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Introduction

Major challenge humanity will face in the future is its harmonious coexistence in a balanced way with its natural surroundings: the environment. It appears increasingly clear that impacts of human activities on the environment are becoming significant due to the size of the human population and its technological choices [17]. Environmental negative side effects of these activities are called pollution, they involve important domains as air, water and soil. Therefore, efforts are and will have to be undertaken in order to face this challenge. In this respect, besides monitoring the environment and human activities, decisions will have to be taken and corresponding policies implemented at very different levels (individual, local, regional and global). However, the environment and human activities constitute a very complex network. In order to obtain a sustainable human development, it is also necessary to identify and investigate rapidly the major bio-physico-chemical nature of the environmental constraints and to integrate them with the human ones. A systemic approach may be useful in this respect [16].

In this context, the operational instruments for decision making will likely be very diverse (besides the "wait and see" option!). However, recent developments point to
Integrated Decision Support System (IDSS) tools operating with a Geographical Information System (GIS) core.

The purpose of this paper is to present such a system recently developed in the Geneva area for air quality management (AIDAIR) and to focus in more details on the integration of biological indicators (lichens) of the state of the environment.

What is an IDSS?

A DSS is a computer-based problem solving system that assists choice between alternatives in complex, controversial and (often) expensive domains. It provides a structured presentation of alternatives, context, tools for evaluation and selection for decision making [7]. A passive DSS provides only information, whereas active DSS (intelligent, integrated: IDSS) suggests possible actions (knowledge) and inform about the criteria used (preferences) [11].

An IDSS can potentially address WHAT-IF questions via dynamic simulation models (by forecasting the evolution) and also HOW-TO questions via optimisation models (minimisation or maximisation of functions like cost, efficiency, health, etc.). Thus, an essential component of DSSs is modelling. The present and future state of computer science will allow both dynamic and simulation modelling of "reality" with different scenarios to be performed with increasing resolution and accuracy.

What is GIS?

![GIS Systems Components Diagram]

*Figure 1.* A schematic representation of a Geographical Information System tool and its mapping facilities.
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A Geographical Information System (GIS) is also a computer-based tool which allows one to acquire, manage, analyse and represent data with a spatial reference [6]. It is a very important tool for environmental management and study. Indeed, major challenges we face today have a critical geographic dimension. A typical GIS integrates different components which are shown in Figure 1 [6].

![GIS components diagram](image)

**Figure 2.** "Reality" representation in a GIS. The raster and vector mode.
Information is stored in the database as a collection of different thematic layers (e.g. population density, streets, buildings, pollution emissions, etc..) which can be linked together by their common location (geography). As schematically presented in Figure 2, the layers might be of two different kind: either from a raster type (images), or from a vector (points, lines, polygons). Raster data consists in a digital image, which is divided by a grid with the resolution of a pixel. Vector data consists in "lines" each with a magnitude (length) and a direction.

Part of the "real World" is thus (artificially) confined in different thematic layers (raster / vector) which can be manipulated by computer technology in more or less complex manners in order to analyse and represent various environmental and human activities together.

The AIDAIR project

Air pollution and its management is an important challenge for the society [26]. AIDAIR is an IDSS operating with a GIS core for air pollution management in urban areas. It is the result of a University - Industry collaborative project supported by CTI (Commission pour la Technologie et l'Innovation, Berne) in the framework of an EUREKA-EUROENVIRON (EU1388) project initiated by ESS-ACA [1,8,13]. The system is built around three different modules TAP (Traffic and Air pollution); Energy GIS (EGIS) and Air Pollution and Public Health (APPH) which are dynamically interconnected (Fig. 3).

The AIDAIR system has been implemented for the Geneva region as a case study. The GIS contains comprehensive data for the whole Geneva region and uses the tools and analytical structure of AIRWARE (a product of ESS-ACA) to:

- Display the different information layers
- Perform times series analyses
- Permit 3D visualisation
- Perform statistical analyses
- Design source and network editors
- Run expert system (Data coherence control)
- Model Gaussian dispersion (long and short term)

For each module and simulation the system can display and analyse the results through different graphical interfaces (scenario comparisons, isolines, cross-thematic analyses, etc.). The GIS provides the common framework for AIDAIR-Geneva, it currently contains the following data:

- Map backgrounds:
  - Swiss map at 1: 200'000
  - Satellite image (Landsat, Spot)
  - Urbacarta, vectorised map of the canton of Geneva (precision of 5 meters) from Inter-Survey Consultants (Geneva)

- Data
  - Statistical socio-economical data per hectare (population, buildings, workplaces)
  - Traffic network
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- Digital elevation model
- NOx emissions due to space heating, transports and industrial activities
- Meteorological data (wind direction and speed, solar radiation, mixing high).

