6.2 (Ezz I.)
56th Pugwash Conference
Cairo, Egypt, 11-15- November 2006

A Proposed Transdisciplinary GIS Framework for Health Hazards in the Context of Land-Use

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Abstract

This paper presents examples of some health hazards under the framework of sustainable development, highlighting the importance of integration of variables affecting health not only in the context of each particular category such as air pollution and electromagnetic fields, but also integrating the effects of multiple threats within a geographical area, where some interaction of these variables can rise the threat of disease. Thus, to identify health hazards within geographical areas, where citizens are normally exposed to, every effort should be done to eliminate the risk, in the context of land use. This paper suggests an integrated transdisciplinary framework using GIS in the context of health hazards, aiming to assist in suggesting an international law for land-use. One argument for the need of international efforts is that health hazards and environmental risks could be crossing any boarder, affecting any human being no matter age, race, or religion.

Introduction

In the last few years the problem of revealing universal signs of sustainable development is a matter of great concern. In terms of this approach, the environment, economy and social development should be treated as a unified architectural ensemble with its internal connections. For example, on United Nations, The World Commission on Environment and Development (Brundtland Commission) (1987) sustainable development is definition emphasizes on the concept that current generations should meet their needs without compromising the ability of future generations to meet theirs, and the debates of the Millennium Summit as presented by The United Nations Development Program (2001). Hughes and Johnston (2005) have recognized that sustainable development is now as much about social equity—for current generations—as about efficient resource-use and conservation of natural resources for future ones. Thus, sustained growth is the key to greater social equity. We need economic growth that does not leave large segments of humanity behind. One of the aspects of sustainable development is the threat of health hazards as the links between health and economic development have become

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increasingly recognized, especially with respect to the contribution of health to poverty reduction. Furthermore, the growing burden of non-communicable diseases, as well as the communicable disease burden, has become more evident. Addressing the human dimension of sustainable development is increasingly recognized as fundamental to achieving its goals. Indeed, the first principle of the 1992 Rio Declaration emphasized that “Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature”. Sustainable development cannot be achieved if there is a high prevalence of debilitating illness and poverty, and the health of populations cannot be maintained without healthy environments and intact life-support systems. (Schirnding , 2002) Agenda 21 also recognized the importance of protecting and promoting human health, and highlighted five key action areas: meeting primary health-care needs, especially in rural areas; control of communicable diseases; protecting vulnerable groups; meeting the urban health challenge; and reducing health risks from environmental pollution and hazards. Although many relevant issues were addressed, there were also inevitable gaps, some of which have since grown in importance.

Health hazards include but is not limited to the of exposure at carcinogenic or toxic substances, which may be present in air, soil, water, foods, as consequence of anthropic activities, including the risk associated with nuclear power plants and electromagnetic fields. For example, a complete Environmental and Human Health Risk Assessment (EHHRA) requires the integration of information on environmental and chemicals database, inter and intra media dispersion models output, site description maps and demographic database. In the last past years, the use of information technology and systems supporting this process has been extensively used, especially geographic information systems (GIS). For example, the GIS- based exposure maps identify high exposure areas for policy developers and planners in a simple and realistic manner. Satellites with television, spectrometric, photographic equipment are the main means of continuous control of the state of natural systems of our planet. The GIS spatial database does not just allow combining different health hazards but also other variables necessary for the assessment of the social–geophysical *factors*, which depend on the location of the area of interest and its population such as proximity to the radiation risk sites and population density in this area. Although the extensive work concerning some health hazards, these efforts are isolated and need integration. This paper suggests an integrated transdisciplinary framework using GIS in the context of health hazards, aiming to assist in suggesting an international law for land-use.

Griffiths (2006) adds another dimension, which is the reduction of health inequalities to be considered as a high priority. It would have enormous impact if national and local strategies for reducing health inequalities were merged with strategies for reducing environmental inequalities and promoting environmental justice. The concept of environmental justice includes the right of all to a healthy environment: poorer environments (with more exposure to pollution, fuel poverty, etc.) and poorer health are found disproportionately amongst the disadvantaged in society.

Lat, but not least, the sustainable use of finite natural resources is a major determinant of health. The interdependence between the sustainability of the environment and the sustainability of the human species needs full recognition and the development of new public health practices. Environmental sustainability is a key objective of partnership working between health and other government agencies at local level. Partnerships between health organizations and local authority planning departments concerning spatial planning, particularly for new developments, are important to ensure the design of healthy sustainable communities. . (Schirnding, 2002) thus, this paper concludes with a suggested framework for the policy makers.

Health Hazards

During the last few years the global environmental threats to health and human survival are increasing, including changes in global climate, depletion of the ozone layer, biodiversity loss, and changes in the biosphere and ecological processes. Disruption of complex ecological processes is undermining the geographical distribution of vector-borne infections such as malaria, dengue fever, and leishmaniasis. Other factors include disruptions to weather patterns, increased exposure to thermal extremes, changes in the range, seasonality, and incidence of food-borne and water-borne infections, agricultural crop yields, plant and livestock pests, and salination of water associated with sea-level rise. Further, long-term changes in world climate will affect many prerequisites for health and sustainable development: sufficient food, safe and adequate drinking water, and secure dwellings. Some health effects will be direct, such as heat-wave or flood-related deaths, whereas others will result from disturbances in complex ecological processes, affecting patterns of vectors and infectious diseases. Poor populations are most vulnerable to the health effects of climatic variation and climate change. (Schirnding , 2002) In this section, we are going to introduce some few examples of health hazards to highlight the complexity managing each of these sources.

