injury and fatality based upon different combinations of accidental dwelling fire circumstances. This approach not only enhances interpretability through clear probabilistic insights but also allows for the seamless integration of new data to continually refine our understanding. The novelty of the research presented in this article is the Bayesian modelling of the likelihood of accidental dwelling fire injury and fatality resulting from different circumstances of accidental dwelling fire incidence.

2 | Literature Review

2.1 | Bayesian Statistics

Traditional (frequentist) statistics can be used to interpret probabilities as frequencies of events over time, whilst Bayesian statistics can be used to interpret conditional probabilities which concern estimating the likelihood of an outcome based upon previous outcomes having occurred in similar circumstances. Bayesian statistical approaches allow the incorporation of prior knowledge in the modelling process and can cater for smaller sample sizes and missing data [2, 3]. Bayesian approaches provide inferences that are conditional on the data and interpretable results that are based solely on the observed data and the model, and have been used in a variety of sectors such as drug development [4], risk management [5], and forest fire modelling and management [6, 7]. Bayesian statistical analysis has been used to a limited extent in the analysis of domestic fires in terms of the spatial forecasting of residential fires [8] and the likelihood of different fire responses [9, 10].

2.2 | Accidental Dwelling Fire Incidence, Injury, and Fatality

Accidental dwelling fire prevention involves understanding the causes of fire and increasing awareness of fire safety [11–13]. Accidental dwelling fires do not appear to be distributed evenly throughout UK society, with deprived social groups experiencing disproportionate numbers of incidents [14]. Previous research has indicated that accidental dwelling fire incidence, injury, and fatality were related to demographic and socioeconomic factors such as age [15–19], living alone [20–22], and deprivation [23, 24], as well as contributory factors such as alcohol consumption [15, 25].

The novelty of this research concerns the examination of the Bayesian modelling of accidental dwelling fire injury and fatality associated with the fire incidence circumstances of fire type (based on the fire cause), dwelling occupancy type, impairment due to suspected alcohol or drugs, and level of deprivation from actual accidental dwelling fire incidents recorded by Greater Manchester Fire and Rescue Service over the period 2013/14 to 2023/24. Previous studies of accidental dwelling fire injuries have either examined specific factors associated with fire injury such as old age [16, 20, 26] or deprivation [24, 27], or have examined a range of causal factors, but mainly looking at the factors independently [11, 22]. Previous research has typically examined accidental dwelling fire injuries mainly in terms of frequency (number of overall injuries, or number of injuries of particular types) or population percentages or ratios [23, 25, 28]. This research examines the probability of an accidental dwelling fire injury given a specific and particular set of circumstances, and how the probability alters with further specific circumstances. For example, the probability of an accidental dwelling fire injury resulting from a cooking fire can be estimated, then the probability of an elderly person being injured in a cooking fire, and the probability of an elderly person being injured in a cooking fire when under the influence of alcohol or drugs.

3 | Research Method

The research questions addressed by this research are:

- How can accidental dwelling fire injuries and fatalities associated with different fire incidence circumstances be modelled?
- What accidental dwelling fire circumstances affect the likelihood of fire injury?
- What accidental dwelling fire circumstances affect the likelihood of fire fatality?

This is an important research area since in England the cost of fire injuries to the National Health Service was estimated to be £23 million in 2023 [29]. The research method utilised involved the Bayesian modelling of accidental dwelling fire injury and fatality based upon previous research concerning accidental dwelling fire circumstances [14, 20, 23, 25] relating to the type of accidental dwelling fire, the dwelling occupancy type, impairment due to suspected alcohol or drugs, and the level of deprivation of the area in which the accidental fire incident occurred as factors influencing the likelihood of fire injury [28]. The research utilised accidental dwelling fire incidence, injury, and fatality data recorded in the English fire incident recording system by Greater Manchester Fire and Rescue Service over the period 2013/14 to 2023/24.

The measure of deprivation used for the research was the IMD decile scale [30], where 1 equates to the most deprived 10% of Lower Super Output Areas (LSOAs) in England, and 10 equates to the least deprived 10% of Lower Super Output Areas in England. The LSOAs are a standard statistical geography used to divide England into 32 844 areas, each with a similar total population. An LSOA typically comprises between 400 and 1200 households and a population between 1000 and 3000 individuals [31]. The impairment due to suspected alcohol or drug consumption variable had just two categories of yes or no and was determined by a fire officer at the fire incident. The type of accidental dwelling fire was grouped into seven main categories (cooking, electrical, smoking, appliance, candle, heating, other). The accidental dwelling fire type was based upon the source of ignition of the fire recorded for the incident (for example: Cooking appliance—Cooker incl. oven; Cooking appliance—Microwave oven; Cooking appliance—Ring/hot plate (separate appliance)). The dwelling occupancy types were (Lone person ≥65, Lone person <65, Couple with children, Lone parent, Couple <65 no children, Couple 1+ 65+ no children, 3+ adults no children, 3+ adults with children, Not known). These variables were chosen for the Bayesian analysis based upon their stated importance in previous studies.

The Bayesian modelling approach used conditional probabilities to estimate the likelihood of fire injury and fire fatality from the accidental dwelling fire circumstance variables of fire type (based on the fire cause), dwelling occupancy type, impairment due to suspected alcohol or drugs, and the level of deprivation. The rationale for using Bayesian statistics was that it enabled the examination of the likelihood of an accidental dwelling fire injury or fatality for different sets of accidental dwelling fire circumstances. A Bayesian modelling approach provided a more detailed examination of the likelihood of an accidental dwelling fire injury or fatality resulting from specific combinations of accidental dwelling fire circumstances compared to traditional statistical approaches, and a more transparent model compared to artificial intelligence approaches. A naïve Bayes modelling approach was utilised due to its efficiency, scalability, and ease of interpretation, which allowed examination of the probability of different outcomes associated with different combinations of fire causal factor variables. For example, previous research had indicated that alcohol and drug impairment may be associated with higher levels of deprivation [24], and alcohol and drug consumption may be related to the likelihood of different types of accidental dwelling fire incidence [25] and injury [32].

