

# Evaluation of firework-related harm in Scotland

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## Authors

Mrs Eleanor R Robertson MB ChB BMSc (hons) MRCS MD

- Plastic Surgery Registrar, Canniesburn Department of Plastic Surgery, Glasgow

Mrs Janet Bouttell BA, MA, MSc

- Research Associate Health Economics & Health Technology Assessment (HEHTA), University of Glasgow

Mr Stephen Leonard BEng (Hons), PgD, MPhil

- Data analyst, NHS Greater Glasgow and Clyde

Miss Kerry Davies BSc MSc MBBC MRCS

- Plastic Surgery Registrar, Canniesburn Department of Plastic Surgery, Glasgow

Professor Andrew M Hart MBChB BSc(Hons) MRCS AFRCS MD(Hons) PhD FRCS(Plast),

- Consultant Plastic Surgeon, Canniesburn Department of Plastic Surgery, Glasgow
- Chair of Plastic Surgery Research, University of Glasgow
- Editor-in-Chief of Europe's leading peer reviewed Journal for Plastic Surgery (JPRAS)

Mr Stuart Watson FRCS(Plast)

- Consultant Plastic Surgeon, Canniesburn Department of Plastic Surgery, Glasgow
- Clinical Lead for Care of Burns in Scotland (COBIS) Managed Clinical Network, NHS National Services Scotland

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# Table of Contents

Authors.....	2
Executive summary .....	6
Introduction .....	7
Objectives .....	9
Study 1: A firework injury survey of all Scottish Emergency Department and Minor Injury Units during bonfire night 2019 .....	10
Study 1: Methods.....	10
Study 1: Results.....	10
Study 1: Discussion .....	14
Study 2: Health economic and epidemiological review of firework-related presentations and admissions to NHS Greater Glasgow and Clyde 2008 – 2019.....	16
Study 2: Methods.....	16
Study 2: Results.....	17
Patient demographics .....	17
Clinical management.....	18
Firework injury rate.....	20
Health economic evaluation .....	21
Study 2: Discussion .....	23
Study 3: Health economic evaluation of a paediatric firework injury .....	26
Summary .....	26
Outcome and discussion .....	26
Study 4: Review of literature relating to firework particulates and their health impact .....	28
Study 4: introduction .....	28
Study 4: Firework-specific products of combustion .....	29
Study 4: Particulate concentration over bonfire night in the UK .....	31
Study 4: Firework-specific products of combustion and health .....	33
Study 4: Discussion .....	35
Report Discussion.....	36
Report Conclusion.....	37
Abbreviations.....	38
References .....	39

# Table of Figures

Figure 1 Frequency of firework-related injury, by month of admission[12] .....	7
Figure 2 Study 1: map demonstrating location of patient with firework-related injury .....	9
Figure 3 Study 1: firework injuries presenting to ED/MIU 2019 categorised by age and sex .....	10
Figure 4 Study 1: type of firework and event where firework-related injury occurred .....	11
Figure 5 Study 1: date of presentation to ED/MIU 2019 categorised by date presenting .....	11
Figure 6 Study 1: firework injuries presenting to ED/MIU 2019 categorised by SIMD decile .....	12
Figure 7 Total number of patients presenting with firework-related injuries to Scottish ED/MIU & Plastic Surgery from 1976 - 2000[20] .....	13
Figure 8 Study 2: % Patients in each SIMD decile; attending ED and admitted for firework-related injuries in NHS GGC 2008 - 2019.....	17
Figure 9 Study 2: date of first admission to NHS GGC with a firework-related injury.....	18
Figure 10 Emergency hospital admissions result of unintentional injury year ending 31 March 2017 by deprivation [32].....	22
Figure 11 Maps of the risk of PM10 on respiratory hospital admissions; left: whole Scotland; right: central belt[59] .....	27
Figure 12 Hourly trends PM2.5-elements Guy Fawkes Night Central London (Barium, Ba; Copper, Cu; Strontium, Sr; Antimony, Sb) [66].....	29
Figure 13 5th November 2018 Very High pollution levels: North East, Yorkshire & Humberside; High levels: North West & Merseyside, East Midlands [71] .....	30
Figure 14 Particulate matter concentrations measured in York City Centre between November 2018 and March 2019[17]. .....	30
Figure 15 Median hourly PM2.5 and PM10 concentrations (µg/m3), 2017-19[72] .....	31
Figure 16 PM2.5 concentration µg/m3 Newcastle Urban Observatory Network 5th Nov 2018[72] ...	31

Figure 17 Screenshot of <a href="http://www.scottishairquality.scot/">http://www.scottishairquality.scot/</a> , 6th November 2019 [74] .....	32
Figure 18 Summary of findings: PM2.5 concentration and health outcomes [77].....	33
Figure 19 Firework-related morbidity and mortality .....	35

## Table of tables

Table 1 Sale of fireworks[13] .....	8
Table 2 Study 1: anatomical injury, child and adult.....	11
Table 3 Anatomical region of injury, 1999/2000; 2005 and 2019 in Scotland [6, 20] .....	15
Table 4 Study 2: age and bodily location of injury for patients attending A&E and admitted to hospital (injuries exceeds number of patients, n=198, as some patients have more than one injury)17	
Table 5 Study 2: Age and bodily location of injury for female patients attending A&E and admitted to hospital (injuries exceeds number of patients, n=45, as some patients have more than one injury) . 17	
Table 6 Study 2: Age and bodily location of injury for male patients attending A&E and admitted to hospital (injuries exceeds number of patients, n=153, as some patients have more than one injury)17	
Table 7 Study 2: age categories and length of stay for initial attendance (all injuries, n=195).....	18
Table 8 Study 2: Injuries trend for original injuries for NHS GGC (A&E and admissions) .....	20
Table 9 Patients attending Northern Ireland ED/MIU with firework injury[7].....	20
Table 10 Study 2: resident health board of patients requiring admission for firework-related injury	21
Table 11 Total costs of firework injuries by year .....	21
Table 12 Study 2: QALY cost of firework injuries .....	22
Table 13 NHS GGC admissions, comparing NHS GGC coded data with NHS National Services Scotland, Information Services Division[33] .....	24
Table 14 Healthcare resource use as a result of firework injury .....	27
Table 15 health survey reported symptoms following Diwali in Chennai[83].....	34

## Executive summary

During my working lifetime of more than 30 years in Burns and Reconstructive Surgery work, I have seen many devastating injuries from fireworks. The great majority of these have occurred in children and young adults and injuries include: life-threatening major burns; severe facial burns with loss of vision; injuries which maim the hand.

Despite many public information and injury prevention campaigns, these injuries caused by fireworks continue to occur at a fairly steady rate. The more minor injuries cause suffering and have a financial cost to the community. The major injuries devastate families' lives.

The following report explains the current level of harm and compares it to previous years. This important work helps us to determine how much we are prepared to accept as a society before deciding if further action is required to reduce firework-related harm.

Stuart Watson

October 2020

# Introduction

In 2019 the Scottish Government launched a public consultation on the use and sale of fireworks ‘A consultation on fireworks in Scotland: Your experiences, your ideas, your views’. This was undertaken in response to fireworks being used as weapons against emergency service workers. The 14 week consultation closed on 14<sup>th</sup> May 2019 and received over 16,000 responses[1]. 87% of respondents supported a ban on the public sale of fireworks or an increase on regulation of fireworks (94%)[2]. In addition to this open-access survey, a ‘Progressive’s Scottish Opinion’ online omnibus survey of a representative sample of the Scottish population achieved 1,002 responses. 58% supported a ban of public sale of fireworks and 71% welcomed an increase in control of fireworks in Scotland [3].

In parallel, the UK Government’s Petition Committee responded to multiple e-petitions calling for increased restrictions on the use of fireworks which accumulated a total of 750,000 signatures in 3 years[4]. The committee launched an inquiry into Government’s stance on firework legislation and received over 42,000 responses to an online survey[4]. Government responded to the e-petition committee and confirmed that the Office for Product Safety and Standards has been tasked with: firework testing for noise levels; review of data relating to firework noise, health and environmental impacts and population ethnographic work on firework attitudes[5].

The epidemiology and aetiology of firework-related injuries were routinely collected in the United Kingdom from 1997-2005[6], and Northern Ireland until 2015[7]. There has been no routine collection of firework-related injuries in the UK and NI since. In Scotland the Care of Burns in Scotland Managed Clinical Network (COBIS) manages a clinician-entered database of patients admitted for burn care; however it is known that the majority of firework injuries do not require hospital admission. NHS Digital reported that almost 2,000 people attended the Emergency Department in England and Wales for firework-related injury in 2018/19[8]. Firework-related injuries are thought to conform to the injury pyramid where the injury severity is inversely related to frequency[9]. In more populous nations, firework-related fatalities and life-altering injuries are still regularly reported, with 5 deaths reported in the USA and 2 in the Netherlands in 2019[10, 11].

Fireworks are used to mark culturally significant events such as: July 4<sup>th</sup> (Independence Day, USA); New Year's Eve (December 31<sup>st</sup>, International); Chinese New Year; Diwali and Guy Fawkes Night (November 5<sup>th</sup>, UK). It is noted that the majority of firework-related injuries in the UK present for treatment during bonfire night[12](Figure 1). This coincides with the sale of fireworks by unlicensed traders as well as national practice of holding non-professional firework displays.

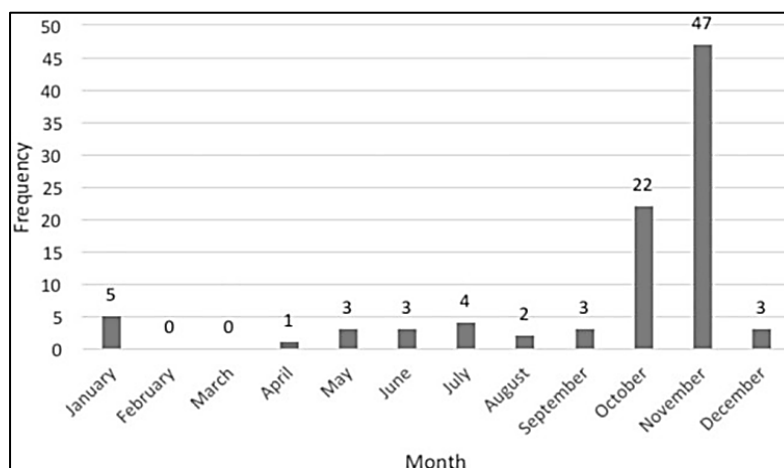


Figure 1 Frequency of firework-related injury by month of admission[12]

UK legislation covers the sale, storage and use of fireworks[13]. Unlicensed vendors are permitted to sell fireworks within pre-defined periods, with the longest over the 5<sup>th</sup> November(Table 1).