Chemicals

The assessment of health risks due to exposure to environmental pollutants has been usually focused on analyzing the impact of a single compound. However, people are rarely exposed to individual substances, but to a notable variety of chemicals (Haddad et al., 2001). In recent years, new efforts have been made in order to take into account the possible adverse health effects of an exposure to pollutant mixtures, rather than to single chemicals (Pohl et al., 2003, Cizmas et al., 2004, Jonker et al., 2004, Wilbur et al., 2004 and Monosson, 2005). One of the basic premises to carry out a good analysis of a chemical mixture is the evaluation of each substance separately. Moreover, the study of the individual characteristics of each pollutant, with respect to the remaining chemicals of the mixture, is highly valuable. The comparison of substances has sometimes been executed by applying different prioritization schemes (Groten, 2000 and Mowat and Bundy, 2002). This is an easy way to develop ranking and scoring systems (Swanson and Socha, 1997, Lerche and Sorensen, 2003 and Lerche et al., 2004). These new methodologies are aimed to establish an order of importance of different chemicals depending on individual characteristics, such as human and ecological effects. Often, ranking systems have been based on three basic characteristics to quantitatively assign a score to each substance: persistence, bioaccumulation and toxicity, commonly known as PBT (Knekta et al., 2004). Different approaches in governmental environmental policies have been carried out to integrate these tools in the management of the environment.

Air Pollution

As Scoggins (2003) discusses, urban air pollution is a major focus of public health concern and regulatory activity (WHO, 2002). Appropriate guidelines and effective interventions require knowledge of the burden of illness and premature deaths attributable to specified pollutants. A long-term worldwide research program is concentrating on effects of particulates and other criteria pollutants such as NO_2, O_3 and CO (Brunekreef and Holgate, 2002).

Short-term exposure studies have reported positive associations between air pollution and all-cause mortality (Schwartz and Dockery, 1992 and Touloumi et al., 1994), cardiovascular mortality (Morgan et al., 1998), and respiratory mortality (Lebowitz, 1996 and Hales et al., 2000). Similar associations have been reported with deaths due to pneumonia, chronic obstructive pulmonary diseases mortality, lung cancer, and heart disease (Cohen, 2000; Fischer et al., 2003 and Pekkanen et al., 2002). Relatively fewer long-term studies have been conducted, however, these have also reported positive associations between annual average particulate pollution levels (PM_{10} or $PM_{2.5}$) and annual all-cause mortality, lung-cancer and cardiopulmonary mortality (Pope et al., 1995; Dockery et al., 1993 and Pope et al., 2002). Early ecological studies conducted in the USA during the 1970s and 1980s also showed significant and positive associations between total mortality and annual air pollution (particles and sulfates), even after including variables for home heating, socio-economic status, population and climate (Lave and Seskin, 1970; Lave and Seskin, 1972 and Ozkaynak and Thurston, 1987).

Electromagnetic fields

According to the WHO (2006) Mobile telephony is now commonplace around the world. This wireless technology relies upon an extensive network of fixed antennas, or base stations, relaying information with radiofrequency (RF) signals. Over 1.4 million base stations exist worldwide and the number is increasing significantly with the introduction of third generation technology.

Other wireless networks that allow high-speed internet access and services, such as wireless local area networks (WLANs), are also increasingly common in homes, offices, and many public areas (airports, schools, residential and urban areas). As the number of base stations and local wireless networks increases, so does the RF exposure of the population. Recent surveys have shown that the RF exposures from base stations range from 0.002% to 2% of the levels of international exposure guidelines, depending on a variety of factors such as the proximity to the antenna and the surrounding environment. This is lower or comparable to RF exposures from radio or television broadcast transmitters.

There has been concern about possible health consequences from exposure to the RF fields produced by wireless technologies. This fact sheet reviews the scientific evidence on the health effects from continuous low-level human exposure to base stations and other local wireless networks.

Media or anecdotal reports of cancer clusters around mobile phone base stations have heightened public concern. It should be noted that geographically, cancers are unevenly distributed among any population. Given the widespread presence of base stations in the environment, it is expected that possible cancer clusters will occur near base stations merely by chance. Moreover, the reported cancers in these clusters are often a collection of different types of cancer with no common characteristics and hence unlikely to have a common cause.

Scientific evidence on the distribution of cancer in the population can be obtained through carefully planned and executed epidemiological studies. Over the past 15 years, studies examining a potential relationship between RF transmitters and cancer have been published. These studies have not provided evidence that RF exposure from the transmitters increases the risk of cancer. Likewise, long-term animal studies have not established an increased risk of cancer from exposure to RF fields, even at levels that are much higher than produced by base stations and wireless networks.

Few studies have investigated general health effects in individuals exposed to RF fields from base stations. This is because of the difficulty in distinguishing possible health effects from the very low signals emitted by base stations from other higher strength RF signals in the environment. Most studies have focused on the RF exposures of mobile phone users. Human and animal studies examining brain wave patterns, cognition and behavior after exposure to RF fields, such as those generated by mobile phones, have not identified adverse effects. RF exposures used in these studies were about 1000 times higher than those associated with general public exposure from base stations or wireless networks. No consistent evidence of altered sleep or cardiovascular function has been reported.

