Environmental Science and Policy 96 (2019) 18–26

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

A pragmatic public health-driven approach to enhance local air quality management risk assessment in Wales, UK

Huw Brunt, Sarah J. Jones

Public Health Wales, Tyndall Street, Cardiff, CF10 4BZ, United Kingdom

ARTICLE INFO

Keywords:
Local air quality management
Air pollution
Public health
Triple jeopardy
Risk assessment

ABSTRACT

Air pollution, poor health and deprivation are inextricably linked. These stressors can combine to create a triple jeopardy effect where more deprived individuals and communities can be disproportionately affected by exposure to air pollution. Despite acknowledgement of this, however, the current statutory Local Air Quality Management regime prescribes that air pollution risks are considered in isolation. This project aimed to develop and test application of a practical method for carrying out air pollution risk assessment in the context of wider health determinants.

A number of data components describing health, air pollution and deprivation at small area level were identified for one health board area (comprising two local authority areas) in Wales for 2011-15. These data were then combined within each of the triple jeopardy domains and then overall to assign each small area a prioritisation score to inform air quality management action. Areas were then ranked in order with a view to identifying priority areas (and clusters) for integrated air quality management and public health intervention. Local environmental and public health stakeholders were involved throughout the process and asked to provide feedback on the approach, particularly in relation to applying it in practice and evaluating its merit in terms of helping achieve local and national wellbeing policy goals.

The piloted tool - called Health and Air Pollution Risk Assessment/Area Prioritisation (HAP-RAP) - offered a contemporary public health-driven approach to risk assessment intended to complement existing [narrow focus] prescribed air quality management approaches. It highlighted areas for action that were different in location, scale and size from local air quality management areas declared through existing processes. Further, stakeholder comments suggested the approach can help support more collaborative, effective and efficient ways of working, facilitate stronger policy and practice integration and achieve greater population health impact.

1. Introduction

Outdoor air pollution is a significant environmental determinant of health (World Health Organization, 2018; Kelly and Fussell, 2015; Lim et al., 2012). Exposure to harmful pollutants such as particulate matter ($PM_{10,\ 2.5}$) and nitrogen dioxide (NO_2) – from transport, industrial, domestic, agricultural and natural sources – can reduce healthy life and life expectancy through increased risks of heart disease and strokes, respiratory diseases, lung cancer and other conditions (Royal Colleges of Physicians and Paediatrics and Child Health, 2016; World Health Organization, 2013a,b). The health burden and linked societal costs are substantial; an estimated equivalent of 40,000 early deaths are attributed to air pollution exposure each year in the UK (Royal Colleges of Physicians and Paediatrics and Child Health, 2016).

While these headline statistics offer scope and profile to the UK situation, they mask local-level variations in pollution concentrations, exposures, risks and impacts. Locally, socio-economic stressors play a significant role in influencing variations; evidence suggests that increased deprivation levels can modify and compound associations between air pollution and health outcomes (Brunt et al., 2017; Fecht et al., 2015; Richardson et al., 2013). This ‘triple jeopardy’ of influence (Goodman et al., 2011; O’Neill et al., 2003; Jerrett et al., 2001) means that the most disadvantaged society groups (relative to least) face:

i) increased risks from social and behavioural determinants of health;
ii) greater risks from higher ambient pollution exposure potential; and
iii) modified effects that make exposure to pollutants exert disproportionately large impacts.

To tackle problems effectively, air quality assessment and management actions must be informed by a good understanding of them in the broadest possible public health context. However, despite a long-

E-mail address: huw.brunt@wales.nhs.uk (H. Brunt).

https://doi.org/10.1016/j.envsci.2019.02.008
Received 1 February 2019; Received in revised form 21 February 2019; Accepted 21 February 2019

standing acknowledgement of this, the statutory approach for work of this kind in the UK – framed by the Local Air Quality Management (LAQM) regime (HM Government, 1995; Department of the Environment, 1997) – has historically prescribed a risk assessment processes that consider air pollution in isolation (Brunt et al., 2016). While attempts have been made to encourage broader thinking in the UK (e.g. Wales' LAQM policy guidance and reporting templates (Welsh Government, 2017a; DEFRA, 2018), no standardised method exists to facilitate this in practice. It remains that LAQM requires local authorities to assess risks by only reviewing air pollution data and take action in only air pollution 'hotspot' areas where Air Quality Objectives (AQOs) are actually or likely breached. These Air Quality Management Areas (AQMA) are typically defined as small areas that cover few residents/households.

This approach not only misses opportunities to assess air pollution risks in the broader 'triple jeopardy' context, but may actually be detrimental. Public health problems may be exacerbated by air pollution mitigation decisions made on the basis of incomplete information or knowledge which results in poorly informed, targeted and implemented intervention (Bowen, 2002). By considering air pollution problems in a broader context, there is a greater potential to understand problems and solutions, and act in informed and integrated in ways to maximise health benefits (Brunt et al., 2017; Deguen and Zmirou-Navier, 2010; O'Neill et al., 2003).

To address this LAQM gap, here, the development and application of a tool for considering air pollution risks in the context of health and socio-economic determinants. The tool, called *Health and Air Pollution Risk Assessment/Area Prioritisation* (HAP-RAP), is intended to complement, not replace, existing UK LAQM arrangements. Piloted in Wales, HAP-RAP seeks to encourage and support LAQM stakeholders, especially local authority air quality management experts and public health specialists, to think beyond air pollution data and localised problems and act in pursuit of maximum health gain.

Wales is the only part of the UK where action such as this is supported by formal, broad public health and wellbeing legislation and policy - the Wellbeing of Future Generations (Wales) Act 2015 (WFGA) (Welsh Government, 2015a) and linked implementation policy *Prosperity for All* (Welsh Government, 2017b). The WFGA aims to improve the social, economic, environmental and cultural well-being of Wales through seven linked 'well-being goals'. To support and monitor progress, a suite of national indicators lie beneath goals (complementing Wales' Public Health Outcomes Framework), with one dedicated specifically to air quality improvement. Working through the WFGA and goals, all public bodies (including National Health Service agencies and local authorities) are required to think sustainably, set prevention-focused shared objectives, undertake joint planning and action, and work with people and communities. Notably, Wales' LAQM policy guidance aligns with WFGA principles. These factors all make Wales an ideal location in which to develop and test HAP-RAP.

2. Methods

The basis for HAP-RAP was the 'triple jeopardy' air pollution, deprivation and health domains.

2.1. Data collection

2.1.1. Study location and geographical scale

The Cwm Taf Health Board area was the pilot study area (Fig. 1). Cwm Taf is one of seven health boards in Wales; its boundary is coterminous with Rhondda Cynon Taf (population 238,300; 31 MSOAs) and Merthyr Tydfil (population 63,500; 7 MSOAs) local authorities. The area covers a large part of the South Wales valleys, and now has some of the highest levels of deprivation in Wales. In the past, coal mining made it extremely prosperous.