Table 1 Sale of fireworks[13]

Day where fireworks are allowed	Period you can sell fireworks
5 November	From 15 October to 10 November
New Years	From 26 December to 31 December
Chinese New Year	The first day of Chinese New Year and the 3 days before it
Diwali	The first day of Diwali and the 3 days before it

In addition to the potential for physical injury, fireworks can cause harm which is challenging to quantify. The noise from fireworks causes upset to those with life-long hypersensitivity conditions such as autism[14], or acquired such as post-traumatic stress disorder (PTSD)[4, 15, 16]. A public engagement event in 2019 with military veterans found ‘problems associated with the “randomness” of fireworks; it was impossible to use the usual “avoiding behaviours” [...] you didn’t know when a firework might be set off.’[4]

There is increasing concern about the acute and long term effect of particulate matter (PM) and heavy metal pollution from firework displays[17, 18]. Exposure to PM is correlated with conditions including: cardiovascular; respiratory (asthma, bronchitis, lung cancer); developmental (pulmonary and intelligence) and obstetric (pre-term births and low birth weight)[19].



## Objectives

This report seeks to encompass the incidence and consequence of firework-related injury in Scotland:

- Study 1: A firework injury survey of all Scottish Emergency Department and Minor Injury Units during bonfire night 2019
- Study 2: Health economic and epidemiological review of firework-related presentations and admissions to NHS Greater Glasgow and Clyde 2008 – 2019
- Study 3: Health economic evaluation of a paediatric firework injury
- Study 4: Review of literature relating to firework particulates and their health impact

## Study 1: A firework injury survey of all Scottish Emergency Department and Minor Injury Units during bonfire night 2019

The incidence and aetiology of firework injuries were collected in Great Britain from 1997-2005. A database of burn patients requiring admission is managed by COBIS (Care of Burns in Scotland Managed Clinical Network). However, it has been demonstrated that the majority of firework injuries do not require hospital admission and will therefore be omitted by this database. A prospective data collection exercise was undertaken to coincide with the sale of fireworks by unlicensed vendors over bonfire night from 15.10 – 12.11.2019.

### STUDY 1: METHODS

This firework injury survey was based on 'Firework Injuries in Great Britain' and Northern Ireland 'FWK1'[7]. All attendances from 15.10 - 12.11.19 to Scottish minor injury units (MIU) and emergency departments (ED) from firework injuries were included. The 9 questions covered: patient demographics; firework-related history and injury details. All ED and MIU units were contacted directly (email and phone call) and asked to record attendance and send to COBIS for processing.

### STUDY 1: RESULTS

84 Scottish ED and MIU units from 15 NHS Health Boards were invited to submit firework injury attendance data from 15.10.19 – 12.11.19 (Figure 2). There were no attendances in 59 ED and MIU. A total of 41 forms were returned from 23 ED and MIU (mean: 1.8, range 1 – 5).

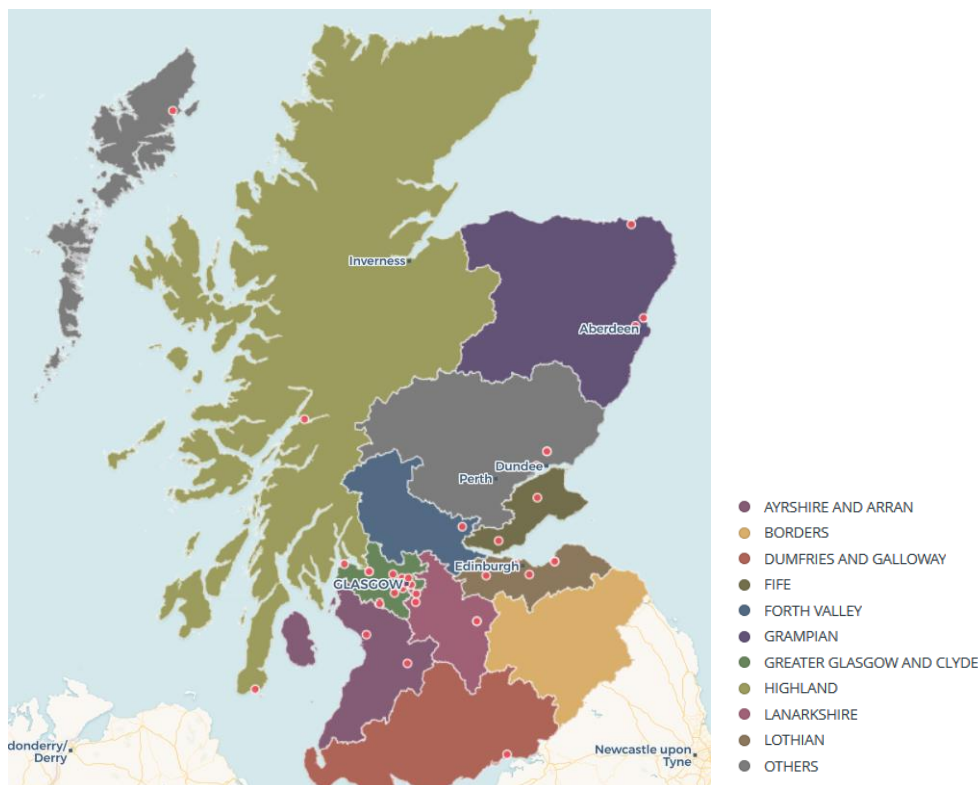


Figure 2 Study 1: map demonstrating location of patient with firework-related injury

Of those attending, 26 (63%) were male and 23 (56%) were ≤16 years old (Figure 3).

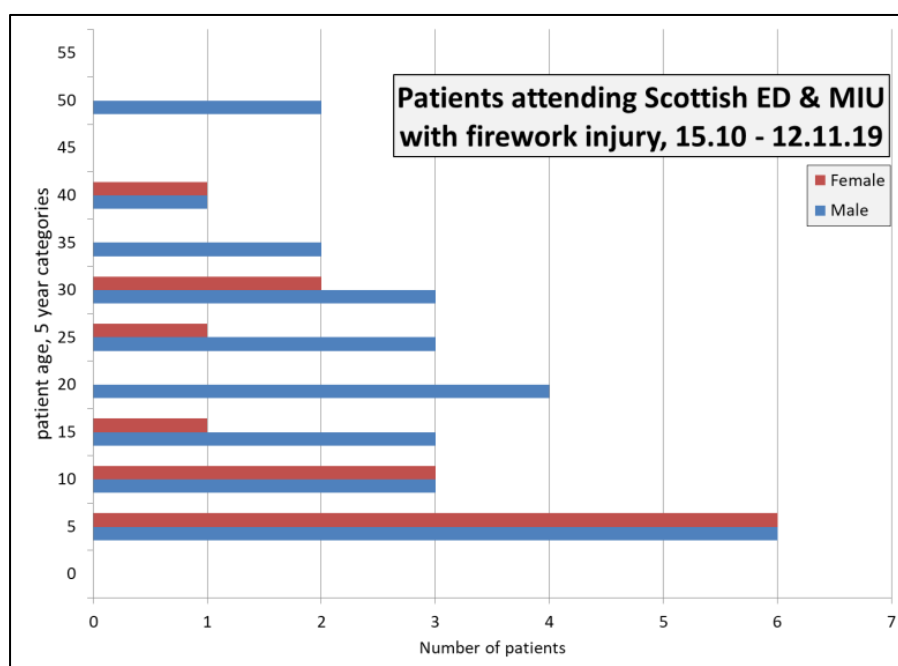


Figure 3 Study 1: firework injuries presenting to ED/MIU 2019 categorised by age and sex

Injuries were to: hand and wrist (n=20); face, head, neck (n=8); lower limb (n=6); eye (n=4); trunk (n=2) and arm (n=1)(Table 2). The majority of patients were discharged following assessment and treatment. 15 (37%) required follow-up in hospital outpatients and 3 patients required admission by plastic surgery.

Table 2 Study 1: anatomical injury, child and adult

	Child (16 years and under )	Adult (17 years and over)
Face/ Neck	22% (n=4)	35% (n=8)
Chest/ Back	-	9% (n=2)
Arms	-	5% (n=1)
Hand/ Wrist	52% (n=12)	44% (n=8)
Lower limb	13% (n=3)	17% (n=3)

2 injuries were sustained at organised public displays and 13 injuries were due to sparklers(Figure 4).

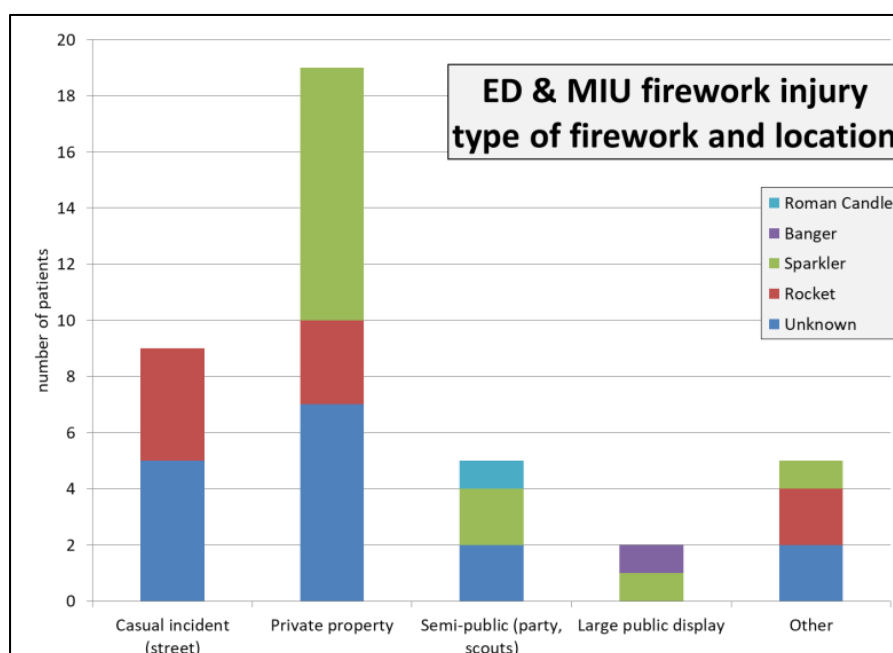


Figure 4 Study 1: type of firework and event where firework-related injury occurred

Most patients presented in November, with 18 patients (44%) attending on the 5<sup>th</sup> November 2019 (Figure 5).

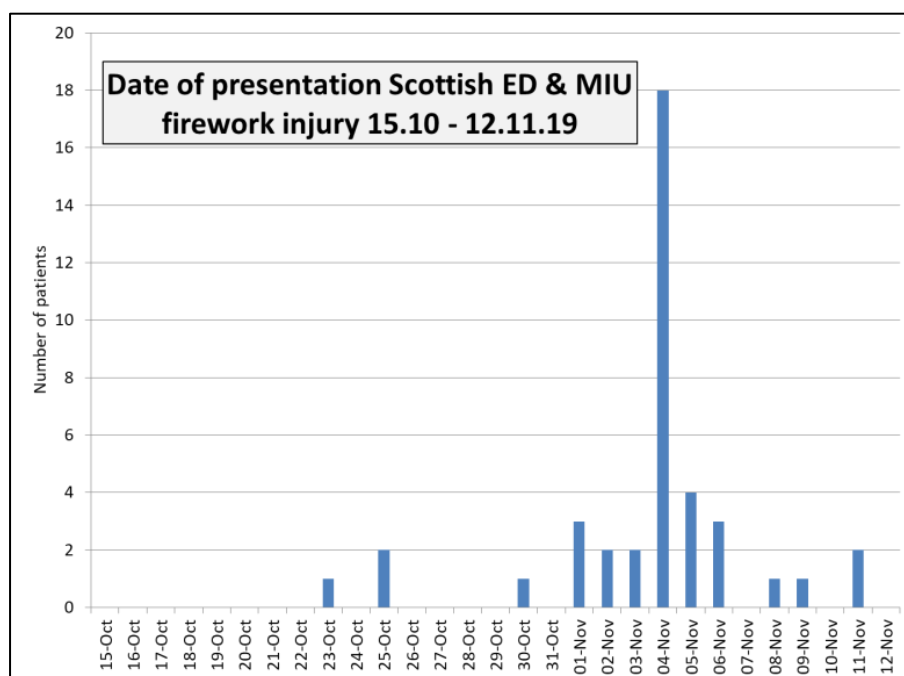


Figure 5 Study 1: date of presentation to ED/MIU 2019 categorised by date presenting

Analysis of SIMD (Scottish Index of Multiple Deprivation) was undertaken on available postcodes (n=38) and a significant correlation was demonstrated between lower SIMD and firework injury (p=0.01)(Figure 6).

