# DESIGN OF SPATIAL DECISION SUPPORT TOOL FOR UNDERSTANDING CUMULATIVE ENVIRONMENTAL EXPOSURE

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March, 2014

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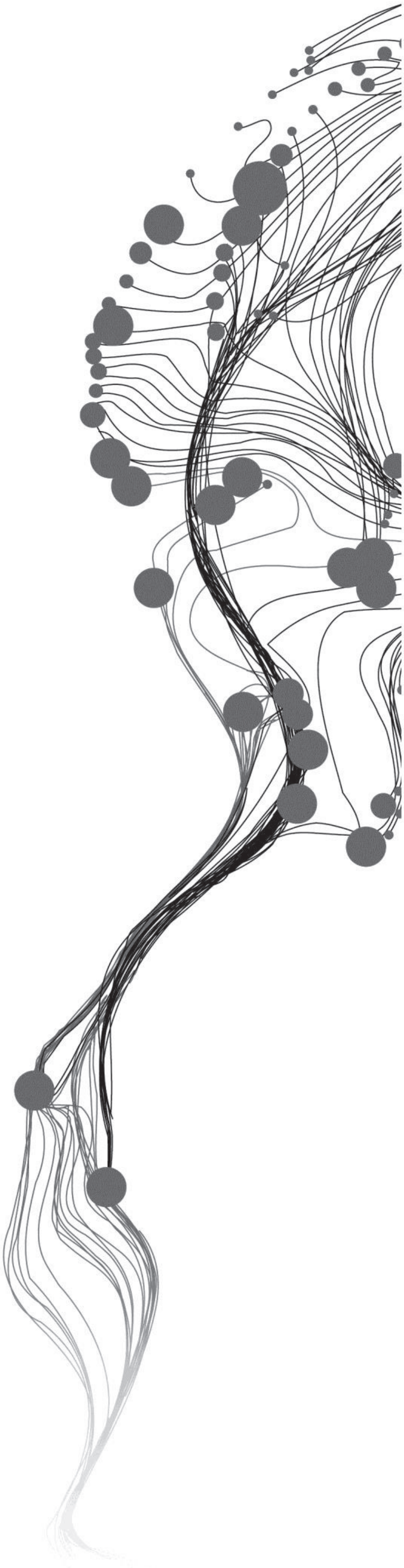

# DESIGN OF SPATIAL DECISION SUPPORT TOOL FOR UNDERSTANDING CUMULATIVE ENVIRONMENTAL EXPOSURE

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Specialization: Urban Planning and Management

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# ABSTRACT

Cities are the major human habitant, it is very important that the cities are planned and maintained as the healthier place to live; however, a large number of people especially in urban area are exposed to multiple environmental stressors. To create a healthy city it is important that the experts such as planners, health practitioners, environmentalist and decision makers work in collaboration. Although the concept of multiple exposures is not a new topic, the understanding of the geographic extent of cumulative environmental exposure is nearly absent.

Therefore, to support the experts and decision makers with the information on cumulative environmental exposure this research designed a spatial decision support tool for understanding cumulative environmental exposure ($SDST_{CE}$). Online questionnaire was conducted to collect primary data on "Importance of Visualization, Functions and Tools in Understanding Cumulative Environmental Effects in Spatial Decision Support System (SDST)". The survey involved experts from public health, environment, urban planning together with authors and professionals dealing with DSS. Combined visualization of either two or more representations (maps, graphs, 3D's, time series) was preferred by the experts to better understand the environmental condition of the area. The ROMC design approach and the use case approach were used to design the $SDST_{CE}$. It was operationalized as $SDST_{CE}$ EnL in Community Viz by using secondary data from Dortmund. It is capable of producing index maps, graphs; which is interactive in nature. It is also capable to assess the area and population exposed to cumulative environmental stressors. Furthermore, it is also capable to overlay different layers over index map for the analysis. The index was used to understand the geographic extent of cumulative environmental stressors. It was found that the city of Dortmund is struggling with multiple environmental stressors such as air pollution and noise pollution. The hot spot of multiple environmental deprivation was recognized in the city of Dortmund along the transportation network and central statistical districts.

The conceptualized design of $SDST_{CE}$ was tested by developing $SDST_{CE}$ EnL, which successfully produced results as anticipated. Therefore, it needs further development to realize its full capability.

Key words: Multiple environmental stressors, Cumulative environmental exposure, Spatial decision support tool, Index, Visualization, Conceptual design, Dortmund

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Nilima Thapa Shrestha
March 2014.

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| | |
|---|---|
| AirQUIS | Air Quality Environmental system |
| APHEKOM | Improving Knowledge and communication for decision making on air pollution and health in Europe |
| BaP | benzo(a)pyrene |
| CASA | Centre for Advanced Spatial Analysis |
| CE | Cumulative Effects |
| CEF | Combined exposure factor |
| $CO_2$ | Carbon dioxide |
| dB | Decibel |
| DBMC | Database management component |
| DMC | Dialog management component |
| DST | Decision support tool |
| EEA | European environmental agency |
| ENHIS | Environment and Health Information System |
| GIS | Geographic information system |
| HC | Hydrocarbons |
| HELP | Health exploratory analysis tool for practitioners |
| MEDIx | Multiple environmental deprivation index |
| MEME | Multiple exposure-multiple effect |
| MMC | Model management component |
| NO | Nitrogen Oxides |
| NOISE | Noise Observation and Information Service for Europe |
| O3 | Ground level ozone |
| OLAP | on-line analytical tools |
| OOO | Oxidant |
| Pindex | Combined pollution index |
| PM | Particular matter |
| SDLC | System development life cycle |
| SDSS | Spatial decision support system |
| SDST | Spatial decision support tool |
| $SDST_{CE}$ | Spatial decision support tool for cumulative exposure |
| $SO_2$ | Sodium dioxide |
| SR | Solar radiation |
| WHO | World health organization |
| CO | Carbon monoxide |

# 1. INTRODUCTION

*This chapter provides an introduction to the research starting in the first section with background and justification on the need of studying multiple environmental stressors. Furthermore, it discusses on the need of designing a spatial decision support tool to understand the geographic extent and exposure to cumulative environmental conditions. The second section presents the identified research problem. The third section introduces the objectives and sub objectives followed by research problems undertaken by this research study. The fifth section explains on the conceptual framework embraced in this research. The sixth section provides a figure that explains about the research design. The last section presents the structure of this research.*

## 1.1. Background and justification

Various environmental stressors exist in an urban environment. According to Briggs (2003) environmental stressors do not work in isolation nor do they lead to single and specific health outcome, indeed they act in consort and lead to a wide array of health outcome. This leads to the concept of multiple environmental stressors and its cumulative effects. According to Vlachokostas et al. (2012) urban environment is mostly effected by two environmental factors, air and noise pollution. He measured the combined exposure of air and noise and further highlighted on the importance of considering several environmental stressors. According to several authors (Curtis et al., 2006; Hoek et al., 2002; Katsouyanni et al., 2001; Pope III et al., 2011) air pollution is one of the most significant urban environmental health stressor that exacerbates morbidity and leads to the premature mortality. Similarly, exposure to excessive (Prasher, 2002) and prolonged noise (Jonsson & Hansson, 1977) is associated with annoyance and reduced quality of life due to environmental noise.

According to Barton in 'Strengthening Of The Roots Of Planning' (Crawford et al., 2010) individuals state of health is determined by many different factors apart from the biological sphere; one of the major factors affecting health is the environment; furthermore, he argues that we ignore environmental factors at our peril. According to Pearce et al. (2010) there are basically two types of physical environment that are either health promoting or health damaging and stress on considering both these factors to have a better understanding of multiple environmental stressors. Additionally, it is important to be mindful of the fact that environmental stressors are not equally distributed in all areas due to which people are exposed to different levels and type of environmental stressors.

According to the EEA (2013) history suggest us that environmental stressors can be tackled with the proper integration of new technology and policies. Plans, policies and innovative ideas are important for the reduction and prevention of environmental burden. Hence, for that planners and decision makers should have the overview of the situation and actual problem. To create a healthy city it is important that planners, health practitioners, environmentalist, policy makers and other stakeholders work in collaboration. It is important to have a good understanding of health and environmental condition of the city, for that there should be enough data, and outputs should be simple and understandable to all the stakeholders. Quality information helps to identify and prioritize problems which lead to well informed solutions and decisions making.

Spatial decision support system (SDSS) is flexible problem solving environment, where stakeholders can first understand the condition then generate and evaluate alternative solutions. According to Densham (1991) most of the SDSS provide them an opportunity to investigate the possible trade-offs between conflicting objectives and identify solution with maximum potentials.

There is a difference in notion of understanding about a decision support tool (DST). In literature indicators, indexes, frameworks (Hambling et al., 2011) checklists (Capon & Blakely, 2007) database, guidelines, handbook and software model (Liu et al., 2013) are termed as tools for measuring and analysing health and environmental condition. Indicators are among the most important tools that can show the picture of cities and its environmental condition. There is a list of eighty health indicators (European Commision Public Health, 2013) and ten environmental indicators (OECD, 2004). Pearce et al. (2010) developed the multiple environmental deprivation index (MEDIx) which included both health promoting and health damaging environments to study the environmental condition of the neighbourhood. It was found that, those environmentally disadvantaged neighbourhoods have poor health condition. Similarly, Vlachokostas et al. (2012) used combined exposure factor (CEF), an index to study the combined exposure of air and noise.

There are various model based spatial decision support system that are used for urban air quality management; for example major European cities such as Berlin, Geneva, Vienna, Oslo and Athens are using Austrian AirWare : An urban and industrial air quality assessment and management information system (Fedra & Haurie, 1999), the Norwegian AirQUIS : Air Quality Information System (Bøhler et al., 2002) and Swedish EnviMan : Environmental Management (TARODO, 2003) for urban air quality management.

Environment and Health Information System (ENHIS) is a database information system that aims to understand public health and environmental condition/policies in the WHO European region. Similarly, Noise Observation and Information Service for Europe (NOISE) is a database system maintained by the European Environmental Agency that intents to provide information on population exposed to noise along with the noise maps.

## 1.2. Research problem

Some places in the cities are more environmentally deprived then others, meaning that some part of the city are well planned with parks and less environmental stressors but other might have one or more kind of pollution such as air, noise, soil, water, radio waves, polluting factories together with that level of pollution also might vary. In some area people are exposed to multiple environmental stressors leading to cumulative effect, meaning that the whole is much more than the sum of the parts.

At present there is a large volume of spatial decision support systems (SDSSs) developed to address individual environmental stressors such as air pollution in major cities of the world. Such application provides an opportunity to improve the environmental condition of the city. Liu et al. (2012) presents some facts explaining that only 3% of decision support tools (DST) deals with 36 environmental stressors, 25% of deals, with only one stressor and 50% deals with only one disease; additionally, most of the tools are non-spatial. This leads to the realization that there is a need of a spatial decision support tool (SDST) covering more environmental stressors and more diseases.

Therefore, this research attempts to make a contribution to that apparent void by designing and developing a spatial decision support tool for mapping cumulative environmental exposure. According to Couclelis (1991) the challenge lies in finding out the problem rather than solving it. Therefore, this tool will help the stakeholders to identify and understand the geographical extent of environmental condition of an area rather than solve the problem. According to King et al. (1989) visualization provides a common language to which all participants, technical and non-technical can relate. According to Brath and Peters (2005) practitioners claim that visualization of information allows better, faster and more confident decision. Hence the design of the SDST will mainly focus on different methods and visualization techniques to better communicate the cumulative environmental exposure.