In national statistics terms, local authorities in Wales can be broken down into small areas, Middle Super Output Areas (MSOAs; n = 410, population 5000–15000 people, 2000–6000 households) and Lower Super Output Areas (LSOAs; n = 1909, population 1000–3000 people, 400–1200 households). Both were developed by the Office of National Statistics to support longitudinal small-area analysis across the UK, with boundaries and populations being stable over time (ONS, 2012). Here, MSOAs were preferred because data needed for HAP-RAP prioritisation are routinely collected at this level.

2.1.2. Air quality

Three pollutants comprised the air quality domain of HAP-RAP: NO_2, $PM_{2.5}$ and PM_{10}. Annual average modelled concentrations (μg/m^3) of each were obtained from Welsh Government for the period 2011 to 2015 (Welsh Government, 2018). These were at the MSOA level and were population-weighted.

Data were derived from UK Government Pollution Climate Mapping model, which generates validated estimates of area-level pollutant concentrations (based on a 2011 baseline and projected annually) (DEFRA, 2011; Stedman et al., 2003). Modelled air pollution data were preferred over measured data from discrete monitoring points (where distances, and probability of pollution variation, between receptor and the nearest monitor can be significant) since they more accurately reflect area concentrations and population exposures (Krewski et al., 2009; Jerrett et al., 2005). Modelled data also allows risk assessments to move beyond localised problem identification and quantification, so population-level risks are considered in the context of wider health determinants. This emphasises the intention for HAP-RAP to complement, not replace, existing LAQM processes.

For HAP-RAP, MSOA annual average concentrations were calculated for pollutants, using data for period 2011-2015.

2.1.3. Health

Six demographic and health outcome measures were chosen for the health domain of HAP-RAP: population proportion aged 0–4 years and 60+ years, population density aged 0–4 and 60+ years, all-cause mortality, cardiovascular and respiratory disease emergency admissions, low birth weight.

The proportion of young children (aged 0–4 years) and older people (aged 60+ years) was used as a proxy measure of population vulnerability, along with the density of this group per hectare (based on 2011 Census). These metrics were chosen because of the disproportionate impacts that socio-economic stressors and air pollution can have on sensitive groups (Brunt et al., 2017; Fecht et al., 2015; Richardson et al., 2013).

A number of health outcomes were also selected because of their well-documented links with deprivation and air pollution. MSOA-specific European Age-Standardised Rates (EASR) per 100,000 population (ONS mid-year estimates) were calculated for all-cause, non-accidental mortality (Armitage and Berry, 1994) for 2011–2015, for cardiovascular disease (CVD, ICD-10 I00 to I99) and respiratory disease (ICD-10 J00 to J99) emergency hospital admissions for 2009-15 (NWIS, 2015; Brunt et al., 2017) and low birthweight births (proportion of all live singleton births weighing < 2500 g) for 2011-15 (Smith et al., 2017).

2.1.4. Deprivation

The deprivation domain of HAP-RAP was made up of only one measure – income deprivation.

The Welsh Index of Multiple Deprivation (WIMD) is the preferred composite measure of deprivation in Wales and is a summary score derived from a weighted combination of data across eight domains: income (23.5%); employment (23.5%); health (14%); education (14%); access to services (10%); community safety (5%); housing (5%) and physical environment (5%). Each domain includes several indicators e.g. income-deprivation is calculated from numbers of income-related benefit claimants, tax credit recipients and supported asylum seekers (Welsh Government, 2015b).

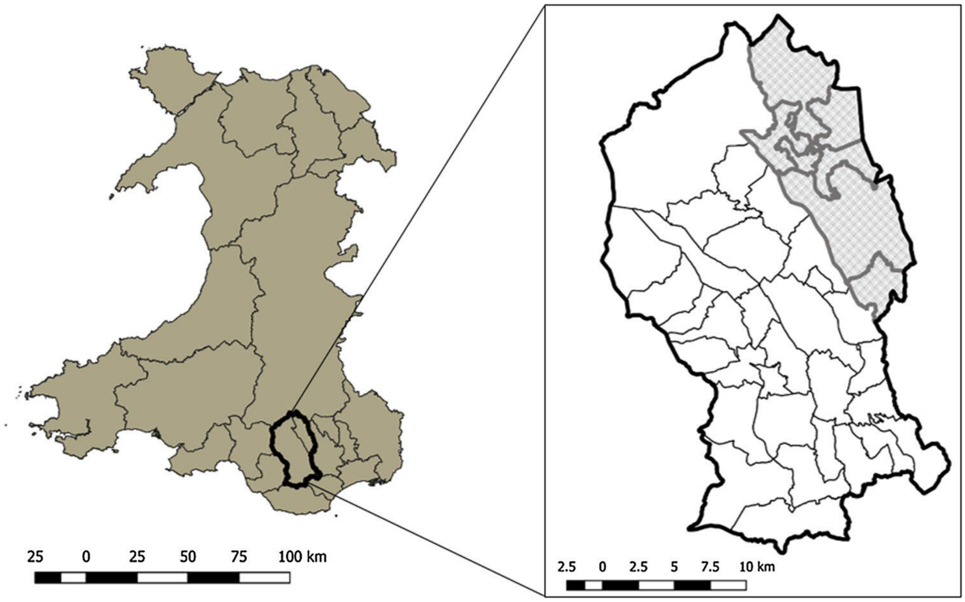

Fig. 1. Wales map showing local authority boundaries and Cwm Taf Health Board area (highlighted).
Zoomed figure - Merthyr Tydfil area (shaded grey) and Rhondda Cynon Taf (unshaded) with MSOA boundaries.

The indicators within each WIMD domain are updated at different times, dictated by the data source, meaning that not all of the WIMD indicators are available at MSOA level. Of the MSOA-level indicators, income deprivation data was chosen to avoid problems associated with double-counting and has also been used previously as a proxy for multiple deprivation (Fecht et al., 2015; Richardson et al., 2013; Kruize and Driessen, 2007; Naess et al., 2007).

2.1.5. *Data collection summary*

The three HAP-RAP domains were informed by ten components (six 'health', one 'deprivation' and three 'air pollution') (Fig. 2).

2.2. *Data linkage and analysis*

Component data were combined for each MSOA in a way that allowed comparison and for local authority MSOA(s) to be identified as being more in need of intervention than others because of the combined effects of air pollution, ill-health and high deprivation status.

