EcoServ-GIS v3.3

Technical Report: "Air Purification Service"

1. Ecosystem Service Definition and Description

Short definition:

Regulation of air quality through exchange of air pollutants with vegetation

Long definition:

Urban areas where people benefit from vegetation cover that helps to remove vehicle emissions from the air. The capacity of the natural environment to provide air purification is mapped by assigning air purification scores to broad habitat types based on their ability to trap pollutants, and then identifying areas around the vegetation where air pollution may be reduced. Societal demand (need) for air purification is mapped by calculating population density and relative population health levels in urban areas. The regulatory demand (need) for air purification is mapped by estimating traffic-based air pollution levels. These levels are calculated using reverse distance from roads, by road type, assuming higher traffic volumes on higher category roads.

Descriptive text:

Trees and vegetation near roads and within urban areas help to protect the most vulnerable people from the negative effects of air pollution. Roads and built-up areas are sources of pollution. Air pollution causes respiratory disease and other health problems. People with existing lung disease and the old and young are most at risk from air pollution. Trees provide a service by intercepting particles in the air and absorbing harmful pollutants.

Service benefits description

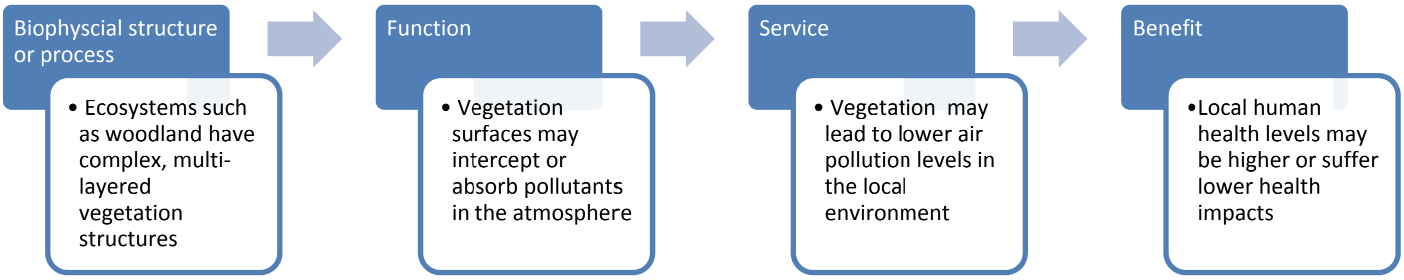
People benefit from this service where local air pollution levels may be reduced in areas where people live, recreate or regularly commute, such as walking or jogging along roadsides, cycle commuting or when relaxing or playing within gardens or yards. The link between the composition and status of the natural environment and positive impacts on local people's health is likely to be strongest in situations where people frequently and regularly undertake such activities in areas where there are air pollution problems. The benefits of existing vegetation cover, or of increased future cover are assumed to be higher where larger numbers of people live in, or near, to areas of predicted high air pollution levels. People living at a far distance from air pollution events are not considered to benefit from this service. The benefits are predicted to be higher for those people who currently have poor health.

2. Service Cascade

As this toolkit is aimed at a county to regional scale the focus of land management and decision making is local. A timescale of one human generation (e.g. 20 to 30 yrs.) is set within which to consider, assess or measure the impacts of land use planning decisions and management. This is logical in relation to the long-term planning decisions of local authorities, health boards and infrastructure planning.

Land management, land use planning and decision-making

- **Would protection, management, or an increase in the area or condition of the biophysical structure or process lead to maintained or increased human benefits over one human generation?**



3. Literature review

Vehicles and built-up areas are sources of, or are associated with, high levels of air pollution which can impact human health (Zhang & Batterman 2013). Vehicle emissions (gaseous compounds, and particulate matter (PM)) cause respiratory diseases and other health problems (Kagawa 2002; Kampa & Castanas 2008) and may result in reduced life expectancy where people live close to major roads (Hoek et al. 2002). Air pollution may also impair mental health, although the effects are difficult to isolate from other negative impacts in such environments such as higher noise levels (Tzivian et al. 2015). People can be exposed to various pollutants whilst commuting to work (Karanasiou et al. 2014; Kaur et al. 2005).