The Bayesian modelling was developed using Microsoft Excel to estimate the likelihood of accidental dwelling fire injury and fatality based on different combinations of accidental dwelling fire incident circumstances. Microsoft Excel was used for the modelling since it was the established data analysis software tool in use within the Fire and Rescue Service studied. The decision to use Excel was pragmatic: it is available across all UK fire stations and command centres, and staff in various roles, from fire officers to data analysts, are familiar with its use. It is also a low-cost choice, which is particularly important for Fire and Rescue Services operating under significant resource and budgetary constraints. The software is already available and incurs no additional training, hardware, administration, or maintenance costs. Previous studies utilising Bayesian analysis have adopted Microsoft Excel as the chosen software platform both within Fire and Rescue Services [10] and elsewhere [33].

This choice is made in lieu of industry-standard, programming-based, data science toolkits and environments such as Python and R. Whilst such tools provide extensive libraries for advanced analytics and facilitate data sharing, code review, code modularisation/reuse, and experimental reproducibility, they introduce additional layers of complexity that make them currently unsuitable for resource-constrained Fire and Rescue Services. If applied correctly, these tools require, for example, the installation of additional software, the management of development environments (including versioning and library compatibility), the use of integrated development environments (IDEs) to utilise libraries, and the use of source control systems to facilitate testing and bug tracking. This is in addition to the associated technical overhead required to install, administer, and maintain these tools, as well as the training needed to up-skill staff in Python, R, and related platforms.

In terms of analytical rigour, Excel spreadsheets rely on explicit, transparent formulas and built-in functions, which can be straightforwardly checked and tested. While manual formula entry carries some risk of human error, all formulas used in this research were independently verified by team members to ensure correctness. The correctness of formulas in Microsoft Excel was validated by tracing precedents/dependents to ensure that each probability was calculated from the intended cells. The formulas were then validated by comparison with hand calculated examples. Internal consistency was checked via probability rules, such as all probabilities must be between 0 and 1 and posterior probabilities must sum to 1 across mutually exclusive hypotheses. However, Bayesian analysis may only be as valid as its assumptions; therefore, likelihoods were derived from reliable data (recorded by the Fire and Rescue Service concerned), and priors were evidence based (from the recorded data). Sensitivity analysis tests how much posterior probabilities change when assumptions vary. This was clearly demonstrated in the change in probabilities when the assumption of suspected impairment due to alcohol or drugs was changed. Tables were used to show how posterior probabilities responded to changes in suspected impairment due to alcohol or drugs, and level of deprivation.

Although using development environments based upon Python or R can reduce the likelihood of syntactic errors through automation and reusable scripts, they do not eliminate the potential for semantic or conceptual errors in analytical logic. Importantly, such tools would also require domain experts within the Fire and Rescue Services to be able to independently interpret and audit the analytical processes used, which is not currently feasible. The practical realities of the Fire and Rescue Service context mean that, on balance, Excel is currently the most appropriate and accessible platform for ensuring transparency, verifiability, and operational integration within existing systems. Accordingly, the modelling and analysis presented here were undertaken in Excel to align with these practical and organisational considerations.

The novelty of the research reported in this paper is the detailed analysis of use of Bayesian statistics to provide a finer grained analysis of the risk of accidental fire injury and fatality achieved through the examination of risk levels associated with very specific combinations of circumstances.

4 | Results

4.1 | Accidental Dwelling Fire Injury and Fire Fatality Modelling

This research examined the use of Bayesian statistics to analyse accidental dwelling fire instance circumstances and model the likelihood of accidental dwelling fire injury and fatality. The Bayesian modelling estimated the likelihood of accidental dwelling fire injury and fatality based upon the type of fire, occupancy type, impairment due to suspected alcohol or drugs, and deprivation. Figure 1 shows the pattern of accidental dwelling

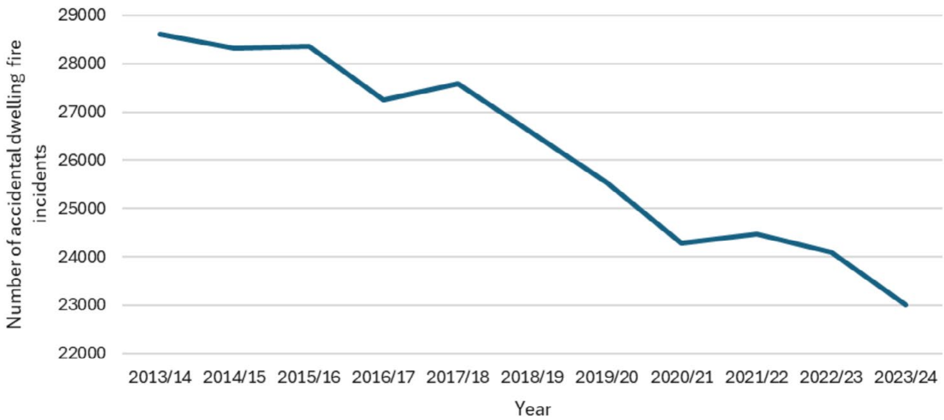

FIGURE 1 | Number of accidental dwelling fire incidents in England 2013/14 to 2023/24.