Data combination was based on the rationale that the three domains should contribute equally, and that it should be simple to use and understand, whether amongst public health or air quality management specialists, local decision-makers (e.g. planners, elected members) or even the public. To achieve this, health components needed to be combined to offer an overall "measure" of health, as did the air pollution components. Given that deprivation was "measured" by just one component already, no combination with other components was necessary.

A simple approach was again taken to rank components across domains. For example, if the proportions of low birthweight babies in three MSOAs were 4% in MSOA X, 5% in MSOA Y and 6% in MSOA Z, then MSOA Z was ranked 1 (highest priority), next MSOA Y ranked 2, and MSOA X ranked 1. This component's rank then contributed to the overall 'health' domain rank. This approach was applied to each components across domains for all MSOAs in Merthyr Tydfil and Rhondda Cynon Taf local authority areas, separately. A worked example is offered for the seven MSOAs in Merthyr Tydfil (Table 1); an identical process was followed for MSOAs in Rhondda Cynon Taf.

The values for the population proportion aged 0–4 years and 60+ years in each MSOA (row A) were ranked 1–7 (row B). MT2 had the highest proportion of vulnerable population at 32.3% and was ranked 1 (highest HAP-RAP priority). MT5 had the next highest (32.2%) and was ranked 2. MT7 had the lowest proportion vulnerable (28.5%) and was ranked 7 (lowest HAP-RAP priority).

This was repeated for each component.

For the health domain, rankings of each component (rows C–H) were then summed (row I). The sums were then themselves ranked (row J), so that the MSOA with the lowest sum of health components (MT3 = 13) was ranked 1 indicating worst health status and highest HAP-RAP priority. The MSOA with the highest sum of health components (MT2 = 31) was ranked 7 indicating best health status and lowest HAP-RAP priority.

This was repeated for the air pollution domain. The deprivation domain had only one component so that ranking became the overall domain rank.

Domain rankings (rows K–M) were then summed (row N). The MSOA with the lowest sum for the three domains was given the HAP-

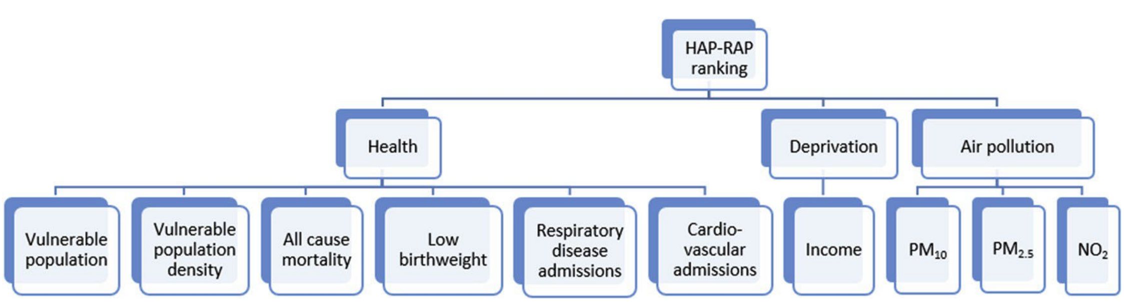

Fig. 2. Summary of HAP-RAP domains and components.

Table 1
Worked example showing HAP-RAP ranking method by MSOA, for Merthyr Tydfil local authority area.

HAP-RAP MSOA label		MT1	MT2	MT3	MT4	MT5	MT6	MT7
A	Popn. aged 0-4 and 60+ years	28.9%	32.3%	31.6%	29.4%	32.2%	30.0%	28.5%
B	Rank	6	1	3	5	2	4	7
C	Popn. aged 0-4 and 60+ years	6	1	3	5	2	4	7
D	Popn. aged 0-4 and 60+ per hectare	5	3	1	2	7	4	6
E	All-cause mortality	5	7	1	6	2	4	3
F	Low birth weight	1.5	6	4	5	3	7	1.5
G	Respiratory disease admissions	3	7	2	6	4	5	1
H	CVD admissions	3	7	2	6	4	5	1
I	Sum of health component ranks	23.5	31	13	30	22	29	19.5
J	Overall health rank	4	7	1	6	3	5	2
K	Overall health rank	4	7	1	6	3	5	2
L	Overall deprivation rank	4	7	2	6	3	5	1
M	Overall air pollution rank	4.5	7	4.5	3	6	1	2
N	Sum of domain ranks	12.5	21	7.5	15	12	11	5
O	HAP-RAP rank	5	7	2	6	4	3	1

RAP rank 1 (highest priority for action; MT7, sum of ranks = 5) and the MSOA with the highest sum was ranked 7 (lowest priority for action; MT2, sum of ranks = 21).

2.2.1. *Sensitivity analysis*

With three components in the air pollution domain and six in the health domain, there were concerns that two or more of the components may be linked. If so, it would be sensible to remove one, or more. To test this, a sensitivity analysis was undertaken using Rhondda Cynon Taf data only. There were too few MSOAs in Merthyr Tydfil to allow robust analysis, and evidence suggests the two populations are not markedly different.

Of particular interest in this analysis was testing the effect of the inclusion of $PM_{2.5}$ in the air pollution domain. Using SPSS 24, a Spearman's Rank Order Correlation test assessed relationships between each of the components of the air pollution domain, based on the concentrations of each of the pollutants. A Wilcoxon-signed ranks test was then used to determine whether there were differences between the resulting air pollution domain and overall priority scores assigned to each MSOA. The former test also assessed relationships between the health domain components, with specific consideration given to correlation between vulnerable population proportion and population density, and likewise, respiratory and CVD emergency admissions.

2.3. *Assessing application of HAP-RAP in practice*

Application of HAP-RAP in practice was assessed by:

i considering findings of HAP-RAP prioritisation with locations of AQMAs (https://uk-air.defra.gov.uk/aqma/), acknowledging their declaration mostly using measured data;
ii obtaining feedback from engaged stakeholders (the steering group for the pilot comprised 12 LAQM experts, public health specialists and environmental regulators) on HAP-RAP's local-level practical application and its contribution to WFGA goals (as has been done in a previous study (Jones and Brunt, 2017)).

3. Results

Component MSOA-level values in 'health' and 'deprivation' domains varied considerably (Table 2). For example, in Merthyr Tydfil, the lowest MSOA-level CVD emergency admission EASR was 1281 per 100,000 population compared with a high of 1709. In Rhondda Cynon Taf, the percentage of income-deprived households ranged from 7%–32%. In contrast, local air pollution concentrations showed little variation e.g. PM_{10} (range 0.8 μg/m^3) and $PM_{2.5}$ (range 0.6 μg/m^3) in Merthyr Tydfil. However, with the ranking approach in use, the actual values and their ranges are only of importance to differentiate between MSOAs.