## 1.3. Research Objective

The main objective of the research is to design and develop the Spatial Decision Support Tool (SDST) for mapping cumulative environmental condition of the area. There are three sub objectives which are listed below along with research questions.

### Sub objectives and Research questions

**Sub objective 1:** To understand the state of art of Spatial Decision Support Tool (SDST) in the environment and health.

1. What are the functions and structure of DST and SDST?
2. What factors of environment and health are addressed by DST and SDST?

**Sub objective 2:** To design and develop a SDST for mapping cumulative environmental exposure.

1. What factors of environment and health are to be addressed by the SDST?
2. Who are the probable users?
3. What functions will be required to assess cumulative environmental effects.
4. How can exposure be effectively communicated to stakeholders?
5. What level of functionality should SDST offer to the users?

**Sub objective 3:** To analyze the state and exposure by using data from the case study area (Dortmund) by implementing SDST

1. What are the most prominent environmental stressors in Dortmund?
2. Which area is most affected by multiple environmental stressors in Dortmund?

## 1.4. Conceptual Framework

Health and the environment are both highly affected by context, such as socio-economic condition, geography, climate etc. Environmental factors can be roughly classified into two domains; pathogenic and salutogenic factors (Pearce et al. 2010). Pathogenic factors such as pollution (air, water, noise, soil) and electromagnetic radiation have a negative effect on human health. Whereas salutogenic factors such as green or open space (Humpel et al., 2002), beaches (Pearce et al., 2007) and the ecology of urban environments such as urban forestry (Heynen et al., 2006) have positive effect on health of people.

However, these factors are not equally distributed in space due to which different places have different environment and related multiple health outcomes. Some places may be well planned with green parks, water bodies and less traffic and other pollutants, but some other places may be unplanned and have different types of pollution. This situation leads to the cumulative environmental exposure.

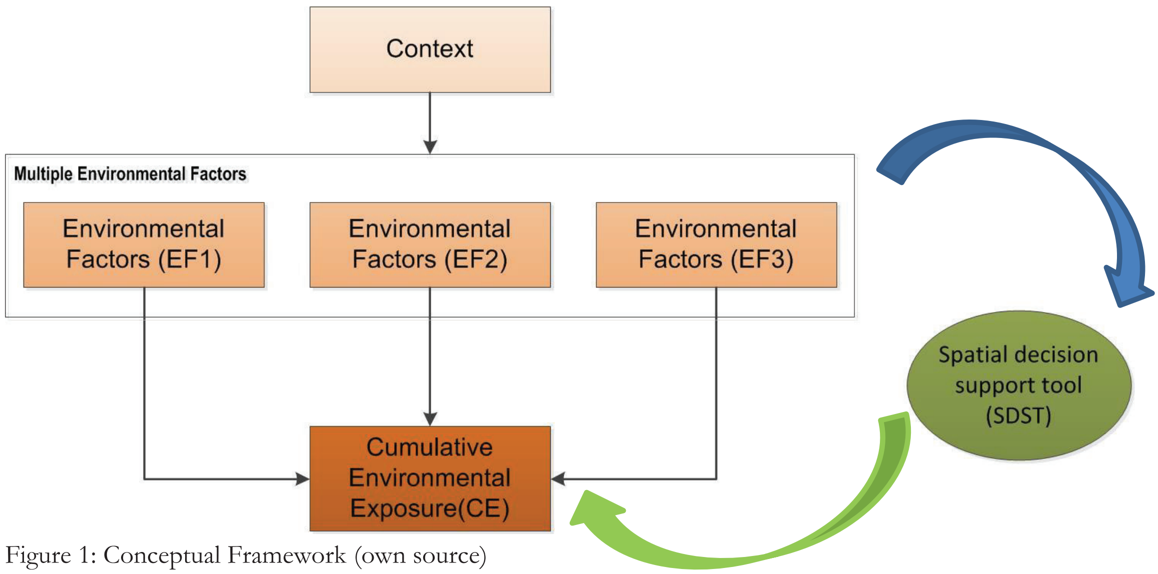


Figure 1: Conceptual Framework (own source)

There have been studies on multiple environmental factors (J. R. Pearce et al., 2010) and combined environmental exposure (Vlachokostas et al., 2012). Cumulative environmental exposure exists in most of the cities however, magnitude may be higher in developing countries and low in developed once, but making decision makers aware about the situation is important for planning better and healthier cities. According to Aphekom (2013) scientific findings on environmental exposure are not well communicated to people involved in decision making.

Figure 1 illustrates the conceptual basis of this research. This research aims to design and develop a spatial decision support tool for mapping cumulative environmental exposure ($SDST_{CE}$) which will allow a better communication of the environmental condition of the city to the decision makers and experts in different field.

## 1.5. Research design

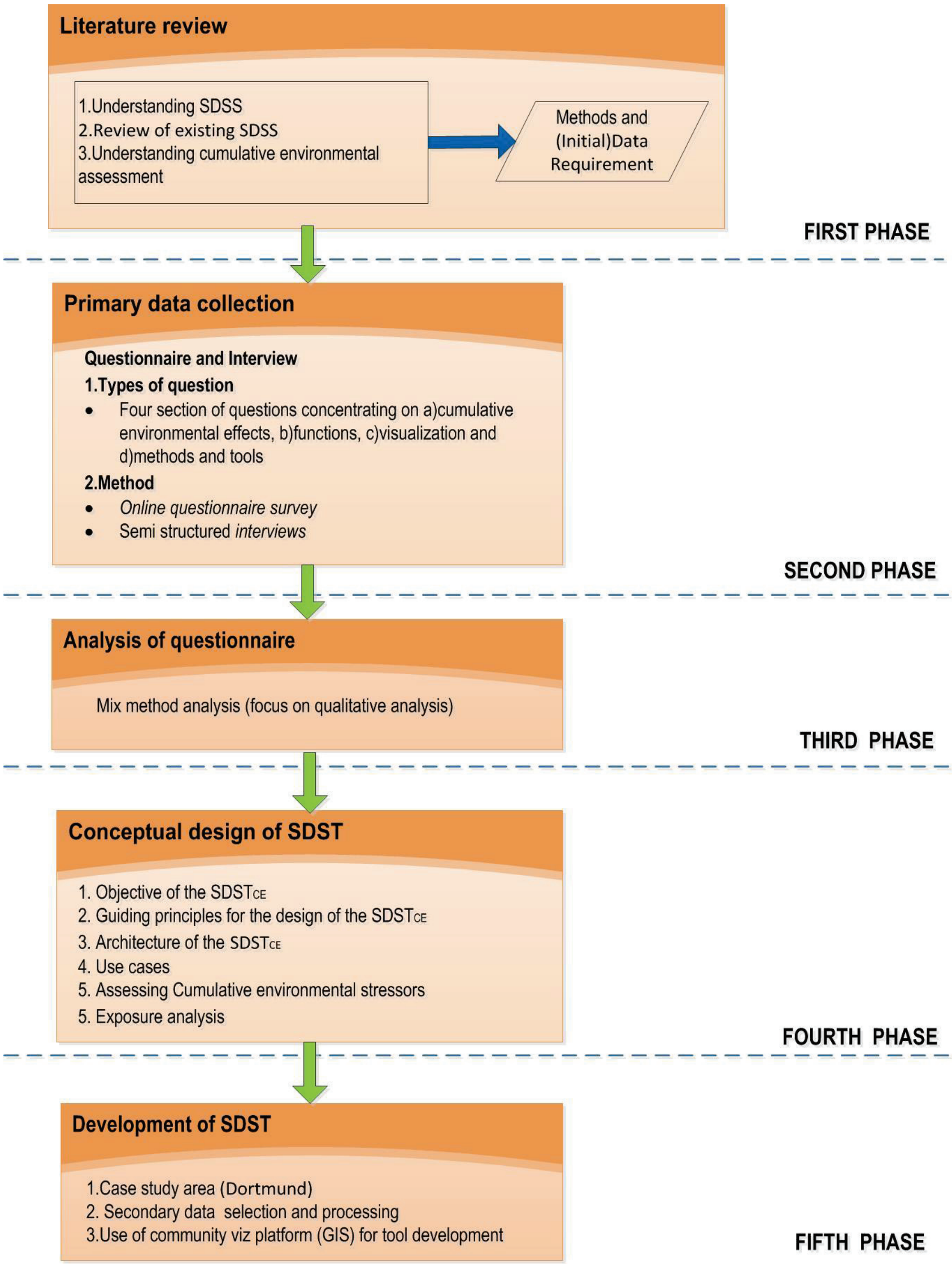


Figure 2: Research design (own source)

### 1.6. Research outline

This section describes the outline of the research, it comprises of seven chapters as per the following sequence.

**Chapter 1**: Introduction
This chapter introduces the research with background and justification on the requirement of study on multiple environmental stressors and the need of decision support tool for the better understanding of cumulative environmental condition. It further discusses on the research problem which is followed by research objective, sub objectives and problems.

**Chapter 2**: Literature Review
This chapter discusses on the relevant literature for this research study. Literature mainly was carried out to understand the major concepts of this research i.e cumulative environmental exposure and spatial decision support tool. It also presents the review on existing SDSS in the field of environment and health.

**Chapter 3**: Process of Building $SDST_{CE}$
This chapter describes the different methodologies implemented to accomplish this research. It describes the overall research methodology together with the methodology used for the questionnaire survey and its analysis. It also briefly discusses on the availability of secondary data and it's pre-processing.

**Chapter 4**: Analysis and discussion on responses of the questionnaire
This chapter provides analysis on the responses collected from the online questionnaire survey.

**Chapter 5**: Conceptual Design of $SDST_{CE}$
This chapter provides the conceptual design of spatial decision support tool for understanding cumulative environmental exposure. It provides information on guiding principles of the tool, targeted user group, major components, required inputs and outputs, unit of analysis, assumptions, different functions and its operationalization. It will also provide possible sequence of interaction between the system and users.

**Chapter 6**: Development of $SDST_{CE}$ EnL
This chapter introduces the case study area (Dortmund) and discusses on the test wise development of the $SDST_{CE.}$

**Chapter 7**: Recommendation and Conclusion
This chapter discusses on the research findings with respect to research objectives as well as recommendation and future research directions.

# 2. LITERATURE REVIEW

*This section discusses the relevant literature for this research study. This chapter is divided into 4 subsections. The first section discusses the relevant literature necessary to understand the cumulative environmental effects and exposure along with the major environmental stressors. The second section discusses on relevant processes for the understanding of the cumulative environmental condition. The third section provides information on spatial decision support system. The last section provides review on relevant existing spatial decision support system.*

## 2.1. Understanding cumulative environmental effects

This section of the chapter discusses on different concepts related to cumulative environmental exposure and its assessments such as functions and methods for assessing cumulative environmental exposure.

### 2.1.1. Multiple exposure multiple effect framework

MEME (Multiple exposure-multiple effect) is a framework designed to derive indicators to improve children's environmental health. According to Briggs (2003) hazards do not work in isolation nor do they lead to single and specific health outcome, indeed they act in consort and lead to a wide array of health outcome; however, some exposures are more immediate or proximal and other more remote and distal. The MEME model emphasizes the divergent, multiple links between exposure and health effects.

Briggs (2003) further explains that both exposures and health outcomes are influenced by the context, such as social, economic and demographic context. MEME helps to recognize a spectrum of exposures in the environment side and an array of effects on health side which may be expressed on different level of severity.

### 2.1.2. Conceptualizing cumulative exposure and effects

According to US National Research Council (1991) exposure is defined as contact of human beings to the surroundings; it may be biological, chemical or physical agents. Therefore, exposure assessment is used to identify and define the exposure that occurs or is anticipated to occur in human population (Environmental health criteria, 1993).