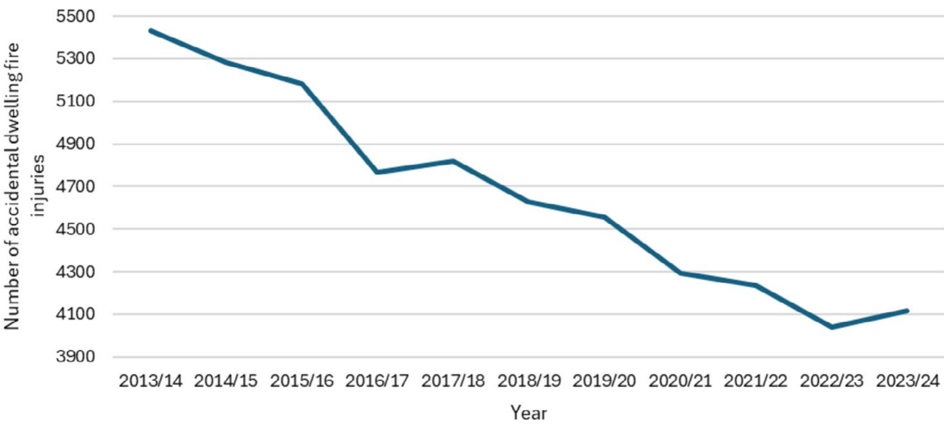

FIGURE 2 | Number of accidental dwelling injuries per year in England 2013/14 to 2023/24.

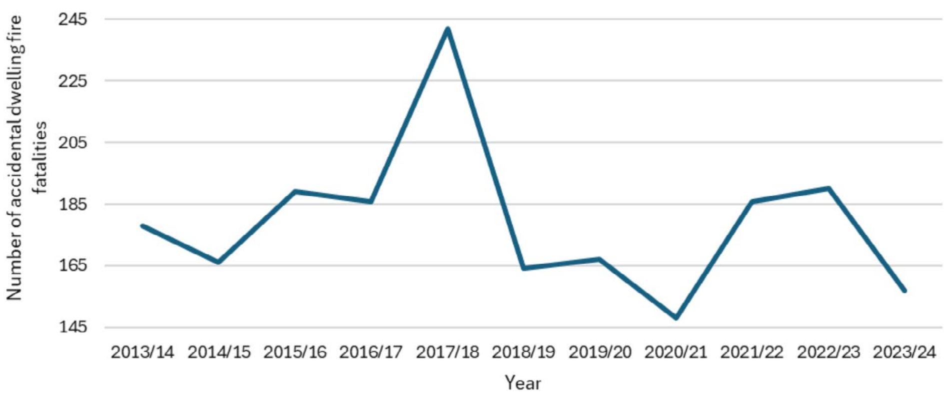

FIGURE 3 | Number of accidental dwelling fire fatalities per year in England 2013/14 to 2023/24.

fire incidences over the periods 1st April 2013/14 to 31st March 2023/24 in England.

There was a 19.6% reduction in accidental dwelling fire incidents over the period studied with an annual percentage reduction of 2.03% and an uncertainty range of ±0.33%, and a 24.2% reduction in accidental dwelling fire injuries with an annual percentage reduction of 2.68% and an uncertainty range of ±0.44% as shown in Figure 2. In addition to fire prevention activities by Fire and Rescue Services, behavioural changes such as reduced smoking and alcohol consumption rates may be contributing to the downward trend in accidental dwelling fire incidences and injuries in England [34] as shown in Figures 1 and 2. Figure 2 shows the number of accidental dwelling injuries per year in England 2013/14 to 2023/24.

Figure 3 shows the number of accidental dwelling fire fatalities per year in England 2013/14 to 2023/24.

The number of accidental dwelling fire fatalities in England reduced from 178 to 157 (an 11.8% decrease); however the number of accidental dwelling fire fatalities per year ranged between 242 and 148 over the study period. The peak in 2017/2018 included the Grenfell Tower fire in London in which there were 72 fire fatalities. To improve the reliability and interpretability of the analysis, a 95% confidence interval was used to estimate the upper and lower bounds of the range within which the true average number of fatalities per year likely falls. For England as a whole, the average number of accidental dwelling fire fatalities per year was 179.36, with a 95% confidence interval of 162.54–196.19.

Figure 4 shows the pattern of accidental dwelling fire incidents over the period 2013/14 to 2023/24 in Greater Manchester.

Although there was a 29.6% reduction with an annual percentage reduction of 3.28% and an uncertainty range of ±0.50% in accidental dwelling fire incidents over the period studied (a larger percentage reduction than England as a whole (19.6%)), there was only a 1.5% reduction with an annual percentage reduction of 0.47% and an uncertainty range of ±1.66% in accidental dwelling fire injuries as shown in Figure 5 compared to a 24.2% reduction in accidental fire injuries for England. In Greater Manchester, fire prevention activities as well as behavioural changes relating to smoking and alcohol consumption rates may be contributing to the downward trend in accidental dwelling fire incidences as seen overall in England as shown in Figure 4. Figure 5 shows the number of accidental dwelling fire injuries per year in Greater Manchester 2013/14 to 2023/24.

Figure 6 shows the number of accidental dwelling fire fatalities per year in Greater Manchester 2013/14 to 2023/24.

