STRATEGIC DECISION MAKING FOR ENVIRONMENTAL HEALTH IMPACT: THE 5-I MODEL

Anitha K. Chinnaswamy[a], Ian M. Marshall[a], Alexeis Garcia-Perez[a] and Raouf Naguib[b]
[a]*Faculty of Business and Law, Coventry University, UK*
[b]*BIOCORE Research & Consultancy International, UK and The Faculty of Science, Liverpool Hope University*

Abstract

This study highlights the significant impact of Knowledge transfer, knowledge sharing/management in the mitigation of cardiovascular diseases (CVD) health risks due to pollution. It is well acknowledged that the application of Knowledge Management (KM) techniques would synchronise disjointed knowledge in a public health domain and assist a more co-ordinated approach of tackling public health issues. This paper presents an empirical model that advocates an integrated approach to generate a strategic knowledge driven decision support system to enable knowledge management for the mitigation of air pollution induced CVD health.

There is limited research output from Asia and in particular, from India on studies of the deleterious effects of air pollution on CVD. This research investigated the barriers in developing countries and used a spatiotemporal methodology to assess the effects of air pollution on CVD by developing an application based on a GIS platform. Choosing Bangalore as a case study area, secondary data from various governmental departments that included demographic data from the 2001 and 2011 census, air pollution data from six fixed monitoring stations and mortality data of over one million death records were obtained. Data quality assessment was carried out on these datasets that resulted in the recommendation of a generalizable data quality framework to enable better data collection that will aid in strengthening health development policies.

An Environmental Health Information system application based on GIS platform was developed specifically for Bangalore and with the characteristics of the datasets available. The data was analysed using spatial and non-spatial techniques. Results showed that levels of PM10 were of concern to the city with all areas having either high or critical levels of pollution. CVD deaths also were of concern contributing to almost 40% of total mortality. The potential years of life lost (PYLL), which is an estimate of the average years a person would have lived if he or she had not died prematurely was calculated for the years from 2010 to 2013; CVDs were responsible for 25% of the total of potential years of life lost. The potential value of lifetime earnings were computed that highlighted a loss in excess of 8 billion INR over the four years. These potential years lost is an important factor to consider, as preventive measures taken by the Government will result in a significant economic impact on the city.

The limitations of few monitoring stations were overcome by using spatial interpolation techniques such as Inverse Distance Weighted interpolation technique. The performance of the interpolation was tested using cross-validation techniques and the results revealed that Bangalore city would benefit from increased measuring stations for PM_{10}. Logistic regression was conducted that highlighted pollution especially PM_{10} was a likely predictor of CVD in the city. Spatial analysis was conducted and included buffering, overlay maps, queries and Hotspot analysis highlighting the zone hotspots.

The results from the research guided the development of a novel model that would assist other similar developing cities to assess the effects of air pollution on CVD. The impetus is that based on knowledge sharing and management, intervention policies and programs may be implemented to inform research and practice which will ultimately have social, economic and health impact on the

population. The model proposes a valuable strategic planning and management resource to the relevant stakeholders that will ultimately prevent millions of deaths and enhance overall quality of life in developing nations.

Background

Knowledge Gaps

There is a noticeable absence of studies that highlight the harmful effects of air pollution and CVD in Bangalore. Further there is a lack of knowledge and insufficient understanding of CVD risk factors and these gaps are some of the factors contributing to the prevalence and rise of CVDs in the city/country. Based on the knowledge gaps identified in this research, a novel model is proposed to tackle the growing concern of air pollution and CVD in developing countries. The model captures the key steps to collaboratively plan the reduction of risk factors in areas and population groups of dire need. The use of Information Systems such as GIS plays a vital role in formulating policies that are targeted at population groups with an aim to prevent cardiovascular disease.

The 5-I Model

This research provides a new model to support the analysis of air pollution and CVD in developing countries. It has been developed to address the challenges faced by developing countries in engaging in activities involving the study of the harmful effects of air pollution. The model considers the important factors that affect the implementation of such studies. The importance and objectivity of data collection and data quality is highlighted.

Based mainly on the findings of this research, a 5-I model is designed and developed (Figure 1) that would facilitate the effectiveness of a spatial temporal methodology using GIS to better understand the effects of AP on CVD in developing countries. The model is named 5-**I** as it represents the five important components that is a synthesis of many important elements that coherently work together to produce positive health outcomes. The use of innovative technology such as GIS will result in an efficient and timely detection of disease effects and enable to act on the findings. Partnerships between stakeholders will allow focusing and working with an integrated approach to address and achieve the same goals. An integrated system will support a systematic approach and will provide a basis for an effective prevention plan that is based on timely and best evidence. The findings will also lead to prevention and intervention planning that is clearer and logical.