$PM_{2.5}$, PM_{10} and NO_2 concentrations were all significantly correlated, as would be expected, at $p < .05$, and were moderately to strongly correlated (Rho > 0.65), except for NO_2:$PM_{2.5}$ (Rho = 0.366). No significant differences were observed between air pollution domain ranking when $PM_{2.5}$ was excluded/included ($p = 0.829$) or in overall prioritisation when $PM_{2.5}$ was excluded/included ($p = 0.779$).

When the health components were tested for correlation, vulnerable population percentage and vulnerable population density were very poorly correlated (Spearman's Rho = -0.031, $p = 0.870$). There was a significant correlation between CVD emergency admissions and respiratory emergency admissions, but the correlation between the two was weak (Rho = 0.357, $p = 0.048$), therefore inclusion of both components was justified. Respiratory emergency admissions were also significantly correlated with low birthweight (Rho = 0.422, $p = 0.018$) and all-cause mortality (Rho = 0.552, $p = 0.001$), but again the low to moderate correlation was felt to be more important than the p value and all components were retained. The remaining correlations were all poor at < +/-0.3.

3.1. *Area ranking, prioritisation and comparison with AQMA locations*

The three HAP-RAP domain ranks were then studied, along with the overall prioritisation and current AQMA provision, to see how each contributed to overall prioritisation and the implications of HAP-RAP for current practice (Table 3). In Merthyr Tydfil, HAP-RAP identified the highest priority area for action as MSOA 7 (shaded red, along with the second highest priority area); this area does not have any declared AQMAs. MSOA 4 (where an AQMA *is* declared) was ranked as the 6th highest priority area by HAP-RAP (shaded green, along with the lowest priority area MSOA 2).

Table 3 also shows HAP-RAP outcomes for Rhondda Cynon Taf, with the top three (shaded red) and lowest three (shaded green) priority MSOA areas highlighted.

In Rhondda Cynon Taf, MSOA 8 was HAP-RAP's top priority area (Table 3); there is no declared AQMA in this MSOA. The second-highest ranked MSOA in Rhondda Cynon Taf, MSOA 13, has two declared AQMAs. To add further perspective to the contrast between the prescribed AQMA approach and the added value of HAP-RAP, in Rhondda Cynon Taf, we estimate that AQMAs cover a total population of 3024

Table 2
Descriptive summary, showing minimum, maximum and range of values for each HAP-RAP component.

HAP-RAP domain	HAP-RAP component	Merthyr Tydfil local authority area		Rhondda Cynon Taf local authority area	
		Minimum and maximum values	Range	Minimum and maximum values	Range
Health	Vulnerable population (% age 0-4yrs and 60+)	28.5% to 32.3%	3.8%	21.0% to 39.1%	18.1%
	Population density (popn. age 0-4 yrs and 60+ years per hectare)	0.6 to 6.6	6.0	0.4 to 7.9	7.3
	All-cause mortality EASR (per 100,000 popn.)	971 to 1391	420	874 to 1446	572
	Low birthweight (%)	4.1% to 7.9%	3.8%	3.9% to 10.9%	7%
	Respiratory disease emergency admissions EASR (per 100,000 popn.)	1533 to 2394	861	1577 to 2722	1145
	CVD emergency admissions EASR (per 100,000 popn.)	1281 to 1709	428	1160 to 1585	425
Deprivation	Income deprived households (%)	13% to 34%	21%	7% to 32%	25%
Air pollution	PM_{10} (μg/m³)	13 to 13.8	0.8	12.8 to 14.8	2.0
	$PM_{2.5}$ (μg/m³)	9.6 to 10.2	0.6	8.8 to 10.8	2.0
	NO_2 (μg/m³)	9.4 to 11.6	2.2	7.8 to 16	8.2

(assuming an average 2.4 people per household) (ONS, 2017), around 1.3% of the population, and in Merthyr Tydfil AQMAs cover around 260 people, just 0.4% of the population. AQMA declaration does not require consideration of any population profiles and, because the area covered does not conform to any geo-political boundary, it is not possible to say anything about the demographic or health status of these people, including whether they are any more or less vulnerable or susceptible than any others in the area (with the exception of elevated

Table 3
Results of MSOA ranking and prioritisation, by HAP-RAP component and domain (red shading indicates highest priority MSOAs, green shading indicates lowest priority MSOAs).

		Health	Deprivation	Air pollution	HAP-RAP	AQMAs declared (using measured data)
Merthyr Tydfil local authority area	1	4	4	4.5	5	0
	2	7	7	7	7	0
	3		2	4.5	2	0
	4	6	6	3	6	1
	5	3	3	6	4	0
	6	5	5		3	0
	7	2		2		0
Rhondda Cynon Taf local authority area	1	27	6.5	20	21	0
	2	10	20	18.5	15	
	3	22	23	26	29	1 (partial)
	4	16	20	15	19	0
	5	17	8	17	9.5	0
	6	13	9.5	12	7	1
	7	14	4	31	16	0
	8	1	2	7	1	0
	9	11	3	27	8	1 (partial)
	10	7	16.5	30	21	0
	11	4	16.5	29	17	0
	12	24	12	6	9.5	0
	13	2	1	23	2	2 (1 whole, 1 part)
	14	3	6.5	24	6	
	15	28	12	18.5	25	0
	16	9	12	25	13	0
	17	6	16.5	8	4.5	0
	18	5	9.5	16	4.5	0
	19	20	23	3	13	2 (1 whole, 1 part)
	20	8	5	14	3	1
	21	26	25.5	13	27.5	1
	22	21	20	5	13	2 (1 whole, 1 part)
	23	12	14	28	23.5	0
	24	15	16.5	22	21	0
	25	18	27	9	23.5	1
	26	19	25.5	1	11	0
	27	30	31	11	30	2 (1 whole, 1 part)
	28	23	23	4	18	0
	29	29	28	21	31	0
	30	25	29.5	10	27.5	0
	31	31	29.5	2	26	1

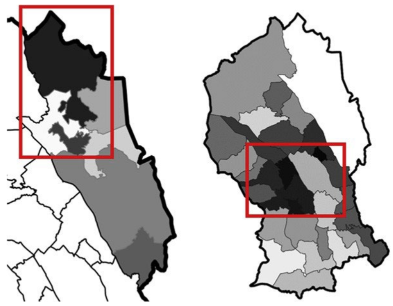

Fig. 3. Suggested HAP-RAP priority area clusters in Merthyr Tydfil (left) and Rhondda Cynon Taf (right).

air pollution concentrations).