Modelling can be used to estimate or predict atmospheric pollution and air quality levels in relation to traffic rates or road densities (Fallah Shorshani et al. 2015). Many methods have been proposed and can be used in different situations; complex models may be required within urban areas with very tall buildings and "canyon" like street formations (Fallah Shorshani et al. 2015). Tools have recently been developed to encourage community input to the planning process by illustrating the impact of road use and infrastructure planning on human health (Barzyk et al. 2015).

The positive impact of trees and urban woodlands on air pollution levels is now widely reported, and has been known for some time (Beckett et al. 1998; Nowak et al. 2006; Freer-Smith et al. 1997). Benefits have been shown to have potentially significant economic value (Nowak et al. 2014). Research indicates that reducing air pollution levels in European cities could have significant life expectancy and financial implications (Pascal et al. 2013), and that such benefits can be provided by parks and greenspace (Tiwary et al. 2009). City-wide studies have illustrated the range of current benefits of urban woods to health (Tallis et al. 2011; Jim & Chen 2008). Modelling of the potential benefits of different types of greenbelt indicate that effectiveness tails off at a width of approximately 700–800 m (Khan & Abbasi 2001), however many studies indicate that vegetation closest to the source of air pollution adsorbs or traps most of the pollutants at distances of tens of metres (Al-Dabbous & Kumar 2014; Obara et al. 2011). Measurements of pollution levels have indicated that urban parks can be effective in reducing local air pollution levels (Cohen et al. 2014).

A recent review has highlighted how the design of urban vegetation can aid air pollution levels. This suggested that vegetation should be close to the source, be composed of species that include needles or hairy leaves, and may benefit from a mix of tall and short vegetation to benefit both dispersion and deposition (Janhäll 2015). Implementing such advice may be complex, but this could be interpreted in a UK context as advising a well-managed multi-tiered woodland including conifers and broadleaved species such as yew (*Taxus baccata*), Scots pine (*Pinus sylvestris*), downy birch (*Betula pubescens*), hazel (*Corylus avellana*) and elms (*Ulmus sp*.). Interestingly, recent work has also highlighted that herbaceous vegetation could contribute to air purification levels in towns and cities and thus that more biologically diverse greenspace may be beneficial (Weber et al. 2014). Such benefits can include the positive contribution of green roof vegetation to particulate matter reduction (Speak et al. 2012).

Several insights from the following research were used to help construct the current GIS model:

- A study in Brisbane, Australia of charged particles emitted from vehicles on busy roads found that concentration dropped with distance from roads, rapidly up to 100 m, but was detectable up to around 400 m from roads. Potentially dangerous smaller particles travelled less distance from roads, up to 25 m (Jayaratne et al. 2014).
- A study in Melbourne, Australia showed that indoor NO_2 levels can be elevated in dwellings near roads (<50 m) compared to houses further from roads (>300 m) (Lawson et al. 2011).
- A study in Japan examined NO_X and carbon levels in air close to roads (max distance examined = 100 m) and found elevated levels up to 100 m from roads (Naser et al. 2009).
- A modelling system in the USA used a maximum 500 m buffer distance from roads, and considered this sufficient to capture most "near road" air pollution impacts on people (Barzyk et al. 2015).
- In Taipei, land use regression models have successfully used land use type, road length and distance categories to model known air pollution levels (Lee et al. 2014).
- Measurements from over 700 recordings from roads in the USA indicate that almost all air pollutants reduce back to background levels between 115 and 590 m from the road edge (Karner et al. 2010).
- A study in Raleigh, USA showed that presence of structures and vegetation can significantly impact air pollution levels from roads, up to several hundred metres from a road. Highest concentrations occurred close to the roads e.g. <50 m but this was impacted by sound barriers or vegetation presence. Generally levels dropped by 200 or 300 m from roads, depending on the pollutant and site conditions (Bowker et al. 2007).
- A study in Guildford, England showed that presence of near road vegetation and/or tree barriers could result in reduced nanoparticle respiratory deposited doses by approximately 36% (Al-Dabbous & Kumar 2014). The study measured levels very close to the road (<5 m) and with very narrow strips of vegetation (<5 m).
- Several UK studies have shown that trees can intercept a range of pollutants such as metals at close distance to roads, with such interception declining with distance from road (Obara et al. 2011).
- Leaf surface of conifers can result in higher pollutant capture levels than broadleaved species (Beckett et al. 2000).
- Pollution from roads is best modelled by logarithmic decay function (Merbitz et al. 2012).
- PM pollution levels have been shown to correlate with building density at 50 m to 400 m scales (Merbitz et al. 2012).