The number of accidental dwelling fire fatalities in Geater Manchester reduced from 11 to 9, an 18.2% decrease, (compared to an 11.8% decrease for England as a whole) as shown in Figure 6; however, the number of accidental dwelling fire fatalities was very small and ranged between 8 and 14 over the study period. A 95% confidence interval was used to estimate the upper and lower bounds of the range within which the true average number of fatalities per year in Greater Manchester likely falls. The average number of accidental dwelling fire fatalities per year in Greater Manchester was 11.55, with a 95% confidence interval of 10.19–12.90. This supports the rationale for examining accidental dwelling fire injuries and fatalities based upon fire circumstances, since the accidental dwelling fire injuries in Greater Manchester had not shown a similar level of decrease compared to the accidental dwelling fire incidents, nor a similar level of decrease compared to accidental dwelling fire injuries in England as a whole. In addition, there did not appear to be a clear overall trend in the numbers of accidental fire fatalities per year either in Greater Manchester or England. The coefficient of variation, which is a statistical measure that expresses the extent of variability in relation to the mean of a dataset was then used to compare the degree of variation between the England dataset of accidental fire fatalities and the Greater Manchester dataset of accidental fire fatalities. The coefficient of variation for fire fatalities over the study period in England was 0.14, compared to 0.17 for Greater Manchester, indicating that the fire fatalities in

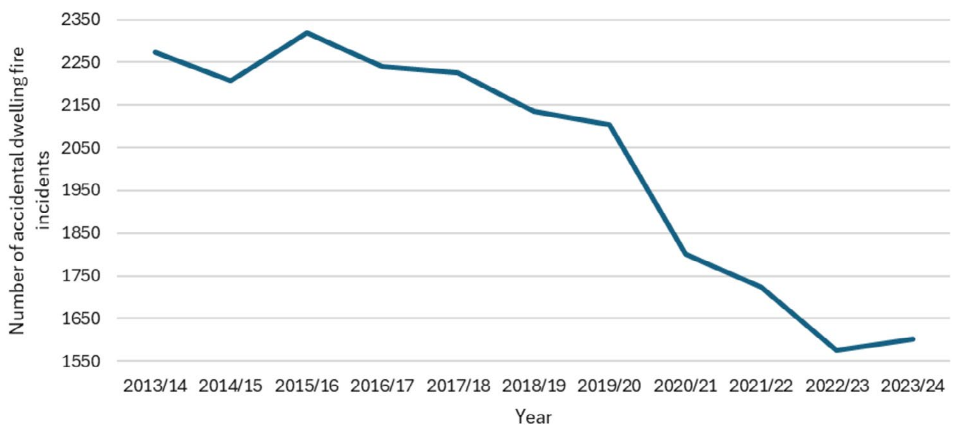

FIGURE 4 | Number of accidental dwelling fire incidents per year in Greater Manchester 2013/14 to 2023/24.

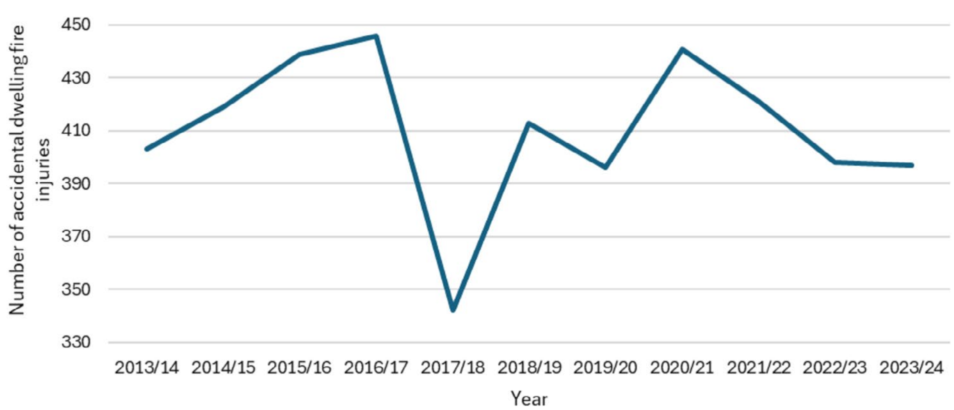

FIGURE 5 | Number of accidental dwelling fire injuries per year in Greater Manchester 2013/14 to 2023/24.

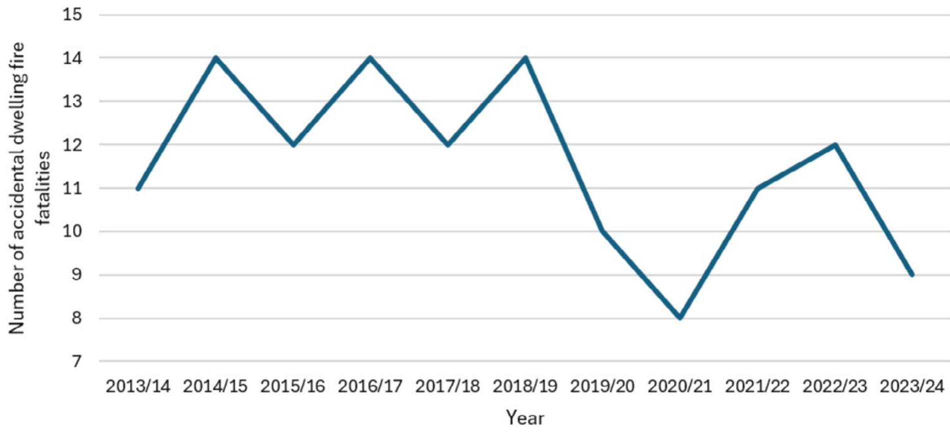

FIGURE 6 | Number of accidental dwelling fire fatalities per year in Greater Manchester 2013/14 to 2023/24.