The model consists of five modules described as:

- IDENTIFY
- IMPROVE
- INTEGRATE
- INTERVENE
- IMPACT

The model highlights the first stage as identification of the nature of the research problem, the investigation process that might be adopted and the area to narrow down and focus on. It is vital at this stage to also identify the datasets required for the research and the stakeholders from whom the data is required. Data quality is vital, not only because of its importance in promoting high standards of healthcare but accurate, timely and accessible healthcare is important in the planning, development and maintenance of its services. Quality improvement and timely dissemination of quality data are essential to maintain healthcare at an optimal level.

The application of Knowledge Management (KM) techniques would enhance the current phase of CVD activities and synchronise disjointed knowledge in public health domain, so that there could be a more coordinated approach towards tackling CVD mortality rate in Bangalore. Bali *et al*. (2011) described knowledge management (KM) as an organisational knowledge with meaningful interaction of people, processes, activities and technologies that enable the sharing, creation and communication of knowledge. Knowledge is interpreted information, which will enable to apply the information in reasoning, decision-making, or performing actions. Based on these principles, this model will:

- Allow the creation of knowledge
- Enable the critical evaluation of knowledge
- Ensure the effective integration and application of knowledge

Public health has always been more evidence based than other health sciences. Jenicek (1997) states that Evidence-based public health (EBPH) might be seen as " *the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of communities and populations in the domain of health protection, disease prevention, health maintenance and improvement (health promotion)*". Based on this definition of EBPH, this model:

- Formulates a clear question for a public health problem
- Searches for evidence
- Appraises evidence
- Selects the best evidence for a public health decision
- Links evidence with public health experience, knowledge, and practice
- Recommends to implement useful evidences in policies and programmes
- Recommends good practice for evidence-based public health

IDENTIFY

Air Pollution in India

An extensive literature review was carried out that highlighted the deleterious effects of air pollution on CVD. A conceptual framework was then developed as a guide to the overall methodology process and information system development. Part of the process also required the identification of choice of location for a case study to test the methodology. Providing an overview of the capabilities of the proposed methodology and GIS as an analytical information system, the data requirements from various sources was identified such as basemaps, attribute data, demographic data, air pollution and CVD data. India is gaining reputation as one of the fastest growing economies in the world today. While the country is benefiting from the economic boom due to its rapid development, there is a negative impact on the nation's environment. A World Health Organization (WHO) study of 1,600 cities released in May 2014 found New Delhi had the world's dirtiest air with an annual average of 153 micrograms of small particulate matter ($PM_{2.5}$). According to the 2012 Environmental Performance Index (EPI), which ranks countries on performance indicators tracked across policy categories that cover both environmental health and ecosystem vitality, India ranks 125th of the 132 countries whose environments were surveyed. Moreover, it ranks as the bottom country in the category of air effects on human health (Yale University, 2010). Thirteen of the dirtiest 20 cities worldwide were in India [WHO,2014] with 527,000 people annually dying prematurely in India due to air pollution (Bhatnagar, 2011).

CVD in India

Cardiovascular disease is one of the world's leading causes of mortality (Ramaraj and Chellappa, 2008), and is equally one of the major causes of mortality in India (Gupta et al., 2011) with an increase in the explosion of cardiovascular diseases over the past decade. The Registrar General of India (RGI) report state that the highest cause of mortality for all age groups, areas and genders is CVD. In 1990, CVDs accounted for 63% of all deaths in India and contributed to 17% of worldwide mortality. In one study by the World Health Organisation (WHO) it was estimated that by 2010, 60% of the world's cardiac patients would be Indians (Ghaffar, Reddy and Singhi, 2004) and that 50% of the Indian population who die from CVD are below the age of 70 (Gaziano, 2006). Moreover, there is scientific evidence that Indians tend to acquire the disease at least 10 years earlier than their western counterparts (Vamadevan et al., 2011). India is estimated to have lost US$8.7 billion in 2005 due to affliction from CVD and diabetes (Prabhakaran et al, 2007), and the WHO estimates that this figure will reach US$237 billion by 2015 (Goenka et al, 2009). Furthermore, the GDP of the country is estimated to fall by 1% due to the combined economic impact of CVD and diabetes (WHO, 2005).