Despite the range of supportive literature it should be noted that much further research is required to fully understand vegetation - roads - pollution - health dynamics. For example a study in Finland failed to show positive impacts of tree cover on measured pollution levels in open and tree covered sites near roads (Setälä et al. 2012). Similarly a Swedish study reported only very minor positive reductions of roadside vegetation on NO_2 and O_3 levels (Grundström & Pleijel 2014). One American study showed only moderate positive impacts of woodland belts on black carbon levels and no impact on particulate levels (Brantley et al. 2014). Authors have noted a need for caution as some measurement and modelling work suggests that urban vegetation could actually lead to local air pollution hotspots, due to reducing air speed and thus the dilution effect on pollution (Vos et al. 2012; King et al. 2014).

4. Summary of constructing the GIS mapping service model

Sufficient information was available in the literature and sufficient detailed GIS data was available to build a logic based model of the service, however a large number of approximations and assumptions had to be made. The main literature-identified rules used to build the models were:

Capacity

- Presence of vegetation, especially trees and woodland can reduce air pollution levels, most effectively at sites close to the pollution source, but also over longer distances.
- The effectiveness of vegetation was calculated at a *short* scale and a *local* scale and these were then combined to give patch scores.
- A *short* scale distance of 40 m (20 m search radius) was selected as several studies reported sharp drops in certain pollutants with vegetation cover.
- A *local* scale maximum effective distance of 200 m (100 m search radius) was used, informed by measured pollution decline rates in open land areas and after vegetation. Beyond this distance presence of vegetation may not contribute additional benefits to reducing pollution levels.
- Coniferous trees are more effective at trapping pollution, due to a combination of leaf characteristics, density and seasonality of cover.

Demand

- Vehicular air pollution declines rapidly with distance from roads; this can be modelled by a logarithmic function and may be detectable at levels above background values for some distance from roads. A relatively conservative maximum air pollution zone distance of 300 m (max search distance) was selected to model this.
- The benefits of pollution reduction by trees and greenspace may continue for a distance beyond the area of greenspace itself, or may occur in areas adjacent to the greenspace boundary, where complex air movement circulation may occur. Little research was available on which to base this distance, therefore an arbitrary default value of 10 m was used. This is particularly difficult to model as the zone would ideally be directional in response to the pollution source. The model does not currently account for air movement direction. The distance can be set to 0 if required in order to limit the benefits only to greenspace areas.
- Health benefits via any reduction of pollution levels are difficult to quantify. These were approximated by modelling potential local scale use by residents, using 300 m to indicate likely nearby use by residents or regular walking or cycling commuting use. Health scores were measured at the same scale.
- The % surface coverage by buildings is correlated with pollution levels, and can be represented by % cover within 400 m buffer (200 m search radius).

The model estimates general air pollution / traffic emissions rather than specific pollutants due to lack of data and information. The model assumes that emissions relate to the type of road. The distance over which emissions exist is approximate and indicative only. From the background literature, this is a conservative estimate of the distance over which emissions travel. It is assumed that as distance from roads increases, emission concentrations decrease rapidly (logarithmic decay function).

Assuming all buildings are of equal height is likely to overestimate the number of buildings whose presence affects air circulation and therefore have an impact upon the concentration of air pollutants. The relationship between coverage of buildings and air pollutant concentration may not be as simplistic as the linear relationship used in this model. Ideally building height data would be included.

In mapping the demand (need) for the service LSOA based health scores were used from the Index of Multiple Deprivation (IMD) (English, Welsh and Scottish versions), although these scores may not always relate to illnesses that are exacerbated by low air quality. Data linking the concentration of air pollutants to specific illnesses was unavailable. The effect on general health was estimated instead. The relationship between pollutant concentrations and poor health was assumed to be linear, this relationship may not be so simple.