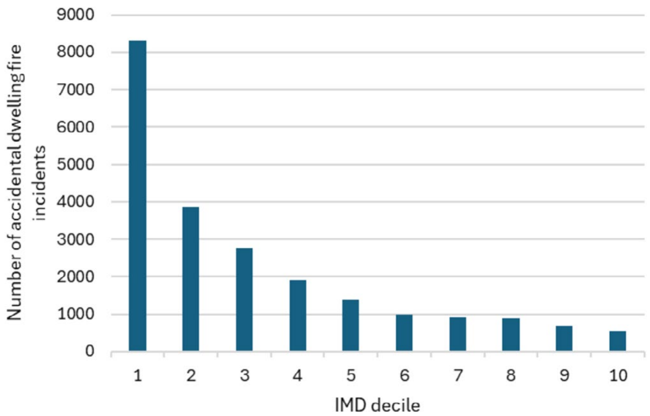

FIGURE 7 | Number of accidental dwelling fire incidents by IMD decile in Greater Manchester 2013/14 to 2023/24.

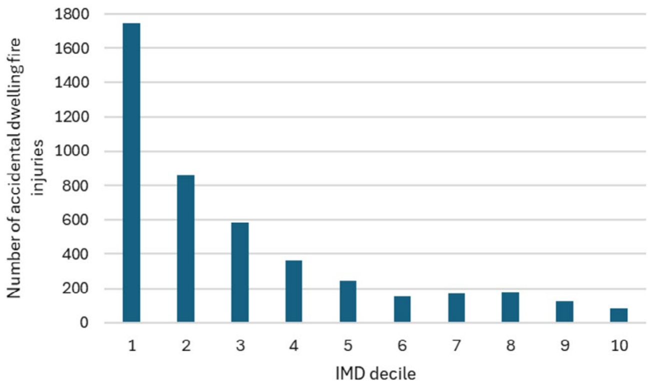

FIGURE 8 | Number of accidental dwelling fire injuries by IMD decile in Greater Manchester 2013/14 to 2023/24.

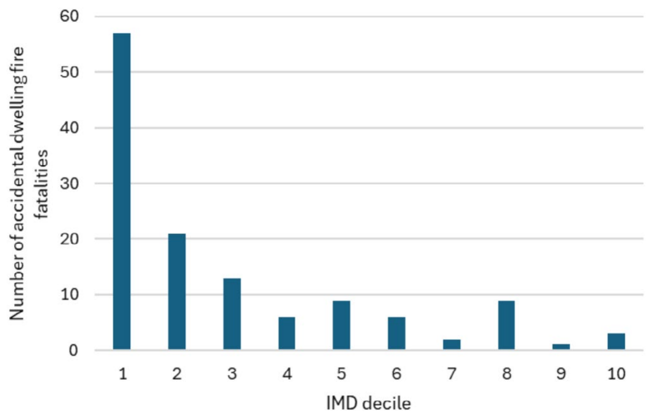

FIGURE 9 | Number of accidental dwelling fire fatalities by IMD decile in Greater Manchester 2013/14 to 2023/24.

Greater Manchester per year had a higher level of variability than for England as a whole.

Over the period studied in terms of the type of accidental dwelling fire incidences, 53.7% were cooking fires, 15.1% were electrical fires, 7.9% were appliance fires, 7.5% were fires associated with smokers' materials, 4.3% were candle fires, 3.4% were heating fires, and 8.0% were due to other causes. Impairment due to suspected alcohol or drugs consumption was a factor in 9.0% of the fire instances over the period studied. This also supported the rationale for examining accidental dwelling fire type (based on the fire cause) in terms of the likelihood of fire injury and fatality, as there were marked differences in the frequency of the different types of fires over the period studied. Figure 7 shows the number of accidental dwelling fire incidents by IMD decile in Greater Manchester 2013/14 to 2023/24.

Figure 8 shows the number of accidental dwelling fire injuries by IMD decile in Greater Manchester 2013/14 to 2023/24.

Figure 9 shows the number of accidental dwelling fire fatalities by IMD decile in Greater Manchester 2013/14 to 2023/24.

37.5% of accidental dwelling fire incidents, 38.7% of fire injuries, and 44.9% of fire fatalities occurred in areas with the highest level of deprivation (IMD decile 1), which supported the rationale for examining the level of deprivation in terms of the likelihood of fire injury and fatality in terms of deprivation. This appears to indicate that deprivation is an influencing factor in terms of accidental dwelling fire incidence, injury, and fatality, and therefore should be considered in terms of fire prevention strategies. Previous research had identified a connection between the level of deprivation and fire injury rates [24].

4.2 | Bayesian Analysis of Accidental Dwelling Fire Injury and Fire Fatality Circumstances

Bayes theorem uses conditional probabilities:

$$P(A|B) = P(A \cap B) / P(B)$$

Probability of A given B equals Probability of A and B/Probability of B.

The probability of an accidental dwelling fire injury associated with accidental dwelling fire circumstances would be:

$$P\text{ (fire injury | fire circumstances)} = \frac{P\text{ (fire injury} \cap \text{fire circumstances)}}{P\text{ (fire circumstances)}} \quad (1)$$

The probability of an accidental dwelling fire fatality associated with accidental dwelling fire circumstances would be: (Equation 2)

$$P\text{ (fire fatality|fire circumstances)} = \frac{P\text{ (fire fatality} \cap \text{fire circumstances)}}{P\text{ (fire circumstances)}} \quad (2)$$

Table 1 shows the number and percentage of the different fire types and the Bayesian probability of injury and fatality for the different fire types (based on the fire cause), given the occurrence of that type of fire.