The term cumulative effect (CEs) is broad in its meaning. A Core understanding of cumulative effect may be the same in the discipline of environment, public health and urban planning; however there is difference in the details and mechanism of measurement. Since this research is a link between these disciplines it is important to understand and conceptualize 'cumulative effects' for the scope of research.

According to Sexton and Hattis (2007) in the public health sector cumulative exposure refers to past and present exposure of individual to multiple environmental stressors occurring by all relevant routes, pathways and sources. While studying the cumulative effect (CEs) the background exposure also need to be studied because health is not only affected by present exposure, past exposure also has an effect on human physiology, for example; benzene can produce adverse effect long after the chemical are no longer present in the body.

However, in the discipline of environment, the study of CEs is carried out to assess environmental impact of any proposed project (MacDonald, 2000). According to Therivel and Ross (2007) ultimate goal of cumulative effect assessment is to help protect and improve the quality of the receiving environment and is important because it is only the total effects that matter to the environmental resources or people affected by them.

The great challenge in analysing CEs is recognizing and predicting the numerous interaction and indirect effect (Dixon & Montz, 1995). The publication have claimed that there has been a consensus between various disciplines concerned with CEs (Williamson & Hamilton, 1989). However, with time methods for cumulative effect assessment have grown, ranging from simple checklists to complex model (MacDonald, 2000). Cumulative effect assessment is a data intensive, there are exposure models such as CARES (Cumulative and aggregate risk evaluation system) and APEX (Air pollutant exposure) for the assessment of the cumulative effect (Price & Chaisson, 2005).

Identifying the key cause and effect of cumulative effect is very important to focus the assessment on the most important mechanisms and processes to avoid getting lost in the infinitely large universe of indirect effect and interaction (NCASI). According to MacDonald (2000) selection of key mechanism needs to be justified by reference to current knowledge and understanding of professionals so for that questionnaire and interviews with experts should be done. We should bear in mind that several iterations may be necessary to complete the identification of key cause and effects.

Cumulative impact assessment is certainly a simplified representation of an extremely complex, and hence ultimately unknowable system (Stakhiv, 1988) so while carrying out CEs it should be started from simple and add complexity as needed.

### 2.1.3. Environmental factors

There are various environmental factors that have been proven to be affecting human health. They can be categorized as pathogenic and salutogenic factors (J. R. Pearce et al., 2010). Pathogenic factors are those factors which negatively affects health such as air pollution, climate, industrial facilities where as salutogenic factors are those physical environment that have potential therapeutic properties.

According to (EEA, 2013) one of the most prominent environmental hazard is air pollution. WHO (2013) describes that the environment is responsible for as much as 24% of the total burden of disease, which could be prevented through well-targeted interventions. According to (WHO, 2011) air pollution is a major factor for the global burden of disease caused due to respiratory infections, heart disease and lung cancer. Urban air pollution is estimated to cause 1.3 million deaths worldwide.

The European Environmental Agency has been studying the relation between air pollution and the health for more than 15years. A Scientist working for APHEKOM project estimated the cost of air pollution by 10,000 polluting factories in Europe to be between 102 and 169 billion of euros in 2009. They claim that air pollution in Europe leads to reduction in life expectancy of around 8.6 months per person. However, they predict that reducing the annual average level of particular matter PM 2.5 to 25 μg/m3 as per the guideline provided by WHO would result in concrete gains in life expectancy. They claim that achieving this target will lead to the gains ranging from 22 months in Bucharest, 19 months in Budapest, 2 months in Malaga and to half a month in Dublin (EEA, 2013). This data allows us to see the invaluable insights into the health improvements that could be expected with reduction of air pollution.

Not all substances in the air are considered pollutants. Some of the most harmful pollutants are particulate matter (PM), nitrogen oxide (NO2), ground level ozone (O3), sulphur dioxide (SO2), benzene, benzo(a)pyrene (BaP)(Aphekom, 2013; Salter et al., 2009). In general pollution from particulate matter, ozone and nitrogen dioxide pose serious health risks to people affecting their quality of life and also reducing their life expectancy. There exists a huge literature on the health effecting pollutants such as PM (Brunekreef et al., 2005; Leitte et al., 2009; Zanobetti et al., 2009) which points out that a small amount of PM can lead to health impairment. Similarly, epidemiological studies on $No_2$ show that it can damage the health of people. Moreover, according several authors (Forastiere et al., 2005; Jerrett et al., 2009; Pattenden et al., 2006; Samoli et al., 2006) $NO_2$ contributes to the formulation of PM. According to Kindler in 'Socio Spatial Distribution of Ambient Air Exposure in Berlin' (UMID, 2011) these PM and $NO_2$ can for example lead to respiratory and cardiovascular disease and mostly in urban areas the source of these environmental stressors is traffic.

After air pollution, noise is considered as one of the most significant environmental factors affecting health in the urban area (Niemann et al., 2005), cited in (UMID, 2011). According to several authors Huss et al. (2010), Ising and Kruppa (2004) noise pollution from air traffic and road traffic has a strong correlation to the health (sleep loss, hypertension, myocardial infarction) of the people. Excessive exposure to noise pollution is associated with annoyance, headache, dizziness and fatigue(Vlachokostas et al., 2012) or hearing loss(Prasher, 2002). Furthermore, noise is associated with number of negative emotions such as anger, disappointment, unhappiness, anxiety, and depression (Fields, 1998; Michaud et al., 2005; Murphy et al., 2009); it also can lead to cardiovascular disease(Babisch et al., 2005).

It has been postulated that environmental 'goods' such as green or open space (Ellaway et al., 2005; Groenewegen et al., 2006; Humpel et al., 2002; Mitchell & Popham, 2008), beaches (Pearce et al., 2007) and the ecology of an urban environments such as an urban forestry (Heynen et al., 2006) have a positive effect on the health of people. Availability of green space is an indicator of healthy environment but however its use may largely depends up on accessibility and walkability. All the green spaces in proximity might not be accessible; for example: location of gates to the park may reduce its usability. According to Shriver (1997)recreational walks for exercise and socialization are longer than walk for commuting, shopping and reaching to transportation nodes which is usually suggested to be quarter of a mile (Association, 1997; Wolch et al., 2002)

### 2.1.4. Functions for cumulative environmental assessment

Functions are the particular task that will help decision makers to perform and obtain knowledge building outputs (for example index maps) from the existing products (for example individual indicator maps) through the single or chain of action.

This section will discuss on different functions and models that are used to assess environmental stressors. Moreover, this section will try to discuss on function that could be used in the SDST for better understanding the cumulative environmental exposure.

#### 2.1.4.1. Modelling

There are various models based spatial decision support system that are is used for urban air quality management. For example: the major European cities such as Berlin, Geneva, Vienna, Oslo and Athens are using Austrian AirWare (Fedra & Haurie, 1999), the Norwegian AirQUIS(Bøhler et al., 2002) and Swedish EnviMan (TARODO, 2003) for urban air quality management. The application of such model based SDSS allows cities to improve the air quality.

These air quality SDSS generally applies the air quality dispersion model and are used for the exposure assessment (Solvang Jensen, 1999). This is not very easy to operate for experts from different domains such as environment, public health and policy making; working with these tool requires training (Karatzas et al., 2000). Additionally, these systems are designed for marketing in different countries, so modifying them according to the local conditions and its databases is not possible. Moreover, these SDSS lack the capacity of cumulative assessment.

#### 2.1.4.2. Index

There are different indexes used to assess multiple environmental stressors. This section will discuss on three different indexes; multiple environmental deprivation index, combined pollution index (Pindex) and combined exposure factor (CEF).

Multiple environmental deprivation index is an area based measure that represents health related physical environmental disamenities (J. R. Pearce et al., 2010) of an area due to the combined effect of multiple environmental factors. It included pathogenic factors such as air pollution (particular material, Nitrogen dioxide, sulphur dioxide, carbon monoxide), climate, industrial facilities and salutogenic factors such as UV radiation, green space. It was initially inspired from the multiple deprivation measure done in the UK. (J. R. Pearce et al., 2010). Index making in general is used to access the combined effect of multiple factors, whether it be the environmental or social factors.

The Multiple environmental deprivation index was used to compare with income deprivation of an area and it was found that multiple environmental deprivations increased with the increase in degree of income deprivation. It was also found that health progressively worsened as the multiple environmental deprivations increased. It emphasises that there is an importance of the physical environment in shaping the health of people. It concludes that the development of such an index can help decision makers in understanding the correlation between health and environmental factors.

According to Babcock Jr (1970) Combined Pollution Index (Pindex) is an overdue necessity. It sums air pollution contributions from Particular matter(PM), Sodium dioxide (SO2), Nitrogen Oxides (NO), Carbon monoxide (CO), Hydrocarbons(HC), Oxidant (OOO), Solar radiation (SR). An index of pollution is generally used to give more meaningful assessment of air pollution severity and to compare level of pollution in different cities.

$$PM + SO2 + NO + CO + HC + OOO + SR \longrightarrow Pindex$$

Similarly, Combined Exposure Factor (CEF) is an index used to assess the combined effect of noise and air pollution. According to CEF is an easy to comprehend approach for assessing co-exposure of air and noise pollution. Rather than visualizing air and noise pollution separately for planning and environmental sustainability CEF allows holistic assessment of air and noise pollution. CEF was created keeping in mind the usability of index for planning and environmental sustainability. Moreover, the author claims that CEF could be of importance for decision makers and local authority.

Therefore, indexes are flexible; number of environmental factors can be included according to the requirement, unlike in dispersion model where single environmental stressor is modelled. Mostly importantly, an index can be used for the cumulative environmental assessment. In this research an index will be used to assess the cumulative environmental stressors. An Index will be created by compiling the simulated (modelled) maps of various environmental stressors.

#### 2.1.5. Functions for exposure assessment

According to US National Research Council (1991) exposure is defined as contact of human beings to the surrounding; it may be biological, chemical or physical agents. Therefore, exposure assessment is used to identify and define the exposure that occur or is anticipated to occurs in human populations (Environmental health criteria, 1993). In this research exposure assessment will be used to identify the population exposed to cumulative environmental stressors.

##### 2.1.5.1. Proximity based method

Proximity analysis follows the Tobler's first law of geography "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). Proximity analysis has been carried out for the relation between cancer in adult and proximity from the road(PM was studied)(Huss et al., 2010), children's respiratory health and proximity to a busy road (Nox, No2, $PM_{10}$, $PM_{2.5}$, BC was studied) (Kim et al., 2004). According to Huss et al. (2010) the risk of death from different diseases such as myocardial infarction, cancer of the trachea, bronchus or lungs was high among the people living near the major road (<100m).

According to Stroh (2006) it is one of the basic exposure assessment methods. It is a fairly straight forward and easy to execute. Other methods such as dispersion model are costly due to the need of complex computing facilities and data requirements; moreover implementation of these models requires expertise in programming and GIS. It also requires cross-validation with monitoring stations and temporal mismatches can lead to substantial errors in estimation.

##### 2.1.5.2. Kernel density

Kernel density calculates a magnitude of concentration per unit area from any point or polyline (ArcGIs Resource Center, 2011a). In Delmelle et al. (2011) kernel density was successfully used to find the clustering of disease which was then related to environmental condition. This helped in assessing the correlation between the location of disease outbreak and environmental condition at the very location. A map produced by kernel density assisted health specialist to hypothesize on the correlation of disease and environmental condition; therefore helping them in taking appropriate preventive measures. Clustering of disease was also related to the socio-economic condition of the area. This helped in examining the correlation between socio-economically deprived neighbourhood and health of the people.