3.2. Area prioritisation clusters

The HAP-RAP area-prioritisation output identified MSOA-level priorities. However, when mapping the data to compare it with existing AQMAs, it was also possible to identify priority MSOA 'clusters' that can inform decision-making/actions across larger geographical areas (Fig. 3). For example, it may be more useful, especially when implementing population-level interventions, to define a cluster extending MSOA 13 in Rhondda Cynon Taf to MSOAs 14, 16, 17, 18, 20, than to focus only on MSOAs 8 and 13.

3.3. Assessing application of HAP-RAP in practice

Stakeholders provided the following comments on the application of HAP-RAP in practice:

1 *Do you understand HAP-RAP*?

Yes, HAP-RAP can improve understanding of air pollution problems in a broader public health context. It also helps highlight and prioritise areas for more integrated intervention.

2 *Would you use HAP-RAP to guide priority-setting and decision making*?

Yes, HAP-RAP encourages partnership working and investment in action to deliver multiple health benefits. It also helps incorporate LAQM's relatively narrow prescribed processes into wider policy and practice and makes LAQM relevant to a wider audience.

3 Do you think HAP-RAP can add value to LAQM?

Yes, HAP-RAP can add value if used in the right way, namely, as a risk assessment tool that complements processes already prescribed by the LAQM regime that focus more on use of measured data.

4 Does HAP-RAP contribute to the goals of the WFGA?

Yes (see Table 4).

4. Discussion

4.1. Main findings

Through LAQM, air pollution risks and solutions are rarely considered in a broad public health context. HAP-RAP offers a standardised approach to risk assessment that can help address this current shortfall. The tool is simple and transferable, yet robust and repeatable, and uses routinely-collected data. It can complement and add value to LAQM by placing emphasis on domain and component interactions at population level and promoting consideration of these in the context of community vulnerability and susceptibility. In turn, this can inform and enhance LAQM decision-making and action, and facilitate stronger integration with wider public health practice.

The integrated public health-driven air pollution risk assessment advocated by HAP-RAP can improve collective understanding of links between air pollution risks and broader public health priorities, and raise awareness amongst wider audiences through better risk communications. This can help LAQM and public health stakeholders overcome investment dilemmas concerning action to tackle competing priorities in isolation. It is also conceivable that, because HAP-RAP's outputs will have broader appeal, its use can increase interest and engagement across the public health community.

This pilot study of HAP-RAP found the influence of MSOA 'deprivation' and 'health' status domains on ultimate HAP-RAP area-level ranking considerable; the influence of 'air pollution' less so. This aligns with findings from other research (Brunt et al., 2017). Interestingly, when HAP-RAP priority areas were compared with locations of existing declared AQMAs (denoting localised "hotspots"), there was little geographical alignment. This is to be expected given that LAQM mostly relies on measured data. However, this adds weight to the argument that considering air pollution data in isolation is a mistake since risk assessments using this approach ignore important 'big picture' public health evidence which highlights where linked population health needs are greatest.

Opportunities are missed to integrate LAQM risk assessment and management actions with wider public health intervention across larger geographies. Doing so can maximise synergies and yield multiple public health benefits across bigger populations. Further, by helping LAQM stakeholders look beyond very localised air pollution "hotspots" (where relatively few people live), HAP-RAP can not only inform and support population-level action likely to result in greater public health gain, but also increase options for robust air quality management and health impact evaluation.

HAP-RAP's ability to help visualise priority clusters offers an extra layer of intelligence which might prove extremely useful when implementing population-level interventions (whether to achieve air quality and/or public health improvement). The findings of this work suggest there is merit in integrating air quality assessment and management with wider public health action and applying it in MSOA priority clusters rather than targeting less-effective, usually small-scale, action in isolated AQMAs or individual HAP-RAP-priority MSOAs. Doing so can inform, promote and facilitate delivery of the two-pronged approach to air quality management previously called for (Brunt et al., 2017) where:

- universal action (e.g. general risk communication, policy development, active travel promotion, advocacy, leadership) can reduce air pollution risks for everyone; and
- where appropriate, enhanced targeted action (e.g. tailored risk communication, targeted behaviour change initiatives, Clean Air Zone intervention) is implemented to address problems in communities with the poorest air pollution and/or health and/or socio-economic status.

4.2. Implications

Continuing to implement LAQM as an isolated regime in Wales and the rest of the UK is short-sighted and likely problematic. This is because acting on a limited understanding of scope and relationships between HAP-RAP domains and components, or worse ignoring them altogether, may serve to exacerbate existing, or create new, problems at the local/regional level (Bailey et al., 2018; Bowen, 2002). It is beneficial to integrate LAQM with wider public health policy and practice (Brunt et al., 2018). Considering air pollution problems and solutions in a broad public health context can improve understanding and link air

Table 4
Assessment of approach against WFGA wellbeing goals.

WFGA goal	Goal description	Contribution of HAP-RAP
A prosperous Wales	Innovative, productive, low carbon society. Recognises limits of global environment & uses resources efficiently & proportionately. Develops a skilled & well educated population in an economy which develops wealth & provides employment opportunities, allowing people to take advantage of the wealth generated through securing decent work.	Encourages a much broader view of public health context of air pollution than is currently the case. Could lead to improved priority-setting, decision making and sustainable interventions.
A resilient Wales	Nation maintains & enhances a biodiverse natural environment with health functioning ecosystems that support social, economic & ecological resilience & the capacity to adapt to change	As above. Also, could lead to the identification and implementation of interventions across wider subject and geographical areas, to improve the natural environment.
A healthier Wales	A society in which physical & mental wellbeing is maximised & in which choices & behaviours that benefit future health are understood	Encourages health to be considered routinely when determining local air quality management risks and priorities for action.
A more equal Wales	A society that enables people to fulfil their potential	Encourages area-level inequalities to be considered routinely when determining local air quality management risks and priorities for action.
A Wales of cohesive communities	Attractive, viable, safe & well connected communities	Enhances current LAQM approach to identify local air pollution “hotspots”, to consider the effects of air pollution, health and inequalities and address community-level priorities. Interventions can then benefit entire communities.
A Wales of vibrant culture & thriving Welsh language	A society that promotes & protects culture, heritage & the Welsh language & which encourages people to participate in the arts, & sports & recreation	By adopting a broader public health view of air pollution problems, HAP-RAP can facilitate action that can help people to become more active in society for longer.
A globally responsible Wales	A nation which, when doing anything to improve the economic, social, environmental & cultural wellbeing of Wales takes account of whether doing such a thing may make a positive contribution to global wellbeing & the capacity to adapt to change	Encourages stakeholders to take a much broader view of air pollution than is currently the case. Action across larger geographies could contribute more to achieving health and environment improvement nationally and internationally. Further, HAP-RAP can help inform global evidence base.

pollution with other priorities. In turn, this can strengthen collaboration and collective commitment to tackle identified problems.

