DEC-DECISION SUPPORT SYSTEMS

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A GIS APPLICATION AS DECISION SUPPORT FOR AIR MONITORING NETWORK

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ABSTRACT

The results of a GIS application in designing an air monitoring network in Northern Italy are presented. In order to understand the distribution of pollutants (NO_x, NO_2, O_3 and VOCs), four specific campaigns (October to August 2004) were carried out using diffusive samplers. Maps showing spatial distribution of each pollutant were created, and a land cover map was obtained using a mosaic of orthophotos. By overlaying pollutant distribution maps and land cover map, it was possible to determine the suitable location of monitoring stations.

Key Words: Air Pollution, Monitoring Network, GIS, Land Cover/Use Map, Digital Ortophotos

1. INTRODUCTION

Air pollution and its impact has become one of the most important problem throughout the world, and the quantification of emissions as well as their spatial distribution are essential for any air quality program (Aleksandropoulou and Lazaridis, 2004; Sengupta et al., 1996).

One of the most difficult tasks in designing an air monitoring network is the choice of the location of the monitoring station, taking into account the harmful effects of pollution on both human health and environment (Allegrini et al., 2004). The European and Italian Directives provide the criteria to select areas suitable to install monitoring stations; these directives indicate the minimum distance that should exist between the pollutant source and the monitoring station, the minimum number of sample points and the reference measurement and sampling techniques to be used on a macro and micro scale. In the past, the Italian legislation indicated areas with higher concentration of pollutants as the most suitable measuring sites. Recently the European Directive (EEA, 1999) on atmospheric pollution required a detailed evaluation of the environment on a local and regional scale, by means of field data and thematic maps, particularly if industrial sites are located close to urban areas.

A GIS technology can be adopted to fulfil this Directive: a Geographic Information System (GIS) is a computer-based information system that enables storing, modelling, manipulation, retrieval, analysis and presentation of geographically referenced data (Burrough, 2001). The organization of all this information by means of geographic coordinates allows data from a variety of sources to be easily combined in a uniform framework. GIS mainly involves overlaying different data sets such as environmental, chemical, population and meteorological data, thus allowing to perform arithmetical and relational operations. In addition, the integration of multitemporal data allows the monitoring of environmental parameters related to an area or to a particular process, highlighting the dynamic process that develops over a long time period.

Every environmental analysis should be based on the land cover/use maps (Weirs et al., 2004). By means of an automatic classification method applied to satellite images or digital aerial photographs (Foody, 2000), it is possible to obtain an accurate map to be integrated with atmospheric data.

Maps indicating the concentration of air pollutants such as NOx, NO_2 or ozone can be used to assess the possible impact of pollutants on human health (Stedman et al., 1997). By overlaying the land cover/use map with pollutant concentration maps, urban and vegetated areas subject to long periods of high level of pollution can be identified, and consequently the monitoring station in according to current directives can be located.

This paper presents the results of a GIS application in designing an air monitoring network, according to the European Criteria; the test site is a complex area in Northern Italy characterized by urban and rural agglomerates surrounded by industrial plant and agricultural areas.

2. MAIN TEXT

The study area is located in Northern Italy, close to the city of Mantova, in Po Valley. It is a large alluvial and fertile plain, characterised by open agricultural land, intermingled with scattered rural dwellings and farmhouses. The agricultural areas are associated with permanent crops under a continuous rotation system, flooded crops such as rice fields and other inundated croplands, and complex cultivation patterns. Natural vegetation systems are represented by two small regional reserves, named “Marsh of Ostiglia” and “Isola di Boschina”, and also include hedge and trees rows along croplands.

The marshes of Ostiglia are international wetlands according to the Ramsar Convention and are connected with Natura 2000 network in line with the Birds directive (79/409/CEE) and the Habitats directive (92/43/CEE). The principal vegetation is large reed beds and sedge communities, and covers an area of 123 ha. The “Isola Boschina” reserve is close to the Po river. The vegetation is composed of broadleaved woodlands with *Quercus pedunculata* and *Populus* sp. pl., associated with *Ulmus minor*, *Acer campestre*, *Prunus avium* and *Fraxinus oxycarpa*. The reserve covers a small surface area (about 38 ha) and represents the last residual plain forest that once constituted the landscape of the Po Valley.

In the study area an hydroelectric station is located at about 40 km from Mantova, surrounding Sermide countryside. Toxic emissions of NO_x and CO are controlled by a monitoring emission system (SME).

In order to understand the distribution of air pollution throughout the study area, four specific assessment campaigns (October 2003 to August 2004) were carried out using a diffusive sampling method. The diffusive samplers were developed at the Institute for Atmospheric Pollution of CNR; the samplers are particularly suitable for preliminary assessment since they may be exposed for several months in an specific location, providing average concentrations over the entire exposure period (De Santis et al., 1997 and 2004). The sampler is a modification of the open-tube design obtained by using a filter treated with appropriate reagents to trap the pollutant. The body of the sampler is a cylindrical vial with a threaded cap at one end. The pollutant is collected on an impregnated disc placed at the bottom of the vial and held in position by a stainless steel ring. To avoid turbulent diffusion inside the vessel, the open end is protected using a fine stainless steel screen.

More than hundred diffusive samplers were used and an exposure time of 30 days was selected. Nitrogen Oxides, Nitrogen Dioxide, Ozone and Volatile Organic Compounds (VOCs) were monitored during the campaigns.

The samplers were distributed in a regularly spaced 3 km x 3 km grid in the study area. Concentration values of the measured pollutants and the geographic co-ordinates of the samplers were organized in a database.

Using GIS routines, concentration maps for each pollutant were created for each campaign and used as layers in the Geographic Information System.

To perform pollutant concentration maps, Inverse Distance squared Weighted (IDW) interpolation technique was applied. IDW estimates cell values by averaging the value of sample data points in the vicinity of each cell. This method assumes that each measured point has a local influence that decreases with distance. To classify the concentration maps, the range of pollutant values was divided into eight equal-size intervals.

In order to perform landscape assessment, as required by the European criteria, a preliminary analysis was performed using a mosaic of orthophotos of the Po River Plain. Because of high spatial resolution, orthophotos represent excellent base maps for recognising territorial features and for determining the precise location of the sites where the monitoring system should be installed. The nominal scale of the orthophoto is 1:5000, satisfying the requirements of the European Community.

Using the orthophoto mosaic, a land cover classification was performed using photointerpretation techniques and nearest neighbourhood interpolation algorithm. The land cover/use classes were selected and analysed according to CORINE Land Cover Classification as reported in Table 1. Twelve land cover/use classes were recognized and particular attention was paid to urban areas.

Table 1. CORINE land cover/use classes

Level 2	**Level 3**
1.1 **Urban fabric**	1.1.1 Continuous urban fabric
	1.1.2 Discontinuous urban fabric
1.2 **Industrial, commercial and transport units**	1.2.1 Industrial or commercial units
	1.2.2 Road and rail networks and associated land
2.1 **Arable land**	2.1.1 Non-irrigated arable land
	2.1.3 Rice fields
2.4 **Heterogeneous agricultural areas**	2.4.1 Annual crops associated with permanent crops
	2.4.2 Complex cultivation patternes
3.1 **Forest**	3.1.1 Broad-leaved forest
3.2 **Scrub and/or herbaceous vegetation associations**	3.2.4 Transitional woodland-scrub
4.1 **Inland wetlands**	4.1.1 Inland marshes
5.1 **Inland waters**	5.1.2 Water bodies

Since the orthophotos were taken in different periods, the spectral response varied in several parts of the mosaic consistent with phenological phases of vegetation and water colour of the Po River.
Therefore the following processing steps were carried out to obtain the land cover map:

- a regular grid of 250 m^2 was overlaid on the photo mosaic;
- each grid cell was associated to a land cover/use class listed in Table 1;
- Nearest Neighbour algorithm was applied to the grid to obtain the land cover map (Figure 1);
- the orthophoto mosaic was georeferred to an cartographic base map on a 1:100.000 scale.

The use of a regular grid and the photointerpretation of each cell grid were suitable tools to represent all landscape features and, in particular, they were very useful to characterize the scattered rural buildings that are peculiar elements of the Po Valley. Since this study was focused on preventing the effects of pollutants on human health, coding of each cell was carried out overestimating the urban fabric. The cell was classified as discontinuous urban fabric even if a single farmhouse was identified; the same procedure was applied to road and rail networks and industrial or commercial units (Table 1). The land cover map was afterwards obtained using Nearest Neighbour interpolation technique. The Nearest Neighbour is a point interpolation which requires a point map as input and returns a raster map as output. Each pixel in the output map is assigned to the class of the nearest point, based on the shortest distance according to the Euclidean distance.

The concentration maps of each pollutant, carried out using the IDW method, were analysed in order to understand the temporal distribution of each pollutant in the study area. In Figure 2 concentration maps of ozone achieved during the monitoring campaigns are shown. For all campaigns, the areas with concentration values above average were selected and the results were resumed in four different summery maps, one for each pollutant (NO_x, NO_2, O_3 and VOC respectively). Afterwards, from each summery map, areas with values above average for three or four campaigns were extracted and plotted together in a new map. This map, called multiple occurrence map (Figure 3), shows all the areas with high concentration values of each pollutant over a long period. In the north-east part of the map, an area where all pollutants have high concentration values is shown, while in the central part of the map, a large area with a high concentration of ozone is present.

Suitable areas for monitoring station were determined by integrating the land cover map and the multiple occurrence map (Figure 4). Areas related to urban fabric and road network classes were extracted from the land cover map and were crossed with the occurrence map in order to identify suitable areas for each type of monitoring station (traffic, exposition and background station), according to EUROAIRNET criteria (EEA, 1999). In the traffic stations, the emissions from motor vehicles are considered as a major source of pollution while in the industrial stations only the emission from industrial zones are considered. The background stations are located where the pollutants come from all windward sources.

GIS techniques using pollutants distribution maps and land cover maps together with supplementary territorial analyses data was therefore used to retrieve information needed to determine the potential location of measuring stations.