Data on woodland ecosystem type was used at a broad habitat type level to link likely air pollution amelioration capacity to habitat type. Mixed tree stands may contain any proportion of coniferous and deciduous trees. The value given to mixed tree stands is therefore an approximation. It is unlikely that all tree stands are mature. This model is likely to overestimate the area of tree stands which are mature. Detailed data on which to base exact scores for the effectiveness of woods to capture air pollution would be complex to create, based on wood composition and management. Because deposition rates depend on leaf presence, a higher score was given to conifer woods and intermediate levels set for mixed woods, compared to broadleaved woods. Because for half the year broadleaved woods have no leaf presence the value was set to lower values than coniferous woods. The following scores have been selected to create the capacity scores:

Habitat type	Phase 1 code(s)	Capacity score
Woodland, coniferous	A12, A122, etc	100
Woodland, mixed	A13, A132, etc	90
Woodland, broadleaved	A11, A112, etc	80
Scrub	A2 (all types)	50
Scattered trees (all types)	A3 (all types)	50
Introduced shrub	J14	10

These scores are effectively based on opinion, as inspired by the literature review. A range of selected intermediate scores have been applied to partially classified habitats to allow the models to run in data poor situations. The full range of scores can be seen in the Main data link / lookup table within the Toolkit.

5. Spatial occurrence and service flows

This service is provided by areas of natural or semi-natural habitat or greenspace, primarily by woodland habitats. The flow of the service is considered to be both in-situ, and within an adjacent buffer zone around the habitat, to account for the positive impact of air passing through an area of vegetation. The benefits would largely be experienced therefore where people are walking, cycling or jogging within, or adjacent to, an area of greenspace. Currently the model includes all spatial areas and is not limited to publicly accessible areas.

6. Ideal Data

The ideal data with which to map the service would be locally collected site measurements, at a relevant local spatial scale, compared to reference measures at a national scale. Data would be recently collected and updated regularly. Scientific research would be available which measures the impact of marginal changes in the extent, composition or condition of the natural capital asset on the level of the service delivered to people, and the benefits experienced. There would be detailed data on the number per socio-economic category, age or other suitable classification category of people who could benefit from the service, along with research on how changes in these social characteristics alter their relative levels of service demand over time. Finally there would be data on how levels of human use impact ecosystem condition.

In order to reliably map the Air Purification service the following information would be required:

Capacity

- The type, location, extent, condition, quality and management status of greenspace.
- The extent to which air pollution is reduced by the vegetation currently present.

Demand

- The number of people who visit each site, for how long and with what frequency.
- Population vulnerability to air pollution, e.g. as indicated by age, socio-economic group and health status of the visitors.
- The levels of air pollution present at each locality, and its variation spatially and temporally.

Service flows and benefits

- The long-term health benefits of the reduced air pollution levels compared to undertaking recreation, walking or cycling in other similar areas without vegetation cover.

7. Proxies for ideal data

In the absence of the full range of ideal data to map the service, assumptions have been made, and additionally proxies have been used to represent selected elements of the ideal set of data.

Capacity

- The type, location, extent, condition, quality and management status of greenspace.
  - *Type, location, extent*: BaseMap: A combination of local data and several (optional) national datasets including: OS MasterMap, priority BAP habitat, local habitat data, LCM 2007, local and national nature reserves, combined with Local Authority Open Space Survey / Green Infrastructure Survey (or equivalent).
  - *Condition, quality and management*: No consistent, reliable information.
- The extent to which air pollution is reduced by the vegetation currently present.
  - A score is assigned to each habitat type in the link table "AirPurScore" data field. This represents the relative capacity of each habitat to ameliorate air pollution. Analysis of the BaseMap (default 10 m cell resolution) and calculates the cumulative score (sum of cell values) within a search radius around each cell (default 20 m and 100 m radius).
  - A maximum value represents the distance at which benefits might occur outside the habitat boundary (default 20 m).

Demand

- The number of people who visit each site, for how long and with what frequency.
  - Number of people within local scale walking distance (default 300 m).
- Population vulnerability to air pollution. The age, socio economic group and health status of the visitors.
  - Health score (IMD) (mean) of people within local scale walking distance (default 300 m).
- The levels of air pollution present at each locality, and its variation spatially and temporally .
  - Busy roads (dual carriageways, motorways, A roads, primary roads) are assumed to be sources of air pollution.
  - Distance (log) from roads is assumed to correlate with levels of air pollution in the atmosphere (default 300 m).