#### 2.1.6. Methods

Methods are the different steps that will be used to accomplishing different functions. Standardization and ranking are two very important steps to be carried out while making index, which is explained in the following sections.

##### 2.1.6.1. Standardization

Standardization is the method applied to integrate and make comparable criterion or indicator measurements with different value ranges and scales which will be proportional to original score. Two methods of standardization have been explained by Nyerges and Jankowski (2009); linear and non-linear standardization methods. Malczewski (1999) explain one more method of standerdization; goal standerdizattion.

**Maximum standardization**

Linear standardization (maximum) provides a proportional transformation of raw measurements. Depending upon the nature of criterion, two equations (Equation 1and Equation 2) can be applied. Benefit the criterion (Equation 1) is applied when the higher a value gives better performance. In case of benefit criteria, highest value is standardized as one. Equation 1 is used where, Z'ij is the standardized score, ranging from 0 to 1. Zij is the raw criterion value, and Zjmax is the higher raw value. Cost criterion (Equation 2) is applied when lower value is preferred. In case of cost criteria, lowest value is standardized as one. The advantage of maximum standardization is that the standardized values are proportional to the original value.

$$Z'ij = \frac{Zij}{Zjmax}$$

Equation 1: Maximum standardization, benefit criteria (Nyerges & Jankowski, 2009)

$$Z'ij = 1 - \frac{Zij - Zjmin}{Zjmax}$$

Equation 2: Maximum standardization, cost criteria (Nyerges & Jankowski, 2009)

**Minimun standardization**

Nonlinear standardization produces value based on a relative scale, in an aligned manner between zero and highest score. In case of benefit criteria (Equation 3), absolute highest value is standardized as one (higher the better) and the absolute lowest with zero. In case of cost criteria (

Equation 4), The lowest value is standardized as one (lower the better). After the non-linear standardization values are no longer proportional to the original values.

$$Z'ij = \frac{Zij - Zj\,\mathrm{min}}{Zjmax - Zjmin}$$

Equation 3: Nonlinear standardization, benefit criteria (Nyerges & Jankowski, 2009)

$$Z'ij = 1 - \frac{Zij - Zjmin}{Zjmax - Zjmin}$$

Equation 4: Nonlinear standardization, Cost criteria (Nyerges & Jankowski, 2009)

**Goal standardization**

Goal standardization is mostly used when a threshole limit of the factor is to be fixed for example noise. Similar to earlier standardization methods depending upon the nature of criterion, two equation (Equation 5 and Equation 6) can be applied. Where Z'ij is the standardized score. Zij is the raw criterion value whereas Gmin and Gmax are the lower and the higher limits of the range defined by the stakeholder.

$$\mathrm{Z'ij} = \frac{\mathrm{Zij} - \mathrm{Gmin}}{\mathrm{Gmax} - \mathrm{Gmin}}$$

Equation 5: Goal standardization, Benefit criteria (Malczewski, 1999)

$$\mathrm{Z'ij} = 1 - \frac{\mathrm{Zij} - \mathrm{Gmin}}{\mathrm{Gmax} - \mathrm{Gmin}}$$

Equation 6: Goal standardization, Cost criteria(Malczewski, 1999)

This research will use maximum standardization and goal standardization in the design and development of SDST. Maximum standardization provides standardized values that are proportional to the original value; which is easy to understand. Whereas goal standardization will be used to provide a threshold value for the environmnetal facts.

#### 2.1.6.2. Ranking

Different methods are available for the assigning weights and scoring to the criteria or indicators such as ranking methods, rating methods, pairwise comparison and trade-off analysis and the analytical hierarchy process(Malczewski, 1999; Voogd, 1983). Ranking is mainly important because it allows grading of different factors according to importance. For the scope of this research 'rank sum method', simplest, easily repeatable, less time consuming and easy to understand by stakeholders is chosen.

The various criterion can be ordered from the most to the least important then the rank sum method can be applied to generate numerical weight from a ranked order of criteria's. There are two ways of implementing this method, the straight rank and the inverse rank. In straight rank method low ranked criterion is corresponds to low value (1). According to Voogd (1983) number of criteria to be ranked is very important. This refers to the fact that if the number of criteria's is less accuracy of the weighting will be high. Once the priority is set to the criterion, the ordinal values must be converted to cardinal values in order operate further. Equation 7 is used to calculate the normalized weight (Wj) for the jth criterion; where n is the number of criteria and rj is the rank position of the criterion.

$$Wj = \frac{n + 1 - rj}{n + 1 - rk}$$

Equation 7: Rank sum (Malczewski, 1999)

#### 2.1.6.3. Weighted overlay

According to (ArcGIs Resource Center, 2011b) weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Information exists in different raster layers with different value scales such as dB; μg/m2 can't be added to obtain a meaningful result. Additionally, the factors in the analysis may not be equally important. It may be that controlling noise pollution from road traffic is more important than air traffic simply because more people are exposed to the road traffic noise in their everyday life than that from air traffic. On the basis of that weight can be assigned. Weighted overlay is the technique that will be used while making an index.

#### 2.1.6.4. Weighting or scoring

Weighting is a method in which one gives score to the criteria's (for example air pollution, noise pollution, heat stress) with respect to its importance in the evaluation of cumulative effects. In this method decision makers will use their expertise on different indicators for weighting them. This will be used in creating an index. When the value of a particular factor is changed the index output will be automatically updated. The weighting will be designed as a numerical value within a valid range (as might be displayed in a sliding bar) and the range might be change according to the variation in the value of indicator to be included in the analysis or index.

It is a subjective process so it highly depends upon once knowledge and sometimes preference which is hard be controlled by the design of tool.

#### 2.1.6.5. Simple overlay (overlap)

Overlay helps to compare and evaluate different outputs. Evaluability (Hsee, 1996) refers to the ease with which information can be assessed and compared. When information is easily comparable it enables decision makers to notice changes, recognize outliers and realize patterns more quickly (Lurie & Mason, 2007); moreover, it leads to increased acquisition and processing of information(Ariely, 2000; Hsee, 1996; Jarvenpaa, 1989; Kleinmuntz & Schkade, 1993; Schkade & Kleinmuntz, 1994).

If the data are in point such as mortality, then it can be simply overlapped over the multiple environmental deprivation index maps. Sometimes point data may not be available for mortality and, for instance, only life expectance of the area in ward level may be available. In such a case, data can be displayed in charts and can be overlapped over the multiple environmental deprivation index maps. Such a function will help to understand the correlation between health and environmental condition or it can be simply used to understand the geographical extent of multiple environmental stressors in the area.

## 2.2. Understanding spatial decision support systems

This section provides literature on spatial decision support system. In the literature decision support tool (DST) and decision support system (DSS) are interchangeable used. Similarly spatial decision support tool (SDST) and spatial decision support system (SDSS) are also interchangeable used.

### 2.2.1. Decision making: An intelligent phase

According to Ackoff 1981 there exists a decision problem when an individual or group perceives a difference between a present state and a desired state and has an alternative course of action available for the action. However, in such a case individual or group is always uncertain about the selection of alternatives. However choice of action can have a significant effect on the perceived difference. The well-known model of Herbert A. Simon (1960), which represents procedural rationality; distinguishes three major phases in the decision making process; 1) The intelligence phase 2) The design phase 3) The choice phase.

According to Simon (1960), type of problem determines which phase of decision making should be more emphasized. The most widely quoted taxonomy is the one that categories problems as "well structured", "ill structured" and "unstructured". Totally structured problems usually do not require much decision maker's analysis. In fact, they are usually well served by standard operating procedure. Totally unstructured problems are difficult to support with computer and models; which requires some structure. According to Simon 1960, ill-structured problem requires more emphasis on the intelligence and design phase.

According to (Ali sharifi 2004), many authors believe that enough attention is not paid to the first phase of decision making; much effort is put into the design and choice phases. In practice identifying, defining and structuring a problem is much more important. If intelligent is not given enough attention the wrong problem may be identified and solved. Similarly, if the design is given insufficient attention, a choice may be made from the set of alternative which do not sufficiently correspond to the problem. Hence this research will focus on an intelligent phase so that the problem is well identified

### 2.2.2. General concept of decision support system

Decision support systems (DSS) have experienced scholarly attention and importance over last the 25 years period, according to (Burnstein & Holsapple, 2008). The concept of DSS originated in the 1960s and growth accelerated in the 1970s. Some of the very early definitions stated by Gorry and Morton (1971) explain that DSS has been used for complex spatial problems which are ill or semi structured.

While working with complex semi structured or unstructured problems with huge data set, it becomes hard for our brain to process and analyses. Sugumaran and Degroote (2011) states that human brain lacks the ability to memorize process and analyse huge amounts of data so in order to address complex spatial problems or issues, support system are often necessary and useful.

Densham (1991) explains that SDSS is the tool developed to assist decision makers with complex spatial problems. They are provided with flexible problem solving environment, where they can generate and evaluate alternative solutions. Most of the DST provides them an opportunity to investigate the possible trade-offs between conflicting objectives and identify solution with maximum potentials.

Crossland et al. (1995) studied the impact of using GIS as a spatial decision support system SDSS. They discuss that spatial integrated DSS (SDSS) can create a link between policy makers and the complex computerized models. They found that decisions and solutions developed by decision makers using SDSS were less time consuming and level of accuracy was comparatively higher.

There is difference in notion of DST between public health professionals and planners. According to Liu et al. (2013) in public health DST can be written guidance, data, model or software, but in planning DST mainly represents computer base tools. Basically DST is a package of connected software modules that provides an integrated set of capacities which provides transparency, robustness, and ease in decision making.

Broadly, DST can be classified as data driven or model driven, which is further discussed in section 2.2.4. Figure 3 shows the classification of SDSS; on the basis of development; it can be classified as existing software (user's perspective) and new software development (developer's perspective). Most of the SDSS are built on GIS platform.

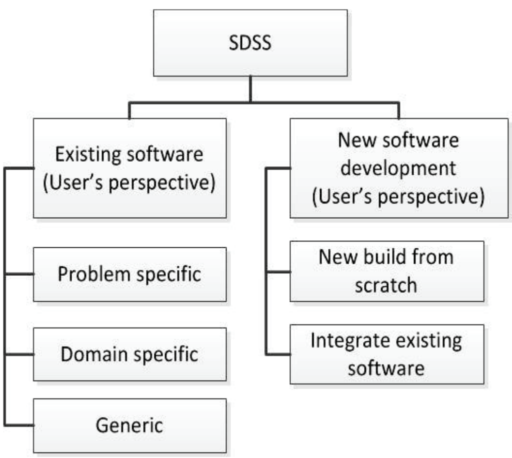


Figure 3: General classification of SDSS [source:Sugumaran and Degroote (2011)]

### 2.2.3. Architecture of SDSS

The components of SDSS can be very simply categorized into three components; database, model and interface. However, SDSS is categorized in different ways by different authors in different point of time. According to Sugumaran and Degroote (2011) there are two main components; Figure 4 shows three core components- database management component (DBMC), model management component (MMC), Dialog management component (DMC) and one optional component is stakeholder themselves.

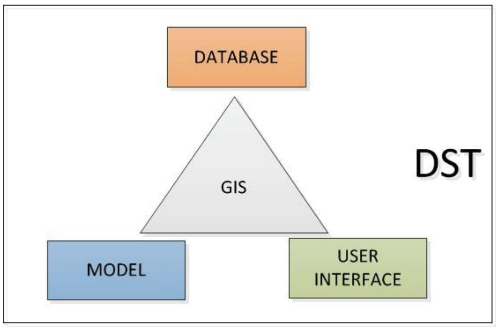


Figure 4: Architecture of SDSS

#### 2.2.3.1. Database management

According to Densham (1991)database management system (DBMS) is the core of any spatial decision support system (SDSS). The database is the organized collection of location, topologic and thematic data types which support easy retrieval of cartographic displays, spatial query and analytical modelling.

