Synergies of environment and health information systems with space observations facilitating new regulatory policies

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Abstract – The integration of environmental monitoring data with harmonized space observations in order to detect and verify health threats, is a process with uncertainties and the spatial resolution is frequently inadequate for identifying the environmental burden of diseases. This work utilizes methods for merging environmental and health data for assessing atmospheric and water pollution.

This approach paves the way to health impact assessments, which examines different level of frequency and severity of health impacts. It facilitates a precise representation of human exposure taking into account the randomness of human activities and liaises them to an accurate representation of environmental stressors at high spatial resolution.

Keywords: Environment, Medicine, Mapping, GIS, Space Technology, Human Settlement.

1. THE INTERGRATION PERSPECTIVES

The concept of an early warning system for the prediction of health epidemics has been in the agenda of many applications from the remote sensing and the data infrastructure communities.

Regrettably, the spatial resolution is frequently inadequate in reporting environmental causes and health effects at the same scale. This work utilizes a new approach for merging information systems for accurately describing chronic and acute representative conditions and reports on health consequences not yet identified with coarse methods integrated over long averaging temporal periods (WHO, 2007).

One of the major challenges in the integration of environmental and health information is the merging of the data layers from heterogeneous sources. The merging is a process dealing with the association, correlation, and combination of data for identifying estimates, and completing timely assessments of situations characterized by disparate data types.

Reported health cases
Sites of local sensor monitoring
Pollutant concentrations
Weather related data
Cofounding land data
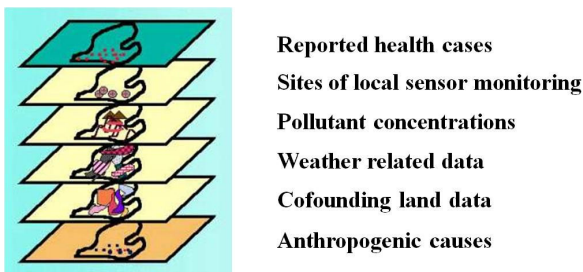Anthropogenic causes

Figure 1. Methodology of environmental and health data fusion in levels of increasing integration from bottom to the top.

Spatial data fusion can be classified into three types based on the data format structure: Raster to raster fusion, vector to raster fusion and vector to vector fusion.

The matching of spatial data can be performed using feature geometry and attributes. However, health data will not always include a spatial reference. For this reason corresponding thematic attributes have to be found and utilized within the matching process to merge environmental and health data. The process of environment and health data fusion is described in figure 1. It is carried out by the overlaying of layers of raster data. In this process only the spatial resolution and extent of the original parameter will be of importance.

In order to avoid uncertainties in the conclusions, the environmental parameters and the population level must refer to compatible elevations. For this reason, the remote sensing data must represent the environmental conditions at ground level. It is also essential for the sake of the validity of the fusion process to characterize the elements of severity versus the number of

E1. Background concentration and local dispersion effects
E2. Local historical mean conditions
E3. Environmental limits affecting local biodiversity
E4. Conditions and alerts for local abatement strategies
E5. Targets for local annual mean concentrations
E6. Targets for regional/national concentrations
E7. Lower limits for acute health effects
E8. Upper limits for human health effects
E9. Permanent irreversible environmental damage

effects according to the following two tables: one for environmental data and one for health related data.

Table 1: The nine levels of environmental data characterization

Table 2: The nine levels of health data characterization

H1. Restrained minor health effects
H2. Impaired function of organs
H3. Appearance of health symptoms
H4. Utilization of medicines
H5. Reduced performance / restricted activity
H6. Visit to local General Practitioners
H7. Emergency room visits
H8. Hospital admissions
H9. Premature mortality

The objective of layer integration, as shown in Figure 1, is to identify in the environmental layers of information the area that is influenced by the environmental index of table 1 and the

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frequency of occurrences in terms of annual percentiles. For the health layers, the integration should provide information in the overall number of cases and the percentage of the total population affected. For the latter it will be essential to overlay maps of local population density like those shown at figure 2.
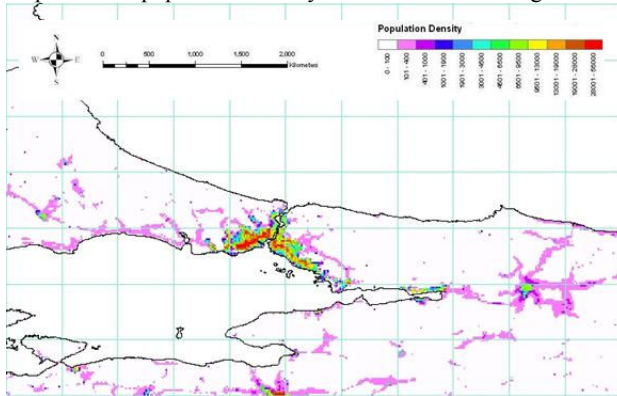

Figure 2.Layer of population density (EEA, 2005) at Istanbul, Turkey, in high spatial resolution.