  - The percentage cover of man-made surfaces is assumed to correlate with the presence of air pollution in the atmosphere (default 400 m).
  - Other sources of air pollution are not covered.

Service flows and benefits

- The long-term health benefits of the reduced air pollution levels compared to undertaking recreation, walking or cycling in other similar areas without vegetation cover.
  - Spatial overlay of capacity and demand is used to indicate potential flow and benefits of the service.
  - Ranking by quintiles is used to identify areas of relative high priority, improvement areas and gaps.

8. Limitations to the model and potential future improvement (where relevant)

A key limitation of the model is its reliance on modelled air pollution events from road traffic use, estimated from road type. Ideally, a wider range of air pollution impacts would be considered, and this could be partly achieved by examining the capacity maps against maps of Air Quality Management Areas (AGMA) identified by local authorities.

To address the limitation that air movement is not modelled, the prevailing wind direction could be used, although the impact of street alignment and canyons on channelling wind would have to be investigated.

Further investigation of the habitat-based scores for air purification would be beneficial. Use of roughness scores, as used e.g. in the CEH AMBER project could be investigated.

Limitation	Impact
Source data	Habitat mapping is often only available at the broadest level. Fine scale variations in population demographics are masked. There may be errors in classification of households / domestic building location
Literature	Relatively few published sources on which to base the mapping rules, more information on pollution levels from different roads types, and impact distances are required.
Mapping rules transferability	Ideally specific locations of different illness hotspots would be included rather than general health scores. Capacity scores given to each broad habitat type require further clarification
Study area extent	Very small study areas may not contain the type of large roads predicted to cause air pollution
Landscape composition	In rare cases of upland or entirely arable landscapes there may be no areas of mapped capacity Building height in urban areas may impact air pollution levels via air circulation, but is not well covered by the models
Buffer zone impacts	N/A
Landscape pattern	N/A
Topography	Topography will impact on the capacity of habitats due to its influence on air movement and circulation, but it is not currently included in the models.

9. Final List of Indicators

Indicators with a suffix of _IndC or _IndD are saved in the Indicators Geodatabase.

Indicator Name	Type	Description
AP site IndC	Capacity	Site cell Air Purification Capacity score
Man Made2 IndD	Demand	Proportion (%) of man-made surface within search distance
Health2 IndD	Demand	Health deprivation score (mean) within local search distance
Popn IndD	Demand	Population size (sum) within local search distance
Road Dist2 IndD	Demand	Proximity score to nearest busy road (high score = close distance)

Detailed GIS Analysis steps

Model: ES1AirPurificationCapacity

Estimates the capacity of each cell to filter air pollution from the surrounding area

- Defaults are set for cell size and extent, but can be altered by the user.
- Sub models delete all previously run data from Scratch, Outputs, Indicators, Shapefiles geo database and folders (mainly required during model testing rather than the final models).
- Raster is created based on the "AirPurScore" in the link table.
- A distance analysis is carried out from areas with capacity to create a mask of areas in which the service occurs (default 10 m from habitats).
- Focal statistics score (SUM) in the short search neighbourhood (default 20 m).
- Focal statistics score (SUM) in the local search neighbourhood (default 100 m).
- Two focal scores are summed.
- Values greater than 0 are extracted.
- Values above a threshold for minimum functional patch size are extracted (default > 500 m^2).
- Extract by mask is applied (default Study Area buffer).
- Values are re-scaled onto a 1 to 100 scale.
- A version of the dataset with No Data replaced by 0 is created.
- Datasets (raster) saved as AirPurification_Capacity and AirPurification_Capacity_0_100.
- A sub model converts the raster data to vector shapefiles. The values are grouped into simplified categories, e.g. 1-10 (10), 10-20 (20), 20-30 (30) etc.