Table 1 presents an analysis of the number of fire incidents in the different fire type categories, the percentage of fires within the different fire type categories, and the probability of fire injury and fire fatality associated with each fire type category. Table 1 indicated that the probability of accidental dwelling fire injury and fatality was highest for candle and smoking-related fires compared to the other types of fire. In addition, although cooking and heating fires had a relatively high probability of fire injury compared to electrical, appliance, and other fires, they had a lower probability of fire fatality. Previous research had identified a higher risk of accidental dwelling fire injury for smoking fire incidences [15, 23]; however, candle fire injuries had not been identified as being higher risk. This would appear to indicate that activities involving the use of naked flames and burning materials (tobacco and candles) increase the probability of accidental dwelling fire injury and fatality.

Table 2 shows the number and percentage of the different fire types (based on the fire cause) and the Bayesian probability of injury and fatality for the different occupancy types, given the occurrence of fire incidents in properties with that type of occupancy.

TABLE 1 | Number and percentage and Bayesian probability of injury and fatality across the different fire types (based on the fire cause).

Fire type	Number of fire type incidents	Percentage of fires	Probability of injury (%)	Probability of fatality (%)
Cooking	11 920	53.7	21.6	0.2
Electrical	3359	15.1	11.9	0.2
Smoking	1668	7.5	27.8	3.5
Appliance	1765	7.9	17.3	0.1
Candles	961	4.3	29.8	3.5
Heating	759	3.4	21.9	0.2
Other	1775	8.0	17.7	0.7

TABLE 2 | Number and percentage and Bayesian probability of injury and fatality across the different occupancy types.

Occupancy type	Number of incidents for occupancy type	Percentage of fires	Probability of injury (%)	Probability of fatality (%)
Lone person ≥ 65	4367	19.7	24.7	1.2
Lone person < 65	4137	18.6	22.1	0.7
Couple with children	3965	17.9	16.4	0.2
Lone parent	2203	9.9	19.7	0.1
Couple < 65 no children	1952	8.8	19.2	0.3
3+ adults no children	1096	4.9	21.4	0.2
Couple 1+ 65+ no children	993	4.5	26.9	1.3
3+ adults with children	673	3.0	23.6	0.1
Not known	2821	12.7	14.4	0.5

TABLE 3 | Number and percentage and Bayesian probability of injury and fatality across the different deprivation deciles.

Deprivation (IMD decile)	Number of fire incidents	Percentage of fires	Probability of injury (%)	Probability of fatality (%)
1	8319	37.5	21	0.7
2	3853	17.4	22.3	0.5
3	2765	12.5	21.1	0.5
4	1895	8.5	19.2	0.3
5	1376	6.2	17.8	0.7
6	987	4.4	15.8	0.6
7	910	4.1	19	0.2
8	887	4.0	19.6	1
9	677	3.0	18.6	0.1
10	538	2.4	16	0.6

Table 2 presents an analysis of the number of fire incidents across the different occupancy type categories, the percentage of fires within the different occupancy type categories, and the probability of fire injury and fire fatality associated with each occupancy type category. Table 2 indicated that the probability of accidental dwelling fire injury and fatality was highest for the elderly and those living alone, similar to previous studies [13, 20]. In addition, elderly couples were associated with the highest probability of fire injury and fire fatality. This would appear to indicate that the elderly should be the highest priority in terms of fire prevention interventions such as home fire safety checks.

Table 3 shows the number and percentage of accidental dwelling fires across the different IMD decile areas, and the Bayesian probability of injury and fatality for the different IMD decile areas across Greater Manchester.

Table 3 presents an analysis of the number of fire incidents across the different IMD deciles, the percentage of fires within the different IMD deciles, and the probability of fire injury and fire fatality associated with each IMD decile. Table 3 indicated that the probability of accidental dwelling fire injury was higher in higher levels of deprivation (IMD deciles 1, 2, and 3) with the majority of fire incidences occurring in those deciles, similar to previous research [24, 27], however, there was less of a relationship between the level of deprivation and fire fatality. There were, however, very few numbers of fire fatalities (127) over the period studied, making statistical analysis more difficult.

Overall, the probability of accidental dwelling fire injury associated with suspected alcohol or drug consumption was 37.6%, compared to 17.7% where this was not a factor. The probability of accidental dwelling fire fatality associated with suspected alcohol or drug consumption was 1.5%, compared to 0.2% where this was not a factor, similar to previous research on the effects of alcohol and drug consumption on accidental dwelling fire injury [32].

In order to examine the likelihood of accidental dwelling fire injury and fatality further using Bayesian statistical modelling, the combinations of accidental dwelling fire circumstances can be viewed as a vector in four dimensions (type of fire, occupancy type, impairment due to suspected alcohol or drugs, and deprivation). The categories of the four variables (type of fire, occupancy type, impairment due to suspected alcohol or drugs, and deprivation) were:

Fire type categories: {cooking, electrical, smoking, appliance, candle, heating, other}.

Occupancy type categories: {Lone person ≥ 65, Lone person < 65, Lone parent, Couple with children, Couple < 65 no children, Couple 1+ 65+ no children, 3+ adults no children, 3+ adults with children, not known}.

Impairment due to suspected alcohol or drugs categories: {Yes, No}.

The IMD decile (measure of deprivation) categories: {1 = most deprived 10% of LSOAs in England, ... 10 = least deprived 10% of LSOAs in England}.

Using Bayes theorem, it was possible to calculate the conditional probability of fire injury and fatality given different combinations of accidental dwelling fire circumstances based upon the actual recorded fire instances that occurred, rather than incidents that conceivably could have happened but did not.