In Figure 4a, the most suitable locations for traffic monitoring stations are recognized in the northern portion of the study area, while exposition stations should be located close to the small town where in three different seasons a maximum concentrations of ozone was measured. During the monitoring period, in the other small town present in the study area, the pollutant concentrations were always lower than the maximum value for that period. For this reason, monitoring stations close to this area are not necessary. In Figure 4b, the sites for background stations were indicated by large areas where the concentration of NO_x and Ozone was above the mean values for that period.

The final resulting maps obtained can be used for developing air pollution management strategies, such as the delineation of control areas and the selection of monitoring sites. Site that matches best fitting criteria were located on the maps and their location was indicated to local authorities to establish a permanent measuring network.

3. CONCLUSION

A decision support system was developed for air quality management in the Po River Valley. Concentration of NO_x, NO_2, O_3 and VOCs have been measured using diffusive samplers during four campaigns. Pollutant concentrations and ortophoto mosaic were used to created a GIS project to perform spatial analysis.

Pollutant concentration maps were computed with IDW method. To obtain a land cover map of the study area (scale 1:5000) a multi-stage approach which includes photointepretation and spatial interpolation was performed. Overlaying pollutant distribution maps, multiple occurrence map and land cover map, areas suitable as monitoring station were detected.

In this study, GIS techniques have been used as an efficient tool for planning the monitoring network and for assessing the exposure level of population.. The final maps obtained from GIS analysis can be used for developing different air pollution management strategies, such as the delineation of control areas or the position of monitoring stations, taking into account the European directives.

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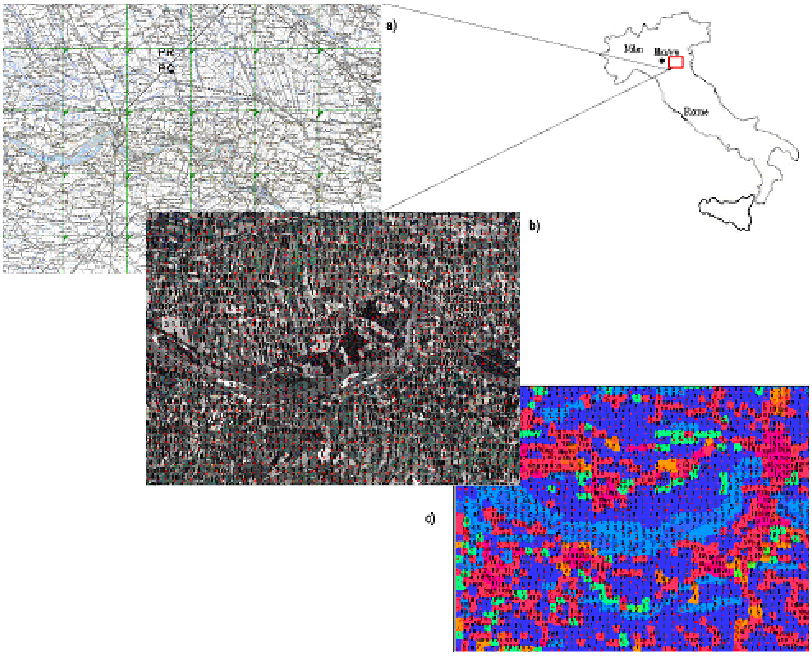

Figure 1. Location map (a), ortophoto detail with land cover codes overlaid (b), and land cover map obtained with nearest neighbour interpolation (c).

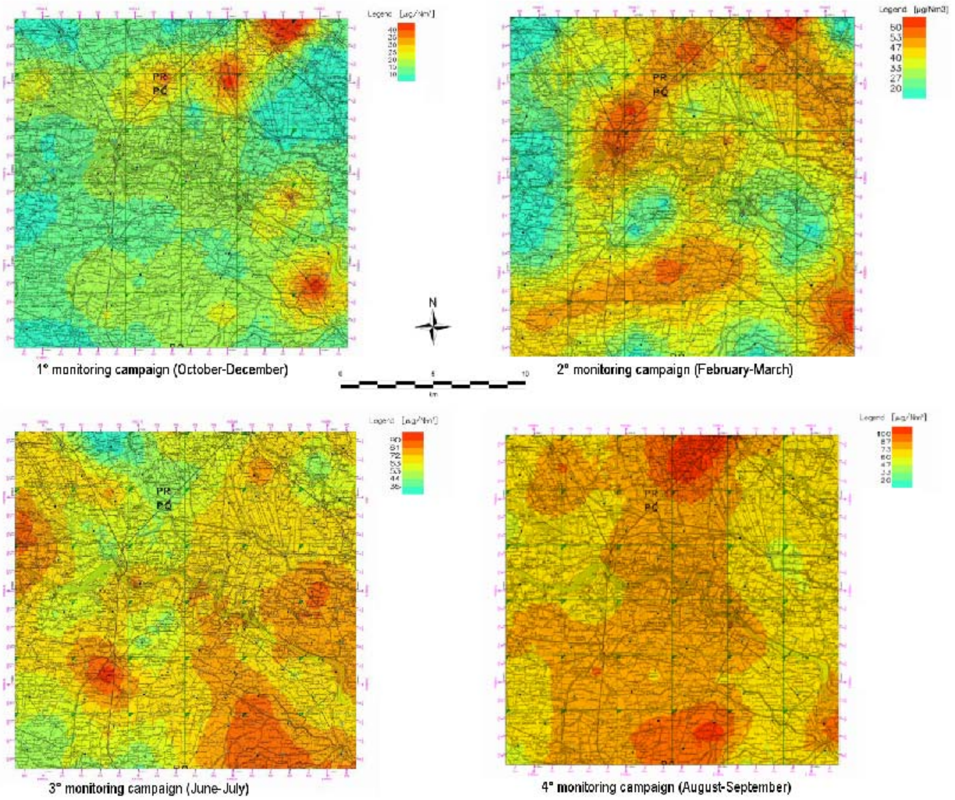

Figure 2. Concentration maps of Ozone during the different monitoring campaigns.

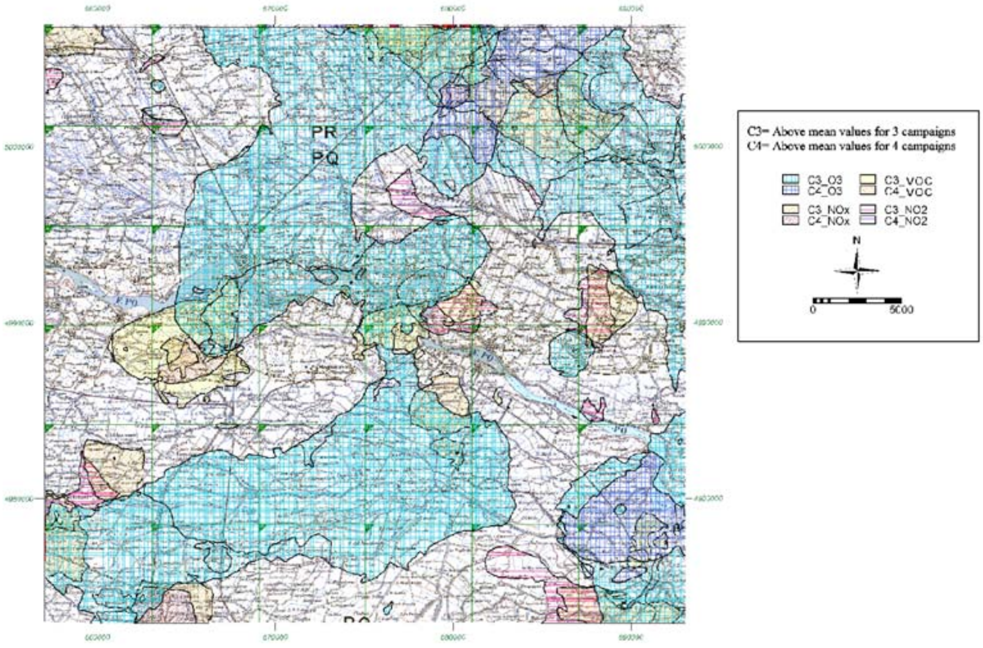

Figure 3. Multiple occurrence map.