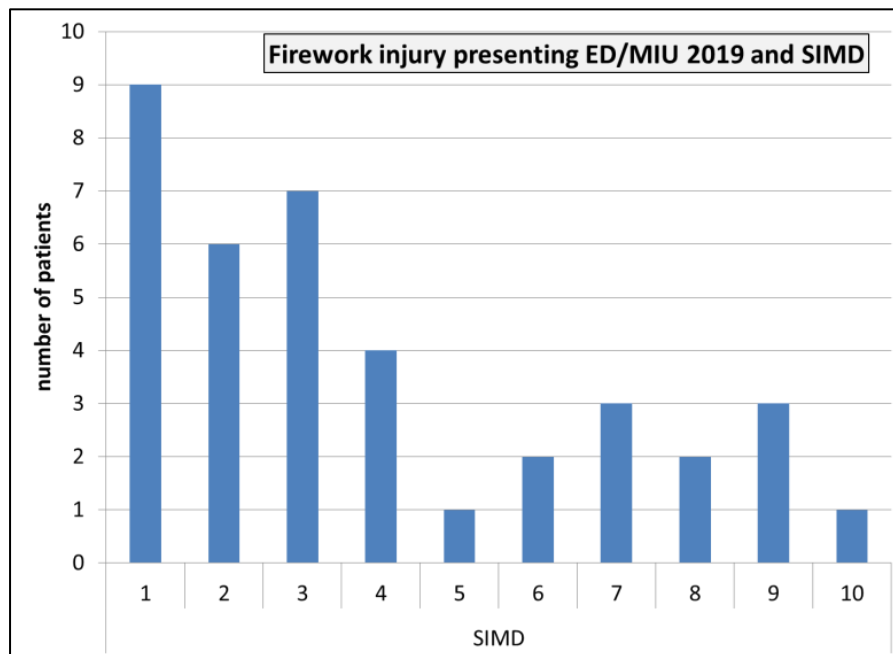


Figure 6 Study 1: firework injuries presenting to ED/MIU 2019 categorised by SIMD decile

## STUDY 1: DISCUSSION

Recording of firework-related injuries in Scotland ceased 2005[6]. During the 2005 bonfire season, 93 patients attended ED or MIU for treatment of firework-related injuries. In this dataset, 14 years later, there has been a >50% reduction in attendance, with 41 patients attending for treatment.

It should be noted that firework presentations are sporadic, with some years demonstrating greater number of presentations than others. Data from the NHS Information and Statistical Division in Scotland from 1976 demonstrates the non-linear nature of injury presentations[20].

There continues to be a correlation between firework injuries and age. In 2000, 66% of all presentations were children (<16 years old) compared with 54% in 1919[20](Figure 7).

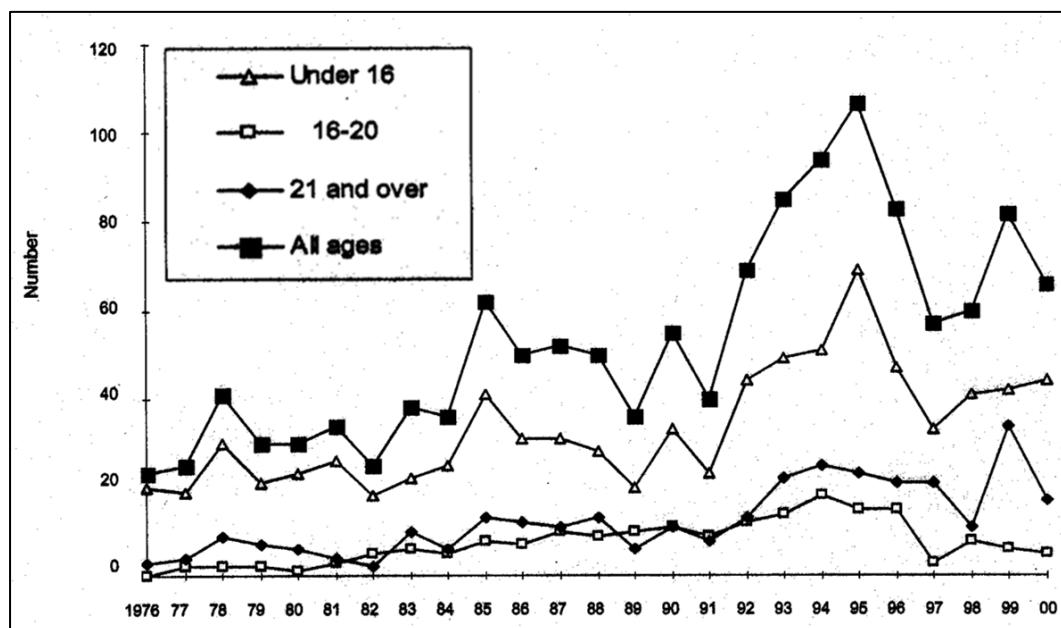


Figure 7 Total number of patients presenting with firework-related injuries to Scottish ED/MIU & Plastic Surgery from 1976 - 2000[20]

As in the year 2000, the vast majority of patients in 1919 presented for treatment of firework-related injuries between 4<sup>th</sup> and 6<sup>th</sup> November, indicating a continuing correlation with bonfire-night related injuries. Injuries also primarily occur at family or informal events, this is also consistent with historical data from the 1970s – 2005, indicating greater likelihood of physical injury from fireworks when they are handled or operated by untrained individuals in informal settings[6, 20].

The anatomical location of injuries the hands, head and eyes still predominate (Table 3).

Table 3 Anatomical region of injury, 1999/2000; 2005 and 2019 in Scotland [6, 20]

	1999		2000			2005			2019	
	n	%	n	%		n	%		n	%
eye	17	21	14	21		20	20		4	10
head	21	26	8	12		23	23		8	20
hand	29	35	26	39		37	36		20	49
arm	5	6	7	11		4	4		1	2
leg/foot	8	10	12	18		10	10		6	15
torso	7	9	8	12		8	8		2	5

## Study 2: Health economic and epidemiological review of firework-related presentations and admissions to NHS Greater Glasgow and Clyde 2008 – 2019

NHS Greater Glasgow and Clyde (NHS GGC) Health Board provide medical care for the population of 1.2 million people. The Canniesburn department of plastic surgery serves 3 million patients in the west of Scotland, over half of the estimated 5.4 million Scottish population.

### STUDY 2: METHODS

A request was made to NHS GGC for coded admission and procedure data from 2008 – 2019. Permissions were granted and a query was developed using: WHO ICD-10 diagnosis code W39: 'discharge of fireworks'[21]. Patient care episodes were exported from Trak (ICD-10 diagnosis codes) and OPERA (OPCS-4 procedure codes)[22].

Episodes of care were extracted from Scottish Morbidity Records where fireworks were mentioned as a cause of injury or firework injury included as a diagnostic code (ED/MIU attendance:AE2 Admission: SMR01 - General / Acute Inpatient and Day Case). Case notes were reviewed by an experienced data analyst (SL) and plastic surgical registrar (ER) to ensure compliance with inclusion criteria. Cases were included if a patient of any age attended ED/MIU and/or admitted for care of a firework-related injury. Analysis was undertaken to investigate: patient demographic information; injury pattern, treatment modalities and health economic evaluation. Costs per episode of care were applied using hospital level specialty costs for the year 2018-19 (the latest data available).



## STUDY 2: RESULTS

### PATIENT DEMOGRAPHICS

Between 2008 – 2019, 198 patients attended an ED or MIU in NHS GGC for management of 251 injuries (Table 4). The majority of those attending were young men (Table 5, Table 6).

Table 4 Study 2: age and bodily location of injury for patients attending A&E and admitted to hospital (injuries exceeds number of patients, n=198, as some patients have more than one injury)

Age (years)	Hand and wrist	Head, neck and face	Eye	Foot	Trunk	Arm	Other	Total
0 - 5	10	9	0	1	1	1	1	23
6 - 10	6	9	7	0	3	1	3	29
11 - 15	20	14	7	1	2	3	0	47
16 - 17	12	7	6	0	2	2	2	31
18 >	55	25	15	0	5	8	13	121
Total	103	64	35	2	13	15	19	251

Table 5 Study 2: Age and bodily location of injury for female patients attending A&E and admitted to hospital (injuries exceeds number of patients, n=45, as some patients have more than one injury)

Age (years)	Hand and wrist	Head, neck and face	Eye	Foot	Trunk	Arm	Other	Total
0 - 5	4	3	0	0	0	1	1	9
6 - 10	1	3	2	0	1	1	2	10
11 - 15	2	0	2	0	1	1	0	6
16 - 17	0	0	2	0	1	0	1	4
18 >	6	4	3	0	2	3	4	22
Total	13	10	9	0	5	6	8	51

Table 6 Study 2: Age and bodily location of injury for male patients attending A&E and admitted to hospital (injuries exceeds number of patients, n=153, as some patients have more than one injury)

Age (years)	Hand and wrist	Head, neck and face	Eye	Foot	Trunk	Arm	Other	Total
0 - 5	6	6	0	1	1	0	0	14
6 - 10	5	6	5	0	2	0	1	19
11 - 15	18	14	5	1	1	2	0	41
16 - 17	12	7	4	0	1	2	1	27
18 >	49	21	12	0	3	5	9	99
Total	90	54	26	2	8	9	11	200

There is an over-representation of patients from areas of greater deprivation. People residing in decile SIMD1 are twice as likely to require treatment for a firework-related injury than those residing in decile SIMD2 (Figure 8).