Housing

As Jacobs (2005) presents, the World Health Organization (WHO) has recently issued a series of publications on the link between substandard housing and health (WHO, 2005a) and has conducted several international conferences on the subject in recent years (WHO (World Health Organization), 2004a and WHO, 2005a).

Several reviews show many links between health (both physical and mental) and housing quality, especially with regard to specific chronic diseases and injuries (Matte and Jacobs, 2000; Breysse et al., 2004; Krieger and Higgins, 2002; Jacobs, 2005). For example, inadequate ventilation, excess moisture, and other deficiencies in housing still contribute to asthma, mold-induced illnesses, carbon monoxide poisoning, and other diseases and injuries (Matte and Jacobs, 2000; Krieger and Higgins, 2002). Excessive moisture, whether it is caused by roof or plumbing leaks or more complex flows across building membranes and vapor barriers, has been tied to improperly planned ventilation that failed to consider walls as dynamic systems (ASTM, 1994).

A visual assessment was found for each of the seven protocols. The specific element of each protocol that was determined through visual assessment was then placed into one of the following visual hazard subcategories:

• electrical hazards,

• structural hazards,
• moisture/mold hazards,
• presence of pests,
• ventilation,
• injury hazards,
• fire, and
• miscellaneous

Examples of the Use of Health GIS

As Kistemann et al. (2002) clarify; the domain of health is no typical area to applicate Geographical Information Systems (GIS). In environmental sciences, GIS have been widely used to analyze a huge variety of land characteristics, and to solve problems related to human activities (Carlon et al., 2001, Facchinelli et al., 2001, Thums and Farago, 2001, Nam et al., 2003, Blanco and Cooper, 2004 and Elbir, 2004). Nevertheless, the recent development clearly shows that also within the domains of environmental health, disease ecology and public health GIS have become an indispensable tool for processing, analyzing and visualizing spatial data. In the field of geographical epidemiology, GIS are used for drawing up disease maps and for ecological analysis. The striking advantages of GIS for the disease mapping process are the considerably simplified generation and variation of maps as well as a broader variety in terms of determining area units. In the frame of ecological analysis, GIS can significantly assist with the assessment of the distribution of health-relevant environmental factors via interpolation and modeling. On the other hand, the GIS-supported methods for the detection of striking spatial patterns of disease distribution need to be much improved. An important topic in this respect is the integration of the time dimension. The increasing use of remote sensing as well as the integration into internet functionalities will stimulate the application of GIS in the field of Environmental Health Sciences (EHS). In future, the integration and analysis of health-relevant data in one single data system will open up many new research opportunities.

Another example for GIS use is that a large number of chemicals are used on a regular basis in modern society. Thousands of new chemicals are added each year, many of which may have toxic properties constituting potential health hazards. Rapid assessment of the risk associated with the use of these chemicals is therefore essential to protect people from exposure to potentially harmful substances. Exposures to chemicals (and physical agents) are typically unevenly distributed geographically as well as temporally. Disease occurrence also shows geographically varying patterns. Geographic information systems (GIS) may be used to produce maps of exposure and/or disease to reveal spatial patterns. Exposure mapping using advanced GIS modeling may enhance exposure assessment in environmental epidemiology studies. Disease maps can be valuable tools in risk assessment to explore changes in disease patterns potentially associated with changes in environmental exposures. Spatial variations in risk and trends related to distance from pollution sources may be studied using software tools such as the Rapid Inquiry Facility, developed by the U.K. Small Area Health Statistics Unit and enhanced in the European Health and Environment Information System project, for an initial quick evaluation of any potential health hazards associated with an environmental pollutant. (Lars, 2004)

In the context of health risk assessment, GIS has been used for quantifying the human health risk through a system able to manage all the steps in a georeferenced structure was introduced (Bagli et al., 2004). According to Morra et al. (2006) GIS tool is considered as an integrated approach for assessing the risks to human health; in order to display maps of ISO-dose and ISO-risk contours. In the numerical code the modules of the procedure are integrated in a system with a graphical user interface through which specific territorial pattern are represented in great detail to provide an example of GIS supporting human health risk analysis in the context of calculation of the upper-bound excess lifetime cancer risk and noncarcinogenic hazards. The procedure usually adopted in performing this evaluation, as assumed in the developed GIS tool, is based on the following paradigm:

1. Identification of Chemicals of Concerns (COC)
2. COC Fate and Transport Assessment
3. Exposure Scenario Definition and Exposure Intake Assessment
4. Dose–Response Assessment
5. Risk Characterization.