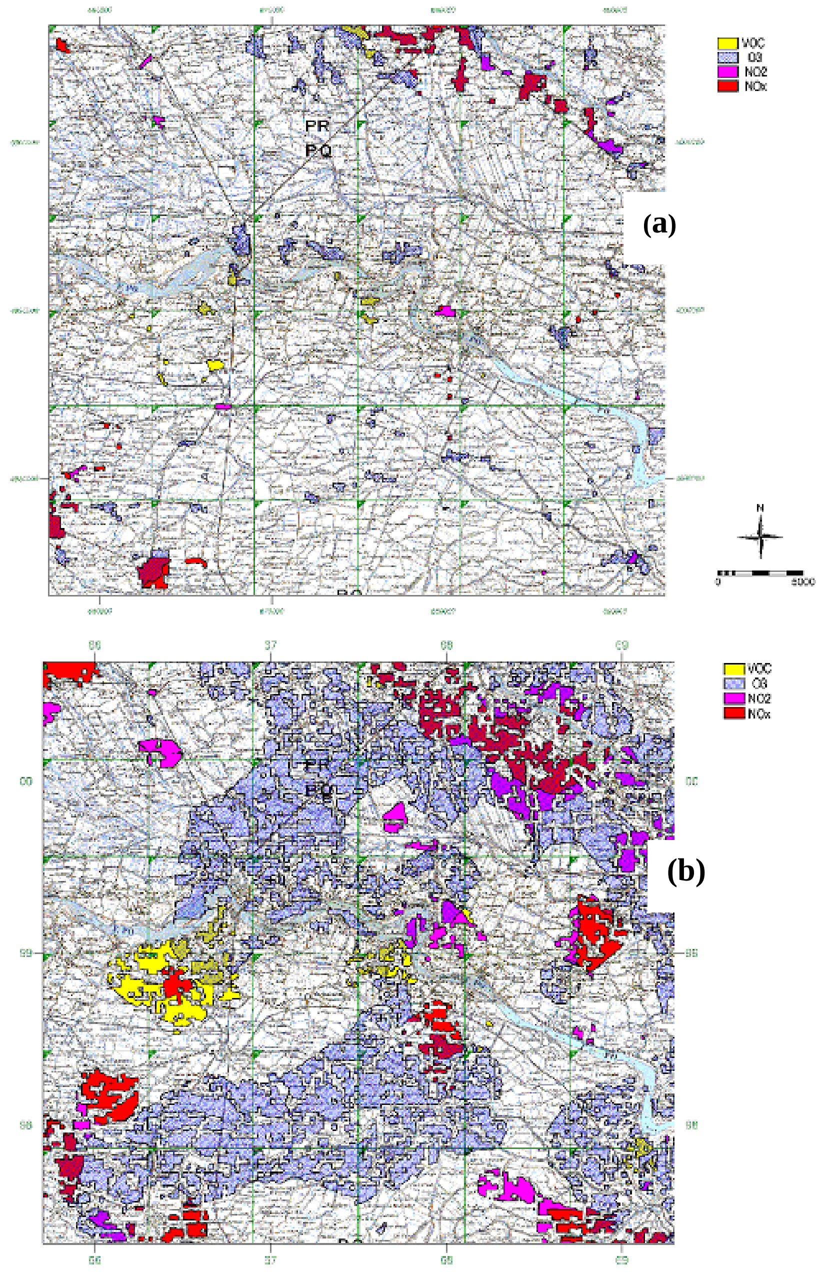

Figure 4. Areas suitable for monitoring stations: (a) traffic station, (b) background station.

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SAGA: A Decision Support System for Air Pollution Management around a Coal Fired Power Plant

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ABSTRACT

Since the use of meteorological models for weather forecasting, the need for specific meteorological modeling and the complexity of the air pollution dispersion and chemical transformation delayed the use of model-based air pollution forecasting approaches.

From the experience of one of the first source-oriented modeling approach for air pollution forecasting 1994 (Souto et al., 1996; Souto et al., 1998), a new Decision Support System for Air Quality Management, SAGA, was developed to provide support to the power plant staff. SAGA is an operational system for air pollution forecasting and data analysis around air pollution point sources.

SAGA provides 1-day forecasts for the hourly evolution of the most significant meteorological and local air quality parameters; these results are presented in several reports adapted to provide useful information to the power plant staff. Additionally, meteorological and local air quality measurements are available through SAGA, to either confirm or correct the forecast-based decisions.

In this case, the use of meteorological and air quality measurements in real-time is not enough, so the power plant decisions have to be based in the results of meteorological and air quality models, provided by SAGA.

Key Words: Decision Support, Air Quality, Meteorological Forecast

1. INTRODUCTION

As Pontes Power Plant (APPP) is a 1400 MW coal-fired power plant located in Galicia (NW of Spain) that burns a mixing local lignite (with up to 2 % of sulphur) and foreign coal (with less than 0.1 % of sulphur). The combustion gases are emitted through a 350-m stack, in order to prevent local air pollution episodes. However, a complex terrain environment with sea-influence from the Atlantic Ocean can produce meteorological conditions favourable to poor local air quality.

The development of air pollution forecasting systems in APPP, based in source-oriented models, started in 90's. The main goal of these model-based systems was to forecast, 24 hours in advance at least, unfavourable meteorological and SO_2 air quality conditions due to the plume dispersion emitted by the power plant, in order to prevent SO_2 air pollution alerts and to plan changes in the power plant operation (low production, mixing of coals with less sulphur).

The work started in 1990 with the study of the state-of-the-art in meteorological and plume dispersion modeling (Souto et al., 1994), those could be operationally applied to prevent the local air quality around an industrial plant, with limited computational time. First conclusions shown that,

- available operational weather forecasts cannot provide meteorological fields accurate enough in the planetary boundary layer to be coupled to appropriate plume dispersion models, so a local micro-mesoscale meteorological model is necessary,
- some advanced Lagrangian puff models and newer Lagrangian particle models are the most adequate for estimating the local plume dispersion, and
- complexity of the models (specially, the meteorological model) is limited by the available computational time in a workstation environment (less than 1 Mflop).

With these considerations, a plume dispersion forecasting system was developed (Souto et al., 1996; Souto et al., 1998) and started to run in 1994. This system included an emissions module (based in mass balances in the coal-fired plant), a hydrostatic meteorological model coupled to the Spanish National Weather Service forecast, and an operational version of the Adaptive Puff Model (APM, Ludwig et al., 1989) for plume dispersion estimation. Models results could be analysed by using an X-window graphical user interface (GUI), as time-series and maps of meteorological and air quality parameters. The use of this system and the analysis of its results required a good knowledge and experience in both GUI (over UNIX systems) and air quality modeling. Therefore, an expert in these issues provided the recommendations to the power plant staff, in order to prevent future air pollution episodes.

With the increment of the personal computers performance, the possibility of porting this system to a MS-Windows environment was considered. At the same time, the accumulated experience in data analysis for air quality decision support would allow to select the most significant meteorological and air quality data to obtain automatic reports for the power plant staff. With this base, SAGA Decision Support System for Air Quality Management was developed and launched (for testing) in 2003.

In this work a description of SAGA software and its modules are introduced, including the capabilities to adapt SAGA to different environments and numerical models. Following, the use of SAGA at As Pontes Power Plant is considered. Next, some results from the main forecasting parameters provided by the operational SAGA software at APPP are shown. Finally, the main conclusions are presented.

2. SAGA

As a decision support system oriented to air quality management around a point source, SAGA is configured by the combination of three types of models,

a) An emissions model, that estimates the emissions and flow of the flue gas from the point source (typically, an industrial plant), depending on the planned operation, at least one day before.

In APPP, this is based in a coal combustion model, that estimates the flow and composition of flue gas depending on the coals selected and the electric power that is planned to produce tomorrow.

b) A meso-β meteorological model, that provides a high resolution numerical weather forecast, with specific interest in the meteorological parameters with significant effect in the plume dispersion.

At APPP, two meteorological models, ARPS model (Balseiro et al., 2001) and MM5 (Grell et al., 1995), have been tested. Currently, ARPS is the operational model, providing a high resolution numerical weather forecast (24 hours in advance), for the surrounding area 30 km around the power plant. Recently 2-km and 10-km horizontal resolutions were compared (Saavedra et al., 2005) without any significant differences.

c) A Lagrangian atmospheric diffusion model that estimates the local primary pollutants concentrations around the point source. Although secondary pollutants (like O_3) are an significant air quality issue nowadays, the relationships between secondary pollutants levels and local point source emissions are usually more specific to each environment. Therefore, SAGA is currently limited to primary gaseous pollutants.

At APPP, SO_2 emissions dispersion is estimated by using two different Lagrangian diffusion models: Adaptive Puff Model 2 (APM2, Souto et al., 2000) and Lagrangian Particle Model (Souto et al., 2001; Penabad et al., 2002). Both models are currently in testing, so their results are not definitive to the power plant staff.

As the main results, any of each meteorological model can provide one-day forecasts (1-hour and 6-hours average periods) of selected parameters at the point source location: Wind, temperature, lapse rate, solar radiation and cloud cover. In addition, the Lagrangian diffusion models provide one-day ground level concentration forecasts (1-hour average periods) at selected locations around the point source.

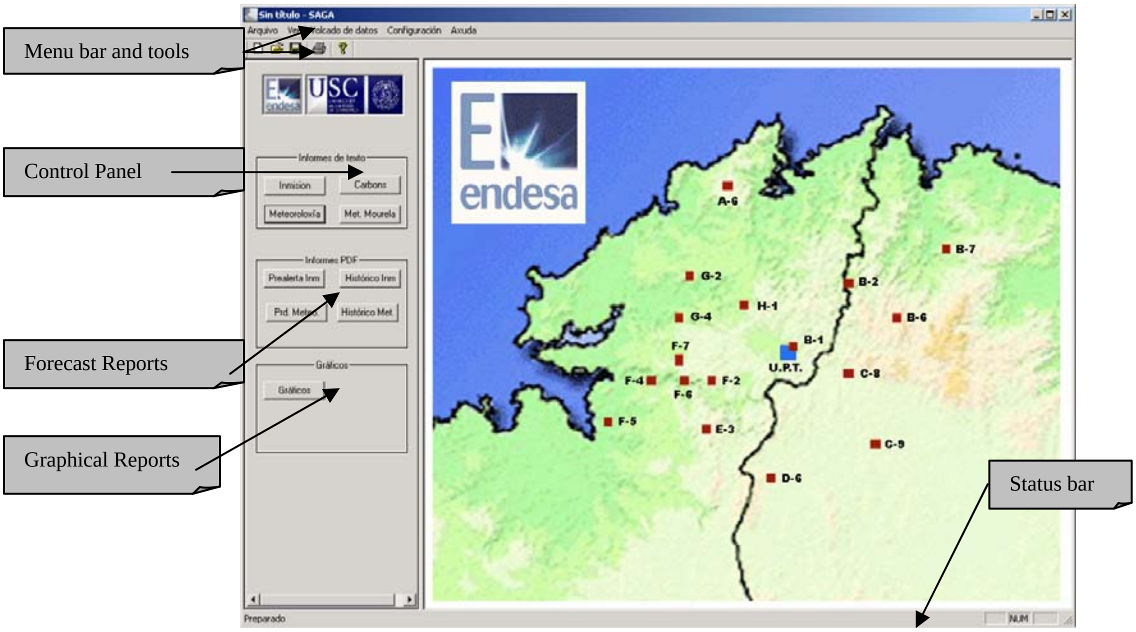
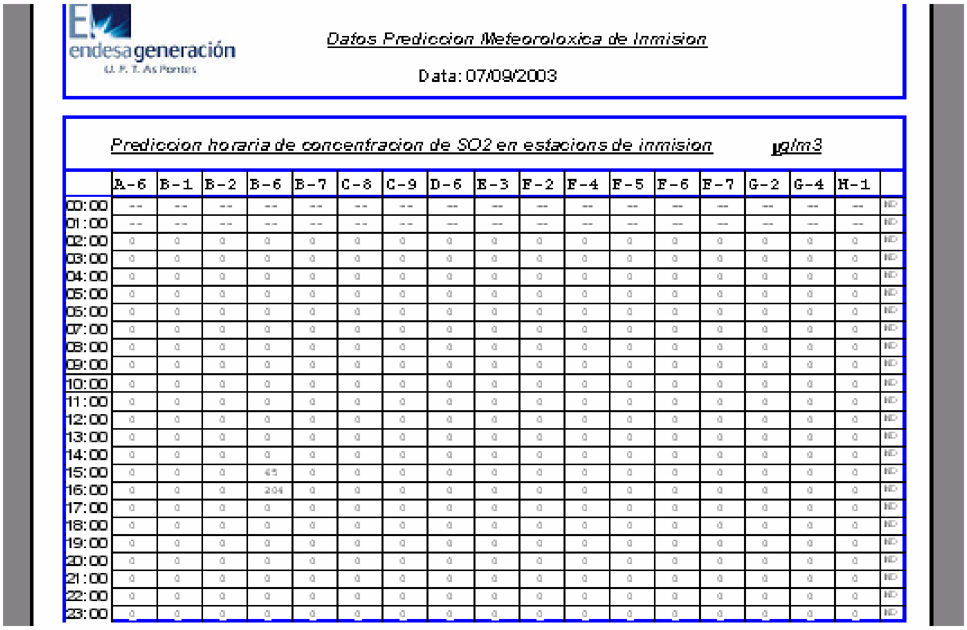