Two areas of applications are proposed within this work: one for airborne and one for waterborne health problems. The synthesis of these promotes the use of remote sensing for innovative opportunities of exploiting new regulatory applications.

2. METHODOLOGY FOR AIRBORNE OBSERVATIONS

Epidemiological statistics incorporate uncertainties due to inherent difficulties of associating health effects in population groups that are sensitive to specific environmental threats. The assessment of health consequences due to atmospheric exposure must based on information regarding potential or known threshold values or ranges to cause health effects. Until now, these are usually indicated with risk maps and the probability of non-quantifiable disabilities, e.g. the days of shortening of live of large population group. Nevertheless, the regular observation from satellite sensors allows the characterisation of acute episodes or outbreak associated with the time-series, the severity or intensity based on changes in environmental conditions. For atmospheric pollution the datasets of interest are listed in table 3.

Table 3: Data layers with Direct (D) or Indirect (I) contribution on health effects.

Datasets from satellite sensors	Precursor to Health Effects
Atmospheric pressure	I
Atmospheric temperature	D
Cloud cover/sunshine duration	I
Relative Humidity	D
Wind speed/direction	I
Rainfall	I
NO_2 concentrations	D
O_3 concentrations	D
$PM_{0.1}$, $PM_{2.5}$, PM_{10} concentrations	D
SO_2 concentrations	D
CO concentrations	D
Land Use (Urban/Rural/inland waters/land inundation)	D
Vegetation activity	I

Comparisons or such types of layers of observations can provide direct and indirect quantifications of health effects. It also predicts the actual health case numbers that are linked to environmental exposures and/or exceedance of certain threshold values of pollutant concentrations.
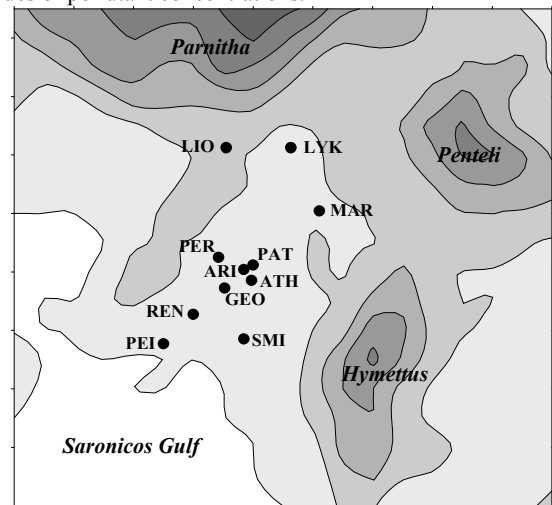

Figure 3.The topography of the Athens metropolitan area. Elevation contours every 200m.
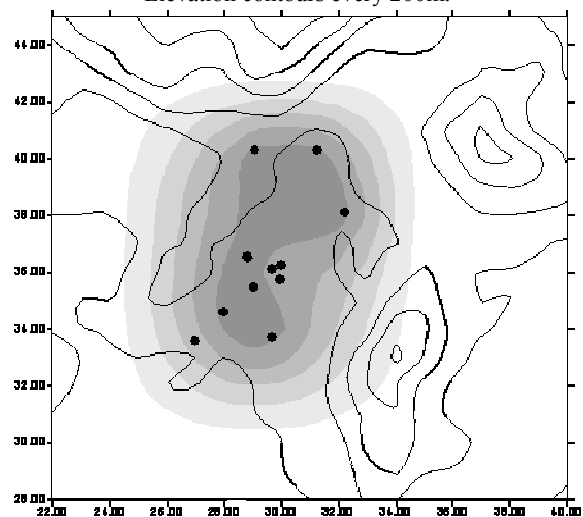

Figure 4. The 9 levels of ozone iso-lines according to table 1, for winter months of 1987 to 1995.
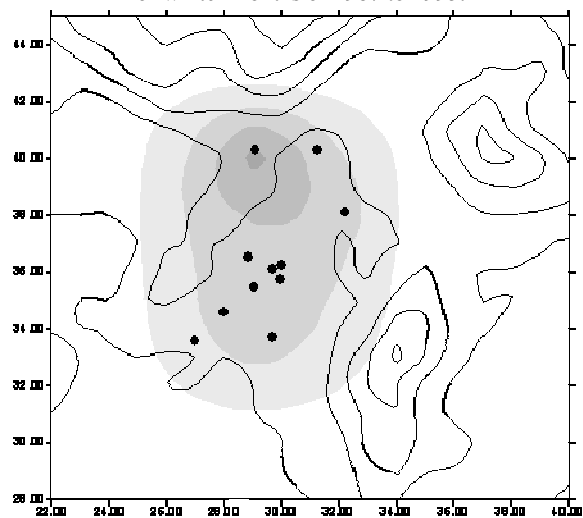