The first step is the identification of substances which cause adverse effects and involves consultation of any toxicological and epidemiological data. In the second phase the distribution of concentrations of contaminants in various environmental media is analyzed. The Exposure assessment of the third step requires the determination of the emissions, pathways and rates of movement of a substance and its transformation and degradation with the aim to estimate the "concentration/doses to which human populations (i.e. workers, consumers and men exposed indirectly via the environment) or environmental compartments (aquatic environment, terrestrial environment and air) are or may be exposed" (CEC, 1993). Dose–response assessment is obtained from epidemiological and toxicological data. Usually this is a tiered process that progresses from the use of short-term (acute) tests and conservative assumptions to longer-term (chronic) tests paired with more realistic assumptions. The risk characterization, which concludes the procedure, is essentially a summary of the data compiled in the risk assessment process including the uncertainties associated with each stage and the presentation of a risk estimate. The digital site and facility description is an input of GIS Spatial DB; it consists in identifying and mapping contaminant sources, collecting facility and site information (e.g. the localization of rivers or lakes, soil properties, groundwater level, terrain elevation), estimating emission rates, and identifying Chemicals of Concern. For each chemical of concern identified in the contaminated area, estimates of the concentrations must be defined for each environmental medium of interest (e.g. soil, ground water, surface water, sediment, air, vegetation). User may derive concentrations from two broad methods: direct monitoring (e.g. sampling and chemical analysis of media at the site coupled with summary statistics) or environmental modeling (e.g. mathematical modeling to predict contaminant concentrations in various media). In both cases the output of the analysis is a series of maps describing the distribution of the toxic and carcinogenic chemicals concentrations in the environmental contaminated media.

Scoggins (2004) presents a study showing the use of GIS in the context of air pollution that relates ambient air pollution levels to mortality in Auckland, New Zealand. Urban airshed modeling and GIS-based techniques to quantify long-term exposure to ambient air pollution levels and associated mortality. The GIS-based exposure maps identify high exposure areas for policy developers and planners in a simple and realistic manner. Taken together with overseas studies the study provides additional evidence that long-term exposure to poor air quality, even at levels below current standards, is a hazard to the public health.

Ecological studies are targeted on the description of relations existing between the geographic variation of diseases and risk factors and their analysis by means of statistical procedures. As mentioned above, the risk factors include the exposure to relevant biological, chemical or physical environmental agents, but they also comprise social, economic and behavioral factors.

The space-related analysis of epidemiological data to be performed in an ecological study can be subdivided into several steps (van den Berg and von der Ahe., 1997):
_ **Identification of a possible health problem** (assumption of an increasing number of cases).
_ **Verification that an observed spatial pattern of disease cases** considerably differs from the pattern expected.
_ **Ecological analysis**: based on the knowledge of disease distribution and considering the spatial distribution of risk factors, certain hypotheses regarding the cause of disease distribution are generated and checked by means of statistical methods.

For example, geographic-ecological analysis is also based on the principle of the spatial linkage of health data and risk factors. The current place of residence is frequently taken as point of reference. The exposition of a population to a risk factor, e.g. to air pollutants, is assessed by means of the emission level of the place of residence. In many cases, this procedure proves to be more reliable than the collection of individual exposition data (English, 1992; Morgenstern, 1998). It implies the differentiated mapping of environmental risk factors in terms of the area to be covered ± a task for which GIS are highly suitable.

Since the beginning of the 90ies, the U.S. Centers for Disease Control and Prevention (CDC) have carried out several GIS-supported analyses covering infectious diseases' occurrence due to environmental factors (Croner, 1996). Initially, GIS were used in the field of epidemiology in order to control parasitic diseases because the complex interactions between environmental factors and pathogens, vectors (e.g., mosquitoes, ticks), the various host animals and pathogen reservoirs can be recorded in one single system (Mott et al., 1995). In Maryland, e.g., a risk model for the occurrence of the Lyme disease, transmitted by ticks, has been established, in which numerous ecological data influencing the appearance of ticks could be included (Glass et al., 1995).

The remote sensing data are increasingly used for investigations in the field of environmental health sciences for risk mapping, surveillance or monitoring, In one of the projects, a satellite-based Global Positioning System (GPS), methods of remote sensing and GIS have been used as complementary tools (Seto et al., 1998). Remote sensing is frequently applied on the investigation of the malaria risk.

The use of GIS as a Transdisciplinarity Tool

Lawrence and Després (2004) discuss some key questions about the natural and human-made environment, at whatever geographical scale; need to be understood by innovative concepts and methods. This stems from the fact that the capacity of human societies to deal with environmental questions (such as climate change, health, land-use, forestry management, renewable and non-renewable resources, housing, poverty and urban planning) are insufficient even though many professionals are convinced that they have the "right answers". The incapacity to deal with the above-mentioned problems is related to their complexity, to the compartmentalization of scientific and professional knowledge, to the sectoral division of responsibilities in contemporary society, and to the increasingly diverse nature of the societal contexts in which people live. In addition, the lack of effective collaboration between scientists, professionals and policy decision-makers has led to the "applicability gap" in sectors that deal with both the natural and human-made environment. There is an urgent need for innovative approaches in many situations, such as the blatant failure of the wealthiest countries of the world to provide all citizens with secure employment, affordable housing and appropriate health care that meet at least minimal requirements.

As Kistemann et al. (2002) argue environmental health sciences (EHS) are dealing with the effect of natural and social environment on human health. Reflecting the complex and heterogeneous character of this structure, many sciences make specific contributions to its analysis, among them environmental hygiene and environmental medicine, toxicology and epidemiology, but also natural sciences, economics and social sciences. In many cases, the investigation requires a close interdisciplinary co-operation (Eikmann and Herr, 2001). If the aspect of spatial relation between human health and environmental factors is to be dealt with, the expertise of geographical science as being focused on a spatial approach is required. Along with the reintroduction of classical literature into medicine and the ™neo-Hippocratic∫ refocusing since the 18th century, the notion that place was an types of data: on one hand geometric data which are the co-ordinates of points defining also curves and areas and on the other hand the attribute data containing the factual information.