Bangalore

Bangalore city is one of India's fastest growing economies and is the IT capital for the country, with the largest IT exports for the country. It is also commonly referred to as the 'Silicon Valley of India'. The city within a span of a decade went from a quiet city, previously referred to as the 'Pensioner's Paradise' to a rapidly growing city. This tremendous growth of Bangalore has boosted the city's economy but has also presented it with unique challenges, such as increasingly deteriorating infrastructure, water shortages, frequent power cuts and increased air pollution. Although Bangalore is growing rapidly as the largest economy in India, it is also gaining a reputation as one of the worst polluted cities in the country (TERI, 2007). According to a study in 2010, Bangaloreans are at a higher risk of being afflicted by CVD (54.3%) than the rest of the nation (with an average of 44.8%) (Daily News and Analysis, 2011). Having highlighted the research gaps Bangalore was chosen as the case study area that will be a significant contribute to the gap in knowledge. The datasets required for the study were identified and the governmental organisations contacted for support with the study. The datasets obtained were:

- Air pollution data from the KSPCB responsible for the air quality monitoring in the city
- Demographic data was obtained from BBMP
- CVD data was obtained from BBMP and DES.

IMPROVE

Analysis on the data quality indicators was conducted. This revealed that Bangalore has a robust and functional system in place for data collection but which could be improved. With a few improvements made to the system to collect data with the recommended parameters could assist in the design of health information systems. The system can monitor not only CVD but can be extended to monitor other health issues in the city that will lead to improved health and better economic performance resulting in a better quality of life. A data improvement framework is proposed which when implemented will assist in the objectivity of wider monitoring of the effects of the air pollution on health. The data parameters that are proposed for demographic, air pollution and mortality data are:

Demographics

With respect to the data quality factors for demographics, Bangalore has a good robust system for census data collection and have been accurately producing census data reports that are relevant, timely, accurate and accessible. But the parameters recorded and stored also play a vital role in the analyses of the data and their interpretations. The only issue that was highlighted with the census data of Bangalore was that data was unavailable for age breakdown, hence crude death rates cannot be calculated; this can be easily overcome by inputting the variables and the data accordingly.

Air Pollution

Bangalore has a good system that monitors and collects the air pollution data. It was determined that there is no coverage for the entire city over a period of time to assess the long-term effects of air pollution on health. Although it is appreciated that Zones Bommanahalli and RR Nagar are the newer extended areas of Bangalore, they do not have any fixed monitoring stations. Policies should include the provision of continuous monitoring in fixed locations to assess effects of pollutants over time. $PM_{2.5}$ is gaining reputation of being a major contributor to CVD health, the inclusion of the monitoring of $PM_{2.5}$ is recommended.

Mortality

Bangalore also has a good robust system for collecting CVD data, the data satisfies the data quality indicators such as timeliness, the objectivity for data collection, the relevancy of data collection and completeness. However, mortality data collection in Bangalore hospitals does not include the home address of the patients, only the hospital address resulting in a 52% of deaths unable to be analysed spatially. About 19.4% of deaths, both institutional and home deaths were recorded as 'Unknown', Awaiting PM report, Natural Death and Old age. According to WHO cause of death must be appropriately coded according to the guidelines provided. It is concluded from this research assessment that Bangalore has a system that is functional but could be improved. Having identified the data quality issues, it is determined that if there is a focus on improving the elements that can be easily rectified, Bangalore will see an improved mortality database which will provide credible and trustworthy information that will assist in determining any patterns or trends in the deaths.
Certifying deaths by the 'cause-of-death' is important as it describes and explains levels and trends. Emerging diseases and conditions can be identified and the scale of how different groups are affected by the burden of specific diseases can be tracked. This will then guide the priorities for intervention programmes by the government and the decisions on directing and/or allocating resources according to areas of priority. According to the WHO, due to the many important public health uses to which the cause of death statistics are put, the accurate diagnosis of the cause of death should be ensured and coded according to international standards.

INTEGRATE

The next step in the model is focussed on integration which can be described as:

- Data Integration
- Stakeholder Integration

i. Data Integration

Data integration involves combining data residing in different sources and providing users with a unified view of this data. An Environmental Health Information system based on GIS was developed that allowed the integration of data and perform analysis.
Non-spatial analysis was conducted using SPSS and spatial analysis was carried out using GIS. The non-spatial analysis included both descriptive statistics and inferential statistics. The results of the descriptive statistics demonstrated that air pollution SO_2 was well under control in the city never exceeding the recommended standards and was classified as low to moderate in almost all areas. NO_X on the other hand was classified as being moderate to high. However, the pollutant of concern was PM_{10} which has an increasing trend in almost all areas of the city and levels of PM_{10} was mostly high or critical for all areas. Spatial interpolation techniques using GIS were used to obtain pollution values of pollution at unrecorded locations.
CVD accounted for almost 34% of Total deaths in the city between years 2010-2013. Simple binary logistic regression was carried out on the data and the results demonstrated that there is a statistical association between PM_{10} and CVD mortality for all the four years in the city while controlling for factors such as age, gender and zone of death. However, to determine a significant association,