Figure 5. The 9 levels of ozone iso-lines according to table 1, for summer months of 1987 to 1995.
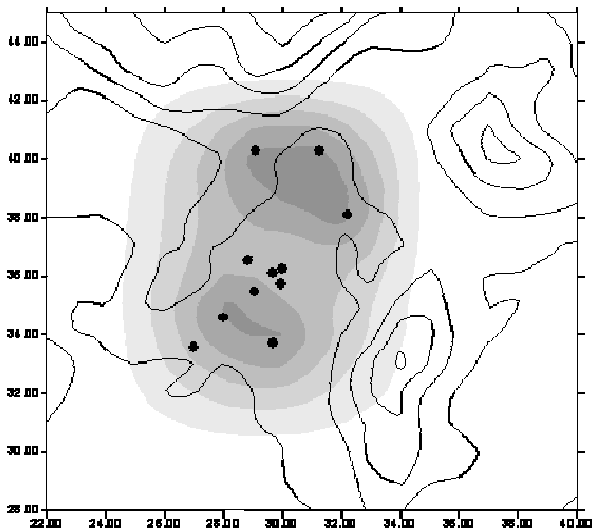
Figure 6. The 9 levels of ozone iso-lines according to table 1, for the transitional months of 1987 to 1995.

The dominant approach for exposure assessment today has been to use ambient concentrations as a proxy for exposure. But, the process of accurate exposure assessment is more complicated as many other parameters will need to be interpolated or extrapolated and exposure and transmission pathways need to be identified and quantified over representative time series. In the following figures 4-6 it is shown how this can be done for ozone in the Athens metropolitan area, which is characterised by the topography shown in figure 3, within which live 4 million inhabitants according to the Eurostat estimate for 2004. The dots at this figure represent the in-situ air-quality monitoring stations and it evident that such a network can be hardly representative over the whole domain of the metropolitan area. Better representation can be attained with satellite sensors of improved resolution (ESA, 2005). The evaluation of the environmental conditions carried out for this case is an adaptation of the approach we used by Kassomenos et.al. (1999), and by Kassomenos et.al. (1998) for liaising with synoptic-scale meteorological classifications.
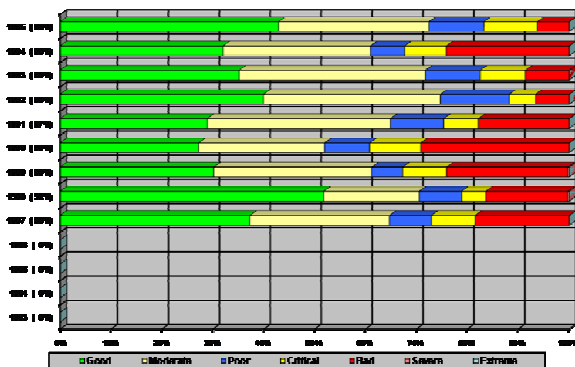

Figure 7. The temporal percentage of the occurrence of the 9 levels of ozone according to table-1 during 1987-1995 (y-axis).

The temporal evolution of these indices can be also examined at specific locations through a systematic analysis of spatial images as those used for figures 4 to 6. The outcome is shown at figure 7. This figure examines the frequently of occurrence of adverse environmental conditions, which might result in health effects. These layers of atmospheric pollution when compared with layers of health information as per table 2 can provide an assessment of consequences from exposure to airborne

pollution. By overlaying data from population density maps we can identify areas where health statistics diverge from the national mean and indicate if improvements due to reducing air-pollution levels would be feasible.

3. METHODOLOGY FOR WATERBORNE OBSERVATIONS

The process is similar for waterborne diseases. As an example one can possibly consider vibrio cholerae. Vibrio cholerae O1 and O139 are the only two known strains of more than 200 Vibrio cholerae strains that cause cholera outbreaks in human populations. Outbreaks occur in areas where the reported cases at a given time are more than the expected cholera cases for a given area. This pathogen can survive outside the human body where it can survive and persist, multiply and also change in its virulence status. However, this also contributes in important functions in the aquatic system (e.g. break down of chitin nutrients) into forms accessible to other living water organisms.