Not only this; HAP-RAP can generate new evidence needed to create greater opportunities for informed, innovative population-level approaches and sustainable solutions that make effective and efficient use of scarce resources. This is particularly important as it supports delivery of the recommended two-pronged air quality management approach described above. This underpins air pollution risk assessment and management activities with the principle of *proportionate universalism* (i.e. where resourcing and delivery of universal services is at a scale and intensity proportionate to the degree of need (Marmot, 2010)) and encourages population-level *prevention paradox* mass remedies that have potential to achieve greater health gain action (Rose, 1981).

Engaging local public health and air quality management specialists in this pilot helped embed and promote the benefits associated with adopting a public health-driven approach to LAQM. In both Merthyr Tydfil and Rhondda Cynon Taf areas, the collaborative approach to develop and test HAP-RAP application helped foster better relationships between health and local authority agencies, as well as with environmental regulators. This improved recognition of respective organisation roles and responsibilities.

Specifically, stakeholders reported how HAP-RAP created opportunities to achieve stronger policy integration and more effective and efficient ways of working locally, through enhanced LAQM implementation that allows the regime to legitimately reach beyond prescribed consideration of air pollution risks to ensure their regard in a broader population health and geographical context. The stakeholders engaged in this study are now considering how local arrangements, policies and intentions can be modified to integrate routine application of HAP-RAP locally (through LAQM) in the future, and how training for broad audiences can raise awareness and build capacity around its use. Development examples include using HAP-RAP to identify/justify air quality management action in areas which LAQM implementation has overlooked, prioritise interventions to tackle linked triple jeopardy domains, bid for funding to support actions, and consider other relevant datasets that to add more value to HAP-RAP.

If used routinely, it is likely that HAP-RAP can build on the improved integration and collaboration between environmental and public health partners (as observed in this pilot), and facilitate stronger links with a broader network of stakeholders. Its use will be extremely relevant to local authority policy developers, transport and land-use planning officials, and decision-makers such as local elected members. From a health perspective, with HAP-RAP encouraging the consideration of air pollution in the context of adverse health outcomes and inequalities, its appeal and usefulness amongst health service commissioners, planners and clinicians will likely grow too. Beyond this, the tool’s ability to generate new evidence will be of interest to academia, third sector organisations, the private sector, and probably local/community interest groups too.

While this pilot study is set in a Wales context, and framed by the LAQM regime and WFGA, the need to adopt enhanced public health-driven sustainable ways of assessing and managing air pollution risks is not unique to Wales, or even the rest of the UK. From an LAQM perspective, the requirement to act locally to identify and address air pollution problems is driven by EU legislation, mainly in the form of 2008 ambient air quality directive (2008/50/EC) (European Parliament, 2008). As such, other European countries with similar local air quality management regimes will likely be interested in the findings of this pilot study, for example the Netherlands (see Bondarouk and Liefferink, 2017; Busscher et al., 2014), Italy (see D’Elia et al., 2009), Denmark (see Jensen et al., 2001) and France (Padilla et al., 2014; Laurian and Funderberg, 2013), Spain (Soret et al., 2011) and Sweden and Hungary (European Environment Agency, 2006). Countries beyond Europe will also be interested as local air quality regimes in some share similarities with LAQM, for example South Africa (Naiker et al., 2012), China (Wang and Hao, 2012), India (Gulia et al., 2018, 2015), and New Zealand and United States (Longhurst et al., 2009).

In relation to sustainable development, failing to adopt HAP-RAP’s proposed long-term, prevention-focused approach to air pollution risk assessment is at odds with the principles and requirements of the WFGA. While this is most relevant in Wales, given that the WFGA seeks to fulfil the ambition of the United Nation’s Agenda for Sustainable Development (which was adopted by all member states in 2015; UN, 2015), the findings of this pilot study are of international relevance and importance too as they will be useful in informing and supporting learning and achieving change in practice.

4.3. Limitations

HAP-RAP is the first step towards helping LAQM stakeholders consider health and deprivation, alongside air quality, in a clear, consistent, robust and structured way. However, the limitations of this approach should be acknowledged:

- As with many other area-based studies of this nature, is the issue of ecological fallacy. The level of geography chosen – MSOAs – was a practical decision based on the availability of data, but given that each MSOA covers 5,000–15,000 people, the actual air quality, health and deprivation experience of these people will be very variable; the values assigned to the MSOA are merely a generalisation across the whole area. The selection of MSOAs is supported by LAQM having a population-focused approach where it would be inappropriate to apply population-level findings at the individual level.
- Building on this is the issue of variation, not just within-area but between-area too; the MSOA-level 'health' and 'deprivation' component values showed variation in both local authority areas. However, the air pollution concentrations showed little variation because the data used in HAP-RAP were modelled concentrations. Measured data would have shown much greater variation, but be relevant only to very small areas. Both modelled and measured data are important to inform local air pollution/health risk assessments, but given that HAP-RAP is intended to be a population-level approach (that complements LAQM and its use of measured data) to understanding the context of air quality problems and prioritising solutions, point-source measured data would compromise the tool's ability to generate evidence to inform broad public health policy and practice integration. Also, since HAP-RAP is intended to complement existing LAQM risk assessment requirements, not replace them, local, measured data will likely form part of local decision-making anyway.
- Within the domains, the components selected for use in HAP-RAP may be debated. The 'vulnerable population', so the total 0–4 year old and 60+ year old population, was considered the most robust and appropriate vulnerability measure, accounting for age and geographical distribution (WHO, 2018). By also calculating the vulnerably population density, the vulnerability distribution was also considered. Although evidence for use of these components was less robust, they described vulnerability in a way that is easy to comprehend by local decision-makers. The use of overall population density was also considered, but it was felt to be insufficiently sensitive for use in this study; the same for population aged over 30, the usual denominator in air pollution and health-burden related calculations (World Health Organization, 2013). This is more an indicator of the often-chronic nature of air pollution related health problems and when these onset. Using data relating to women of child-bearing age was also considered but, again, thought to be too insensitive. Emergency hospital admission rates for respiratory and cardiovascular conditions were the chosen indicators of the health effects of air pollution, although it is recognised that smoking, obesity, physical inactivity and other lifestyle/behaviours factors are more important predictors (Lopez et al., 2006). Any evaluation of the HAP-RAP approach that is based on health and health service use would need to be mindful of this. Similarly, low birthweight was included in HAP-RAP as an indicator of chronic air pollution exposure, even though smoking is the leading contributor to low birthweight (Kramer, 1987). Air pollution exposure is increasingly linked to low birthweight (e.g. Smith et al., 2017) and as smoking prevalence declines, the relative importance of air pollution as a contributor to this outcome will only increase. As for the air pollution components, the $PM_{2.5}$–related sensitivity analysis performed showed that its inclusion made little difference to HAP-RAP ranking and area prioritisation. While it is acknowledged that $PM_{2.5}$ pollution management is beyond the direct scope of LAQM, it was retained in HAP-RAP because of its well-documented health-harming status and also because LAQM is committed to reducing exposures to fine particulates over wide geographical areas (Welsh Government, 2017a; DEFRA, 2016).
- Finally, more resource are required to take forward HAP-RAP at local level e.g. collaboration, information sharing, data linkage, analysis, interpretation and communication. However, to overcome concerns in resource-constrained times, it is notable that any additional burden would need be spread across multiple agencies. This includes public health specialists given that the tool is also intended to increase engagement and collaboration. Practically, this may require underpinning formal working agreements. However, public health specialists would likely be keen to contribute because of the significance of considering wider health determinants and inequalities in air pollution risk assessments and the greater potential to maximise impacts of actions by realising synergies and efficiencies across linked public health priorities.