#### 2.2.3.2. Model base management

Model manager helps to manage, execute and integrate different models (Chakhar & Martel, 2004). The process of creating new product from existing products through single or chain of calculations is known as modelling. According to Sugumaran and Degroote (2011) there is a wide variety of spatial modelling techniques being used in spatial decision support system such as statistical models, spatiotemporal models, land suitability model e.t.c. Among all these models, land suitability models are one of the most used models in SDSS.

#### 2.2.3.3. Dialogue base management

The user interface is the medium through which communication between user and system takes place. According to Sugumaran and Degroote (2011) spatial decision making process involves iterative, interactive and participative involvement of the end users, interface acts as a platform through which user connects to the computer system to generate and compare different alternative solution and alternative conditions. It is very important, since usability is the key to the success of any software product.

According to Densham (1991)the user interface of SDSS generally requires two spaces; objective space and map space. Objective space is provided for the parameters of an analytical model, whereas map space is provided for the cartographic output of the model. It is important that these spaces are interactive. According to Densham (1991) providing users with such an interface will allow selection of data, model parameters as well as view the output easily and intuitively. SDSS allowing such capabilities will provide end users with a problem solving environment. According to Hurion (1986) visual interactive modelling can be used as the key element in decision making process. According to Densham (1991) visual interaction will be computationally intensive, but responsiveness (Alter, 1980) of the SDSS are very important to determine its utility.

### 2.2.4. General Characteristics of SDSS

Although the above discussion has provided an overall idea on the nature of SDSS; however, it is important to characterise SDSS. According to (Sugumaran & Degroote, 2011) the general characteristics of the SDSS are 1) semi or ill structure problem solving 2) spatial data management 3) spatial modelling capacity 4) scenario evaluation 5) iterative problem solving 6) Easy to use interactive user interface 7) visualization 8) report generation. Hence, in summary, SDSS must be built to accommodate preference and criteria's of various stakeholders. It should allow effective user interaction in an iterative and interactive problem solving environment. It should be able to solve semi or ill structure problems. It should be provided with spatial as well as non-spatial data management, modelling, scenario evaluation, visualization through maps, graphs, tables and report generation.

### 2.2.5. Process of developing SDSS

According to Sugumaran and Degroote (2011) there are considerable numbers of methodologies discussed in the literature for the development of decision support system. According to Veronica (2007) on the basis of driving factors the general methodology adopted for the development of the DSS are 1) Decision driven methodologies: It emphasises on the comprehensive analysis of the decision process using DSS. 2) Process driven methodologies: In this method robustness of the process used in the system are given importance. 3) Data driven methodologies: In this method focus is given to the availability of data alone with the design, construction and management of the DSS. 4) System driven methodologies: Theory of the system is given more importance while selecting the system for the development of DSS.

On the basis of course of development Veronica (2007) again classified SDSS development methodology into other four categories namely

1) **Phased methodology [System development life cycle (SDLC)]:** This methodology follows a linear path for the development of SDSS. It is also termed as waterfall method. Generally there are six phases; problem definition, requirement analysis, design, programming and developing, testing and finally implementation.

   The phased method is not one of the most suitable approaches. It is rigid, requires large documentation cost, the end users are not involved in the process and quick update of the system is not possible.

2) **Evolutionary method:** This method is one of the better alternatives for the development of SDSS. In this method, it involves the four most important phases of the development life cycle: requirement analysis, design, construction and implementation in a single step which is iteratively repeated. In this approach sub-problems are addressed one by one and the functionalities are added to the system over time. This approach captures the stakeholders need by involving them in the process.

3) **End user approach:** In this method end user functions as the developer of the system. They develop the decision support system by using the DSS tools or a DSS generator available in the market such as spread sheets, GIS (especially for SDSS) etc. The main advantage of the process is that it properly addresses the user's requirement; however, due to the lack of expertise in the programing and system development such an approach is viable for problems of smaller magnitude.

4) **Prototyping:** In this method at first a rough concept is developed with the functionalities required in the system. The conceptual design of the system is then developed into the prototype; unlike in the evolutionary method where finished pieces of the system are developed one at a time. It is then evaluated by the end users. By using the iterative process of design, development and evaluation they get close to the final product through prototyping.

According to (Power, 2002; Veronica, 2007) evolutionary and prototyping are the best DSS development methods. However, Veronica (2007) discusses one more methodology; ROMC analysis. According to these methods requires involvement of different stakeholders throughout the process

5) **ROMC analysis :** ROMC design approach was proposed by Sprague Jr and Carlson (1982). This method is descriptive (Veronica, 2007) and helps in system analysis and design (Power, 2014). According to Sprague Jr and Carlson (1982) it is a process driven methodology and is based on four major components; representation, operations, memory and controls. Representations(R): It can be defined as the presentation of information such as a chart, a map, a table, a text document or an equation. This information is used by the decision makers to communicate while working in collaboration. Operations (O): These are the particular task that will help decision makers to perform and obtain certain outputs or the representations. Memory aids (M): These are the elements that support in executing operations and creating representations for example database, libraries, help tools, reminders, triggers, alarms and profiles are the memory aids (Veronica (2007). Controls(C): These are the elements that help the decision makers to operate DSS and produce the outputs.

According to Sugumaran and Degroote (2011) development of SDSS requires a carefully planned and iterative process. Therefore, whatever may be the method adopted it should go through the sequence of phases for the development of the SDSS. Figure 5 shows the sequence of phases generally used in the development of the SDSS.

This research will follow the ROMC design approach as this approach is suitable for the design of a specialized decision support system. This research will create a conceptual design of the spatial decision support system that will specialize on understanding cumulative environmental exposure. Therefore, the focus will be on representation, operations, memory and controls.

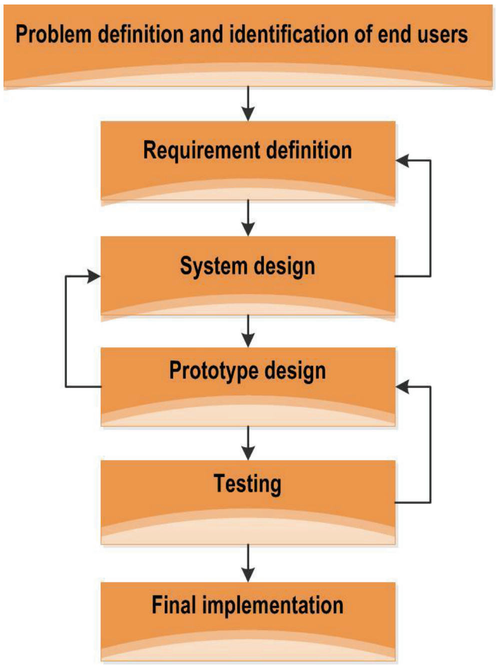


Figure 5: Phases used in the development of DSS and SDSS

#### 2.2.6. Importance and of visualization in spatial decision support tools

The SDST targeted in this research is a tool for collaborative decision process that will help the decision makers to understand the cumulative environmental condition of the city or neighbourhood. In the collaborative decision making process it is very important that all the stakeholders have common understanding of the issues and problem in hand. Stakeholder from diverse field may have different understanding of the same subject matter. The topic that this research tries to deal is an interdisciplinary one so it's important that all the stakeholders can communicate and understand each other.

According to the findings of Jankowki, P. and Nyerges, T. (2001) on average, people can understand graphics more easily than tables for many types of problem. According to Feldman (1989) 1/3 of the brain is devoted to vision and visual memory, engaging that sense can help scientist and non-scientists alike in the better understanding complex problem. Visual perception or visualization helps in cognition by increasing the speed of understanding and makes brain efficient.

While dealing with the big data in a collaborative environment it is becoming widely accepted that representing the information is as important as the information itself. According to King et al. (1989) visualization provides a common language to which all participants, technical and non-technical can relate. Visualization offers a method for seeing the unseen. It enriches the process of scientific discovery and fosters profound and unexpected insights(Al-Kodmany, 2001).

This research deals with heterogeneous problems of environment and health, which is added with the geographic dimension. Since we are dealing the problems with respect to geography; Geo-visualization plays an important role. Different Geo-visualization tools such as maps, 3D models, animation, and interactive stimulated models have been successfully used in the participatory spatial planning and decision making. According to Van Den Brink (2007) 3D model enforces communication, understanding, learning, awareness and empowerment among the stakeholders. This shows that adequate and proper Geo-visualization becomes a learning and education tool for all the stakeholders (Lobera, 2007).

### 2.2.7. Comparison of Visualisation Techniques

In the intelligent phase it is very important that problem is well understood; visualisation can play a key role in understanding, analysing and interpreting the underlying relation between data. There are a wide variety of visualization techniques; these are all based on the theory that effective visualization is the key for communicating ideas and engaging public participation.

What kind of visual representation will better inform the problem at hand to the decision makers is the one of the sub questions of this research. Much research has been done to understand which representation better inform decision makers; tabular versus graphs or graphs versus maps. However the compatibility hypothesis (Gilovich et al., 2002) suggests that information that is compatible with a given task will be get more weight. A study that compares between different spatial maps has not been carried out. Hence, to see which spatial representation is more compatible in understanding the pollution in the city several different representations will be presented in the questionnaire (see annex).

Research on cognitive capacity suggests that humans can process more information when it is presented graphically than in text form (Miller 1956; Tegarden 1999,Holbrook and Moore 1981) or in tabular form ( jankowki). Similarly, tabular forms of data are superior for retrieving specific data values (Benbasat & Dexter, 1986; Jarvenpaa & Dickson, 1988; Vessey, 1991). Moreover, displays that combine both tabular and graphic information may lead to better performance than either graphic or tabular displays along (Benbasat & Dexter, 1986)

According to Brath and Peters (2005) practitioners claim that visualization of information allows better, faster and more confident decision. Which representation, graph or table is better depends on the fit between the way alternatives are presented and the nature of the task (DeSanctis, 1984; Vessey, 1991). However, graphic representations are expected to be better for detecting trends, comparing patterns, and interpolating values (Lurie & Mason, 2007).

Tool that enables visualization of multiple elements of the data at once enhances analytical power and leads to the compensatory decision making rather than those that provide information on a few attribute at a time (Jarvenpaa, 1989).On the basis of this combination of graphs and spatial maps were presented in questionnaire to understand if the combination is more preferred by respondents compared to spatial or non-spatial representation along.

### 2.2.8. Tools

Tools are the major part of human computer interface design creates communication between the user and the system and help to accomplish different functions and methods to get stated goal. According to Sprague Jr and Carlson (1982) controls or tools are the elements that help the decision makers to operate DSS and produce the outputs. In value enter system end users are allowed to enter any number, slider bar helps to avoid this by providing the limit which is generally displayed by the scale (Pettit & Pullar, 1999).

#### Slider bars

According to Heywood et al. (1995) slider bar provides a dynamic visual environment which enables viewing of the outputs after the modification in the weighing of the parameters or factors. It allows stakeholders to make subjective evaluations of factors. Several authors/ designers (Jankowski & Milosz, 1997) has integrated slider bar within the GIS based SDSS. Slider bars are one of the very commonly, used elements in the graphical user interface (GUI) due to its ease in operation.

### 2.2.9. Aid

'Aids' are the element that guides and supports the user by providing information such as pop-up windows.