**Figure 3.** The different logical and functional subunits of the whole AIDAIR-Geneva system.

The TAP module (Traffic and Air Pollution) permits the integration of a traffic equilibrium model in the system. The street network comes from a traffic simulation model, based on the EMME/2 software, developed for the Geneva region by B. Dériaz, partner in the AIDAIR-Geneva project. All the main roads except block connections are included in the street network. Each street segment description contains the following information: number of lanes, traffic direction (one or two ways street), average speed, hierarchical classification of streets (highway, main road, street, etc.) and the geographical distribution (inner city, suburbs, canton, etc.). With the help of a validated EMME/2 model (traffic equilibrium model based on Origin-Destination matrices) the traffic loads are computed (emissions). Then, the AIDAIR-Geneva system estimates the immissions of pollutants due to traffic.

The EGIS module is designed for assessing urban energy policies and their impacts on air pollution. With this module it is possible to model energy and technology choices for an urban region. EGIS is based on a technical-economic model of energy and technology choices (MARKAL-Geneva), the results of this model will be displayed on the GIS and the different technology choices directly integrated in the module APPH simulating atmospheric pollutants emissions and dispersion. One of the objectives of this latter module is the estimation/calculation of the impacts of air
pollution on public health, based on the atmospheric pollutants immissions map. The APPH module is divided in two complementary but distinct parts; the first one deals with the modelling of atmospheric pollution dispersion, the second deals with the application of epidemiological studies on air pollution effects on the population of the Geneva canton. Three different types of dispersion models have been adopted:

- Gaussian model
- Lagrangian model
- Yearly statistical model

Each of these models has its own specificities, i.e. special topography, a varying range of pollutants to consider, etc. For example, a Gaussian or a Lagrangian model does not include a chemical reaction module; it thus concerns only primary pollutants. The AIDAIR-Geneva system will provide all the needed input data for the dispersion models to compute/simulate the atmospheric pollution at different precision levels. The US Environmental Protection Agency developed the Gaussian model used; short and long term simulations are possible with this model. Quite easy to use, its main shortcoming is the absence of topography considerations. In order to have access to more sophisticated models, the AIDAIR-Geneva system has been being developed with a client-server architecture. With this new approach, it is possible to run outside AIDAIR the following models:

- A 3 dimensional meso-dispersion model coupled with a Lagrangian dispersion model (MAESTRO system), that has been developed by the Belgian Company ATM-PRO. This model can precisely compute primary pollutants dispersion for regions with a complex topography.
- The CIT model, developed by the Carnegie Institute of Technology in Atlanta, currently adapted to studies on air quality in European cities by the Swiss Institute of Technology in Lausanne. It is a three dimensional photochemical Eulerian model. It can compute the time-space distribution of pollutants concentration, for chemically reactive or non-reactive compounds (some 50 chemicals are taken into account). The wind transportation is dealt with a finite elements approach, the chemical dynamics and the vertical dispersion are solved simultaneously [21]. The photochemical reactions mechanisms integrated in the model are based on the researches of Lurman et al. [18-20].

Important features of the system are:

- The implementation of dynamical links between the three modules such that the results of a simulation, e.g. an energy scenario, could be integrated in other models (e.g. air pollution dispersion).
- The development of a client-server architecture between the AIDAIR-Geneva system interface and external models (for example: MARKAL, EMME/2, MAESTRO, etc.) needing important time and power computations. The results of these computations could be fed back and visualised in the AIDAIR-Geneva system.
- The linkage in real time between different sensors (pollution monitoring stations, meteorological stations, traffic meters, etc.) and the AIDAIR-Geneva system.
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- The integration of an information layer of the environmental state as assessed by biomonitoring of air quality with lichens. The layer includes description of the method and basic information to interpret results in a hypertext format. The bioindication layer is mainly situated in the APPH module, it provides information on air quality by living systems (Fig. 3).

What is bioindication?