Figure 1. SAGAwin: Main window, including the MS-Windows menu bar, the Control Panel, the Active Window and the Status bar.

2.1. SAGA interfaces

SAGA is a modular software package with two different interfaces,
a) A MS-Windows interface (SAGAwin), that provides general reports about meteorological and air quality measurements and forecasts at the selected point source environment.
b) A Web-based interface (SAGAweb), that provides specific reports adapted to the requirements of the air quality control around the selected point source.
Figure 1 shows the main window of SAGAwin, showing the typical MS-Windows menu bar, a Control Panel to get text or graphical reports, an Active Window (with the APPP environment) for showing the selected reports, and a Status bar for showing any incidence.
As an example of text report, figure 2 shows a ground level concentration (glc) text reports. It can include hourly glc values either measured or forecasted along a selected date.



Datos Prediccion Meteoroloxica de Inmision

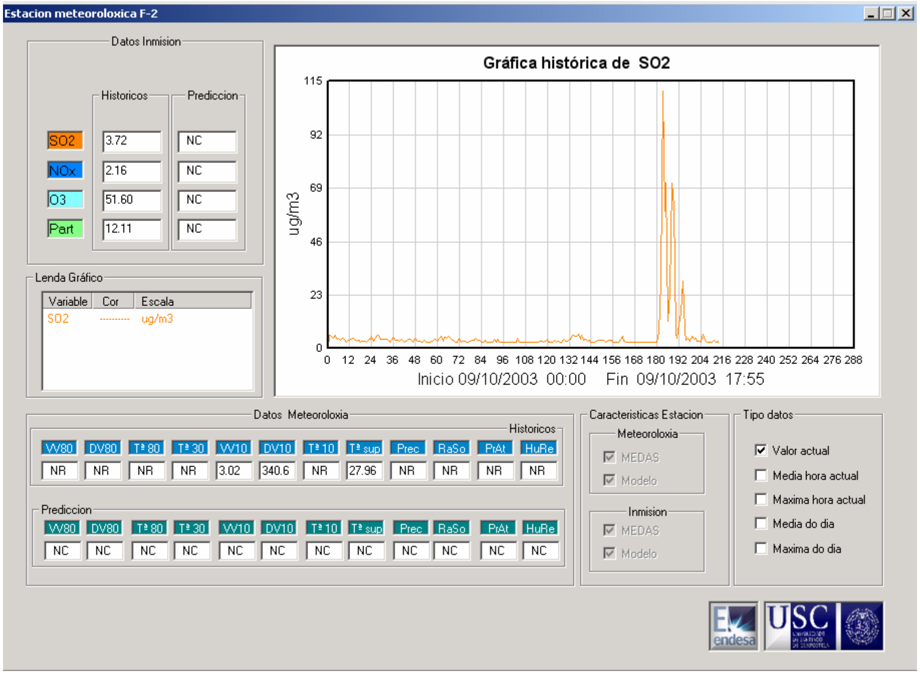
Data: 07/09/2003

Prediccion horaria de concentracion de SO2 en estacions de inmision μg/m3

	A-6	B-1	B-2	B-6	B-7	C-8	C-9	D-6	E-3	F-2	F-4	F-5	F-6	F-7	G-2	G-4	H-1	
00:00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	ND
01:00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	ND
02:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
03:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
04:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
05:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
06:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
07:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
08:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
09:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
10:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
11:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
12:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
13:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
14:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
15:00	0	0	0	65	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
16:00	0	0	0	204	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
17:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
18:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
19:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
20:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
21:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
22:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND
23:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ND

Figure 2. SAGAwin: An example of ground level concentration text report, showing some of the forecasted glc hourly values for September, 7th 2003.

Graphical reports combine either meteorological or air quality data, measured and forecasted by SAGA. As an example, on figure 3, SO_2 glc (5-minutes averages) measurements along one day at a specific monitoring station are shown; and, figure 4 includes temperature measurements at 4-levels in the A Mourela meteorological tower, for the same day.



Datos Inmision

	Historicos	Prediccion
SO2	3.72	NC
NOx	2.16	NC
O3	51.60	NC
Part	12.11	NC

Lenda Gráfico

Variable	Cor	Escala
SO2	---------	ug/m3

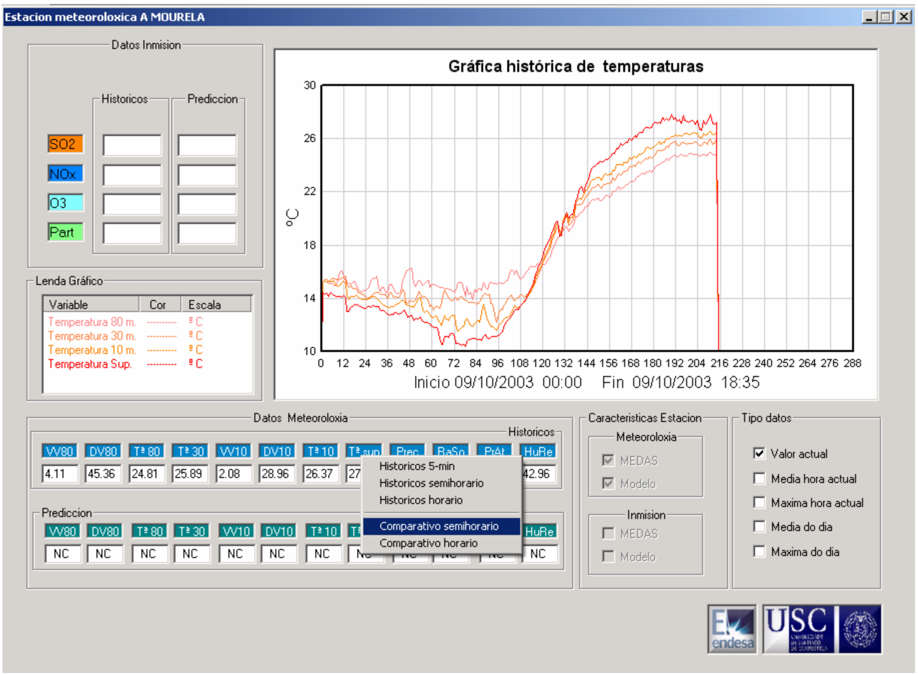
Datos Meteoroloxia

	VV80	DV80	Tª 80	Tª 30	VV10	DV10	Tª 10	Tª sup	Prec	RaSo	PrAt	HuRe
Historicos	NR	NR	NR	NR	3.02	340.6	NR	27.96	NR	NR	NR	NR
Prediccion	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

Caracteristicas Estacion
Meteoroloxia: ☑ MEDAS ☑ Modelo
Inmision: ☑ MEDAS ☑ Modelo

Tipo datos
☑ Valor actual
☐ Media hora actual
☐ Maxima hora actual
☐ Media do dia
☐ Maxima do dia

Figure 3. SAGAwin: Measured SO_2 ground level concentration (5-minutes averages), along October, 9th 2003.



Datos Inmision

	Historicos	Prediccion
SO2		
NOx		
O3		
Part		

Lenda Gráfico

Variable	Cor	Escala
Temperatura 80 m.	---------	ºC
Temperatura 30 m.	---------	ºC
Temperatura 10 m.	---------	ºC
Temperatura Sup.	---------	ºC

Datos Meteoroloxia

	VV80	DV80	Tª 80	Tª 30	VV10	DV10	Tª 10	Tª sup	Prec	RaSo	PrAt	HuRe
Historicos	4.11	45.36	24.81	25.89	2.08	28.96	26.37	27				42.96
Prediccion	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