#### Pop-up windows

Although, in general graphic or maps may be more informative than text, but certain types of visual representation such as pop-up windows as shown in Figure 6 may add upon the information of the maps. Pop-up windows are greatest salience to human information processing (Benbasat and Dexter 1985; Jarvenpaa 1990; Simkin and Hastie 1987; Treisman 1988). It allows dropping specific and important information; therefore are heavily used in decision making (Lurie & Mason, 2007).According to Lin (1997)pop-up windows helps the user to focus on one area of the map and gives them confidence with the underlying information and encourage people to make judgments

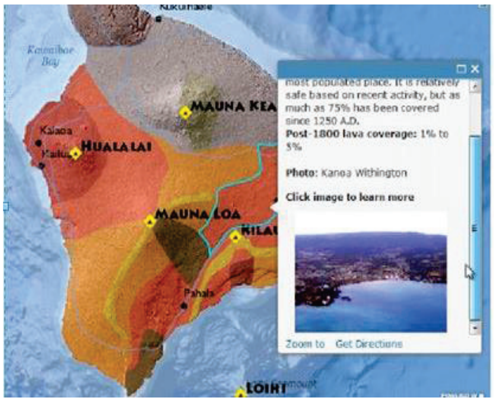

Figure 6: Pop up window

Pop-up window is an easy way of getting some detailed information about certain feature in the map such as road, gas station, industry which might be the cause of pollution or disease outbreak. Such a window may help in drawing a hypothesis. For example 'Industry "A" is the cause of health hazard in the area.' The data presented in the pop up window are directly drawn from attribute table in the shape file (in case of pop up window provided by Arch GIS web server). In addition to pure text it also can consist of charts comparing statistical values, photography's.

### 2.2.10. Problems and factors related to the development and adoption of SDSS

According to Sharifi et al. (2004) although DSS systems seem to have many benefits to decision makers; there are many that are not taken into use. Some of the main causes are 1) lack of field testing 2) end users not being involved during the development of the DSS 3) distrust for the output of DSS because the decision maker do not understand the underlying theories of the models 4) mismatch of the DSS output and the requirement of the decision makers; it generally happens because of the difference in the understanding of DSS designers and users 5) ease to use and usefulness of the system.

According to Al-Kodmany (2001) many people are quite intimidated by computer and will retreat from a computer dominated process. There are some factors that should be considered in the development of the SDSS. One of the very important issues that needs to be taken into consideration while designing SDST is that; it should be sophisticated yet simple and user friendly. According to Uran and Janssen (2003) proper navigation through the system is very important for the high functionality and efficiency of the system. SDSS should be easy and simple enough to be followed by non GIS specialist. "Is it easy to find the path from start to the end?" (Uran & Janssen, 2003) is an important question to understand the "ease" of using the system? Perceived ease of use is a measure of reduced physical or mental effort while using the DSS(Sharifi et al., 2004).

According to Sharifi et al. (2004) "usefulness" is the measure of how well the DSS will enhance a user's decision making capacity. It might be indicated by information produced by the DSS and its use in decision making. According to Sharifi et al. (2004) generally there is a trade- off between the ease of use and the flexibility of the system. It is important that the balance between 'ease of use' and 'usefulness' is maintained.

Therefore, all the outputs are not useful; only the outputs that are informative are useful however all the informative outputs are not easy to understand. Output that increases the knowledge of the end user is informative. Information should be simple to understand; it should not be overloaded with information that might be complicated for the decision makers.

## 2.3. Review on existing SDSS in environment and health

As already explained in section 2.2.10 despite the high effort, time and money that are put into the development of SDSS (Sharifi et al., 2004) and consisting the characterises (some if not all); some of them fail to achieve the state of art and thus less used.

According to (Adelman 1992) it is difficult to perform subjective evaluation of SDSS because of the unpredictable dependency on end user. As already discussed in section **Error! Reference source not found.** many SDSS are not taken in to use and if they are, documentation of end users experience is very rare. Hence, to understand state of the art of SDSS in a systematic manner case study of some representative SDSS in the field of environment and health are reviewed in the following section.

SDSS for the case study was selected on the basis of following criterion.

1. SDSS that deals with number of pollution and health outbreaks.
2. SDSS that focus on visualization (maps and graphs).
3. SDSS developed for environmentalist, planners and health professionals.
4. SDSS that do not focus on modelling.
5. SDSS that do not require GIS and programming expertise for the operationalization.

The outline of the review will be based on 1) structure 2) data required 3) operationalization 4) visualization 5) methods 6) tools in the system and 7) concluding remarks. Review of these SDSS will be done on the basis of peer reviewed papers, online and offline demo's provided by authors.

### 2.3.1. Case Study 1: SOLAP (Map4 decision)

SOLAP is a decision support tool that is built on geographical information system and on-line analytical tools (OLAP). The main objective of the SOLAP is to helps in understanding health risk caused by an environmental source(Bédard et al., 2003). It provides a quick and easy access to environmental and health data for the quick and well informed decision making. SOLAP can be defined as a visual platform built especially to support rapid and easy spatial-temporal analysis and exploration of data following a multidimensional approach comprised of aggregation level available in cartographic display as well as in tabular and diagram displays (Bédard et al., 2001; Proulx et al., 2002).

**Structure**

According to Bédard et al. (2003) multidimensional concepts includes: dimensions, members, measures, granularity, facts and data cubes. Dimension consists of aspects such as time, disease, territorial subdivision etc. Dimensional members consist of (for example: 1999, lungs cancer, Quebec region etc.). Granularity explains the organizational hierarchical levels (For example 'Province', 'Regional health authority', 'Local health authority' etc.). According to Thomsen (1999) data cube is a set of measures(result of the query) aggregated depending up on the available set of dimensions. It highly depends up on the probable query so several data cubes can be built from the source data. Hence, this will increase the speed of data query; which is important in keep up the momentum while tracking down the underlying facts of the data.

**Data**

High resolution data obtained from Quebec ministry of health and social services were used for the testing of prototype. Data consists of detail information in each individual case. For each case (accident, death or hospitalization) the data collected at the time of the event were recorded according to the 'international classification of disease'; sex, age, event date, the municipal code, the postal code of the individual. Population data per year, per sex, per 5 year age group and per community health centre were also obtained from the Quebec ministry of health and social service.

**Operationalization**

Multiple options are provided as the query option in the tool for example cause of disease, hierarchical quarries (months, years, census tract, province or region). If user wants to query the number of patient's hospitalized due to asthma in the region in 1998 then the user needs to click on the desired information elements for example 'Asthma'+ 'Hospitalization '+ 'Comparative figure'+ 'Regional health authorities'+ '1998' in the selection trees of the navigation panel. This will provide thematic map within 10 seconds. If more detail information about the subject matter is required then the user can chose to click on drill down button. The user can change the type of statistical charts such as bar chart or pie chart. This can be again displayed in disaggregated level. According to Bédard et al. (2003) user will require only few mouse clicks to produce maps without even touching their keyboard.

Similarly, to see the relation between health of the region and the environmental quality users can make a selection, 'Air quality monitoring'+ 'So2'+ 'Average concentration'+ 'Regional health authorities' + '1994-1998' in the selection tree. If the result do not seem to have relation then it is possible to change the environmental factor (O3/No2/PM10) and recalculate. In the workshop that was conducted to test the prototype they tried to see the relation between environment and health at first with S02; when it was found that there was not much relation between them, they changed the environmental factor to O3, where they found some relation. To have more detail on this drill down operation was executed directly in the table.

**Visualization**

Different types of diagrams for example bar charts and pie charts along with the thematic maps and tables are used as the visualization techniques. It provided the option of 1) overlay, where graphs are overlaid on the thematic maps 2) multiple charts, which allows side by side comparison of the set of charts conveying different message; these visualisation techniques helps in the analysis. It also provides maps and graphs which are interactive.

**Tools**

It allows user to explore and analyse the data using different operators such as drill-down (shows more detailed inside the data), roll-up(shows more general level in the data), drill- across(shows another theme at the same level of detail) and swap(interchange visible dimension in the chart or table). Such system is built for simple and quick data mining without having to learn a query language(Bédard et al., 2003).

**Concluding remarks**

According to Bédard et al. (2003) if above discussed information is to be obtained by using GIS it will not be straightforward for non-GIS specialists (for example doctors, epidemiologists). In addition to that it is also very challenging for the users to display the maps and graphs in the GIS application. Moreover, such a long process tends to break the line of thought required for the analysis of the output.

Bédard et al. (2003) claim that it's a very easy to use and user friendly tool. An hour of training was provided to the end-users (professionals from public health and environmentalist) on the software which is claimed to be sufficient. This tool aims to support the way public health specialists think and analyse. It allows them to focus on the results and analyse them rather than on the process of finding results (i.e. focus on 'what to obtain' rather than on 'how to obtain it').

### 2.3.2. Case Study 2: H.E.L.P a GIS Based Health Exploratory Analysis Tool for Practitioners

GIS based health exploratory and analysis tool for practitioners (H.E.L.P) is a SDSS which provides a powerful analytical tool. The system output helps in understanding disease dynamics in the area and its correlation to environmental condition of the area. Different methods are used in the tool for the assessment of causal relation between disease and environment.

**Structure**

H.E.L.P is designed as an extension in GIS so that visualization capabilities of GIS can be easily used. There are four different modules in H.E.L.P namely 'select layer ', 'spatial analyses', 'space-time', and 'mapping'. These modules are simply accessed by using tabs.

**Data**

Hospital patients registration system which contained information on patients history and other information such as date of visit, sex, insurance type, age type of consult, diagnostic and their neighbourhood of origin was used to validate the tool. Patient's information is provided in the neighbourhood level and is geocoded. To preserve the privacy of patients, information is randomly redistributed within the boundary of the given neighbourhood which is known as random masking (kwan et.al 2004)

**Operationalization**
H.E.L.P appears as a small button like any other extension in GIS. When it is clicked it opens to a window with four other tabs. To segregate different functions from each other tabs are used which helps in structuring the tool. Complex GIS applications and Matlab calculations are made easily accessible to end users by allowing selection through drop down menus.

**Method**
This system uses spatial clustering (kernel density) to visualize the condition and magnitude of disease in the area. Spatial clustering helps in relating contagious disease to environmental factors and hence helps in taking appropriate preventive measures. The selected sets of patients are instantly visualized in the GIS platform and can be overlaid with socio-economic or environmental data layers to formulate hypothesis on disease etiology.

**Visualization**
Maps and histograms are used to display the output. However cause is not explicitly shown in the maps, it is mostly analysed by the health specialist. Histogram is used to represent the distribution of patients on a monthly basis. This was used to relate to the fluctuation of environmental stressors in the environment with temporal variation.

**Concluding remarks**
Workshop was organized to introduce H.E.L.P decision support tool to the end users. After the work shop they were questioned users on the usefulness, statistical and technical compatibility, and ease in use of the tool.

According to Delmelle et al. (2011) there was clear consensus among the end users that maps produced by the system are informative. Strong concentration of *intestinal parasite* was found in location where there was poor sewage. Hence H.E.L.P decision support tool was successful to recognize the strong relation between health outbreak and environmental condition in specifies location of the city. Users of H.E.L.P think that causal relationship between disease occurrence and the environment is a useful piece of evidence that can encourage city leaders in solving problem. This can lead to evidence based solution in addressing the problem of health and environment

According to Delmelle et al. (2011) although hospital staffs and epidemiologist participated in the workshop had limited statistical knowledge they were not worried on the necessary statistical skills. According to them maps and graphs provided by the tools were extremely clear, easy to interpret and understandable. According to author users found H.E.L.P technically understandable. Author explains that ‘what is function’ is not important to the users but ‘what is the function for’ is more important to them. Depending upon the workshop author explains that high level of training was not necessary to learn how to use H.E.L.P

This shows that users are not worried about the sophisticated functions and statistical calculation behind it, if they can easily get and understand outputs. A very clear start to finish frame is provided in the tool. Since decision makers should be able to concentrate on the analysis of results they should be provided with a simple and ease to operate tool rather than having to go through difficult query language.