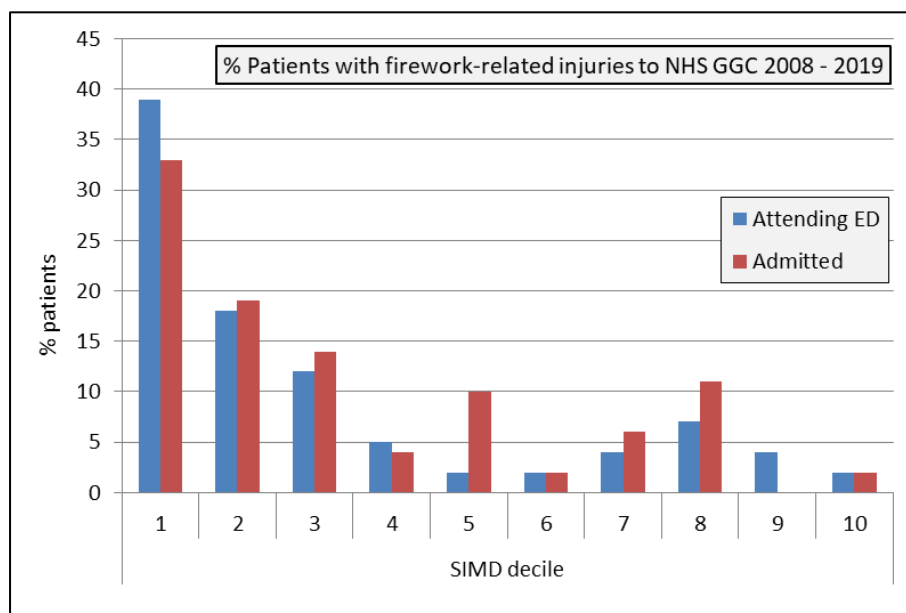


Figure 8 Study 2: % Patients in each SIMD decile; attending ED and admitted for firework-related injuries in NHS GGC 2008 - 2019

## CLINICAL MANAGEMENT

Mean length of stay for index admission was 3 days (SD 4.8), median 1 day (IQR 1-4, full range 0-34 days). Mean total length of stay per patient for all their admissions was 3.4 days (SD 5), median is 1.5 days (IQR 1-4, total range 0-34 days).

Table 7 Study 2: age categories and length of stay for initial attendance (all injuries, n=195)

	Age (years)				Child total	Adult total	Total
	0-5	6-10	11-15	16-17			
No overnight stay	19	13	25	15	72	59	131
1-3 days	1	5	10	4	20	24	44
4-7 days	0	3	3	1	7	6	13
8 or more	1	1	0	1	3	4	7
Total	21	22	38	21	102	93	195

The majority of the patients were admitted in November(Figure 9).

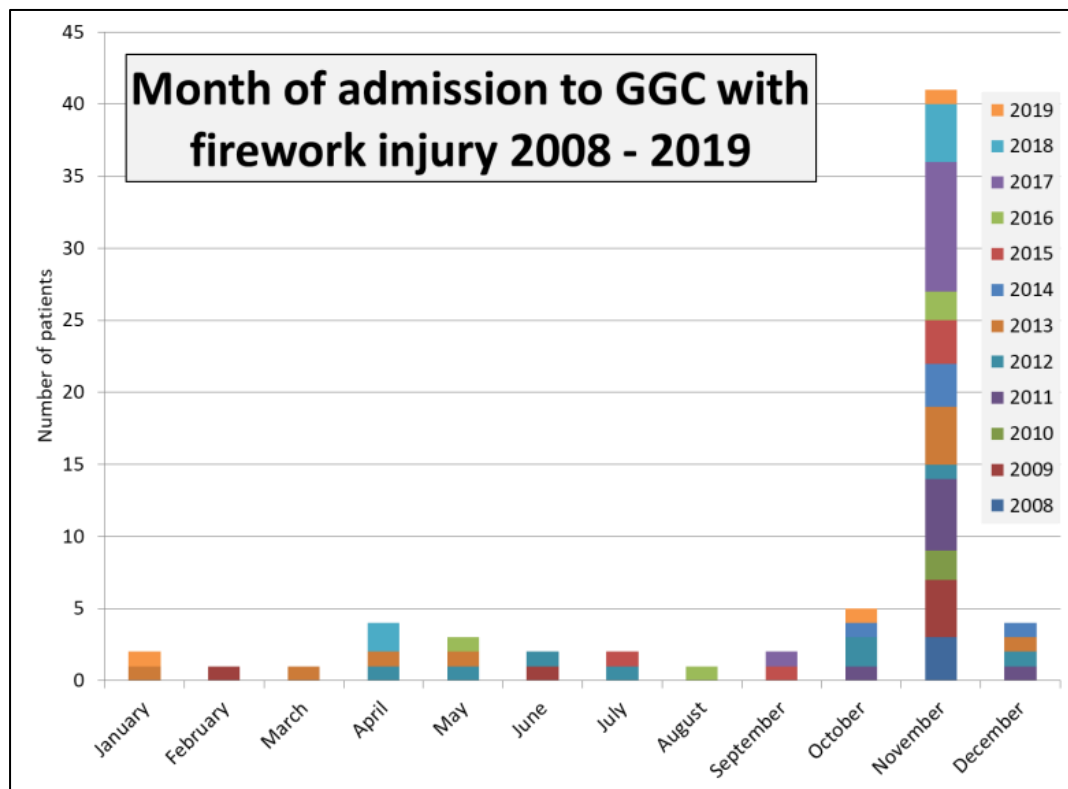


Figure 9 Study 2: date of first admission to NHS GGC with a firework-related injury

On first admission the mean number of operative procedures performed were 2.5 (SD 2.1), median 2 procedures (IQR 0-4, total range 0-6). When all admissions are taken in to consideration, the mean number of operative procedures per admissions is 2.8 (SD 1.9), median 2 procedures (IQR 2-4, total range 0-6).

The type of surgical intervention required to address firework-related trauma ranged from wound cleansing to highly complex management of tissue loss requiring free tissue transfer (whereby a section of tissue is harvested from one bodily location and transplanted to the area with tissue deficit). In this 12 year study period, 2 patients required an enucleation (removal of eye) due to firework-related trauma. These patients subsequently required oculoplastic reconstruction.

## FIREWORK INJURY RATE

Over the 12-year study period, 165 NHS GGC resident patients attended an NHS GGC ED or MIU for management of a firework-related injury. The rate per 100,000 for this period is 1.2, which is in keeping with most recent data from Northern Ireland (Table 8, Table 9). The rate in the USA was recently reported as between 2.3 – 4 injuries per 100,000 [11].

Table 8 Study 2: Injuries trend for original injuries for NHS GGC (A&E and admissions)

Year	Female	Male	Total	Catchment (thousands)	Rate per 100,000
2008	5	11	16	1,117	1.4
2009	2	13	15	1,122	1.3
2010	3	7	10	1,128	0.8
2011	3	11	14	1,135	1.2
2012	4	8	12	1,137	1.1
2013	4	7	11	1,138	1.0
2014	3	13	16	1,143	1.4
2015	3	7	10	1,150	0.9
2016	5	8	13	1,161	1.1
2017	6	18	24	1,169	2.1
2018	2	13	15	1,175	1.3
2019	2	7	9	1,183	0.8
Total	42	123	165	13,758	1.2

Table 9 Patients attending Northern Ireland ED/MIU with firework injury [7]

Year	Total	Catchment (thousands)	Rate per 100,000
2008	32	1,779	1.8
2009	30	1,793	1.7
2010	47	1,805	2.6
2011	25	1,814	1.4
2012	14	1,824	0.8
2013	6	1,830	0.3
2014	18	1,840	1.0
2015	15	1,852	0.8
Total	187	14,537	1.3

During the 12 year period, 104 patients required admission for the management of the firework-related injury. 55 patients were resident within NHS GGC, translating to an admission rate per 100,000 of 0.4. This is approximately 10-time higher than the admission rate of 0.05 per 100,000 from a regional burn centre in England[12].

Table 10 Study 2: resident health board of patients requiring admission for firework-related injury

NHS Health Board of residence	Number of patients admitted to NHS GGC
Ayrshire and Arran	1
Dumfries and Galloway	5
Forth Valley	1
Grampian	1
Greater Glasgow and Clyde	55
Highland	7
Lanarkshire	33
Western Isles	1
Total	104

## HEALTH ECONOMIC EVALUATION

The estimated total expenditure on treating firework injuries over the period 2008 – 2019 in NHS GGC was £463,583, a mean cost of £38,632 per annum (Table 11). The majority of this cost (£438,775) was incurred in treating patients admitted to hospital. There is no evidence of either an upward or downward trend in the costs data.

Table 11 Total costs of firework injuries by year

Year	Admissions	Cost of admissions	ED attendances	Costs of ED attendance (£)*	Total costs (£)
2008	6	31,382	16	1,702	33,084
2009	7	28,392	13	1,408	29,800
2010	4	16,396	15	1,570	17,966
2011	8	49,777	16	2,075	51,852
2012	11	28,794	13	1,317	30,111
2013	17	35,111	16	1,666	36,777
2014	8	21,758	18	2,844	24,602
2015	6	8,874	10	1,033	9,907
2016	10	49,926	17	2,401	52,327
2017	12	60,393	26	4,756	65,149
2018	9	114,988	16	2,603	117,591
2019	7	17,435	10	1,435	18,870
Total	105	463,227	186	24,808	488,035
Mean	8.75	38,602	15.5	2,067	40,669

A&E – Accident and emergency, \*includes cost of ambulance where used

We found that the mean cost per admitted patient was £5,229 (standard deviation £10,450). The median cost per admitted patient was £1,804 (range £955 to £85,797). The difference between the mean and the median is due to a small number of extremely costly cases leading to a skew in the data. It is usual in health economics to quote the mean cost as, although it is not representative of a ‘typical’ case, the costs do have to be met by the healthcare provider (or other payer) so all costs should be included.

In addition to the direct costs of treating firework injuries there is also a loss of quality of life associated with the injuries. For the most part the loss of quality of life will be small and will not last. However, for a number of serious injuries the loss of quality of life will be more significant. Table 12 shows an estimate of the loss of quality of life due to the injuries identified in this study. The loss amounts to 5.9505 patient years of life which can be conservatively valued at £119,010 using the lower valuation threshold commonly applied in the UK [30].

Table 12 Study 2: QALY cost of firework injuries

Injury severity	Patient (n)	Disutility (annual)	Duration (months)	Disutility x duration	Source
ED only	Child (n=72)	0.07	1	0.00583	[23])
Admitted 1-3 days	Child (n=20)	0.18	1	0.015	[23]
Admitted 4-7 days	Child (n=7)	0.32	1	0.02667	[23]
Admitted 8-29 days	Child (n=2)	0.32 0.07	1 8	0.07333	[24]
Admitted 30+ days	Child (n=1)	0.2 0.13 0.027[2]	3 33 Lifetime (67.5 [3] - 11 years)	1.93333	[25-27]
ED only	Adult (n=59)	0.04	2.5	0.00833	[28]
Admitted 1-3 days	Adult (n=24)	0.27	2.5	0.05625	[28]
Admitted 4-7 days	Adult (n=6)	0.27	2.5	0.05625	[28]
Admitted over 7 days	Adult (n=4)	0.31 0.18	1.5 10.5	0.19625	[29]
<b>Total</b>	<b>195</b>			<b>5.9505</b>	<b>£119,010</b>

[1] Value at £20,000 lower threshold in the UK [30]

[2] Long term disability weights for less than 10% burns affecting head, neck or face or hands (0.016) and amputation of thumb (0.011)

[3] Life expectancy for male in Glasgow City most deprived areas for the period 2009-2013

## STUDY 2: DISCUSSION

The rate of ED/MIU attendance from firework related injuries in Scotland is 1.2/100,000. This is comparable to the rate in Northern Ireland, 1.3/100,000. A proportion of those attending for care at ED/MIU required admission. The NHS GGC admission rate is 0.4/100,000. This does not compare favourably with those seen in a regional burns centre in Chelmsford, where the firework-related admission rate is 0.05/100,000. This raises concerns as to the reason for this disparity.