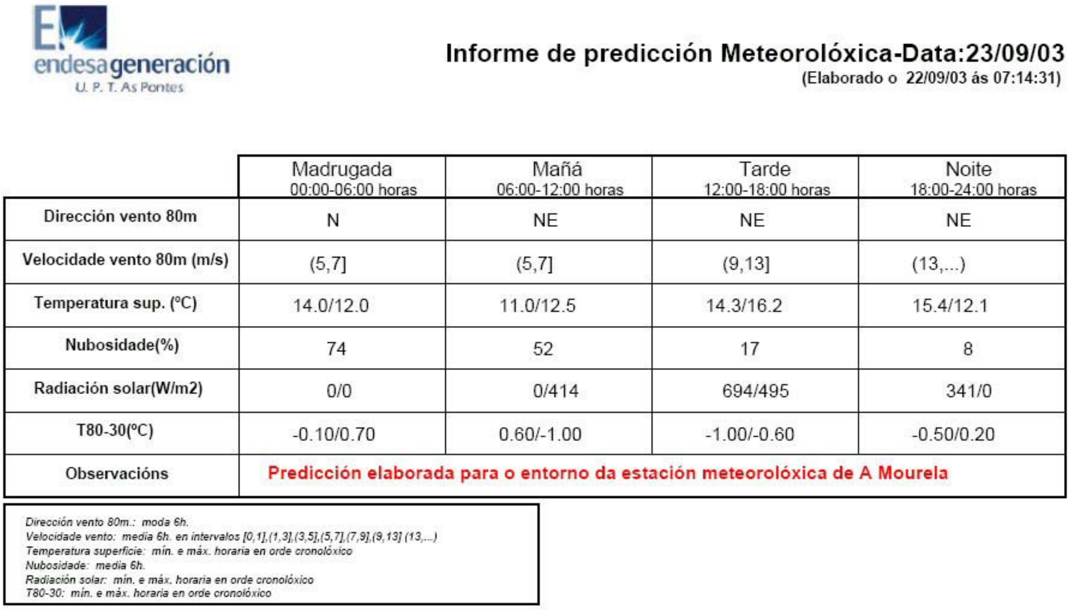
Caracteristicas Estacion
Meteoroloxia: ☑ MEDAS ☑ Modelo
Inmision: ☐ MEDAS ☐ Modelo

Tipo datos
☑ Valor actual
☐ Media hora actual
☐ Maxima hora actual
☐ Media do dia
☐ Maxima do dia

Figure 4. SAGAwin: Measured temperatures (5-minutes averages) at 4-levels (2-m, 10-m, 30-m and 80-m), along October, 9th 2003.

2.2. SAGA reports

Because of the huge amount of information generated by these models (especially, meteorological and dispersion models), specific graphical and text reports were designed to provide the appropriate information to the power plant staff.



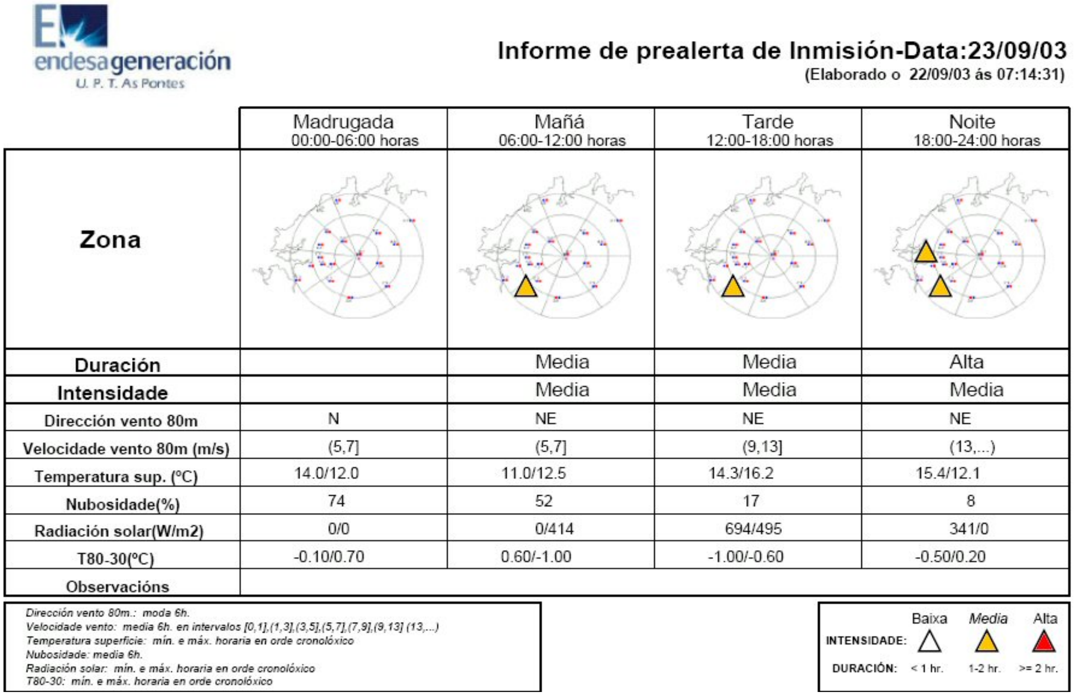
endesageneración
U. P. T. As Pontes

Informe de predicción Meteorolóxica-Data:23/09/03
(Elaborado o 22/09/03 ás 07:14:31)

	Madrugada 00:00-06:00 horas	Mañá 06:00-12:00 horas	Tarde 12:00-18:00 horas	Noite 18:00-24:00 horas
Dirección vento 80m	N	NE	NE	NE
Velocidade vento 80m (m/s)	(5,7]	(5,7]	(9,13]	(13,...)
Temperatura sup. (ºC)	14.0/12.0	11.0/12.5	14.3/16.2	15.4/12.1
Nubosidade(%)	74	52	17	8
Radiación solar(W/m2)	0/0	0/414	694/495	341/0
T80-30(ºC)	-0.10/0.70	0.60/-1.00	-1.00/-0.60	-0.50/0.20
Observacións	**Predicción elaborada para o entorno da estación meteorolóxica de A Mourela**			

Dirección vento 80m.: moda 6h.
Velocidade vento: media 6h. en intervalos [0,1],(1,3],(3,5],(5,7],(7,9],(9,13] (13,...)
Temperatura superficie: mín. e máx. horaria en orde cronolóxico
Nubosidade: media 6h.
Radiación solar: mín. e máx. horaria en orde cronolóxico
T80-30: mín. e máx. horaria en orde cronolóxico

(a) Meteorological Forecast (MF)



endesageneración
U. P. T. As Pontes

Informe de prealerta de Inmisión-Data:23/09/03
(Elaborado o 22/09/03 ás 07:14:31)

	Madrugada 00:00-06:00 horas	Mañá 06:00-12:00 horas	Tarde 12:00-18:00 horas	Noite 18:00-24:00 horas
Zona				
Duración		Media	Media	Alta
Intensidade		Media	Media	Media
Dirección vento 80m	N	NE	NE	NE
Velocidade vento 80m (m/s)	(5,7]	(5,7]	(9,13]	(13,...)
Temperatura sup. (ºC)	14.0/12.0	11.0/12.5	14.3/16.2	15.4/12.1
Nubosidade(%)	74	52	17	8
Radiación solar(W/m2)	0/0	0/414	694/495	341/0
T80-30(ºC)	-0.10/0.70	0.60/-1.00	-1.00/-0.60	-0.50/0.20
Observacións				

Dirección vento 80m.: moda 6h.
Velocidade vento: media 6h. en intervalos [0,1],(1,3],(3,5],(5,7],(7,9],(9,13] (13,...)
Temperatura superficie: mín. e máx. horaria en orde cronolóxico
Nubosidade: media 6h.
Radiación solar: mín. e máx. horaria en orde cronolóxico
T80-30: mín. e máx. horaria en orde cronolóxico

	Baixa	*Media*	Alta
INTENSIDADE:	△	▲	▲
DURACIÓN:	< 1 hr.	1-2 hr.	>= 2 hr.

(b) Meteorological and Air Quality Forecast (MAQF)

Figure 5. (a) MF and (b) MAQF reports provided by SAGA to the APPP staff.

Two main reports were designed to answer to the power plant staff requirements (figure 5),

a) A Meteorological Forecast (MF) report, with meteorological parameters that are significant to local air quality.
b) Meteorological and Air Quality Forecast (MAQF) report, with the same meteorological parameters plus some information about location, duration and intensity of ground level concentration episodes forecasted by SAGA, around the power plant.

Although the MAQF seems to be more useful, because it includes direct information of the impact in the local air quality, the uncertainties in the estimation of the local pollutants dispersion show that meteorological parameters are a better guide for the power plant staff. In fact, before the availability of a specific MF report, they used to analyze the meteorological measurements in order to consider their influence in the air quality in the same day; therefore, with the MF report they can apply their experience directly to a qualitative estimation of the air quality, for the next day.

Predición meteorolóxica para ó 21/06/2005 estación de A Mourela

	Madrugada 00:00-06:00 h.	Mañá 06:00-12:00 h.	Tarde 12:00-18:00 h.	Noite 18:00-24:00 h.
Dirección vento 80m	NE	NE	NE	NE
Vel. vento 80m (m/s)	(9,13]	(9,13]	(9,13]	(9,13]
Temperatura sup (°C)	18.1/18.5	18.6/18.4	18.3/18.4	18.5/19.3
Nubosidade (%)	0	26	78	86
Radiación solar (W/m^2)	0/0	6/737	885/620	464/0
Grad. 80-30(°C)	-0.34(E)/-0.12(E)	-0.10(E)/0.00(E)	0.00(E)/0.08(E)	0.08(E)/0.73(E)
Grad. 800-500(°C/100m)	-0.78(D)/-1.17(D)	-1.23(D)/-1.19(D)	-1.18(D)/-1.06(D)	-1.06(D)/-1.34(D)
Observacións	Predición elaborada o 20/06/2005 ás 11:00:01			

Figure 6. SAGAweb main page, showing the MF report at A Mourela location for June 21st, 2005 (obtained on June 20th, 2005). MF reports for June 20th and June 22nd are available too, at six different locations.

Both reports, MF and MAQF, are available by using the SAGAwin interface. However, because of the usefulness of the MF report, only this last one was included in the SAGAweb. In addition, SAGAweb (figure 6) provides MF reports for six different locations around the power plant (at different meteorological stations), with a 3-days forecast (today, tomorrow and the day after tomorrow), and access to old MF reports (historical data).

3. RESULTS

SAGA system is being applied currently by the APPP is a coal-fired power plant that burns a mixing local lignite (with up to 2 % of sulphur) and foreign coal (with less than 0.1 % of sulphur). The combustion gases are emitted through a 350-m stack, in order to prevent local air pollution episodes.

Every day, the power plant need to evaluate to convenience of changing the coal mixing for the next day, taking into account the risk of local poor air quality (due to SO_2 ground level concentration levels). This risk is evaluated by the power plant staff considering the meteorological parameters included in the MF report, as follows,

Wind speed: Low winds are favourable for mixing a high level emission, as the As Pontes power plant emissions. Therefore, winds above 9 m/s are usually required for causing poor local air quality.