The toxicity of a given pollutant will at the end be measured by the negative effects it has, directly or indirectly, on living systems particularly with an anthropocentric point of view (e.g. health, economic, agronomic impacts). The use of living systems in order to assess the real impacts of a pollutant is called bioindication. The organisms that could be used for this purpose need to be well and homogeneously represented in the ecosystem and possess good specificity towards some pollutants. Due to the diversity of living systems and their complexity, important research efforts are necessary to validate a given bioindicator with respect to some corresponding pollutant(s). When considering evaluation in bioindication studies, different criteria can be considered: morphologic, physiologic, ethologic or demographic. The method could use individual organisms, or part of them, as well as a collection of different organisms. Living systems can be considered as integrators from different point of views: with respect to endogenous (internal metabolic and genetic network) and exogenous factors (environment, light, temperature, water, air quality etc...), and with respect to time itself. Organisms possess, at varying degrees, defences and adaptability mechanisms towards environmental aggressions / modifications. Depending on the defences and adaptability mechanisms considered, very broad time scale ranges may be involved (e.g. adaptation by species selection in a population of lichens). Some other mechanisms may involve fast biochemical reactions which when appropriately calibrated and validated could be used as immediate bioindication. An example is given in plants by some peroxidase studies [2,3,24] which showed that reactions could be detected only hours after the change in ozone concentration. An other example of early bioindication can also be found in the human health domain [25], which illustrate a very active area of research nowadays.

A well-documented example of integrative (medium to long-term) bioindication for air pollution is given by the lichens. These organisms can be often observed (for the non-specialist reader) as patches (e.g. grey or yellow) over tree trunks or rocks. They consist of a symbiotic association between a fungus and an alga. The latter uses the solar energy to fix energy in carbon structures (photosynthesis), whereas the fungus harvests water and mineral nutrients. This unique association has given rise to very efficient and well-adapted organisms in very different ecosystems. They have been used as bioindicators since a long time as Nylander [23] already observed about 130 years ago their relation with air quality: "the lichens give in their way a measure of the air salubrity". They are still currently in use and a new research has been recently published establishing the potential usefulness of their bioindication signal in relation to human health problems [4]. The "Lichenologist" regularly publishes a review of the literature for all the paper published in relation to air pollution and lichens. During the
period from 1995 to 1996, about 214 papers have been published [14]. The interested reader will find more specific aspects on the lichen bioindication in the literature [e.g. 9,12,22,28]. Considerable efforts have been done since the qualitative observation of Nylander in order to obtain a quantitative observation. An index of air pollution (IAP) has been established in the 90s. This index consists to identify some specific lichens and to count them over a calibrated area and in defined conditions over trees trunks (for more details see [15]). The best correlation of the IAP is obtained when different chemical air pollutant are considered (SO$_2$, NO$_2$, NO, Cl$^-$, F$^-$, heavy metals, particulate matters) [15]. This corresponds well to the notion developed by the authors that the IAP reflects an index which is representative of the total air quality rather than only for one given pollutant. From the biological point of view, the IAP represents both the lichen diversity and density. As lichens are sensitive to components present in the gaseous phase (air), the higher the IAP index is the better the air quality. An index $\geq$ 70 is considered typical of a very low to absent air pollution, whereas in areas with an IAP $\leq$ 10, air quality is critical. To summarise: air pollution will diminish the diversity of the lichen population by lowering the frequency (presence) of sensitive lichens species. In an extreme case, this can lead to no more observable lichens.