further investigation has to be carried out to include smoking, alcohol consumption, hypertension, genetic factors and diabetes to obtain more robust results of a significant association.
The GIS system designed was used to carry out spatial analysis. Choropleth maps of the population highlighting the zones with the highest population were produced. Pollution levels at every zone of the city was obtained from the interpolation technique and recorded in the database. CVD deaths was geocoded for every zone was also produced as a layer in the GIS system. Overlay techniques were used to superimpose the layers and visualise any patterns. The zones with the highest CVD levels were mapped. Hotspots were also determined at the zonal level.
A system simulation was also carried out to demonstrate how clusters at ward levels can be determined with a few changes to the way data is collected. Another recommendation that is proposed is that although an information system such as GIS allows for data integration, it is vital that the departments integrate and communicate to work towards the prevention of air pollution induced CVDs. Many disciplines in public health have highlighted how interdisciplinary partnerships can address complex problems related to health by harnessing the collaborative power of multidisciplinary stakeholders.

ii. Stakeholder Integration

Stakeholder integration enables the stakeholders to work collaboratively in order to facilitate change. Evidence-based strategies should be deployed to foster cooperation. An integrated approach to commissioning high quality services for the prevention of air pollution induced CVD may result in an overall total population health improvement.

INTERVENE

Based on the information and evidence from the results of the system interventions to prevent CVD have to be developed. Knowledge is interpreted information, which will enable to apply the information in reasoning, decision-making, or performing actions. Based on these principles, this model will:

- allow the creation of knowledge
- enable the critical evaluation of knowledge
- ensure the effective integration and application of knowledge

To be effective the interventions are described as focussed on the Governance and on populations.

Governance

- Take action to reduce air pollution
- Development, implementation and monitoring policies that reduce the prevalence of CVD
- Reduce inequalities in risks of developing CVD
- Identification of zones with established CVD and offer comprehensive advice or appropriate treatment to reduce risks
- Identify populations who have not yet developed CVD but are at risk to offer appropriate advice to prevent it
- Increase awareness among public health officials, doctors, health workers on the possible links of air pollution and CVD and offer to include it is a risk factor and offer advice on health improvement
- Help raise awareness about the health impacts of air pollution

Populations:
For interventions to take effect it is important to make the interventions people-centric. It is important to advise the populations on the health risks posed by polluted air

- avoid travel to highly polluted regions if possible;
- reduce outdoor exposures as possible;
- exercise or perform heavy exertion during less polluted times and areas
- Reduction in risk factors that contribute to CVD
- Reduce smoking,
- Improve healthy eating and lifestyles
- The most vital of all is an attitude change if behaviours have to change

IMPACT

Once the interventions have been rolled out it is important to measure the impact of the interventions at constant intervals. Without evaluation of the policies it is hard to measure what worked and what didn't. The impact can be measured as:
Economical: how the interventions and the subsequent results had an impact on the economy. Ill health adversely affects the development of human capital, which is crucial for developing a knowledge-based economy.
Societal: Many chronic diseases are preventable. They are often the result of smoking, harmful alcohol consumption, poor diet and insufficient physical activity. These risk factors are further compounded by underlying socio-economic factors as well as environment factors.
Individual: The right investments will lead not only to better health, but also to longer and more productive lives. Foster a health knowledge system, including Scientific Committees, to contribute to evidence-based decision making.
It is vital to continue to explore the health impacts of short term and long term exposure to air pollution and evaluate how public policies and programs affect air pollution levels and the health

CONCLUSIONS

This research makes a significant contribution by designing and developing a model that provides the stages to be adopted to conduct an analysis of the effects of air pollution on CVD and plan prevention policies according to areas at risk and populations in need. Based on a GIS, this model integrates data from various sources and provides mapping, data sharing, visualisation, analysis and decision making. This aids in understanding the magnitude of the air pollution scenario mapping the levels of each pollutant against the occurrences of CVD in the city. The highlighting of hotspots in major cities would enable cost-effective prevention activities to be rolled out. Integration and data sharing across the various stakeholders assist in decision making and introducing interventions to prevent AP induced CVDs. As the GIS system is scalable, in addition to mapping and analysing AP induced CVDs, the design and implementation of this research development also sets the base to allow analysis of other health outcomes caused by air pollution.