Wind direction: Southwest and Northeast sectors around the power plant are usually more affected by the SO_2 plume, because of their complex topography.

Temperature: High surface temperatures (respect to aloft temperatures) are usually favourable to create convective plumes, with higher risk of plume down.

Cloudiness and solar radiation: High solar radiation and clear sky are more favourable to create convective plumes, with the same result.

Surface lapse rate: Lapse rate from 80-m to 30-m is a direct magnitude of the atmospheric stability near surface; as this parameter is measured and considered in the past by the power plant staff, they can be used it to identify the risk of poor air quality.

Aloft lapse rate: Lapse rate from 800-m to 500-m is a direct magnitude of the atmospheric stability around the plume transport layer. Jointly to the surface lapse rate, it can help to consider the influence of thermal inversion in the plume dispersion and the local air quality.

A new MF report is available before 9am. Power plant staff analyzes it and, before the end of the morning, they consider some possible changes in the coal mixing ratio to be applied to the next day. Usually, they keep a 70:30 (lignite:foreign coal) mixing ratio, but the power plant is prepared to change to 100 % of foreign coal, if it is necessary. However, this severe change cannot be applied quickly, in order to prevent fails in the combustion systems; therefore, mixing ratio should be changed several hours before the meteorological conditions for poor local air quality are expected.

4. CONCLUSIONS

The development and application of a decision support system for air quality management around a point source is presented. The system, namely SAGA, provides meteorological and air quality forecasts 1-day before to a 1400 MW coal-fired power plant staff, in order to help in the planning of the plant operation. Currently, a meteorological forecast (MF) report specifically adapted to this point source requirements in the most useful result provided by SAGA. The meteorological parameters included in this report (related to the local plume transport and dispersion) are daily analysed by the power plant staff to decide the changing of the coal mixing for the next day. This coal mixing can be programmed to reduce the SO_2 emissions during short periods, in order to prevent local air pollution episodes.

SAGA is nowaday focused in primary pollutants (like SO_2), but it is planned to include other pollutants (as NO_x and O_3), by changing the air quality models applied. CAMx, STEM-II and, more recently, WRF-CHEM, are possible candidates to be applied in SAGA.

5. ACKNOWLEDGEMENTS

This work was financially supported by Xunta de Galicia (Galician local government) and Endesa company under project PGDIT1C05E.

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THE RELATIONSHIP BETWEEN AIR POLLUTION, HEALTH AND SOCIAL DEPRIVATION IN LEEDS, UK

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ABSTRACT

This study examines the relationship between air pollution, social deprivation and health in the city of Leeds, UK under a baseline and three distance-based road user charging (RUC) scenarios set at 2 pence, 10 pence and 20 pence/km. The RUC scenarios were compared with the ‘base’ scenario, all set for the year 2005. The RUC initiatives result in the differences in ambient concentrations of two pollutants PM_{10} and NO_2. The study correlates their concentrations with derived indices of social deprivation and health. The study concludes that positive relationship exists between air quality and social deprivation, and indicates that deprived population groups are disproportionately exposed to higher NO_2 levels. The relationship between air quality and health status of the population is weak. RUC scenarios result in reducing disparity between affluent and deprived populations. There is a strong relationship between social deprivation and health status of the population.

Key Words: Air Quality, Social Deprivation, Health, Road User Charging, Environmental Justice

1 INTRODUCTION

A great deal of interest has been expressed in the relationships between social deprivation and health (Hawker et al., 2003; Burr et al., 1997), and air quality and health (WHO, 2004; Samet *et al*., 1999; Vedal, 1997; Schwartz, 1994). These studies have shown that air quality and social factors impact upon health, but little is known of their effects upon one another. In literature, little information exist which explicitly links social factors and air quality. In a number of studies of health and air pollution, social indicators were included as explanatory factors for poorer health. For example, overcrowding (defined as more than one person per room), or the presence of a smoker, was frequently cited as a contributing factor to poor respiratory health. The relationship between air quality and social deprivation is also used to test the concept of environmental justice. The concept of environmental justice has gained greater recognition in recent years, as social goals (e.g. equity, fairness, and justice) have themselves gained greater prominence through almost universal efforts to promote sustainable development. The concept draws attention to the questions of whether certain socio-economic groups, including the economically and politically disadvantaged, bear a disproportionate burden of environmental externalities, and whether policy and practice are equitable and fair (Wilkinson, 1998).

Relationships between air pollution and health and deprivation, potentially result in the most cost to both the public and the government in terms of increased mortality and morbidity, hence establishing causal links between them is very important and can be justified.

The main aim of this study was to investigate the possibility of a relationship between local air quality and measures of health and deprivation. The supporting objectives were: (a) to establish if a positive correlation exists between areas with poor air quality and those which are socially deprived and/or experience poor health; and (b) to determine what impacts road user charging initiatives have on air quality, and consequently on deprivation and health in Leeds.

2 METHOD

Traffic assignment, pollutant emission and dispersion models were applied to a 12 x 12 km area of the city of Leeds city, as shown in Figure 1, so as to assess the air quality impacts of five road user charging (RUC) schemes. This work has been described by Mitchel et al. (2002) in detail. This involved the application of a chain of dynamic simulation models of traffic flow (SATURN, SATTAX), pollutant emission (ROADFAC) and dispersion (ADMS-Urban), integrated within a geographic information system model TEMMS (Namdeo et al., 2002). Schemes were evaluated with reference to: exceedance of air quality standards for six pollutants; emission of greenhouse gases; redistribution of pollution, and road network performance as traffic speed and trip distance. Results were compared to alternatives of do nothing, network development and clean fuel promotion. The scenarios addressed included "business as usual" traffic growth to 2015; network development; road pricing with cordon charging; road pricing with distance charging; and the wider adoption of clean fuel vehicle technology. Modelled air quality data from this study forms the base of the current study.

Figure 1. City of Leeds Showing Study Area Boundary

2.1 Air Quality

Out of the several scenarios selected in the original study, the base and three road user charging (RUC) scenarios have been selected for the current study to investigate the possibility of a relationship between local air quality and measures of health and deprivation. The three scenarios selected are road user charging set at three levels – 2 pence, 10 pence and 20 pence/km. NO_2 and PM_{10} levels for the base and three RUC scenarios for the year 2005 have been predicted for 3600 cells of 200 x 200 m size in the study area. Annual mean NO_2 levels for the Base Scenario are shown in Figure 2. Contribution of major radial and ring roads is clearly evident from this figure.

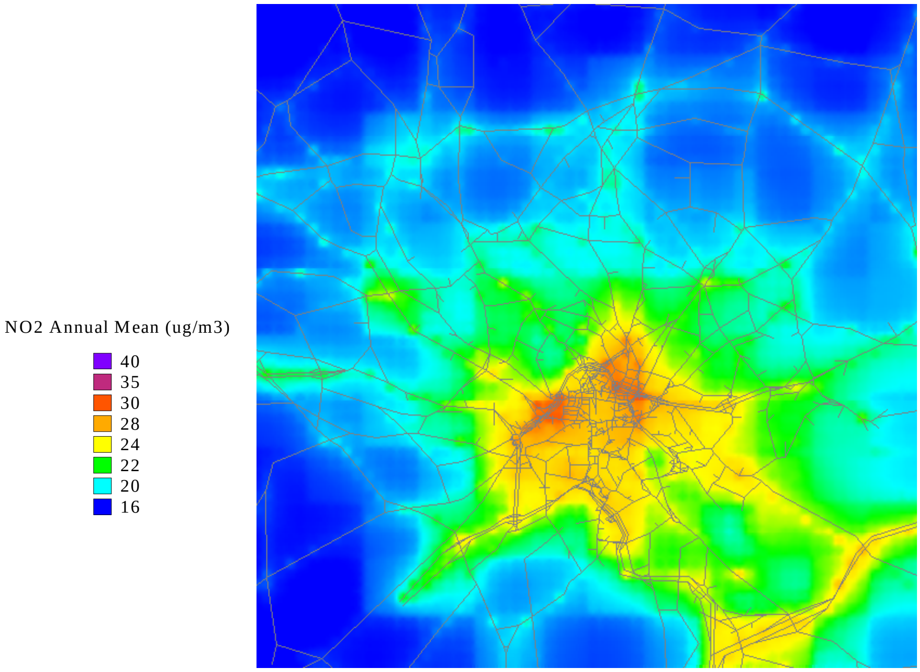

Figure 2. NO_2 Annual Mean for the Base Scenario

2.2 Social Deprivation and Health Indices

The UK Census 2001 data (National Statistics, 2004) have been used to derive indicators of health and deprivation levels of the population in the study area. Census has its own measure of deprivation, which ranks the Census Output Area (COA) population as being deprived in terms of any number of four dimensions. It lists the number of households in the COA which were not deprived, as well as those deprived in one, two, three or all four dimensions. Similarly, for health, it lists the number of households which rated themselves as either having good health, fairly good health or not good health. Cumulative Deprivation Index (CDI) and Cumulative Health Index (CHI) for each COA were derived on a scale of 0 to 100, with 100 representing most deprived or least healthy areas.

CDI was derived by calculating what percentage of the total households in each COA was deprived to each degree, followed by weighting and scaling it to arrive at a score ranging from 0 to 100 with 0 representing least deprived and 100 representing most deprived. The first step was to work out what percentage of households were deprived in each number of dimensions. It was decided to give the degrees of deprivation a weighting between zero and four, with the least deprived being given the smallest weighting, and the most deprived the heaviest. Therefore, the number of households who weren't deprived in any dimension were given a weighting of 0, so were multiplied by 0/10 (as 1+2+3+4 = 10), those deprived in one dimension were multiplied by 1/10 (0.1), those in two dimensions by 0.2, in three dimensions by 0.3 and so on. This resulted in a range of scores from 0 to 40, which was then scaled (multiplied by 2.5) to give an index (CDI) between 0 and 100.