As an example, for a cooking fire incident in a property in an IMD decile 1 area occupied by one person aged 65+, where alcohol or drug consumption was a contributory factor, the probability of a fire injury would be:

$$\begin{aligned}&P\,(\text{injury} \mid \text{cooking fire, Lone person} \geq 65\text{, Impaired, IMD decile 1})\\&= P\,(\text{injury and cooking fire, Lone person} \geq 65\text{, Impaired, IMD decile 1})/\\&\quad P\,(\text{cooking fire, Lone person} \geq 65\text{, Impaired, IMD decile 1})\end{aligned} \tag{3}$$

The fire incident data from Greater Fire and Rescue Service indicated a probability of 43.82% of fire injury given these circumstances.

For comparison, for the same circumstances except that impairment was not a factor:

$$P\,(\text{injury} \mid \text{cooking fire, Lone person} \geq 65, \text{Not impaired, IMD decile } 1) = P\,(\text{injury and cooking fire, Lone person} \geq 65, \text{Not impaired, IMD decile } 1) / P\,(\text{cooking fire, Lone person} \geq 65, \text{Not impaired, IMD decile } 1) \quad (4)$$

The fire incident data from Greater Manchester Fire and Rescue Service indicated a probability of 23.02% of fire injury given these circumstances.

Example Bayesian probabilities of accidental dwelling fire injury for cooking fire circumstances are shown in Table 4.

Table 4 presents a Bayesian analysis of the probability of cooking fire injury associated with different occupancy categories, suspected impairment due to alcohol/drugs, and IMD decile. Table 4 indicated that the elderly were at highest risk of cooking fire injury, similar to previous research [13] and that impairment due to alcohol or drugs greatly increased the probability of cooking fire injury. Although previous research had examined the effects of impairment due to alcohol and drugs on accidental dwelling fire injury [32] this research enhanced knowledge in terms of the probability of fire injury in more specific combinations of circumstances, such age group and impairment due to alcohol and drugs. This indicates that cooking safety awareness promotion by Fire and Rescue Services should reinforce advice regarding avoiding alcohol or drug consumption when cooking.

Table 5 shows Bayesian probabilities of accidental dwelling fire injury for smokers' materials fire circumstances.

Table 5 presents a Bayesian analysis of the probability of smoking-related fire injury associated with different occupancy categories, suspected impairment due to alcohol/drugs, and IMD decile. Table 5 indicated that the elderly were at highest risk of smoking fire injury, similar to previous research [13, 23] and that impairment due to alcohol or drugs greatly increased the probability of smoking fire injury, similar to previous research [32]. However, this research enhanced knowledge in terms of the probability of accidental dwelling fire injury in more specific combinations of circumstances, for example lone parent, living in a higher level of deprivation and impaired by alcohol or drug consumption in a smoker's materials fire incident. This indicates that smoking safety awareness promotion by Fire and Rescue Services should focus more on the elderly.

Overall, impairment due to suspected alcohol or drugs consumption which occurred in 9.0% of the accidental dwelling fire incidents appeared to increase the probability of fire injury across the different types of fire. In terms of validation or testing for predictive reliability, since the probability of fire injury across the different types of fires was increased when alcohol was a factor, this would appear to indicate that alcohol is a reliable predictor for increased likelihood of accidental fire injury. Similarly, the fact that accidental dwelling fire incidences, injuries, and fatalities all occur more frequently in areas with higher

TABLE 4 | Example Bayesian analysis of fire injury for cooking fires.

Fire type	Occupancy	Suspected impairment due to alcohol/drugs	IMD decile	Injury probability %
Cooking	Lone person ≥ 65	Y	1	43.82
Cooking	Lone person < 65	Y	1	32.35
Cooking	Couple with children	Y	1	39.13
Cooking	Lone parent	Y	1	26.09
Cooking	Couple < 65 no children	Y	1	43.4
Cooking	3+ adults no children	Y	1	48
Cooking	Couple 1+ 65+ no children	Y	1	50
Cooking	3+ adults with children	Y	1	33.33
Cooking	Lone person ≥ 65	N	1	23.03
Cooking	Lone person < 65	N	1	18.17
Cooking	Couple with children	N	1	15.36
Cooking	Lone parent	N	1	18
Cooking	Couple < 65 no children	N	1	18.37
Cooking	3+ adults no children	N	1	12.5
Cooking	Couple 1+ 65+ no children	N	1	23.14
Cooking	3+ adults with children	N	1	20.54

TABLE 5 | Example Bayesian analysis of fire injury for smokers' materials fires.

Fire type	Occupancy	Suspected impairment due to alcohol/drugs	IMD decile	Injury probability %
Smoking	Lone person ≥ 65	Y	1	52.38
Smoking	Lone person < 65	Y	1	47.5
Smoking	Couple with children	Y	1	0
Smoking	Lone parent	Y	1	60
Smoking	Couple < 65 no children	Y	1	12.5
Smoking	3+ adults no children	Y	1	36.36
Smoking	Couple 1+ 65+ no children	Y	1	80
Smoking	3+ adults with children	Y	1	0
Smoking	Lone person ≥ 65	N	1	22.12
Smoking	Lone person < 65	N	1	11.11
Smoking	Couple with children	N	1	28.85
Smoking	Lone parent	N	1	19.44
Smoking	Couple < 65 no children	N	1	10
Smoking	3+ adults no children	N	1	13.04
Smoking	Couple 1+ 65+ no children	N	1	52.94
Smoking	3+ adults with children	N	1	23.53

levels of deprivation and in similar distributions across the IMD deciles as shown in Figures 7–9 would appear to indicate that deprivation is a reliable predictor for increased likelihood of incidences, injuries, and fatalities. The majority of accidental dwelling fire incidents in which impairment due to alcohol or drugs was suspected were cooking fires (72.6% of impairment fire incidents) and smokers' materials (16.2% of impairment fire incidents).