It could be that the total number of patients presenting for treatment in ED/MIU are similar, however the injuries sustained in the west of Scotland are more severe, requiring inpatient care with operative intervention. However, as we do not have data relating to total ED/MIU presentations in Chelmsford, it may be that there are simply more firework-related injuries in general, with the ratio of those requiring admission similar to NHS GGC.

It is concerning that the rate of presentation for treatment of firework-related injuries has remained static. Also of concern is the overrepresentation of patients from areas of deprivation. The correlation between social deprivation and the risk of morbidity and mortality from unintentional injury is and these inequalities is not moderating over time[31](Figure 10). It does appear that the relationship between deprivation and firework-related injuries is even more acute than those with general trauma.

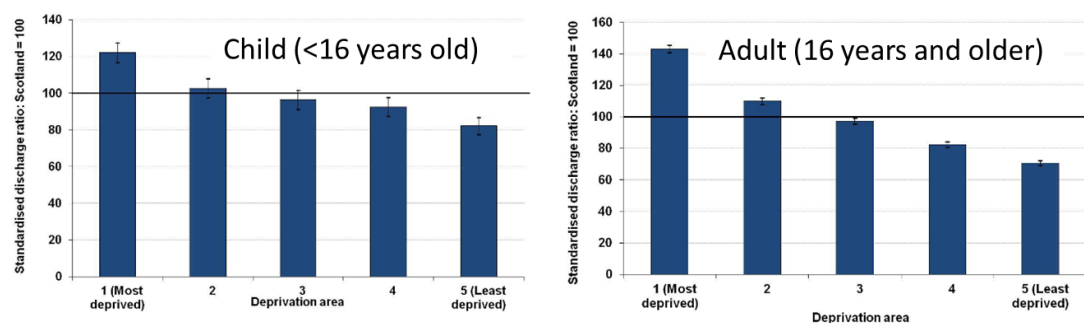


Figure 10 Emergency hospital admissions result of unintentional injury year ending 31 March 2017 by deprivation [32]

Due to methodological advances, our study demonstrated a higher level of firework-related admissions to NHS GGC than NHS NSS ISD (Table 13). Our multi-directional search technique (i.e. going from ED/MIU firework diagnosis code to admission and vice-versa) employed by the data analyst (SL) and surgical registrar (ER) ensured coding accuracy with case note review.

Table 13 NHS GGC admissions, comparing NHS GGC coded data with NHS National Services Scotland, Information Services Division[33]

Year	Nov 5th	NHS GGC cases	NHS ISD
2008/2009	Wed	5	-
2009/2010	Thu	5	-
2010/2011	Fri	2	-
2011/2012	Sat	7	6
2012/2013	Mon	11	11
2013/2014	Tue	7	6
2014/2015	Wed	5	5
2015/2016	Thu	5	5
2016/2017	Sat	7	-
2017/2018	Sun	10	-
2018/2019	Mon	8	-
2019/2020	Tue	3	-
2020/2021	Thu	2	-

Comparison with costs found in other studies is hampered by the heterogeneity of injuries and healthcare systems as well as the limited number of studies looking particularly at firework injuries. Studies of firework injuries have found the cost per patient to be US\$460 (£359) in a study of 97 injuries to children in the period 2012-2016 in Thailand and US\$11,582 (£9,048) in a study of 22 injuries from 1987-1997 in the United States[34, 35]. An Iranian study of injuries associated with a festival in 2009 found the average cost of treatment was US\$156 (£122) for burns, US\$3,471 (£2,712) lacerations and other types of injury and US\$48,597 (£37,966) for amputations[36]. A very recent study identified 63 firework injuries from the South West Netherlands between 1 Dec 2017 and 31 January 2018[37]. Mean costs per patient were €6,320 (£5,544) including €5,045 direct costs (mostly hospital admission costs) and €1,275 (£1,118) cost of work absence. These costs may be underestimated as evidence has shown that many medical services are involved in the care of patients with firework injuries such as occupational therapy, pain service, burn service, home care services, rehabilitation and reconstruction and these may not all be captured in the costing exercises[38].

Studies of injuries to the hand and wrist suggest that work absence may be as long as 1-3 months[39] and that opportunity for future earnings may also be lost as employment opportunities are reduced[40]. Estimates of the healthcare cost of treating hand and wrist trauma (not specific to firework injury) in Ontario, Canada, include burns at an average cost of CAN\$16,100 (£9,527) and amputations CAN\$12,825 (£7,589)[41]. A recent systematic review of hand and wrist trauma states a median cost per case of US\$8,207 (£6,415) (Inter quartile range \$3,858-\$33,939, (£3,014-£26,515) with wide variation dependent on country, healthcare system, pricing and reimbursement methods, types and quality of data[42].



We found that treatment of firework injuries in NHS Greater Glasgow and Clyde cost just under £500,000 over the 12 year period from 2008 to 2019 inclusive. This is likely to be an underestimate as the cause of injury is not always captured in the routine administrative records and certain resource use may not be captured. Other studies have extrapolated costs of firework injuries from their samples to country level estimates. Van Yperen estimated the annual cost of firework injuries to be €2.7 million (£2.4 million) for 17.1 million inhabitants of the Netherlands[37].

There is little specific in the literature about how quality of life is impacted by firework injuries. Robinson et al. note that hand injuries often incur intangible costs such as functional limitations, pain, psychological distress and decreased social interaction. For the majority of patients with firework injuries, the impact on quality of life will be short term. Van Yperen et al report only a few patients with any impact on quality of life or functioning after 12 months[37]. Quality of life data is available for trauma generally and it has been demonstrated 40% of patients suffered from depression after severe trauma and that this impacted upon their quality of life measured 24 months after the injury[25]. Black et al. found that quality of life was still negatively impacted at 36 months for patients suffering burns injuries[26].

## Study 3: Health economic evaluation of a paediatric firework injury

### SUMMARY

An 8-year old boy sustained a catastrophic hand injury from a firework. The child required immediate transfer to theatre for multidisciplinary examination by senior experienced hand surgeons. The patient was managed in a single-stage procedure with wound cleaning, assessment and then reconstruction. Due to substantial tissue loss a plastic surgical tissue transfer technique, a pedicled groin flap, was required. The patient required admission and care in paediatric intensive care. Following extensive involvement by psychological, occupational and physiotherapy, the patient began to incorporate the use of his hand. An assessment of healthcare utilisation estimates the immediate cost of care as £100,000 with a life-long disutility of 2.14

### OUTCOME AND DISCUSSION

The majority of firework-related injuries are sustained to the hands of young males[11, 35, 38, 43-46], and this case bears remarkable parallels with two firework-related injuries which presented to NHS GGC department of plastic surgery over 10 years previously[47]. Despite recent amendments to legislation, children continue to present with serious firework-related injuries, a recent retrospective review reporting that >50% of those requiring inpatient care were <18 years old[12, 48]. These severe, life-altering injuries should not be viewed in isolation, but rather as an apex of morbidity[9].

This hand-threatening injury resulted from a lit firework handed to him by another child which exploded in his hand. This mechanism of injury is common in blast-related hand injuries (n=37, 60%)[49], although this patient was younger than the previous published case series of firework injuries in children (8 vs mean of 9.3 years)[35]. The serious, multi-digital injury with permanent and considerable loss of hand function is in keeping with other series of firework-related hand injuries[50]. The firework blast resulted in a large zone of injury, making microvascular free-flap surgery impractical due to the precarious vascularity to the remaining hand[49].

The healthcare resources used, or to be used, as a result of this firework injury are estimated at around £100,000 (Table 14). This figure under-estimates resource utilisation, as costing of three separate procedures during the 34 day inpatient stay uses standardised cost estimates, not reflective of the additional care cost for the complexity of surgical and allied health care professional care in this case, even for intensive care patients. In addition, the lifelong quality of life impact is estimated as 2.14 quality adjusted life years (QALYs) loss (one QALY equates to a year of life lived in full health). Applying the standard UK threshold QALY value of £20,000 this equates to £42,800. Many predictable costs incurred in caring for, or by, the patient and his family have not been estimated, nor has any family members' QALY loss. For example, costing additional social work and psychological support provision at school or any lost earnings / out of pocket expenses incurred by the family were not possible. Nor were long-term loss of earnings from restricted employment options due to his permanent disability objectively quantifiable.

Table 14 Healthcare resource use as a result of firework injury

	Resource use	Unit cost (£)	Cost (£)	Source
Initial hospital stay	34 days	2,523	85,782	RO40 Specialty Group Costs – NHS Scotland – intensive care
Outpatients follow-up	2 psychologist	100	200	[51]
	17 plastic surgery	150	2,550	RO40 Specialty Group Costs – NHS Scotland – plastic surgery outpatients
	18 physiotherapy	81	1,458	[51]
Future hand surgery	2 days stay, 2 occasions	1,804	7,216	RO40 Specialty Group Costs – NHS Scotland – plastic surgery and burns
Future dental reconstruction	2 intermediate elective dental procedures	721	1,442	National Tariff Workbook, Annex A, NHS Improvement
Total			98,648	

There is a lack of sources of quality of life data specific to firework injuries and so short term estimates were taken from sources examining trauma injuries generally[25, 26]. The long term impact was taken from the disability weights used in global burden of disease studies and is the estimate of disability due to the amputation of a thumb[27]

We have not identified any other study that quantifies the loss of quality of life due to firework injuries. One study estimated the cost of the initial care of paediatric hand injuries due to fireworks to be US\$11,582[35]. A systematic review of direct, indirect and intangible costs of hand and wrist injuries found they resulted in substantial burden to the patient and wider society[42]. When severe injury occurs in childhood, the health economic impact is profound due to the loss of healthy years and the likelihood that those with serious injuries are limited in their occupational choice[52].

## Study 4: Review of literature relating to firework particulates and their health impact

### STUDY 4: INTRODUCTION

Poor air quality is classified as the greatest environmental risk to public health in the UK[53]. Air pollution has been implicated in: increased mortality; morbidity to those with pre-existing cardio-respiratory disease; mortality following short-term exposure (e.g. ozone) and infant mortality[54].

Particulate Matter (PM) is commonly composed of mineral dust, water and compounds (sulphate, nitrates, ammonia, sodium chloride, black carbon). PM<sub>10</sub> (<10micron) is able to travel to the lung, causing local inflammation and oxidation. Smaller particles, PM<sub>2.5</sub> (<2.5micron) can cross the alveolar barrier and enter the blood stream, causing circulatory stress[55]. It is thought that even low levels of particulate exposure can cause clinically significant events in vulnerable individuals (such as exacerbation of chronic conditions)[56, 57].

An association has been demonstrated between long-term exposure to PM<sub>10</sub> and NO<sub>2</sub> and respiratory-related hospital admissions in NHS Lothian and NHS Greater Glasgow and Clyde; with a relative risks of 1.06–1.10 for a 1.7  $\mu\text{g m}^{-3}$  increase in PM<sub>10</sub> concentrations and 1.04–1.12 for an 8  $\mu\text{g m}^{-3}$  increase in NO<sub>2</sub>[58]. A study sought to quantify risk of respiratory-related hospital admissions with PM<sub>10</sub> exposure in Scotland with likely confounding variables (e.g. smoking status, cardiovascular health) controlled for[59]. The mean risk across Scotland is 1.065, with 95% of the risks lying between 0.982 and 1.14. The majority of the largest relative risk was noted in the east of Glasgow, which is also one of the most heavily deprived part of Scotland[59](Figure 11). Historically, the east end of cities have been associated with increased levels of deprivation, however this was not seen prior to industrialisation[60]. No UK cities experience prevailing wind patterns which create a polluted west end. Those able, left the east end once industrialisation commenced[60].