A similar process was intended to devise a single index value for health (CHI), but with this data there were only three possible variations – good health, fairly good health and not good health. As these were quite vague, it was decided that the first two concerned only with people who were not of poor health. The third class was assumed to represent 'not healthy'. The percentage of people 'not healthy' has been used as cumulative health index (CHI) with 0 representing most healthy and 100 representing least healthy.

Figure 3 shows the map of cumulative deprivation index of the study area. It shows that that deprivation is highest in the southern and eastern parts of the city. Deprivation levels are lowest to the north of the city. Map of baseline health status using CHI (Fig. 6) shows that it follows a similar pattern of distribution of CDI. The areas in which poor health is more common are, again, primarily adjacent to main radial routes into the city.

3 ANALYSIS

3.1 Relationship between Social Deprivation and Health

Figure 5 shows the scatter plot of cumulative health and deprivation indices along with the best-fit-line. It is evident from this plot that social deprivation and health are strongly, and positively related, with a high correlation coefficient ($r = 0.68$), and a trend-line gradient of 0.35. This shows quite clearly that as levels of deprivation increase, as do levels of poor health.

3.2 Impact of RUC Scenarios on Air Quality

Three RUC scenarios studied have different effects on the level and distribution of air pollutant concentrations, the general trend being that all distance based road user charging regimes investigated produce a significant improvement in city wide air quality, a consequence of trip suppression and emission reduction. Figure 6 and Figure 7 show change in NO_2 concentrations between the base, 2p/km and 20p/km charge scenarios. It is clear from these figures that 2p and 20p charge scenarios results in significant reduction in NO_2 concentrations, though 20p charging regime results in greater improvements which are distributed to a wider area. Effects on PM_{10} concentrations are not this strong, and are not shown here.

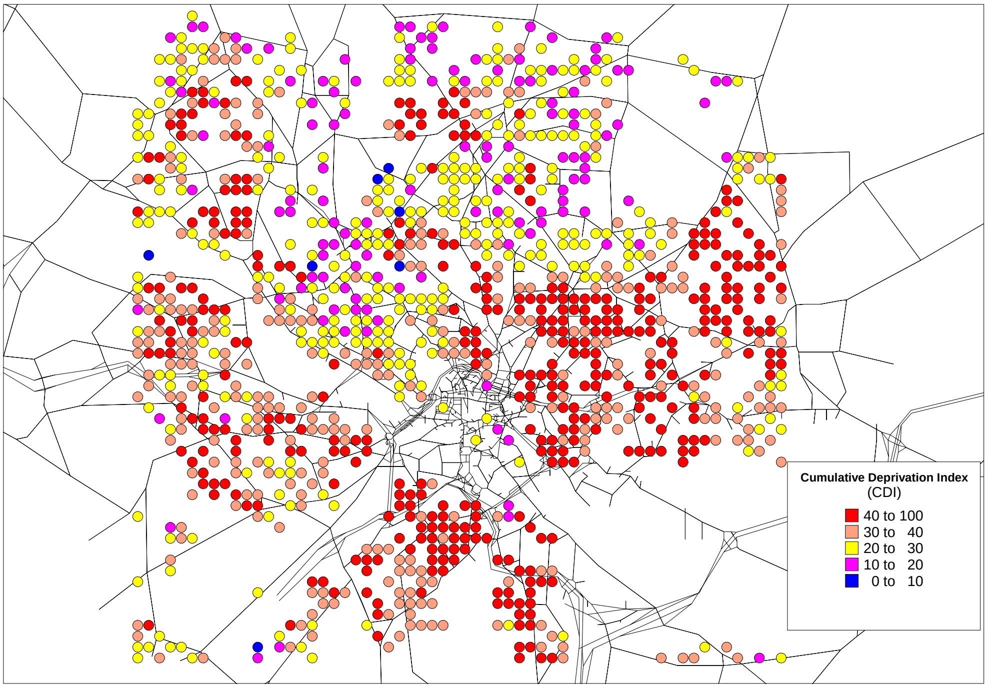

Figure 3. Deprivation (CDI) in Leeds – Census 2001
(Note: 0 = Least deprived; 100 = Most deprived)

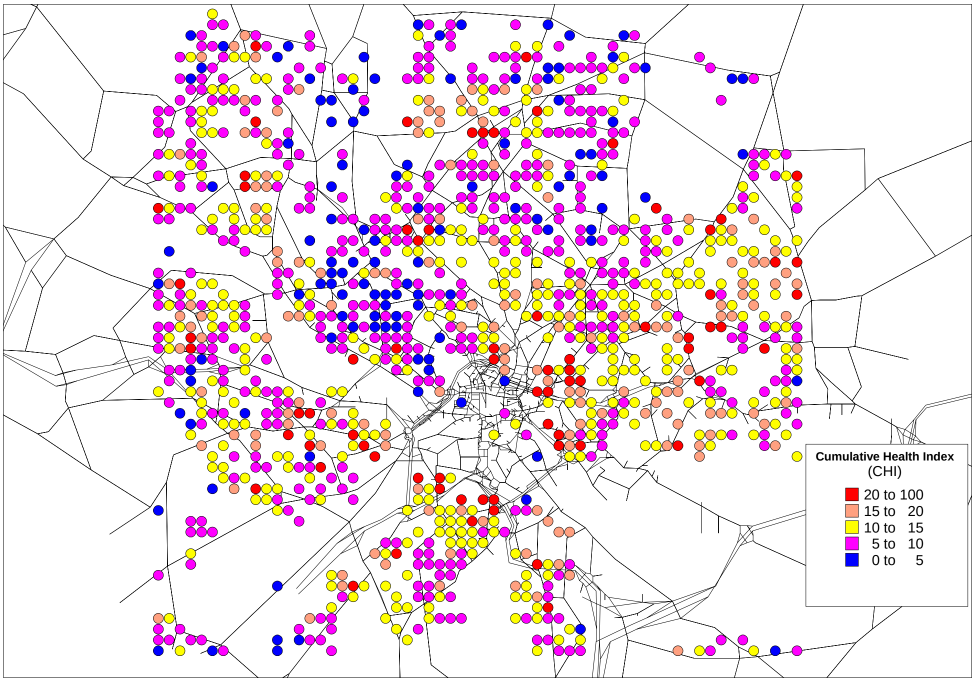

Figure 4. Health Status (CHI) in Leeds – Census 2001
(Note: 0 = Most healthy; 100 – Least healthy)

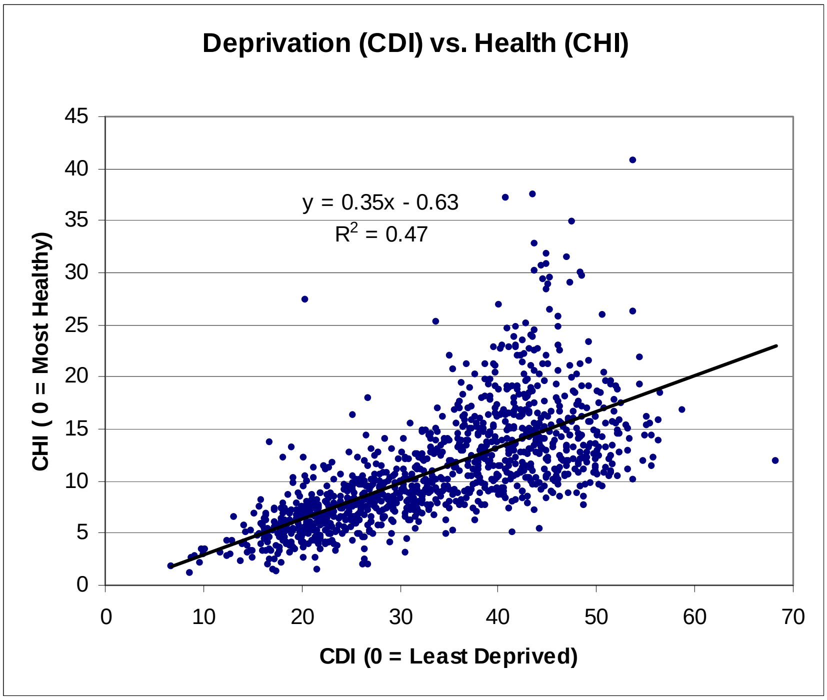

Figure 5. Relationship between deprivation and health

3.3 Relationship between Air Quality and Deprivation

In the environmental justice analysis, air quality data for each 200 m grid cell was paired with social deprivation and health indices for corresponding COA. This analysis focuses on exposure to Nitrogen dioxide (NO_2). Nitrogen dioxide was selected as the study pollutant, as review and assessment exercise carried out, as a fulfilment to NAQS obligations by local authorities in UK, have indicated that NO_2 and PM_{10} are currently the principle pollutants of concern in UK urban areas (ENDS, 2002), and are thought to pose significant risks to health (Vedal, 1997). Secondly, our modelling work (Mitchell et al., 2002) has shown that in the case of Leeds, NO_2 is more sensitive to changes in transport emissions than PM_{10}, due to the large contribution to total particulate emission from point sources.

Two statistical tests were used in the environmental justice analysis. Firstly, for each scenario, an ordinary least squares regression was conducted of annual mean NO_2 and the cumulative deprivation index. Regression is not used here to infer causality between these variables, but is used to test for an association between them. A steeper slope coefficient indicates greater inequality. Jerrett *et al.*, (2001) adopted this approach in their environmental justice analysis of PM_{10} in Hamilton, Canada. Following the regression analysis, different tests were conducted which compared mean NO_2 concentration with deciles, and the upper and lower quartiles of the deprivation index.