A limitation of a Bayesian approach concerns only being able to take account of events that had actually occurred over the time period studied and were recorded in the fire incident recording system. In 2018 a UK government estimate of the proportion of domestic dwelling fires reported to a Fire and Rescue Service (and therefore recorded in the fire incident recording system) [35] was 25%, meaning that 75% of domestic dwelling fires were not reported (and therefore not recorded). This data limitation would affect the posterior probabilities in the Bayesian analysis, since the posterior probabilities concern the probability of a hypothesis or parameter after taking into account observed evidence, and only 25% of domestic dwelling fires could be observed, since only that percentage are reported and recorded. Fire injuries could have occurred following an accidental dwelling fire, however if the fire was not reported to the local Fire and Rescue Service, they would not be recorded in the fire incident recording system. UK Fire and Rescue Services would have a good understanding of all fire fatalities as they would be informed by the appropriate authorities, however, Fire and Rescue Services might not be aware of all fire injuries, in particular minor fire injuries that may have been as a result of a small fire or near miss not reported to the local Fire and Rescue Service. Another potential limitation of the Bayesian analysis was the classification of some of the variables, for example impairment due to suspected alcohol or drug consumption would be dependent on the assessment of the fire officers attending the fire. UK fire officers assess impairment due to alcohol or drugs at accidental dwelling fires using observational cues and lifestyle questions, but this can introduce misclassification bias due to subjective judgment and limited evidence. Mitigation of potential misclassification requires standardised protocols, cross-agency data sharing, and fire officer training. UK Fire and Rescue Services typically assess impairment due to alcohol or drugs at accidental dwelling fire incidents using a combination of scene observations (e.g., presence of alcohol containers, drug paraphernalia, signs of intoxication (e.g., slurred speech, confusion, drowsiness)); casualty behaviour (e.g., if the individual appeared disoriented, had impaired mobility, or was unresponsive in ways consistent with intoxication); lifestyle screening questions (e.g., "Have you consumed alcohol to the point of loss of consciousness or involuntary sleep?"). However, such assessments are not standardized across all UK Fire and Rescue Services, and impairment may be recorded as a suspected contributory factor rather than confirmed. Accidental dwelling fire types (based on the fire cause) might be categorised in different ways if they incorporated multiple aspects such as electrical appliances, which might possibly be categorised as an electrical fire or a domestic appliance fire. Bayesian statistical methods can allow for uncertainty rather than trying to eliminate it. Bayesian statistics can be used to generate probability distributions over parameters or outcomes, as demonstrated in the tables included in the paper. Sensitivity analysis in the Bayesian approach can be achieved through scenario analysis, for example, examining the risk of different types of fire under the influence of different variables such as impairment due to alcohol or drugs, and the occupancy level.

Previous research had indicated how impairment due to alcohol or drugs can increase the likelihood of accidental fire injury [25, 32]; however, this research has further analysed the probability of fire injury when impairment due to alcohol or drugs was a contributory factor across different combinations of fire circumstances. Similarly, although previous research highlighted accidental dwelling fire injury rates for different age groups [19, 21]. This research has further analysed the probability of fire injury for different age groups across different combinations of fire circumstances, and has also further examined the probability of fire injury across different sets of fire circumstances relating to different types of accidental dwelling fires compared to previous research [12, 13]. The practical significance of the research is to further inform accidental dwelling fire injury prevention activities in terms of how combinations of circumstances can alter the probability of fire injury and thus support more targeted fire prevention activities.

5 | Conclusions

In terms of examining how accidental dwelling fire injuries and fatalities associated with different fire incidence circumstances be modelled, the Bayesian approach provided enhanced knowledge of more specific combinations of circumstances, for example lone parent, living in a higher level of deprivation, and impaired by alcohol or drug consumption in a smoker's materials fire incident. Bayesian analysis of how the circumstances of accidental dwelling fires relate to the likelihood of fire injury and fatality can provide deeper insights into the situations in which an accidental dwelling fire incident can result in a fire injury or fatality. This can be beneficial to fire prevention strategies adopted by Fire and Rescue Services in terms of understanding how combinations of individual fire risk factors such as age, living alone, and impairment due to alcohol or drugs consumption can alter the likelihood of accidental fire injury or fatality.

In terms of examining what accidental dwelling fire circumstances affect the likelihood of fire injury and fire fatality, overall, impairment due to suspected alcohol or drugs consumption appeared to increase the probability of fire injury across the different types of fire (based on the cause of fire). This was a similar finding to previous research; however, the Bayesian approach provided further analysis of more specific combinations of fire circumstances. The probability of accidental dwelling fire injury and fatality was highest for candle and smoking-related fires compared to the other types of accidental dwelling fire. Previous research had identified the higher risk of accidental dwelling injury from smoking-related fires, but not candle fires. However, candle fires were much less common than smoking-related fires. The probability of accidental dwelling fire injury and fatality was highest for the elderly and those living alone. The probability of accidental dwelling fire injury was higher in higher levels of deprivation (IMD deciles 1, 2, and 3); however that there was less of a relationship between level of deprivation and fire fatality. There were, however, very few numbers of fire fatalities (127) over the period studied, making statistical analysis more difficult.

Use of a Bayesian analysis approach by a Fire and Rescue Service can enhance knowledge in terms of the specific combinations of circumstances that lead to a higher risk of accidental fire injury, which can inform more targeted fire prevention to vulnerable groups. For example, UK Fire and Rescue Services may target home fire safety checks towards the elderly and people with physical or mental health conditions that may impair mobility or awareness. Further targeting towards those also living in higher levels of deprivation and with alcohol management issues could be beneficial based on the findings of this research.

Disclosure

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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