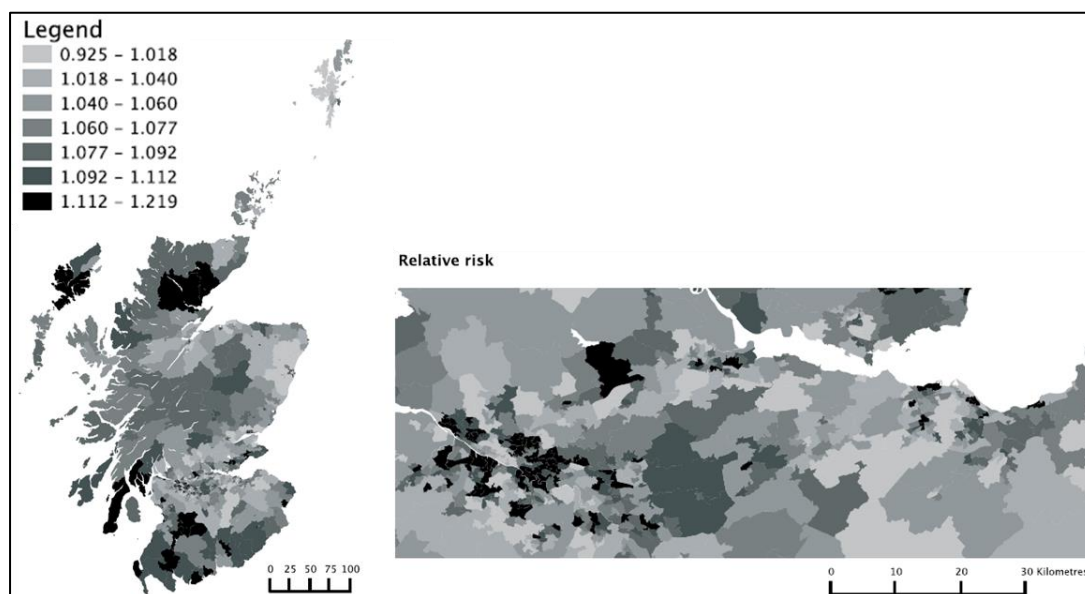


Figure 11 Maps of the risk of PM<sub>10</sub> on respiratory hospital admissions; left: whole Scotland; right: central belt[59]

Significant association between hourly peak concentration of PM<sub>2.5</sub> and mortality was demonstrated in a study of six cities' air quality in Pearl River Delta, China[61]. The study covered 3 years and a total population of 44.5million. For each 10 mg/m<sup>3</sup> increase in 4-day averaged (lag03) hourly peak PM<sub>2.5</sub> corresponded to an increase of: 0.9% total mortality, 1.2% cardiovascular mortality and 0.7% in respiratory mortality[61]. About 3.7% (13,915 attributable deaths) of all-cause mortalities were attributable to hourly peak[61].

29,000 deaths in 2008 in England and Wales were attributed to Human made (anthropogenic) PM<sub>2.5</sub> [54]. If all anthropogenic particulates were removed, an estimated 36.5million life years could be saved over the subsequent 100 years in the UK(i.e. on average an additional 6months added to each new born)[54].

There is growing concern that no safe minimum exists for particulate exposure[62]. A systematic review and meta-analysis of 110 published studies sought to evaluate the health effects of short-term exposures to outdoor PM<sub>2.5</sub>. A positive association with all-cause and cause-specific mortality and hospital admissions was found[56]. Immediate physiological changes are seen following short duration (<1hour) exposure to combustion-derived particles[19]. Estimates of the effect of particulate-attributed mortality in the UK range from 21,000 to 64,000 per year[63]. Consequently, a reduction in total PM<sub>2.5</sub> concentration would lead to: an increased life expectancy; increased average healthy life expectancy and increased survival time for those with ischaemic heart disease[63].

#### STUDY 4: FIREWORK-SPECIFIC PRODUCTS OF COMBUSTION

The stunning effects produced by firework and pyrotechnic displays are dependent upon variable and heterogeneous chemical compositions and can be considered as containing water-soluble ions, crustal elements and trace metals, carbonaceous and organic matter and trace gas elements. When the fireworks are ignited, gaseous (carbon monoxide, nitrogen dioxide etc.) and particulate pollutants are released[64].

In Xinxiang during the 2015 Chinese Spring Festival, a study monitored the environmental contamination of 19 elements, 10 water-soluble ions and 8 fractions of carbonaceous species. They found the population were exposed to heavy metal contamination, in particular: Cr, As and Cd, which exceeded acceptable thresholds[65]. The risk of developing non-carcinogenic disease from heavy metals occurs following order: Zn > Pb > As > V > Cr > Mn > Ni > Cd > Co and for carcinogenic disease: As > Cd > Cr > Ni > Co (see end for abbreviations)[65].

Particulate and heavy metal monitoring in central London during Diwali and Guy Fawkes festival (October 16 – November 16, 2014) demonstrated significant elevation of total PM<sub>2.5</sub> and metals associated with firework combustion [66](Figure 12). Firework-related K and Mg emissions represent 54% and 24% total annual UK emissions respectively[67].

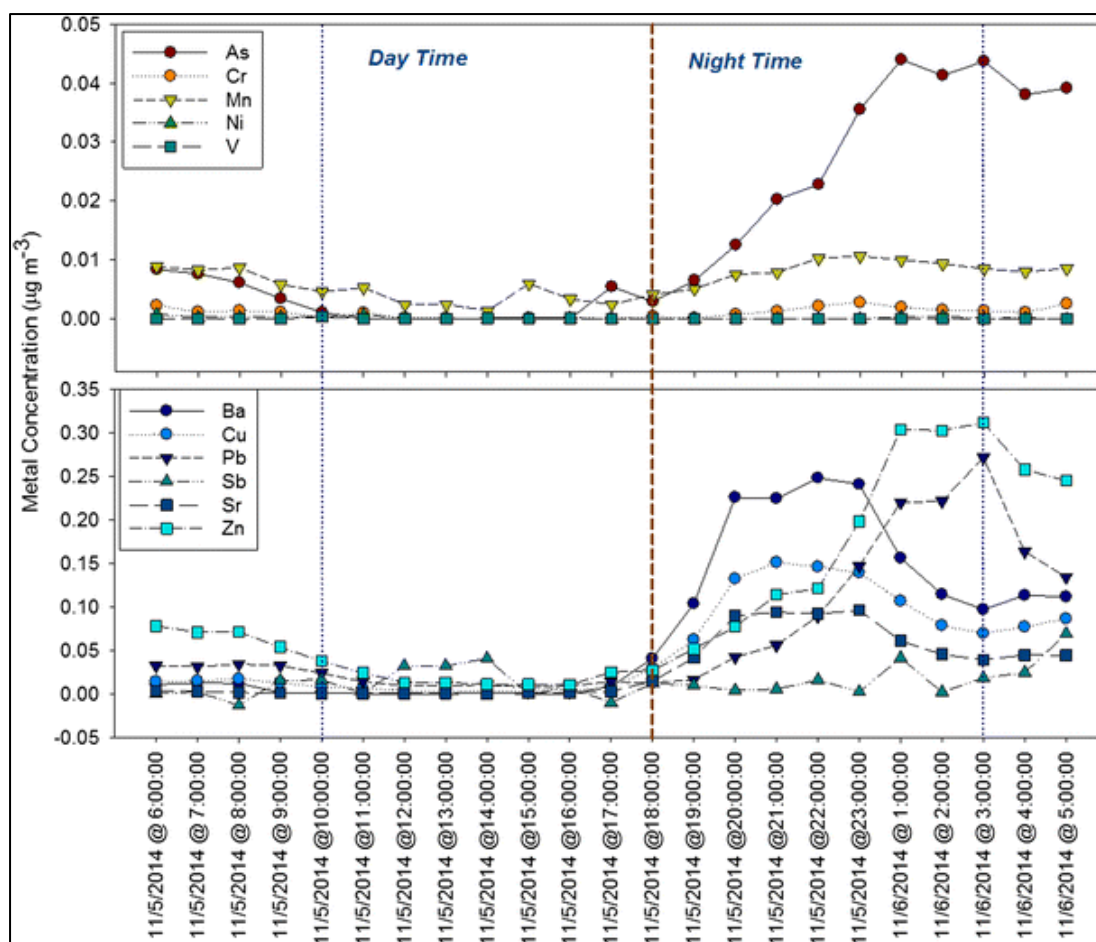


Figure 12 Hourly trends  $PM_{2.5}$ -elements Guy Fawkes Night Central London (Barium, Ba; Copper, Cu; Strontium, Sr; Antimony, Sb) [66]

In Spain, the 'San Juan' firework fiesta is celebrated on the 23<sup>rd</sup> June. Elemental metal particulates were shown to have increased during the firework festival (compared with pre-festival control): Sr (x86), K (x26), Ba (x11), Co (x9), Pb (x7), Cu (x5), Zn (x4), Bi (x4), Mg (x4), Rb (x4), Sb (x3), P (x3), Ga (x2), Mn (x2), As (x2), Ti (x2) and  $SO_4^{2-}$  (x2)[68]. Statistically significant increases in firework-related components of: Al, As, Sb, Ba, Cl, Cr, Cu, Mg, K, P, Sr, S, Ti, and Zn  $PM_{2.5}$  concentrations were also demonstrated in USA-wide air quality measurements[69]. Of note, Ba, Cl, Cu, Mg, K, and Sr were dramatically (>4-fold) increased on the 4<sup>th</sup> July[69].

In Medellín (Columbia) the use of fireworks is widespread during La Alborada and New Year's Eve, with corresponding reduction in air quality[70]. Evaluation of air pollution (using particulate matter) using official air quality monitoring records and low cost PM citizen science network revealed a significant increase in  $PM_{2.5}$  and  $PM_{10}$  from the use of fireworks. The effects were greater in densely populated communes with associated low-quality life conditions. The hourly  $PM_{2.5}$  concentration in these areas ranged from 50 - 100  $\mu g m^{-3}$ . These rises were not observed in areas of low population density[70].

#### STUDY 4: PARTICULATE CONCENTRATION OVER BONFIRE NIGHT IN THE UK

Bonfire night-related pollution episodes, arising from bonfire burning and firework-related emissions are considered to be short-lived but significant. The emissions are frequently compounded by atmospheric conditions, with low cloud, mild temperatures and low wind reducing dispersal of particulates. These conditions aligned on 5<sup>th</sup> November 2018, with consequentially poor air-quality results[71](Figure 13).