Thus, this area calls for transdisciplinary research , which focuses on the organization of knowledge around complex heterogeneous domains, rather than the disciplines and subjects into which knowledge seems inevitably to become organized in academic settings (Nowotny et al., 2001), 'transcending' the academic disciplinary structure. Further, it tackles complexity in science and it challenges knowledge fragmentation (e.g. Klein, 2004; Ramadier, 2004). It deals with research problems and organizations that are defined from complex and heterogeneous domains (e.g. Horlick-Jones & Sime, 2004). Beyond complexity and heterogeneity, this mode of knowledge production is also characterized by its hybrid nature, non-linearity and reflexivity, transcending any academic disciplinary structure (Balsiger, 2004). The following figure shows the transdisciplinarity nature of environmental problems.

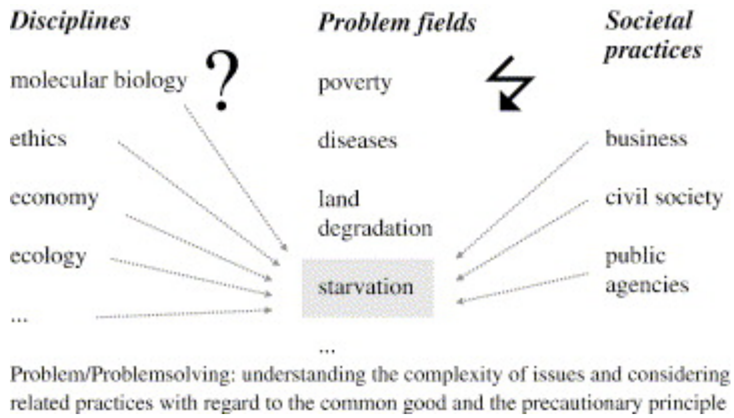

Figure 1. Identifying and structuring problems in transdisciplinary research (Neef, 2005)

Some authors such as Hochtel et al. (2006) have applied a theoretical concept of transdisciplinarity by presenting the successive work stages. It demonstrates why and how transdisciplinary methodology is to be applied. The transdisciplinary strategy was adopted since it enables researchers to cross disciplinary borders and to deal with extra-scientific "real world problems". This can bee seen in figure 2:

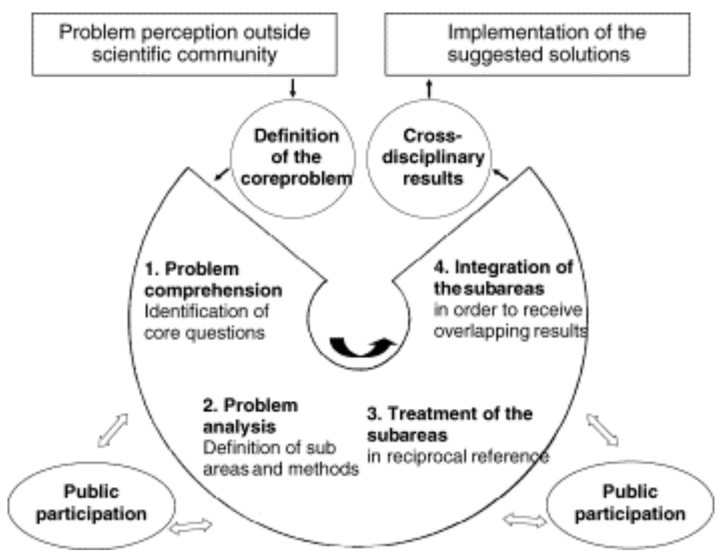

Figure 2. The problem solving strategy in transdisciplinary projects Hochtel et al. (2006)

In the context of health hazards the framework presented in figure 2 applies as we are dealing with the many sources and pathways of single agents (e.g., lead) is a complex process—the complexity is magnified by several orders if considering the effects on health of housing or transport, urbanization and globalization, or changes to the ecosystem and to ecological processes. Health and environmental issues are becoming increasingly complex, crosscutting, and inter-related. **(Schirnding ,** 2002) As been addressed in the above section the GIS can be used an integrator, in this case. The use of GIS is not limited to identify the combinatory health hazards per geographical area, but also for:

- Monitoring the application current agreed upon hazards/ laws
- Identifying new potential hazards
- Identifying new patterns
- Identifying new laws
- Healthcare planning (hospitals distribution, equity)
- Land use
- Crisis management

The proposed GIS use is not just recommended at local level, but should be considered as a global project.

Conclusion:

This paper has presented some examples of some health hazards under the framework of sustainable development. It concludes that there is vital importance for the integration of variables affecting health not only in the context of each particular category such as air pollution and electromagnetic fields, but also integrating the effects of multiple threats within a geographical area, where some interaction of these variables can rise the threat of disease. An integrated transdisciplinary framework using GIS in the context of health hazards has been presented.