We have integrated an information layer in the AIDAIR decision support system project as part of the APPH module containing the bioindication of air quality with lichens. Three studies have been performed over the Geneva canton. The first was in 1975 by Turian and Desbaumes [27]. Unfortunately, these measurements could not as such be integrated in the present study since they were not producing IAP values. The two other pertinent studies were effectuated in 1985 and 1995 [10,15] and could be processed. In order to allow a time comparison only the measurements in 4 different sites have been analysed. Alone this would be definitively insufficient to draw any scientific conclusion, however these results are only an illustration of more extensive studies in the field with the same conclusions [5,10]. Some examples of the results are presented in Figures 4 and 5. In Figure 4, we illustrate some capabilities of the "calculator" module of the ESS-ACA toolkit. This allows one to represent, compare and manipulate different maps. For instance, we have represented the mapping (interpolation) of the IAP in 1985 in the upper left map. The light green represents a value of $\geq$ 30, orange is 30 > IAP > 10 and red is an IAP < 10. To give an idea of the region covered, one has to imagine the red circle over the centre of the town with the orange area covering the city without its suburb. A better view is presented in Figure 5. A simple GIS operation (subtraction) is provided by this toolkit and presented in Figure 4 (upper right). The difference in IAP 1995 less 1985 is presented for the same geographical boundaries. The red and orange zones represent an improvement of the IAP index from 4 to 7 units, whereas the remaining is either no change or a decrease. These numbers are significant if one considers the relative improvement. Indeed, in the centre of the town they may represents an improvement better than 100%! These results are correlated to the decrease in the SO$_2$ content in the air during this period. The Figure 4 lower right map, presents the corresponding difference in SO$_2$ (1985 less 1995). As can be seen, a red and orange surface is present in the centre of the city. It means that the yearly SO$_2$ mean level has decreased. To give an idea of the
Figure 4. Mapping of SO$_2$ and IAP in the DSS AIDAIR-Geneva. The upper left coloured interpolated map represents the IAP (Index of Air Pollution) as calculated from lichen inventories on trees in 1985 over Geneva. A low zone (red and orange colour) is observed around the centre of the city. The upper right map represents the absolute difference between the IAP in 1995 less the IAP in 1985. High (red) IAP difference represents an improvement in the air quality. The lower left interpolated map is the SO$_2$ mean level in 1995 (the corresponding colour scale is shown in IAP units on the left border of the figure), whereas the lower right one represents the difference between 1985 less 1995 for SO$_2$. A high difference (red) is a decrease in the yearly SO$_2$ mean level.
improvement, the measurement site of the ROPAG network of ECOTOX (Service cantonal d’Ecotoxicologie de Genève) at Ste-Clotilde (situated in the red zone of the map) monitored an annual mean level of 61 \( \mu g / m^3 \) in 1985 and of 11 \( \mu g / m^3 \) in 1995. The correlation with the improvement of air quality as given by the IAP index may be thus explained.

Figure 5 is another illustration of the ESS-ACA toolkit functionalities. It represents the difference in IAP 1995 minus 1985 plotted over a recognisable map of the region. Other features of the AIDAIR bioindication information layer include a complete description of the IAP significance as well as the method to obtain and calculate this index. The information text is provided together with hypertext links and figures of lichens, which need to be considered in the establishment of such a bioindication.

Conclusion

As a sound IDSS dedicated to air pollution, the system should be able to perform different tasks. Among these, one should obviously consider the living organisms that are the ultimate targets of pollution or environmental modifications. These targets are of importance at different levels. Firstly, a considerable interest and sensitivity has emerged in an important part of the population towards an increase of wildlife and living species, together with landscape and human health quality preservation. Secondly, living systems are a unique tool in their capacity to provide environmental information on the state of an ecosystem.

Taking decisions could be done on different grounds (economical, political, multicriterias, etc...), but the assessment of the impact of decisions will necessarily include, together with the monitoring of the toxic compounds, an evaluation of the real impacts (improvements) on ecosystems. This can be done with biomonitoring. Therefore, it is important in a decision support system to also provide information on the effective (past, observed) consequences that those decisions have had and could be observed nowadays.

In the case presented here, it clearly appears that the measured improvements in the air quality result from past decisions to reduce significantly the \( SO_2 \) contents in oil. This lead to lower emissions and immissions as measured by the chemical monitoring of toxic components. These policies have had a positive impact on the general air quality also assessed by living organisms (lichens). However, one must not forget that such organisms are not representative of the whole living diversity even if some links have been evidenced recently with human health [4]. Neither are they representative of the complete range of air quality problems, since they are not bioindicators for the ozone problems. This is because important levels of ozone are reached mainly in the summer season where lichens are partly dehydrated and ozone could simply not reach the true active living organism. This emphasises the need for an efficient bioindication approach to possess an exhaustive and representative list of organisms for different environmental problems.
Figure 5. A 3D view of the IAP difference between 1985 and 1995 over the Geneva canton superimposed over a Digital elevation model (DEM) and district map of the Geneva canton elaborated in the AIDAIR-Geneva system. The lake Léman is visible as a deep blue surface in the centre of the figure with the Rhône river emerging from it. The Jura and Salève mountains are partly visible on the upper left and lower right DEM map. The IAP difference (1995 - 1985) "peak" is at ~7 IAP index units over the rest of the 3D surface which itself is at ~0 IAP units. An improvement in air quality is observed over the centre of the town.
From a general point of view, it is obvious that environmental problems have a critical geographical dimension thus rendering GIS tools indispensable in the future. Together with this trend, one must realise that this will have consequences in the experimental field. Indeed, in order to obtain critical evaluation of the environment one must then satisfy to the requirements of GIS analyses which means more spatially distributed measurements, more spatially critical data and more data in general. The efforts to provide more data will need the development of new experimental approaches, new technologies of data acquisition (e.g. sensors) and treatment in order to obtain really pertinent and detailed results.

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