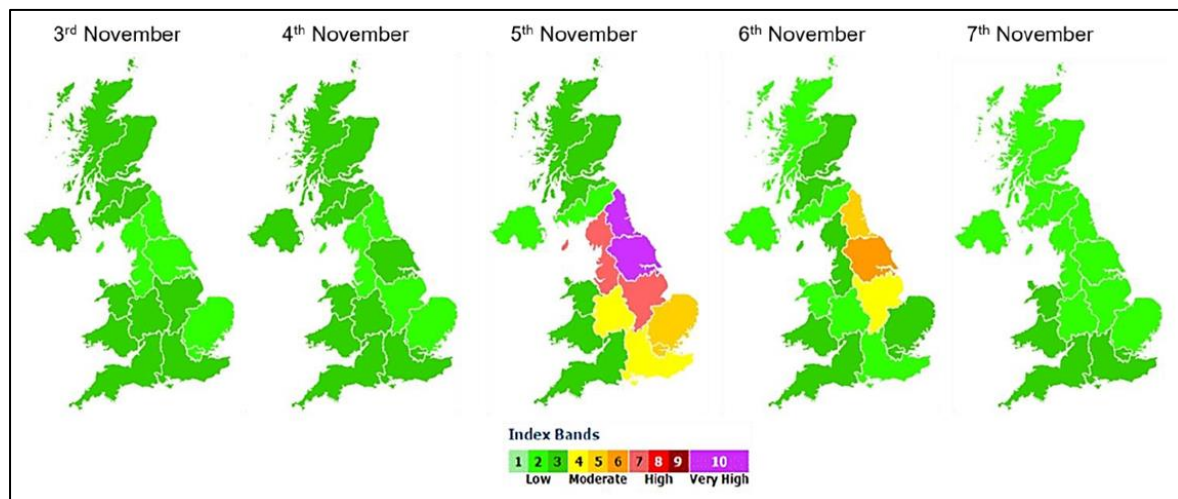


Figure 13 5<sup>th</sup> November 2018 Very High pollution levels: North East, Yorkshire & Humberside; High levels: North West & Merseyside, East Midlands [71]

A study of particulate concentrations in York city centre noted a significant spike across all particulate sizes over bonfire night despite there being no organised displays in close proximity to the monitors[17](Figure 14).

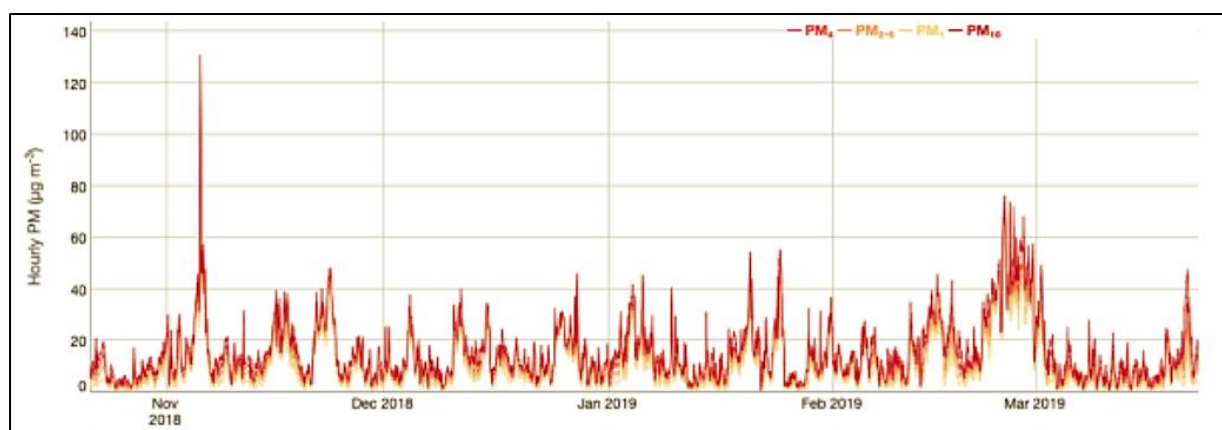


Figure 14 Particulate matter concentrations measured in York City Centre between November 2018 and March 2019[17].

The open-access Newcastle air pollution sensor network noted substantial increase in PM<sub>2.5</sub> and PM<sub>10</sub> concentration across their >100 sensors in the evening of November 5<sup>th</sup> 2017-19[72](Figure 15) Atmospheric conditions impact the dispersion of particulate matter. 5<sup>th</sup> November 2018 was cloudy with no wind, raising the PM<sub>2.5</sub> concentration above DEFRA recommended annual levels(Figure 16).

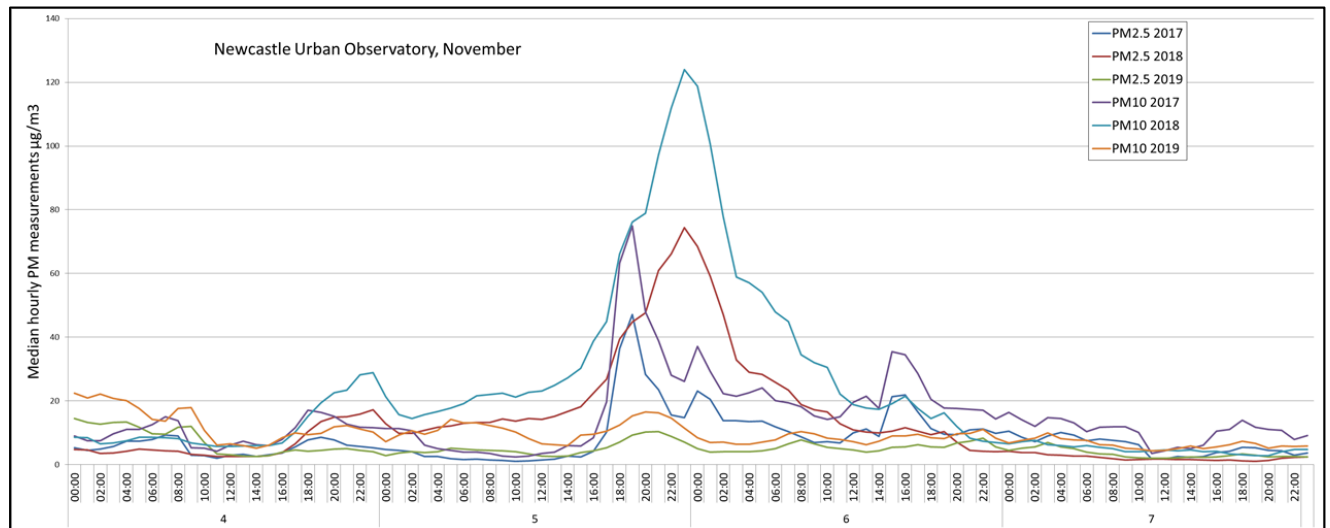


Figure 15 Median hourly PM<sub>2.5</sub> and PM<sub>10</sub> concentrations (µg/m<sup>3</sup>), 2017-19[72]

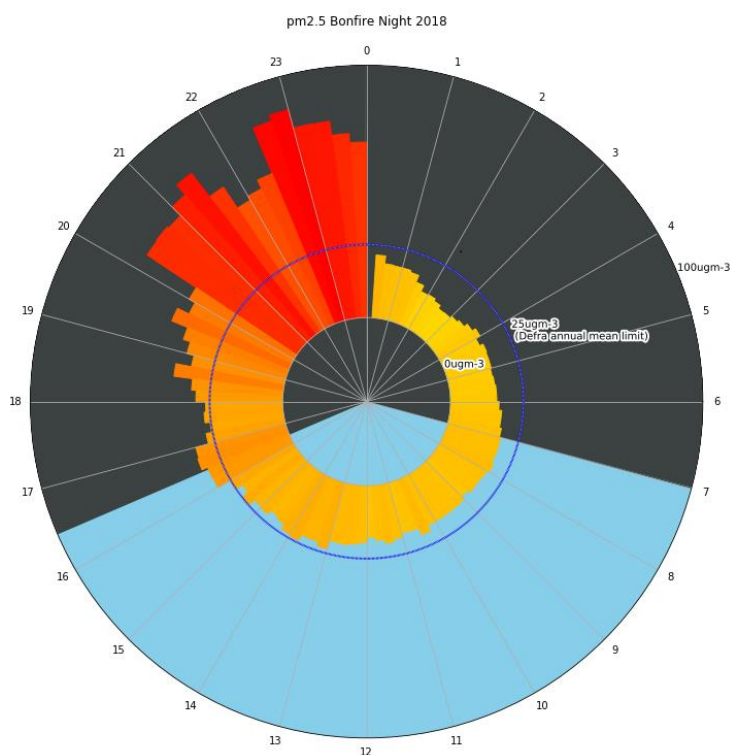


Figure 16 PM<sub>2.5</sub> concentration µg/m<sup>3</sup> Newcastle Urban Observatory Network 5<sup>th</sup> Nov 2018[72]



Bonfire-night related spikes in particulate concentration have also been noted in Scotland with environmental monitoring data from November 5<sup>th</sup> 2009 noting PM<sub>10</sub> to be moderate in 12, High in 1 and Very High in 1 locations in Glasgow[73]. These findings were repeated 10 years later, with high levels of PM<sub>2.5</sub> and PM<sub>10</sub> noted in Glasgow Byers Road and North Lanarkshire Kershaws[74](Figure 17). It is thought that a recirculating weather pattern with low wind speeds resulted in poor dispersal conditions and a high levels of pollution over a short period of time[74].

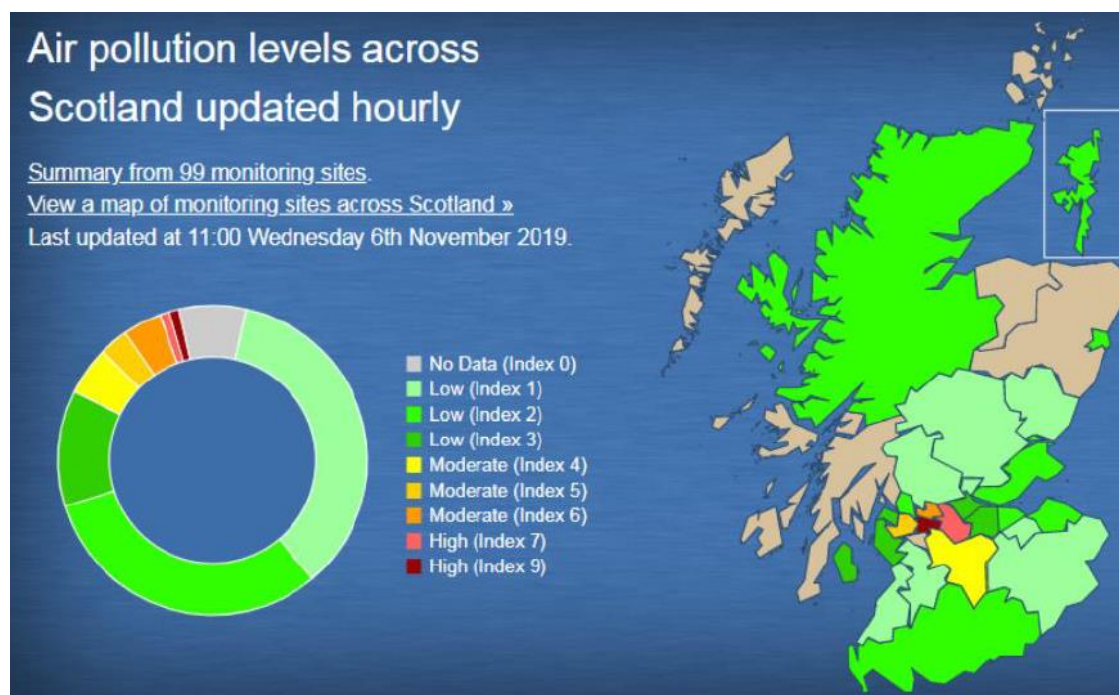


Figure 17 Screenshot of <http://www.scottishairquality.scot/>, 6<sup>th</sup> November 2019 [74]

#### STUDY 4: FIREWORK-SPECIFIC PRODUCTS OF COMBUSTION AND HEALTH

A Dutch epidemiological study of firework events, PM<sub>10</sub> and non-accidental mortality rates showed some positive association between the variables[75]. In Delhi a study of population within 2km radii of 7 air quality monitoring systems found that cardiovascular and respiratory mortality as well as hospital admissions were double those during Diwali 2010 compared with the Commonwealth Games[76].