The toxic characteristics can be switched on or off according to several environmental factors such as available nutrients, pH, salinity, sunlight, water temperature. So although for cholera there is no direct environmental burden of the disease, the observation of remote sensing parameters can serve as an indication of where cholera outbreaks might occur. The parameters of relevance for such case are summarised at table 4. Until now, the presence of this pathogen in different water bodies is monitored via analysis of water samples in situ. This a time consuming and rather costly operation that is not carried out on a regular basis in most places even in areas with historical incidence of outbreaks.

Table 4: Data layers with Direct (D) or Indirect (I) contribution on cholera outbreaks.

Datasets from satellite sensors	Precursor to Health Effect
Atmospheric temperature	I
Wind speed/direction	I
Rainfall	D
Cloud cover/sunshine duration	D
UVR	D
Chl a	D
Sea Surface Temperature	D
Sea Surface Height	D
Sea Surface Salinity	D
Topography-Elevation	I
Land Use (Urban/Rural/inland waters/land inundation)	I

Human interventions on land and water, and the continuous modification of these resources, not only influence the local conditions of this disease, but induce evident hazards. The temporal assessment of these hazards and the classification of data according to indices reported on tables 1 and 2 can facilitate a better understanding for the health burden of cholera outbreaks.

The methodology is based on the processing of environmental data of table 4 according to the contents of table 1. Instead of the classical approach of superimposing risk maps the environmental layers as for airborne diseases are systematic linked with corresponding health data in order to account for the total number of reported cases and identify the percentage of the

local population affected. Obviously, this approach is suitable for areas where the hazards that lead to health consequences on local populations are evident.

4. NEW REGULATORY APPLICATIONS

In the implementation of the aforementioned two methodologies for air and waterborne diseases it should be emphasised that the key element is the temporal series of the data used and not on the data reported over long time periods, which narrow the applicability of combined layers and restrict the regulatory uses of such data structures (WHO, 2007). Such types of regulatory applications introduce the following limitations:

1. The extent of the severity of the environmental damage is not obvious.
2. The spatial dimension of the area influenced is insignificant and falls outside the regulatory requirements.
3. The severity of the health problem is not reported in significant numbers.
4. The number of the affected population is not properly taken into consideration.
5. The current exposure masks the past cumulative effects or acquired immunity lasting for a limited period of time with important health consequences.
6. The individual level of exposure is based on modelled estimates, which ignore the randomness of the human activities, and
7. The relative contribution of environmental versus social effects is difficult to disentangle over time and space.

By integrating observations from satellite sensors, we are effectively introducing systematic monitoring of environmental parameters, which allows the following three new assessments in regulatory applications:

- How big is the area under adverse environmental conditions that is likely to cause health effects?
- How frequently health consequences are happening due to adverse environmental condition, and
- What is the real size and the percentage of the local population effected?

This approach can be implemented for several diseases in worldwide geographical areas, where data for induced excessive mortality or morbidity occur. As the frequency of obtaining satellite data decreases, with shorter sensor revisit periods, this approach can be also used for systematic environmental monitoring. When these images are coupled with multispectral observations, the approach can be used effectively for controlling the exposure of specific population groups or for occupational exposure.

5. PROSPECTIVES AND FINAL REMARKS

Paradoxically for many cases of environmental exposure, there are not clear thresholds above which specific health damage will occur. Hence, it is not easy to exploit all the possibilities that are offered with risk maps for specialized human exposures. Effective legislative policies need to consider the accurate spatial and temporal representation and of real cases and the percentage of the population exposed to health effects due to environmental or climatic exposure. Satellite observations obtained from several sources can change significantly the perception of health effects allowing real-time information

regarding the location of vulnerable population groups and the identification of the causes of environmental burden of diseases.

The data sets needed for the fusion of environment and health systems are classified against a scale of nine levels derived from environmental consequences and against a corresponding scale of health effects with nine steps. This approach paves the way to health impact assessments and to accurately describe short and long term exposures that were until now loosely liaised with environmental observations.

In addition, the advancement of technologies for information systems over the last 20-30 years has made available a set of techniques for effectively connecting heterogeneous datasets. This work has focused on two methodologies that examine the challenges for research in air and water and takes into consideration the continuous evaluation of exposure assessment in disease outbreaks against comparable environment and health criteria.

It restricts the possibility of wrong conclusions due to the elimination of risk maps and allows a realistic description of the relationship between environmental causes to quantifiable health effects.

Merging relevant layers of information is also feasible for the creation of comparable standardized maps, for exploiting environmental data structures in a more timely and cost-effective way, for the integration of recommendations in harmonized monitoring systems, for the testing through the integrated health statistics, and for analyzing exposure effects in pollutants or naturally occurring pathogens.

This work addresses some of the restrictions of existing regulatory approaches and facilitates new regulatory policies addressing the effectiveness of abatement strategies closely linked to real-time satellite images that allow innovative monitoring applications.

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