5. Conclusion

Air pollution, deprivation and health are inextricably linked. While risk assessment is a core component of the UK's LAQM regime, air pollution is rarely considered in the context of wider determinants of health. This is a mistake and a missed opportunity since acting on a limited understanding of problems and underpinning relationships, or worse ignoring them altogether, can exacerbate them or even create new ones.

Intending to help address this gap in practice (and complement existing arrangements), this pilot study of the HAP-RAP tool suggests there is considerable merit in looking beyond air pollution data to take account of important health and socioeconomic status profiles over larger geographies and populations. Using the relatively straightforward method proposed, HAP-RAP can encourage and facilitate a more public health-driven approach to LAQM-related risk assessment. Through it, data linkage and analysis can inform area prioritisation based on an objective consideration of the three triple jeopardy domains. Also, it can raise awareness of domain relationships across the public health community and increase stakeholder interest, engagement and commitment.

Importantly, HAP-RAP can help integrate and align air quality management with public health policy and action to optimise chances achieving the long-term, population prevention-focused sustainability goals set out in strategic sustainability policies. Resulting action can be universal (seeking to reduce risks for all) or enhanced/targeted (seeking to enhance mitigation action in areas with the poorest air pollution and/or health status).

While this pilot study of HAP-RAP is framed in a Welsh context, the requirement to assess (and manage) air pollution risks is not unique to Wales. Given the highlighted merits of considering air pollution in a broader public health context, and doing so to achieve high-level sustainability goals, the findings of this study will be relevant to other parts of the UK, and in countries beyond.

Acknowledgements

The authors wish to acknowledge the contribution to this pilot study from HAP-RAP Steering Group members: Angela Jones (Cwm Taf Health Board Local Public Health Team, Public Health Wales), Kate Cameron (Natural Resources Wales), Susan Gow and Llewellyn Patrick (Merthyr Tydfil County Borough Council), Neil Pilliner and Gareth Purnell (Rhondda Cynon Taf County Borough Council).

References

Armitage, P., Berry, G., 1994. Statistical Methods in Medical Research, 3rd edn).