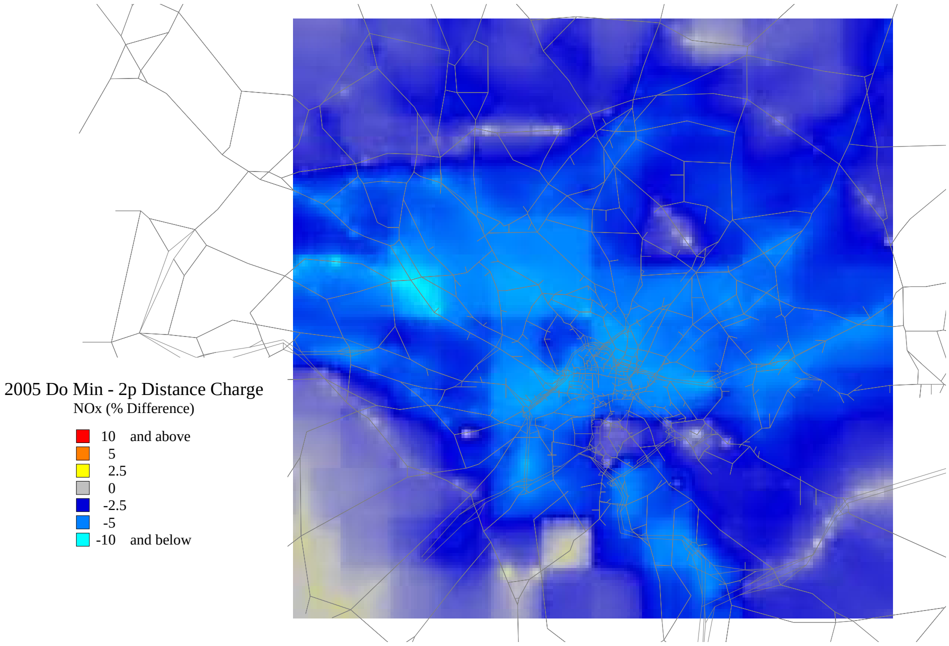

Figure 6. Percentage Change in NO_2 Concentrations between No-Charge and 2p/km Scenarios

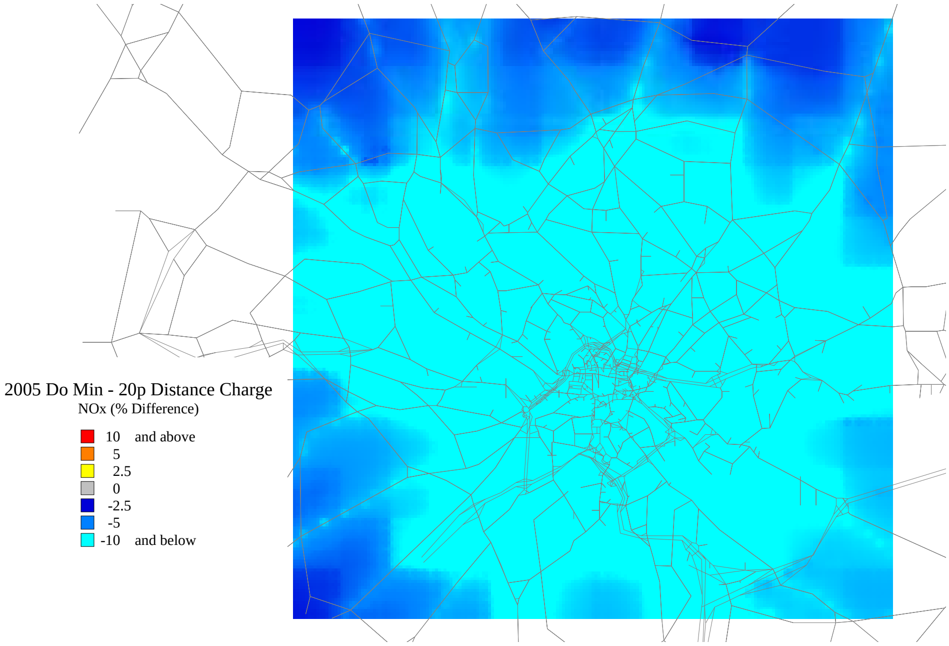

Figure 7. Change in NO_2 Concentrations between No-Charge and 20p/km Charge

Regression analysis shows that for all scenarios, the correlation in terms of the R^2 value was quite low but slopes of the best fit lines were positive (Table 1) indicating that there is an association between air quality and deprivation. The relationship between deciles of deprivation index and NO_2 under the modelled transport scenarios is illustrated in Figure 8. For each scenario, the data (n=1143) have been presented as mean NO_2 against the deciles of CDI classes. For all scenarios, there is a strong positive association between deprivation and NO_2; however 20p and 10p charging regimes result in flatter slopes. This indicates that these scenarios results in reducing the disparity between deprivation and NO_2 exposure or in other words better environmental justice. To assess the statistical significance to the apparent inequalities, difference tests were conducted to compare mean NO_2 concentration in the upper and lower quartiles of the deprivation index. The results of these tests (Table 2) show that deprived groups experience a significantly higher NO_2 concentration in their residential location than affluent groups.

Table 1. Regression Statistics for Pollutants (NO_2 and PM_{10}) and CDI/CHI

	Correlation Coefficient (r)		**RSQ (r^2)**		**Slope**	
Scenario	**CDI**	**CHI**	**CDI**	**CHI**	**CDI**	**CHI**
NO_2						
Base	0.247	0.178	0.061	0.032	1.292	0.470
2p	0.250	0.176	0.062	0.031	1.385	0.494
10p	0.232	0.171	0.054	0.029	2.906	1.080
20p	0.218	0.167	0.048	0.028	3.890	1.505
PM_{10}						
Base	0.225	0.166	0.051	0.027	1.918	0.713
2p	0.139	0.097	0.019	0.009	0.440	0.156
10p	0.128	0.090	0.016	0.008	0.412	0.146
20p	0.126	0.089	0.016	0.008	0.407	0.145

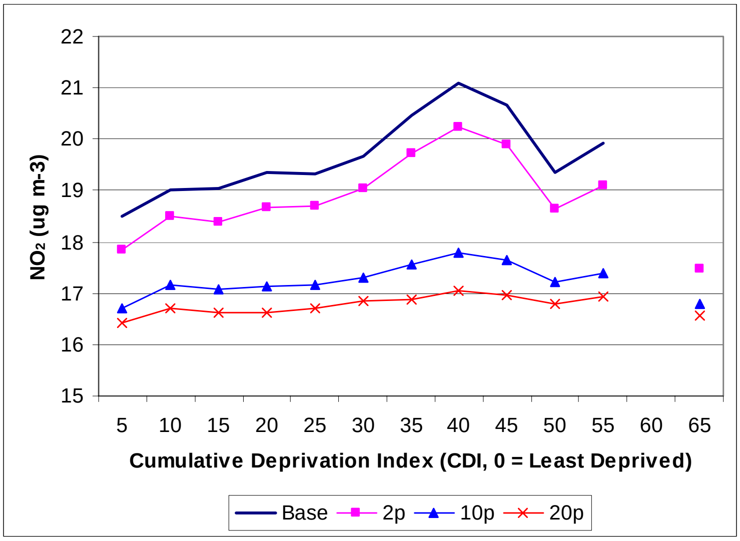

Figure 8. Relationship of Annual Mean NO_2 and Deciles of Deprivation under Base and Road User Charging Scenarios

3.4 Relationship between Air Quality and Health Status

Correlation between health (deciles of CHI) and NO_2 is shown in Figure 9. It is clear from this figure that there is no discernible association between them. This is also evident from the statistics in Table 1.

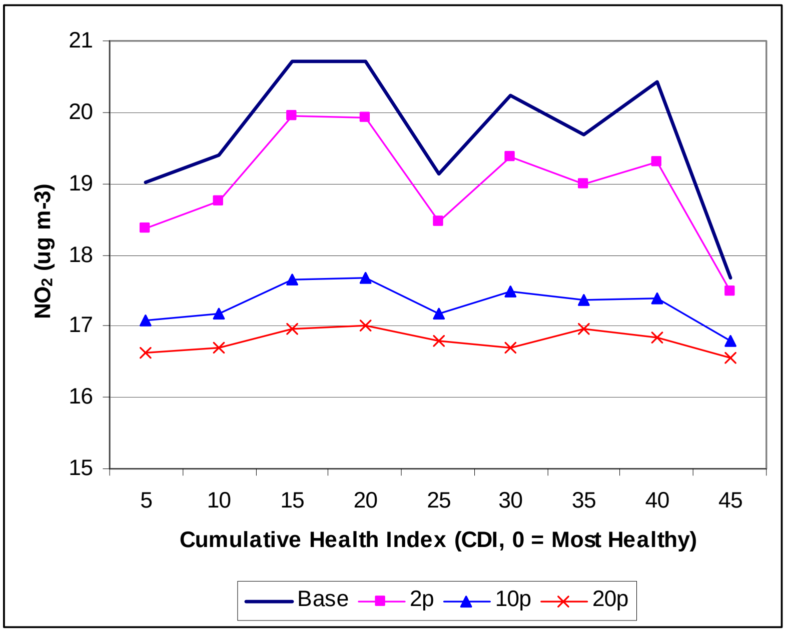

Figure 9. Relationship of Annual Mean NO_2 and Health under Base and Road User Charging Scenarios

Table 2: NO_2 and Quartiles of CDI and CHI

Quartile	**CDI**	**CHI**	**Average of corresponding NO_2 values ($\mu g\ m^{-3}$)**			
			Base	**2p**	**10p**	**20p**
First quartile (25th percentile)	24.53	7.17	19.21	18.55	17.12	16.62
Second quartile (50th percentile)	33.87	10.03	19.46	18.82	17.21	16.75
Third quartile (75th percentile)	42.77	14.03	20.52	19.77	17.59	16.93

4 CONCLUSIONS

The outcome of this study has been that air quality (NO_2) impacts disproportionately on certain, more deprived areas of the city. The analysis shows that there is a significant welfare inequity in the distribution of urban air quality, with more deprived groups clearly experiencing higher atmospheric concentrations of NO_2 in their residential location. The analysis cannot be used to state categorically that deprived communities have a higher exposure, as other exposure specific factors including daily population movement and individual activity rate are neglected. Distance based road user charging scenarios result in varying degree of reduction in NO_2 concentrations. Reduction in NO_2 concentrations in case of 10 p and 20 p per km charge scenarios are significant and in a wider area and consequently results in removing inequity in the distribution of urban air quality, hence better environmental justice.

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