### 2.3.3. Case study 3: OPENAIR 3-D map of air pollution in London

The OPENAIR project provides '3-D map of air pollution in London'. It is a "web based air pollution data analysis tool" king's College London (2013). It is an open source tool. It provides an interactive three-dimensional map that allows users to "fly" above London to see pollution hotspots. It was launched by the Centre for Advanced Spatial Analysis (CASA) - University College London and King's College.


Figure 7: Interface of OPENAIR tool

**Structure**

Structure of the tool is very simple; all the information is displayed in one interface due to which it's very easy to operate the tool. The Figure 7 shows the window of OPENAIR tool that shows the '3-D map of air pollution in London'. In the window there are different components which are numbered for easy identification. '1' is the main visual interface of the tool. It is currently showing aerial photograph of London. '2' is navigation map which helps to overview the map in main interface. '1' and '2' are interactive meaning that zooming in to the main interface is possible by using the 'zoom' slider under '2'. '3' shows the layers in the map such as air quality monitoring sites, 3D zones, roads and rail ways, rivers, parks and green spaces etc. Check box in front of each layer allows switching the layer on and off.

**Data and Method**

Data on air pollutants such as particular matter (PM10), Nitrogen dioxide (No2), ozone (O3), and sulphur dioxide (So2) are collected hourly. The hourly data collected is averaged for the whole year. According to (book) air pollution is mapped and visualized using surface routines in ArcGIS which is then overlaid on the 3Dmodel of the city. This tool was developed in 2003 but it provided the prediction of future air quality till 2010 by using scenarios. Pollution concentrations have been classified according to Defra's air pollution index system, which levels into bands from low to very high. Each band is sub divided in to 10 pollution index; 1 being low and 10 being very high.

**Operationalization**

Each of the pollutants can be visualized by using the drop down bar shown in '4'. The drop down bar consists of different air pollutants such as particular matter (PM10), Nitrogen dioxide (No2), oxides of nitrogen ($No_x$).

**Visualization**

A stimulated map of different air pollution is provided which can be visualized both in 2D and 3D form. This tool provides spatial temporal quality of air pollution. '3-D zone' (triangles in the main interface) provide bird's eye view of the area, along with air pollution. 3D exploration of air pollution is designed such that different air pollution data are overlaid with the 3D of the city.

**Tool**

Very simple and easy to use tools such as slider bars, drop down menus and check box are used which helps users to retrieve information without going through any complications. '5' is the slider bar which helps to change the transparency of the map. This function helps the users to locate themselves in the map. '6' is the slider bar for temporal overview of air pollution in the city.

**Concluding remarks**

According to King College of London (2013), developers of the tool claim the tool to be 'easy-to-use' allowing transport and urban planners, as well as the general public, to zoom in on different areas to see the air quality of particular neighbourhoods. According to The London Air Quality Network, two-dimensional representations can be difficult for non-specialists to understand the pollution condition in the city so with the suggestion from Centre for Advanced Spatial Analysis (CASA) 3D mapping technique was used to create a simple but effective tool. According to King College of London (2013) it is the first time that air pollution for an entire city has been related to the built environment.

According to (King College of London, 2013) this tool allows spatial temporal analysis of air quality of the city which clearly shows the improvement arising from air quality abatement measures. Developers of the tool claim that transport planners are able to identify the most polluted part of London and urban planners will be able to see how building density affects pollution concentration in the city and other high density areas.

This on-line web base tool is extremely easy to use. It is easy to understand the structure and the output maps of the tool. Spatial-temporal variation of air pollution and 3D graphics are particularly interesting and informative.

### 2.3.4. Conclusion on the review of SDSS

From the review of three different SDSS in section 2.3, it can be derived that structure of the SDSS should be simple and easy. First, the ease can be related to different aspects such as 1) end users being able to conduct analysis without having to master the query language (Rivest et al., 2001)2) end users being able to navigate their path from start to end (Uran & Janssen, 2003) and 3) reduced physical or mental effort while using the SDSS (Sharifi et al., 2004). From H.E.L.P it can be inferred that using 'tabs' to separate different functions helps in structuring the tool. As explained in SOLAP, use of multidimensional concepts helps in understanding different aspects in a short time period. Clear structure helps in smooth and fast operationalization which helps in maintaining the line of thought required for the analysis of the output.

For the visualization of data different cartographic and non-cartographic displays are used in these SDSS. Different types of statistical charts for example bar charts, pie charts, histograms are used as the non-cartographic display. Apart from these, tables are used as descriptive component. Temporal dimensions are crucial component for decision making process (Gonzalez & Spatial, 1999; Sinton, 1978). Hence along with spatial dimension temporal dimension is used for exploration, analysis and decision making. Moreover, three dimensional graphics of the city provided in OPENAIR are used to better understand the environmental condition of the city. Similarly, SOLAP provides the possibility of representing different measures at the same time in the different displays for side by side analysis; furthermore it allows superimposing statistical diagrams on the maps. Apart from this, maps and graphs are also made interactive. Hence these visualization techniques help in easy, fast and iterative analysis.

To accomplish any function tools are required; very simple and easy to use tools such as slider bars, drop down menus and check box for turning on or off the layers are used. These tools help easy retrieve of information.

Method such as kernel density, the above discussed visualization techniques and structure has been used in existing SDSS in the context of environment and health study. According to Rivest et al. (2001) different types of representation may highlight different types of information; hence, it is important to understand the proper methods, visualization techniques and tools to represent cumulative environmental exposure. Therefore, different methods, visualization techniques and tools as discussed in the review of existing SDSS together with others from the literature will be validated through expert questionnaire for the context of cumulative environmental exposure.

# 3. PROCESS OF BUILDING SDST$_{CE}$

*This chapter describes the methodology implemented to accomplish this research. The first section of the chapter discusses on the overall research methodology. It will briefly walk the readers through the SDSS development methodology and different phases adopted in the conceptual design and development of the SDST$_{CE}$. The second section describes the process of collecting primary data; which is one of the most important parts of the research. It discusses the process of design and implementation of online questionnaire survey. The third and fourth sections are the follow up of second section. Third section discusses on the follow ups and interviews with the respondents of questionnaire whereas fourth section discusses the method of analysis of the questionnaire. The fifth section discusses on availability of secondary data and it's pre-processing. Finally, the sixth section of the chapter discusses on the method used in the development of SDST$_{CE}$.*

## 3.1. Research methodology

This section of the chapter discusses on the methodology adopted for the development of the conceptual design of SDST$_{CE}$ (see Figure 8).

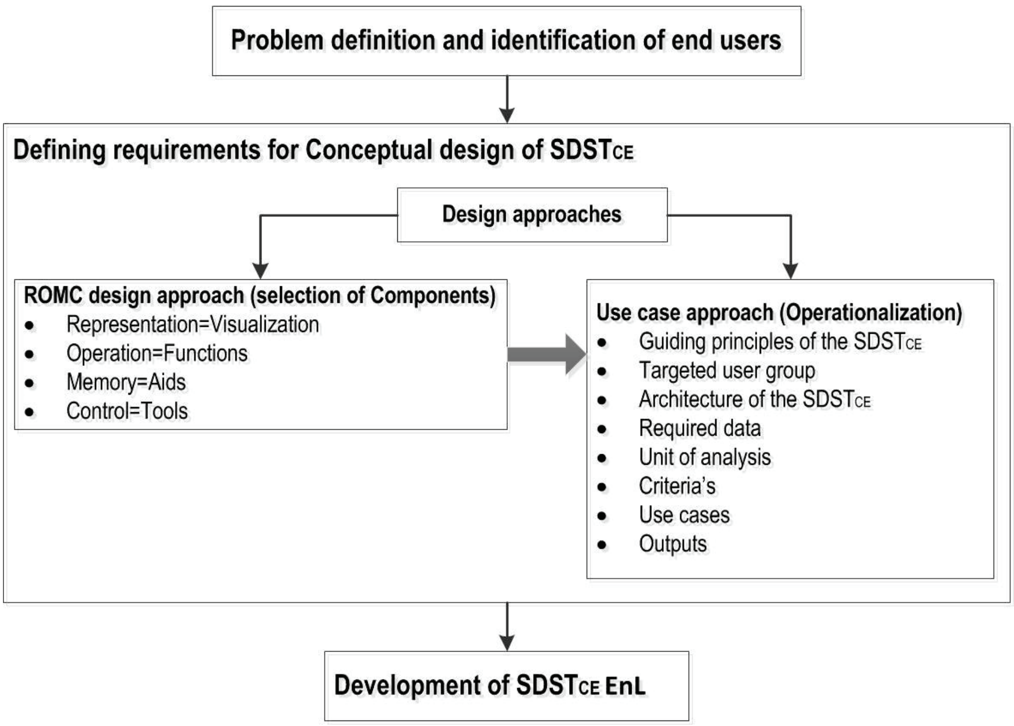


Figure 8: Methodology of developing SDST$_{CE}$ (own source)

### 3.1.1. Problem definition and identification of end users

The first step leading to the development of SDST was recognizing the problem and the benefit of addressing that problem with computerized spatial decision support tool. In addition to the problem recognition, end users of the tool and the contribution that they could make in solving the problem was identified.

### 3.1.2. Defining requirements for the conceptual design of $SDST_{CE}$

This is the most important phase in the research. The main objective of conceptual design of $SDST_{CE}$ is to provide all the information required for the development of the prototype. This research uses two approaches for the design of $SDST_{CE}$ namely 1) ROMC design approach and 2) Use case approach. Additionally, both these approaches go through sequence of phases for defining the requirements; which is briefly discussed below.

#### ROMC design approach

This research uses ROMC design approach (Sprague Jr & Carlson, 1982) as a methodology for the design of spatial decision support tool for mapping cumulative environmental exposure ($SDST_{CE}$) as this methodology is suitable for the design of a specialized decision support system as already discussed in the section 2.2.5. It is a descriptive and process driven method. It mainly focuses on the selection of different components of the SDSS. In this research the four components of ROMC; representation(R), operations (O), memory aid (M) and controls(C) are termed as visualization techniques, functions, aids and tools.

For the design of $SDST_{CE}$ it is important to analyse and select the four components of the tool. On the basis of ROMC design approach four components of $SDST_{CE}$ are selected by using literature review, reviews on existing SDSS, questionnaire and interviews. These four components are used as the input to the use case approach.

#### Use case approach

This research utilizes use case approach for writing the conceptual design of the $SDST_{CE}$. It is a methodology used in the system analysis to identify, clarify and organize the systems requirement (Gibilisco, 2013). It focuses on the operationalization of the tool. Following the theory of use case approach, it extracts some important components for the conceptual design of the $SDST_{CE}$; for example, guiding principles of the $SDST_{CE}$, targeted user group, architecture of the $SDST_{CE}$, required data, unit of analysis, criteria's, different functions and its use cases. Hence it helps to draw the structure of the system. Similar to ROMC design approach these requirements are drawn on the basis of literature review, reviews on existing SDSS, questionnaire and interviews as shown in Figure 9.