References:

1. ASTM (American Society for Testing and Materials), 1994 ASTM (American Society for Testing and Materials), Moisture control in buildings. In: H.R. Trechsel, Editor, *Manual Series MNL 18, 28-018094-10*, ASTM, Philadelphia (1994).
2. Bagli et al., 2004 S. Bagli, P. Morra and G. Spadoni, The EHHRA tool: a decision support system for assessing and managing human health risk from industrial activities, *Proceedings of 11th international symposium loss prevention, Praha* (2004).
3. Balsiger, P.W., 2004, Supradisciplinary research: history, objectives and rationale, *Futures* 36: 4
4. Blanco and Cooper, 2004 G.A. Blanco and E.L. Cooper, Immune systems, geographic information systems (GIS), environment and health impacts, *J. Toxicol. Environ. Health B* 7 (2004), pp. 465–480.
5. Breysse et al., 2004 P. Breysse, N. Farr, W. Galke, B.P. Lanphear, R.L. Morley and L. Bergofsky, The relationship between housing and health, *Environ. Health Perspect.* 112 (2004), pp. 1583–1588.
6. Carlon et al., 2001 C. Carlon, A. Critto, A. Marcomini and P. Nathanail, Risk based characterisation of contaminated industrial site using multivariate and geostatistical tools, *Environ. Pollut.* 111 (2001), pp. 417–427.

7. CEC (Commission of the European Communities), 1993 CEC (Commission of the European Communities). Commission Directive 93/67/EEC, OJ L227/10, 8.9.1993. Brussels; 1993.
8. Cizmas et al., 2004 L. Cizmas, T.J. McDonald, T.D. Phillips, A.M. Gillespie, R.A. Lingenfelter, L.F. Kubena and K.C. Donnelly, Toxicity characterization of complex mixtures using biological and chemical analysis in preparation for assessment of mixture similarity, *Environ. Sci. Technol.* 38 (2004), pp. 5127–5133.
9. Cohen, A.J., 2000. Outdoor air pollution and lung cancer. *Environ Health Perspect* 108 Suppl 4, pp. 743–750.
10. Croner, C.M. , Sperling, J., and. Broome, F.R, 1996, Geographic Information Systems (GIS): New perspectives in understanding human health and environmental relationships, *Statistics in Medicine* 15 (1996), pp. 1961–1977.
11. Dockery, D.W., Pope III, A.C., Xu, X., Spengler, J.D., Ware, J.H., Fay, M.E., Ferris, B.G. and Speizer, F.E., 1993. An association between air pollution and mortaltity in six US cities. *N Engl J Med* 329 24, pp. 1753–1759
12. Eikmann, T. and Herr, C., 2001, Novellierung der (Muster-) Weiterbildungsordnung – eine neue Herausforderung für die Umweltmedizin?, *Umweltmed Forsch Prax* 6 (2001), p. 1.
13. Elbir, 2004 T. Elbir, A GIS based decision support system for estimation, visualization and analysis of air pollution for large Turkish cities, *Atmos. Environ.* 38 (2004), pp. 4509–4517.
14. English, D., 1991, Geographical epidemiology and ecological studies. In: P. Elliott, J. Cuzick, D. English and R. Stern, Editors, *Geographical and environmental epidemiology*, Oxford University Press, Oxford (1991), pp. 1–13 1992. European Community (1991): Atlas of Avoidable Death. Oxford.
15. Facchinelli et al., 2001 A. Facchinelli, E. Sacchi and L. Mallen, Multivariate statistical and GIS-based approach to identify heavy metal sources in soils, *Environ. Pollut.* 114 (2001), pp. 313–324.
16. Fischer, P., Hoek, G., Brunekreef, B., Verhoeff, A. and van Wijen, J., 2003. Air pollution and mortality in the Netherlands: are the elderly more at risk?. *Eur Respir J* 40 Suppl, pp. 34–38.
17. Frumkin et al., 2004 H. Frumkin, L. Frank and R. Jackson, Urban Sprawl and Public Health: Designing, Planning and Building for Healthy Communities, Island Press, Washington, DC (2004).
18. Glass, G.E. , Schwartz, B.S. , Morgan, J.M., Jonson, D.T., Noy, P.M. and Israel, E., 1995, Environmental risk factors for Lyme disease identified with geographic information systems, *Am J Pub Health* 85 (1995), pp. 944–948.
19. Griffiths, J., 2006, The convergence of public health and sustainable development, Public Health, 120 (2006), pp. 581-584.
20. Groten, 2000 J.P. Groten, Mixtures and interactions, *Food Chem. Toxicol.* 38 (2000) (Suppl. 1), pp. S65–S71.
21. Haddad et al., 2001 S. Haddad, M. Béliveau, R. Tardif and K. Krishnan, A PBPK modeling-based approach to account for interactions in the health risk assessment of chemical mixtures, *Toxicol. Sci.* 63 (2001), pp. 125–131.
22. Hales, S., Salmond, C., Town, I.G., Kjellstrom, T. and Woodward, A., 2000. Daily mortality in relation to weather and air pollution in Christchurch, New Zealand. *Aust NZ J Public Health* 24, pp. 89–91.
23. Horlick-Jones, T., Sime, J., 2004, Living on the border: knowledge, risk and transdisciplinarity, Futures 36: 4.
24. HUD, 1999 US HUD, 1999. The Healthy Homes Initiative: a preliminary plan. Report to Congress. Office of Lead Hazard Control. Accessed October 20, 2006,

at
http://www.sciencedirect.com/science?_ob=RedirectURL&_method=externObjLink&_locator=url&_cdi=6774&_plusSign=%2B&_targetURL=http%253A%252F%252Fwww.hud.gov%252Futilities%252Fintercept.cfm%253F%252Foffices%252Flead%252Freports%252FHHIFull.pdf.