The city of Shanghai sought to reduce the concentration of PM<sub>2.5</sub> during the Chinese Spring Festival. Between 2013 – 2017 a statistically significant reduction rate of  $-13.8 \mu\text{g}/\text{m}^3/\text{yr}$  was recorded (79 (max 524) to 32 (max 156)  $\mu\text{g}/\text{m}^3$ ,  $p=0.05$ )[77]. This reduction in total particulate concentration correlated with a reduction in particulate-related morbidity (reduction in disease-specific outpatient attendance) and mortality (2013  $n=75$  (95% CI: 27, 108) to 2017 $n=31$  (12, 45) linear regression:  $-13.1 \text{ cases}/\text{yr}$  ( $p=0.05$ ))[77](Figure 18). Corresponding reductions were demonstrated in the health economic evaluation of firework-related PM<sub>2.5</sub> morbidity and mortality with health-based economic loss in Shanghai during the Festival 2013 – 2017 reducing from ¥129.7 million (£15 million) to ¥ 55.1 million (£6.4 million)[77].

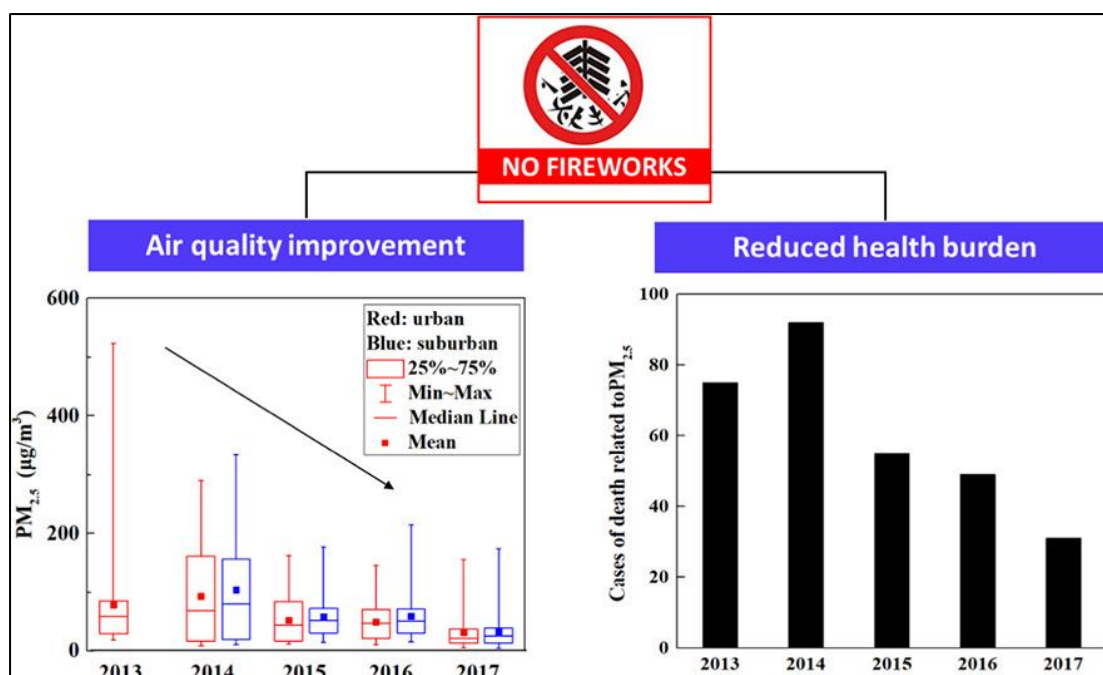


Figure 18 Summary of findings: PM<sub>2.5</sub> concentration and health outcomes [77]

A recent systematic review and meta-analysis of 196 papers from the peer-reviewed literature found positive association between short-term exposure to PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sup>2</sup> and O<sup>3</sup> and all causes of mortality in humans and PM<sub>10</sub> and PM<sub>2.5</sub> and cardiovascular, respiratory and cerebrovascular-specific mortality[78]. These findings are in keeping with other reviews evaluating health effects of PM exposure[79-81]

A systematic review of fireworks on asthma and COPD (chronic obstructive pulmonary disease) noted: NO<sup>2</sup> can cause histological lung damage; O<sup>3</sup> and CO can lead to pneumonia[64, 82].

Environmental monitoring in Chennai during Diwali found total PM<sub>2.5</sub> emissions were three times higher than non-festival times. The majority of these emissions were due to Sulphur Dioxide. A health survey on 994 members of the Chennai population was undertaken during Diwali. The respondents reported symptoms including eye irritation(44.3%), respiratory and gastrointestinal complaints[83](Table 15).

Table 15 health survey reported symptoms following Diwali in Chennai[83]

Types of symptoms	Male (556 persons)	Female (438 persons)	Total (994 persons)	Percentage (%)
Eye irritation	249	191	440	44.3
Cough	158	129	287	28.9
Headache	55	93	148	14.9
Nausea	35	69	104	10.4
Vomiting	31	64	95	9.5
Respiratory issues	35	22	57	5.7
Throat irritation	5	2	7	0.7

## STUDY 4: DISCUSSION

It is noted that between 1990 – 2016 total PM<sub>2.5</sub> and PM<sub>10</sub> concentrations in Scotland have decreased by >60%[62]. Substantial reduction in PM<sub>2.5</sub> have also been achieved throughout North America and Europe[84]. Disparity still persists however, with those residing in areas of greater social deprivation more likely to succumb to diseases with air pollution contribution[85]. As there is no minimal safe threshold for PM<sub>2.5</sub>, public health benefits will result from any reduction[19]. In addition to the reduction in human and environmental harm, reduction in particulates will lead to substantial health economic savings[77].

It is clear that the short and long-term health consequence of firework-related particulates has yet to be fully explored. An independent review of the 'Cleaner Air for Scotland strategy' made seven recommendations for further evaluating health impacts of air pollution, and two of these align with exploring firework-particulate health effects[62]:

1. 'Further consideration of evidence on health impacts of low level pollution in countries with levels of ambient air pollution comparable to Scotland is needed.'
2. 'Commission population research on the long term effects of air pollution using cohort methods to aid further understanding of health impacts and explain the apparently different epidemiology in Scotland.'

The chemical compositions of firework-related particulates is unique and requires specialised epidemiological investigation. Populations are exposed to unacceptable levels of heavy metals following firework displays which are known to be associated with the development of non-carcinogenic and carcinogenic disease[60].

## Report Discussion

It is clear that individuals and communities are continuing to experience adverse health consequences from fireworks. Those at greatest risk of sustaining a physical injury are children from areas of greater deprivation. The literature suggests that particulate matter disease and death are more likely to affect deprived communities.

Firework-related physical injuries, although uncommon, continue to be costly, both in terms of human suffering and health economic consequence. What is more uncertain is the contribution of firework-generated particulates on morbidity and mortality rates. Data from international studies reveals an increase in morbidity and mortality following firework-relevant festivals. It has been estimated that the cost of treating firework-related injuries is €3.2 million, in a context of total consumer expenditure on fireworks being €68–70 million annually[10]. It is thought that further evaluation of the transferability of these findings in a Scottish context would be beneficial.

Overall, we consider fireworks to generate ripples of adverse health consequences(Figure 19). There are the infrequent well-publicised and life-changing, costly injuries. These can be quantified through examination of hospital records. However, there exists a currently unquantified degree of harm from fireworks. These include psychological distress and particulate matter morbidity and mortality. It is known that no safe level of PM<sub>2.5</sub> exists, and so it may be prudent to consider whether communities wish to continue to release optional anthropogenic particulate matter.

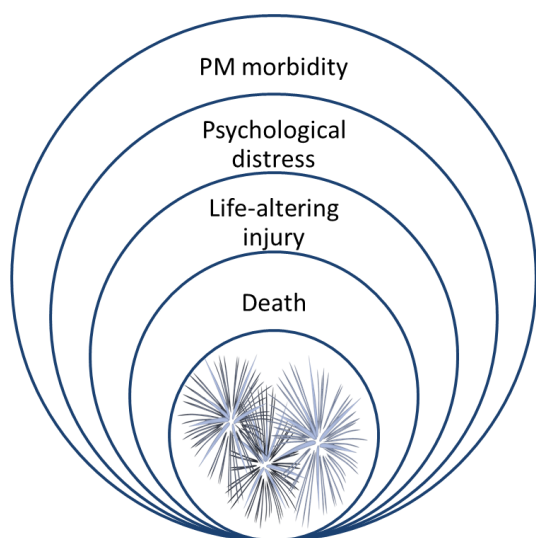


Figure 19 Firework-related morbidity and mortality

## Report Conclusion

The evidence of firework-related harm in Scotland remains evident and substantial. Those most affected are young, male and from areas of greater social deprivation. The health economic costs relating to the treatment of firework-related physical harm to one Scottish NHS Health Board is ~40,000/year. A study of the national health economic costs would be beneficial. The short and long term health effects from exposure to firework-generated particulates warrants investigation.

## Abbreviations

Al	Aluminium
As	Arsenic
Ba	Barium
Bi	Bismuth
Ca	Calcium
Cd	Cadmium
Cl	Chlorine
CO	Carbon monoxide
Cr	Chromium
Cs	Caesium
Cu	Copper
EC	Elemental carbon
Fe	Iron
Ga	Gadolinium
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
NaCl	Sodium Chloride (salt)
Ni	Nickel
NO <sup>2</sup>	Nitrogen dioxide
O <sup>3</sup>	Ozone
OC	Organic carbon
P	Phosphorous
PM	Particulate matter
Rb	Rubidium
S	Sulphur
Sb	Antimony
SO <sub>4</sub> <sup>2</sup>	Sulphate
Sr	Strontium
Ti	Titanium
V	Vanadium
Zn	Zinc
Anthropogenic	Human made (pollution)
COBIS	Care of Burns in Scotland Managed Clinical Network
COPD	chronic obstructive pulmonary disease
ICD-10	International Classification of Disease; 10th version, WHO
NHS GGC	NHS Greater Glasgow and Clyde
OPCS4	OPCS Classification of Interventions and Procedures version 4
PM	particulate matter
PM10	particulate matter, aerodynamic diameter smaller than 10 µm
PM2.5	particulate matter, aerodynamic diameter smaller than 2.5 µm

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