Model: ES2AirPurificationDemand

Estimates the societal demand for air purification based on population density and IMD health scores and the regulatory need for air purification based on proximity to roads

- Defaults are set for cell size and extent, but can be altered by the user.
- Sub models delete all previously run data from Scratch, Outputs, Indicators, Shapefiles geo database and folders (mainly required during model testing rather than the final models).
- A selection is made on the OSRoads layer (source OS VectorMap) to extract busy roads (dual carriageways and motorways, A roads, primary roads). This layer is buffered by 40 m and this is used to clip out the more accurately mapped (higher resolution) polygons from the BaseMap_FINAL layer. From this clipped BaseMap layer any roads are selected that intersect the selected roads in the OSRoads layer. This returns a selection of BaseMap polygons that represent busy roads. Distance analysis is conducted on these selected roads, up to a threshold distance (default 400 m) and this is converted to log10 distance score and then to an inverse distance score and also mask dataset of all areas within the threshold distance of roads. This is converted to Z scores, and also re-scaled 1 to 100.
- The Pop-socioeconomic points data (population) was analysed with focal statistics (SUM) up to the local neighbourhood distance (default 300 m), then masked to areas close to roads. This is converted to Z scores, and also re-scaled 1 to 100.
- Areas of man-made surface are selected from the BaseMap_FINAL and a focal statistics (SUM) calculation is carried out at a local scale (default 300 m). This is converted to Z scores, and also re-scaled 1 to 100.
- The health IMD score data is analysed with focal statistics (MEAN) at the local neighbourhood distance (default 300 m) to create the health score. This is converted to Z scores, and also re-scaled 1 to 100.
- Four indicator scores are therefore produced.
    - Distance to roads (1 to 100).

    - Population density (1 to 100.)
    - Man-made surface cover (1 to 100).
    - Health deprivation (1 to 100).
- Each re-scaled indicator score (roads, population, man-made cover and health) is weighted via an optional user defined weight using the times tool (default 1). The indicator is simply multiplied by the user-defined weighting. Setting a weight of 0 allows one or more of the indicators to be removed from the analysis.
- Values for the weighted indicators are combined using cell statistics (SUM).
- Values greater than zero are extracted.
- Extract by mask is applied (default Study Area buffer).
- Values are re-scaled onto a 1 to 100 scale.
- Datasets (raster) saved as AirPurification_Demand .
- A sub model converts the raster data to vector shapefiles. The values are grouped into simplified categories, e.g. 1-10 (10), 10-20 (20), 20-30 (30) etc.

Model: ES3AirPurificationFlows

The capacity and demand data are converted to quintiles and overlaid to identify benefitting areas and gaps

The service flow model is the same for each service

- Defaults are set for cell size and extent, but can be altered by the user.
- Sub models delete all previously run data from Scratch, Outputs, Indicators, Shapefiles Geodatabase and folders (mainly required during model testing rather than the final models).
- Sub model takes the separate capacity and demand datasets and produces the following datasets for either the Study Area or the Study Area plus buffer:
    - Capacity quintiles based on area and value.
    - Demand quintiles based on area and value.
    - All areas where there is some level of demand.
    - When the quintiles are calculated for capacity these are only created for areas with Demand > 0.
- The service occurrence, demand and quintiles data are combined to create two sets of benefiting area data:
    - Ecosystem Service Benefiting Areas (ESBA) and gaps.
    - Ecosystem Service Benefiting Areas (ESBA) and gaps - prioritised.
- Ecosystem Service Benefiting Areas occur where Demand > 0 and Capacity > 0.
- Service Gaps occur where Demand > 0 and Capacity = 0.
- The prioritised data are defined by selecting the highest quintile (5) as high demand or high capacity, this allows the following categories to be produced:
    - A1 - Service Benefiting Area - High Demand (Q=5) and High Capacity (Q=5).
    - A2 - Service Benefiting Area - High Demand (Q=5) and Low Capacity (Q=1).
    - A - Service Benefiting Area - other (Demand Q>0<5 and Capacity Q>0).
    - B1 - Service Gap - High Demand (Demand Q=5 and Capacity Q=0).
    - B - Service Gap (Demand Q>0<5 and Capacity Q=0).
    - C1 - Restricted Service - High Demand (Demand (Q=5) and Capacity (Q>0 but restricted).
    - C - Restricted Service - other (Demand (Q>0<5) and Capacity (Q>0 but restricted).
- The ESBA and ESBA - prioritised datasets are each comprised of a single dataset to facilitate their use in later zonal statistics analysis.
- A sub model identifies "GI assets" by masking the service capacity maps to illustrate only those areas where there is a level of demand.

- A sub model exports the raster files to shapefiles. An optional patch area threshold allows small areas to be removed during the conversion process (default shape area > 200 m^2).

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