25. Hughes, B. and Johnston, P., 2005, Sustainable futures: policies for global development, Futures 37 (2005), pp. 813-831
26. Jacobs, 2005 Jacobs, D.E., 2005. Housing and health: challenges and opportunities. Keynote address in Proceedings of the Second World Health Organization Symposium on Housing and Health, WHO European Centre for Environment and Health (Bonn), Noise and Housing Unit, September 29–October 1, 2004. Vilnius, Lithuania. Released October 20, 2005, pp. 35–50.
27. Jacobs, 2006, A qualitative review of housing hazard assessment protocols in the United States, Environmental Research, 102(2006), pp.13-21.
28. Jonker et al., 2004 D. Jonker, A.P. Freidig, J.P. Groten, A.E.M. De Hollander, R.H. Stierum, R.A. Woutersen and V.J. Feron, Safety evaluation of chemical mixtures and combinations of chemical and non-chemical stressors, *Rev. Environ. Health* 19 (2004), pp. 83–139.
29. Kistemann , D., Dangendorf, F., and Schweikart, J., 2002, New perspectives on the use of Geographical Information Systems (GIS) in environmental health sciences, International Journal of Hygiene and Environmental Health , 205 (2002), pp.169-181.
30. Klein, J.T., 2004, Prospects for transdisciplinarity, Futures 36: 4.
31. Knekta et al., 2004 E. Knekta, P.L. Andersson, M. Johansson and M. Tysklind, An overview of OSPAR priority compounds and selection of a representative training set, *Chemosphere* 57 (2004), pp. 1495–1503.
32. Krieger and Higgins, 2002 J. Krieger and D.L. Higgins, Housing and health: time again for public health action, *Am. J. Public Health* 92 (2002), pp. 758–768.
33. Kuchuk et al., 1998 A.A. Kuchuk, M. Krzyzanowski and K. Huysmans, The application of WHO's Health and Environment Geographic Information System (HEGIS) in mapping environmental health risks for the European region, *Journal of Hazardous Materials* 61 (1998), pp. 287–290.
34. Lars, J., 2004, Health and Environment Information systems for exposure and disease mapping, and risk assessment , Environmental health perspectives, 112 (2004), pp. 995-997.
35. Lawrence R.J., and Després C., 2004, Futures of Transdisciplinarity *Futures* 36, Issue 4 , May (2004), pp. 397-405.
36. Lave, L.B. and Seskin, E.P., 1970. Air pollution and human health. *Science* 169 3947, pp. 723–733.
37. Lave, L.B. and Seskin, E.P., 1972. Air pollution, climate, and home heating: their effects on US mortality rates. *Am J Public Health* 62 7, pp. 909–916.
38. Lerche and Sorensen, 2003 D. Lerche and P.B. Sorensen, Evaluation of the ranking probabilities for partial orders based on random linear extensions, *Chemosphere* 53 (2003), pp. 981–992.
39. Lerche et al., 2004 D. Lerche, S.Y. Matsuzaki, P.B. Sorensen, L. Carlsen and O.J. Nielsen, Ranking of chemical substances based on the Japanese pollutant release and transfer register using partial order theory and random linear extensions, *Chemosphere* 55 (2004), pp. 1005–1025.
40. Matte and Jacobs, 2000 T.D. Matte and D.E. Jacobs, Housing and health—current issues and implications for research and programs, *J. Urban Health* 77 (2000), pp. 7–25.

41. Monosson, 2005 E. Monosson, Chemical mixtures: considering the evolution of toxicology and chemical assessment, *Environ. Health Perspect.* 113 (2005), pp. 383–390.
42. Morgan, G., Corbett, S., Wlodarczyk, J. and Lewis, P., 1998. Air pollution and daily mortality in Sydney, Australia, 1989 through 1993. *Am J Public Health* 88 5, pp. 759–764.
43. Morgenstern, H., 1998, Ecologic studies In: K.J. Rothman and S. Greenland, Editors, *Modern Epidemiology.*, Lippincott–Raven, Philadelphia (1998), pp. 459–480.
44. Morra, P., Bagli, S. and Spadoni, G., 2006, The analysis of human health risk with a detailed procedure operating in a GIS environment, Environment International
32 (2006), pp. 444-454.
45. Mott, K.E. , Nuttall, I., Desjeux, P. and Cattand, P., 1995, New geographical approaches to control of some parasitic zoonoses, *Bull. World Health Organ* 73 (1995), pp. 247–257.
46. Nadal, M., Kumar, V., Schuhmacher, M. and Domingo, J., 2006, Definition and GIS based characterization of an integral risk index applied to a chemical/ petrochemical area, Chemosphere, 64 (2006), pp.1526-1535.
47. Nam et al., 2003 J.J. Nam, B.H. Song, K.C. Eom, S.H. Lee and A. Smith, Distribution of polycyclic aromatic hydrocarbons in agricultural soils in South Korea, *Chemosphere* 50 (2003), pp. 1281–1289.
48. Nowotny, H., Scott, P., and Gibbons, M., 2001, Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty, *Polity Press*, Cambridge, UK.
49. Ozkaynak, H. and Thurston, G.D., 1987. Associations between 1980 US mortality rates and alternative measures of airborne particle concentration. *Risk Anal* 7 4, pp. 449–461.
50. Pekkanen, J., Peters, A., Hoek, G., Tiittanen, P., Brunekreef, B., de Hartog, J., Heinrich, J., Ibald-Mulli, A., Kreyling, W.G., Lanki, T., Timonen, K.L. and Vanninen, E., 2002. Particulate air pollution and risk of ST-segment depression during repeated submaximal exercise tests among subjects with coronary heart disease: the exposure and risk assessment for fine and ultrafine particles in ambient air (ULTRA) study. *Circulation* 106 8, pp. 933–938.
51. Pohl et al., 2003 H.R. Pohl, N. Roney, S. Wilbur, H. Hansen and C.T. De Rosa, Six interaction profiles for simple mixtures, *Chemosphere* 53 (2003), pp. 183–197.
52. Pope III, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K. and Thurston, G.D., 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *J Am Med Assoc* 287 9, pp. 1132–1141.
53. Pope III, C.A., Thun, M.J., Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E., Clark, W. and Heath, J., 1995. Particulate air pollution as a predictor of mortality in a prospective study of US adults. *Am J Repir Crit Care Med* 151, pp. 669–674.
54. Ramadier, J., 2004, Transdisciplinarity and its challenges: the case of urban studies, Futures 36: 4.
55. Schirnding , Y., 2002, Health and sustainable development: can we rise to the challenge?, The Lancet, 360 (2002), pp. 632-637.
56. Schwartz, J. and Dockery, D.W., 1992. Particulate air pollution and daily mortality in Steubenville, Ohio. *Am J Epidemiol* 135, pp. 12–19.