This research makes a significant contribution to the body of knowledge, involved stakeholders and their collaboration. The knowledge and awareness of populations in the areas highlighted is also significant, as it is not only the government's responsibility to improve health, but also citizens should share responsibility by improving behaviours that contribute to risk factors. Bangalore city has been able to consider the use of the model GIS system and implement it for the benefit of the city and the well-being of its citizens. The study trusts that the concepts and analyses undertaken can provide valuable knowledge on the use of a GIS based model to assess the air pollution effects on CVD not only in Bangalore but also in other cities in India, as well as in other developing cities in the world.

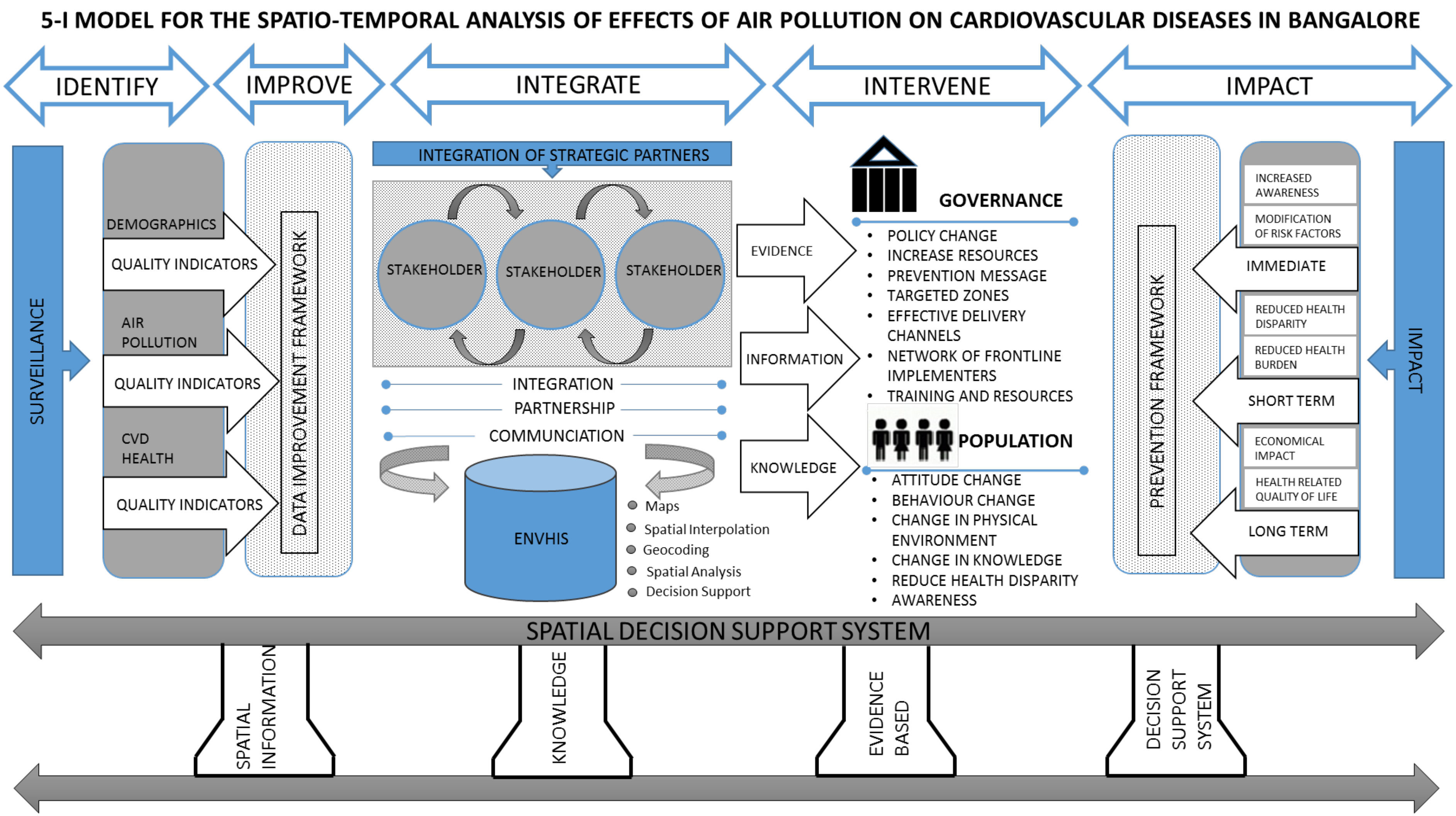

Figure 1: The 5-I model

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