Blackwell, Oxford, UK 1994.
Bailey, N., Dong, G., Minton, J., Pryce, G., 2018. Reconsidering the relationship between air pollution and deprivation. Int. J. Environ. Res. Public Health 15, 629. https://doi.org/10.3390/ijerph15040629.
Bondarouk, E., Liefferink, D., 2017. Diversity in sub-national EU implementation: the application of the EU Ambient Air Quality directive in 13 municipalities in the Netherlands. J. Environ. Policy Plan. 19 (6), 733–753.
Bowen, W., 2002. An analytical review of environmental justice research: what do we really know? Environ. Manage. 29 (1), 3–15.
Brunt, H., Barnes, J., Longhurst, J.W.S., Scally, G., Hayes, E., 2016. Local Air Quality Management policy and practice in the UK: the case for greater Public Health integration and engagement. J. Environ. Sci. Policy 58, 52–60.
Brunt, H., Barnes, J., Jones, S.J., Longhurst, J.W.S., Scally, G., Hayes, E., 2017. Air pollution, deprivation and health: Understanding relationships to add value to local air quality management policy and practice in Wales, UK. J. Public Health 39 (3), 485–497.
Brunt, H., Barnes, J., Longhurst, J.W.S., Scally, G., Hayes, E., 2018. Enhancing Local Air Quality Management to maximise public health integration, collaboration and impact in Wales, UK: a Delphi study. J. Environ. Sci. Policy 80, 105–116.
Busscher, T., Zuidema, C., Tillema, C., Arts, J., 2014. Bridging gaps: governing conflicts between transport and environmental policies. Environ. Plan. A 46 (3), 666–681.
D'Elia, L., Bencardino, M., Ciancarella, L., et al., 2009. Technical and non-technical measures for air pollution emission reduction: the intgegrated assessment of the regional Air Quality Management Plans through the Italian national model. Atmos. Environ. 43, 6182–6189.
DEFRA (2011) https://uk-air.defra.gov.uk/research/air-quality-modelling?view=modelling Accessed 18 December 2018.
DEFRA, 2016. Local Air Quality Management. Policy Guidance (PG16). April 2016. Accessed 10 December 2018. https://laqm.defra.gov.uk/documents/LAQM-PG16-April-16-v1.pdf.
DEFRA, 2018. LAQM. Review and Assessment. Report Templates. . https://laqm.defra.gov.uk/review-and-assessment/report-templates.html.
Deguen, S., Zmirou-Navier, D., 2010. Social inequalities resulting from health risks related to ambient air quality – a European review. Eur. J. Public Health 20 (1), 27–35.
Department of the Environment, 1997. The United Kingdom National Air Quality Strategy. TSO., London.
European Environment Agency, 2006. Assessment and Management of Urban Air Quality in Europe: EEA Monograph 5. Monitoring and assessment Research Centre, King's College London, London, UK.
European Parliament, 2008. Directive 2008/50/EC of the European Parliament and of the Council on Ambient Air Quality and Cleaner Air for Europe. European Parliament, Brussels.
Fecht, D., Fischer, P., Fortunato, L., Hoek, G., et al., 2015. Associations between air pollution and socioeconomic characteristics, ethnicity and age profile in neighbourhoods in England and the Netherlands. Environ. Pollut. 198, 201–210.
Goodman, A., Wilkinson, P., Stafford, M., Tonne, C., 2011. Characterising socioeconomic inequalities in exposure to air pollution: a comparison of socio-economic markers and scales of measurement. Health Place 17, 767–774.
Gulia, S., Nagendra, S.M.S., Khare, M., Khanna, I., 2015. Urban air quality management – a review. Atmos. Pollut. Res. 6, 286–304.
Gulia, S., Nagendra, S., Barnes, J., Khare, M., 2018. Urban local air quality management framework for non-attainment areas in Indian cities. Sci. Total Environ. 619-620, 1308–1318.
HM Government, 1995. Environment Act 1995, Chapter 25 (part IV). HMSO, London.
Jensen, S.S., Berkowicz, R., Hansen, H.S., Hertel, O., 2001. A Danish decision-support GIS tool for management of urban air quality and human exposures. Transp. Res. 6, 229–241.
Jerrett, M., Burnett, R., Kanaroglou, P., et al., 2001. A GIS-environmental justice analysis of particulate air pollution in Hamilton, Canada. Environ. Plan. A 33, 955–973.
Jerrett, M., Burnett, R.T., Ma, R., et al., 2005. Spatial analysis of air pollution and mortality in Los Angeles. Epidemiology 16, 727–736.
Jones, S.J., Brunt, H., 2017. Twenty miles per hour speed limits: a sustainable solution to public health problems in Wales. JECH 71, 699–706.
Kelly, F.J., Fussell, J.C., 2015. Air pollution and public health: emerging hazards and improved understanding of risk. Environ. Geochem. Health 37 (4), 631–649.
Kramer, M.S., 1987. Determinants of low birth weight: methodological assessment and meta-analysis. Bull. World Health Organ. 65, 663.
Krewski, D., Jerrett, M., Burnett, R.T., et al., 2009. Extended follow-up and spatial analysis of the American Cancer society study linking particulate air pollution and mortality. Res. Rep. Health Eff. Inst. 140, 5–114.
Kruize, H., Driessen, P.P.J., 2007. Environmental equity and the role of public policy: experiences in the Rijnmond region. Environ. Manage. 40, 578–595.
Laurian, L., Funderberg, R., 2013. Environmental justice in France? A spatio-temporal analysis of incinerator location. J. Environ. Plan. Manag. 6, 1–23.
Lim, S.S., Vos, T., Flaxman, A.D., et al., 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet 380, 2224–2260.
Longhurst, J.W.S., Irwin, J.G., Chatterton, T.J., et al., 2009. The development of effects-based air quality management regimes. Atmos. Environ. 43, 64–78.
Lopez, A.D., Mathers, C.D., Ezzati Jamison, D.T., Murray, C.J.L., 2006. Global and regional burden of disease and risk factors, 2001: systematic analysis of population health data. Lancet 367, 1747–1757.
Marmot, M., 2010. Fair Society, Healthy Lives: The Marmot Review. UCL Institute of Health Equity., London.
Naess, O., Piro, F.N., Nafstad, P., et al., 2007. Air pollution, social deprivation and mortality: a multilevel cohort study. Epidemiology 18 (6), 686–694.
Naiker, Y., Diab, R.D., Zunckel, M., Hayes, E.T., 2012. Introduction of local air quality management in South Africa: overview and challenges. J. Environ. Sci. Policy 17, 62–71.
NWIS, 2015. Information and Statistics. PEDW Data Online. Accessed 10 December 2018. http://www.infoandstats.wales.nhs.uk/page.cfm?orgid=869&pid=40977.
O'Neill, M.S., Jerrett, M., Kawachi, et al., 2003. Health, wealth and air pollution: advancing theory and methods. Environ. Health Perspect. 111 (16), 1861–1870.
ONS (2012). https://www.ons.gov.uk/methodology/geography/ukgeographies/censusgeography#super-output-area-soa Accessed 23 July 2018.
ONS (2017). https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/bulletins/familiesandhouseholds/2017.
Padilla, C.M., Kihal-Talantikite, W., Vieira, V.M., et al., 2014. Air quality and social deprivation in French metropolitan areas – a localized spatiotemporal environmental inequality analysis. Environ. Res. 134, 315–324.
Richardson, E.A., Pearce, J., Tunstall, H., et al., 2013. Particulate air pollution and health inequalities: a Europe-wide ecological analysis. Int. J. Health Geogr. 12, 34–43.
Rose, G., 1981. Strategy of prevention: lessons from cardiovascular disease. BMJ 282, 1847–1851.
Royal Colleges of Physicians and Paediatrics and Child Health, 2016. Every Breath We Take – the Lifelong Impact of Air Pollution. Royal College of Physicians., London.
Smith, R.B., Fecht, D., Gulliver, J., et al., 2017. Impact of London's road traffic air and noise pollution on birth weight: retrospective population based cohort study. BMJ 359. https://doi.org/10.1136/bmj.j5299.
Soret, A., Jimenez-Guerrero, P., Baldasano, J.M., 2011. Comprehensive air quality monitoring for the Barcelona Metropolitan Area through traffic management. Atmos. Pollut. Res. 2, 255–266.
Stedman, J., Bush, T., Vincent, K.J., et al., 2003. UK Air Quality Modelling for Annual Reporting 2002 on Ambient Air Quality Assessment Under Council Directives 96/62/EC and 1999/30/EC. AEA Technology, Abingdon, UK. https://uk-air.defra.gov.uk/assets/documents/reports/cat05/0402061100_dd12002mapsrep1-2.pdf.
UN, 2015. Sustainable Development Goals. Accessed 10 December 2018. https://sustainabledevelopment.un.org/.
Wang, S., Hao, J., 2012. Air quality management in China: issues, challenges and options. J. Environ. Sci. 24 (1), 2–13.
Welsh Government, 2015a. Wellbeing of Future Generations (Wales) Act 2015. Welsh Government, Cardiff, UK. Available at: http://www.legislation.gov.uk/anaw/2015/2/contents/enacted (Accessed 27 November 2018).
Welsh Government, 2015b. Welsh Index of Multiple Deprivation. Accessed 23 July 2018. https://gov.wales/statistics-and-research/welsh-index-multiple-deprivation/?lang=en.
Welsh Government, 2017a. Local Air Quality Management Policy Guidance PG W 17. Welsh Government., Cardiff.
Welsh Government, 2017b. Prosperity for All – the National Strategy. Welsh Government., Cardiff.
Welsh Government, 2018. Wellbeing of Wales. Accessed 18 December 2018. https://gov.wales/statistics-and-research/well-being-wales/?tab=data&lang=en.
World Health Organization, 2013a. Review of Evidence on Health Aspects of Air Pollution – REVIHAAP. World Health Organization, Copenhagen.
World Health Organization, 2013b. Health Risks of Air Pollution in Europe – HRAPIE. World Health Organization, Copenhagen.
World Health Organization, 2018. Air Pollution and Child Health: Prescribing Clean Air. World Health Organization, Geneva in press. https://www.who.int/ceh/publications/air-pollution-child-health/en/.