57. Scoggins, A., Kjellstrom, T., Fisher, G. , Connor, J. , and Gimson, N., 2004, Spatial analysis of annual air pollution exposure and mortality, Science of The Total Environment, 321(2004), pp.71-85.
58. Seto, E. Y., Maszle, D. R., Spear, R. C., Gong Peng, Wood, B., 1998, Remote Imaging Applied to Schistosomiasis Control: The Anning River Project. In: Geographic Information Systems in Public Health: Proceedings of the Third National Conference (R. C. Williams, M. M. Howie, C. V. Lee, W. D. Henriques, eds.), pp. 331–340. (www.atsdr.cdc.gov/GIS/conference98) 1998.
59. Swanson and Socha, 1997 Swanson, M.B., Socha, A.C., 1997. Chemical ranking and scoring: guidelines for relative assessments of chemicals. Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, Florida, USA.
60. Thums and Farago, 2001 C. Thums and M. Farago, Investigating urban geochemistry using Geographical Information Systems, *Sci. Prog.* 84 (2001), pp. 183–204.
61. Touloumi, G., Pocock, S.J., Katsouyanni, K. and Trichopoulos, D., 1994. Short-term effects of air pollution on daily mortality in Athens: a time series analysis. *Int J Epidemiol* 23 5, pp. 957–967.
62. United Nations Development Programme (UNDP), 2001, Human development report, *Making New Technologies Work for Human Development*, Oxford University Press, New York, 2001.
63. United Nations, The World Commission on Environment and Development (Brundtland Commission), 1987, *Our Common Future*, Oxford University Press, Oxford, 1987.
64. US Surgeon General, 2005 US Surgeon General, 2005. The Surgeon General's Workshop on Healthy Indoor Environment, Natcher Conference Center, National Institutes of Health, Bethesda, MD, January 12 and 13. Accessed July 22, 2006, at http://www.sciencedirect.com/science?_ob=RedirectURL&_method=externObjLink&_locator=url&_cdi=6774&_plusSign=%2B&_targetURL=http%253A%252F%252Fwww.hhs.gov%252Fsurgeongeneral%252Flibrary%252Fhealthybuildings%252F.
65. WHO (World Health Organization), 2004a WHO (World Health Organization), 2004a. In: Second WHO International Housing and Health Symposium. Accessed July 22, 2006, at http://www.sciencedirect.com/science?_ob=RedirectURL&_method=externObjLink&_locator=url&_cdi=6774&_plusSign=%2B&_targetURL=http%253A%252F%252Fwww.euro.who.int%252FHousing%252FActivities%252F20040204_3.
66. WHO, 2005a WHO, 2005a. Environmental health. Accessed July 22, 2006, at http://www.sciencedirect.com/science?_ob=RedirectURL&_method=externObjLink&_locator=url&_cdi=6774&_plusSign=%2B&_targetURL=http%253A%252F%252Fwww.euro.who.int%252FHousing%252Fpublications%252F20020409_2.
67. WHO, 2006, Electromagnetic fields and public health, Fact sheet N°304, May 2006, Accessed October 22, 2006, at http://www.who.int/mediacentre/factsheets/fs304/en/index.html.
68. WHO. 2002. The World health report 2002: Reducing risks, promoting health life. Geneva, World Health Organisation: 248. ISBN 92 4 156207. ISSN 1020-3311.
69. Wilbur et al., 2004 S.B. Wilbur, H. Hansen, H. Pohl, J. Colman and P. McClure, Using the ATSDR guidance manual for the assessment of joint toxic action of chemical mixtures, *Environ. Toxicol. Phar.* 18 (2004), pp. 223–230.