According to Cockburn (1997) use case is a term that describes the possible sequence of interactions between the system and actors in order to achieve a stated goal. A system consists of many use cases depending up on the goal of the system. In this research while writing a use case for any function it takes in consideration some of the issues such as 1) use case title, 2)introduction of the function 3) actors involved, 4) preconditions 5)standard path 6) post conditions. The use case title briefly describes the objective or goal of the use case. Rational of the use case is descripted along with the prerequisites of the system such as data requirements. Standard path describes about the operationalization of the function. Post conditions discusses on the outputs of the use case.

#### Phases used in the design approaches

Both the 'ROMC design approach' and the 'Use case design approach' go through sequence of phases for defining the requirements. Figure 9 shows the phases adopted by these design approaches.

To understand the requirements literature review was done on different concepts relevant to the research such as theoretical study on architecture of SDSS, function, methods and visualization techniques required for assessing cumulative environmental condition. Furthermore, to better understand structure and requirements of $SDST_{CE}$ a few case studies on existing relevant SDSS on environment and health were carried out (see section 2.3). Additionally, to better understand the system offline demos provide by authors and online tools were studied.

Design of the SDST is largely based on literature review, preference and views of end users for the efficient and acceptable tool. According to Sugumaran and Degroote (2011) it is important to be accepted by users to be successful. Hence, to avoid the mismatch of the SDST outputs and the requirements of the end users an expert's questionnaire was carried out.

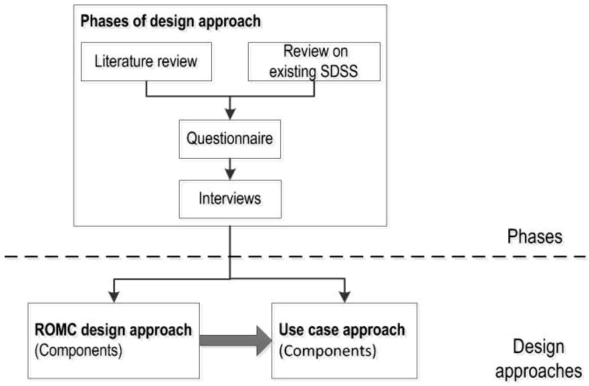

Figure 9: Phases utilized in the design approach

The experts questionnaire was focused on understanding the appropriate methods to assess cumulative environmental effects, preference of end users on different functions, methods, visualization techniques and tools. The questionnaire was drawn on the basis of literature review. The process of questionnaire is explained in detail in section 3.2. Along with questionnaire a few expert interviews were carried out.

Data collection from online questionnaire survey was analysed by using mixed method; however, qualitative analysis was given more importance. Findings from the questionnaire and interviews were used as the primary data which provided basis for the selection of visualization techniques, functions, aids and tools for the design of $\text{SDST}_{\textbf{CE}}$ along with literature review.

A chapter is devoted on the conceptual design of $\text{SDST}_{\text{CE}}$ (see chapter 5).

#### 3.1.3. Development of the tool

Although this research provides conceptual design of the $\text{SDST}_{\text{CE}}$; however, it does not develop the overall tool. This research develops a small section of the $\text{SDST}_{\text{CE}}$ which is termed as '$\text{SDST}_{\text{CE}}$ EnL'. It addresses the few sub objective of $\text{SDST}_{\text{CE}}$ following the evolutionary development method as explained in section 2.2.5.

The $\text{SDST}_{\text{CE}}$ EnL exemplifies the interactive tool where inputs and outputs are interconnected. The end user will be able to enter their input by using the slider bars whereas outputs are displayed in maps and graphs. This tool shows the geographic extent of cumulative environmental stressors in the city. Along with geographic extent it will be able to show the population exposed to cumulative environmental stressors.

The $\text{SDST}_{\text{CE}}$ EnL is used to show the geographic extent of cumulative environmental stressors in the case study city of Dortmund. For this, secondary data on case study city was used.

### 3.2. Primary data collection

This section discusses the methodology used for the primary data collection. In this research primary data collection was done by questionnaire and interviews.

#### 3.2.1. Questionnaire

In this research design of spatial decision support tool (SDST) is based on the concept of cumulative environment condition due to multiple environmental stressors. The potential user of "Special decision support tool for mapping cumulative environmental exposure" will be urban planners, public health experts, environmentalist and municipal officers and other people in decision making position. It is very important to know the preference and understanding of different stakeholders or potential user of the tool. Since this research is a link between these disciplines, it is important that the SDST works as a common platform for people from different discipline.

According to Sharifi et al. (2004) some of the main causes for the failure of DSS are end users not being involved during the development of the DSS and mismatch of the DSS output and the requirement of the decision makers. Hence to overcome the problem of difference in the understanding of DSS designers and user's questionnaire and interviews with the potential users of tool is conducted.

Furthermore, according to Few (2004) it is most important to choose the medium that best delivers the underlying message of the data. Hence questionnaire focuses on understanding the visualization techniques, functions and tools that best communicate cumulative environmental state and exposure due to multiple stressors.

Questionnaire is the tool to understand the preference of different experts on visualization techniques, methods and tools in understanding the cumulative environmental effects. It is very important that their preference is based on their professional background since the SDST is going to be used by them in a professional environment. Therefore questionnaire is an important step in the process of developing conceptual framework of SDST.

Analysed output of the questionnaire will be an important product of this research. Based on literature review, expert's preference, their knowledge and suggestions; conceptual design of the $SDST_{CE}$ with best possible methods, visualization techniques and tools will be designed.

#### 3.2.2. Rational behind online questionnaire

This research requires an expert questionnaire survey to understand the importance of visualization techniques, function and tools in understanding cumulative environmental state and exposure in the spatial decision support tool (SDST). The result obtained from the questionnaire is highly important since it will be one of the very important outputs of the research and will be the basis of conceptual design of the $SDST_{CE}$.

Online questionnaire surveys have been used in this research although it has been rated as slow and low response collecting survey. The respondent of the questionnaire are planners, environmentalists, public health experts, scientists, professors and authors. It is not possible to interview each of them in a limited time and budget so online survey was the best option in this case. This type of survey allows respondent to go through the questionnaire without disturbing their schedule.

Creating questionnaire in an online questionnaire tool is easy and fast. Questionnaire in this research consists of animation, it would have been impossible to have such a question with animation in other type of questionnaire. It provides high degree of flexibility in editing. Editing even after sending the questionnaire to responded is highly helpful since it allows in last minute editing.

Collection of response and analysis is easy. There is flexibility of analysing the response in different format quantitatively in excel and qualitatively in pdf. Details on respondent and time taken to fill the questionnaire can easily be seen. Basically all the required information regarding response and respondent are easily available without any complication and extra work.

### 3.2.3. Sampling strategy

According to (Ludwig et al., 1993; Stuth et al., 1993) many of the problems associated with the development of decision support system can be traced to the limited end users involvement in the development of DSS. To overcome this problem, views of end users are collected via questionnaire.

For the selection of first batch of respondents 35 experts from different field such as urban planning, public health, and environment from the existing network of researchers involved in JuFo Salus project, authors of different article on DST, visualization, environmental justices and pollution together with organization working in the field of pollution, environmental epidemiology and DST were send mail. Among them eleven responded. Non discriminative snowball sampling technic was used to collect second batch of response. However, out of 24 snowball samples 14 replied. Hence 56% of response was collected through this technique.

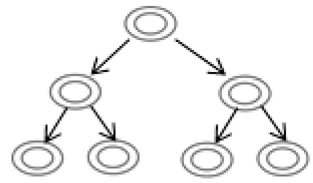

Figure 10: Non discriminative snowball sampling

### 3.2.4. Structure of Questionnaire

There are three parts in questionnaire. **First part** is about general questions on Decision Support Tools (DST). **Second part** is on visualization techniques and **third part** is on functions and tools in DST. There are basically three types of questions close ended, combination of open and close ended questions and comparison by using likert scale depending upon the nature of question.

**Part 1:** General questions on experience of respondents with DST and cumulative environmental effects.

**Part 2:** Specific questions on potential visualization techniques in DST for analysing cumulative environmental effects (CEE) s.

a) General comparison between non spatial and spatial forms of visualization
b) Visualization of (CEE)s in aggregated non spatial form
   i. Bar chart
   ii. Radar chart
c) Visualization of (CEE) in spatial form
   iii. Individual indicator maps (disaggregated maps) versus Multiple Environmental Deprivation Map (MEDM) (aggregated maps)
   iv. Time series versus Animation
   v. Pollution map in 2D versus Pollution map in 3D environment
   vi. 2D pollution map versus 3D pollution map both in 3D environment
   vii. Time Series versus Animation

**Part3:** Potential functions and tools in DST for visualizing and analysing cumulative environmental effects (CEE)s

**A) Functions**

a) Index map
b) Kernel density
c) Weighting/ scoring
d) overlay

**B) Visualizing tools**

a) Weighting/ scoring of single environmental exposures
   i) Slider bars
   ii) Manual scoring
d) Alert
e) Pop up window
f) Browse button or drag and drop box
g) Drop down button

#### 3.2.4.1. General Introduction and Formalities

Questionnaire starts with the brief introduction of research topic. It explains the aim and the major focus of the questionnaire. It also explains important terms in the questionnaire so that all the respondents have common understanding of the terms stated in the questionnaire. After short introduction, respondent are requested for their identification; which off course is not compulsory.

#### 3.2.4.2. Part 1: General questions on experience of respondents with DST and cumulative environmental effects

This section of the questionnaire deals with the general questions on understanding and experience of respondents with decision support tool (DST) and cumulative environmental effects. This part of the questionnaire will direct me to the decision support tool (DST) that experts have been using; which will help in understanding methods, tools, and visualization technics being used in other DST. This part of the questionnaire will also help in understanding the methods that experts have been using to assess cumulative environmental effects.

#### 3.2.4.3. Part 2: Specific questions on potential visualization techniques in DST for analysing cumulative environmental effects (CEE) s.

This section of the questionnaire deals with specific questions on potential visualization techniques in decision support tool (DST) for analysing cumulative environmental effects (CEE) s. This section is composed of simple to complex visualization technics and combination of one or more.

This part starts with a very simple question on general comparison between non spatial and spatial forms of visualization. It aims to understand the preference of respondents regarding spatial representation such as maps versus non-spatial representation such as graphs for the effective understanding of environmental effects. Even in non-spatial form of representation there are different types of graphs such as bar chart, radar chart, scatter plot, space time maps. Similarly there are different ways of visualizing cumulative environmental effects in spatial form. Very simple an 'individual indicator maps' to an 'animation' are presented in the questionnaire.

It is very important to understand the preference of experts on both spatial and non-spatial form of representation since SDST should accommodate experts from different field and provided them with a common language.

#### 3.2.4.4. Part3: Potential functions and tools in DST for visualizing and analysing cumulative environmental effects (CEE) s

This part of the questionnaire will help in understanding the preference of experts on 'functions and tools' to be incorporated in SDST. Functions are the methods which help to assess complex queries or generate knowledge such as cumulative environmental effects in the city. Creating an index map is a function whereas tools are the technique which helps to accomplish different methods.

Some of the potential functions included in the questionnaire are multiple deprivation index, weighting, kernel density etc. whereas pop-up windows, slider bars or interface for scoring, alter functions and browse button or drag and drop box, drop down button are the tool that will help in accessing different methods.

### 3.2.5. Methodology in conducting questionnaire

Figure 11 shows the methodology used to conduct online questionnaire. After preparation of the questionnaire it was send out for pre-test to researchers involved in JuFo Salus project. Responses from the pretesting were analysed. Additionally, questions were improved following the suggestion provided by the respondents.

In parallel to pre-testing, carefully selected group of experts were contacted via mail. Some of the experts willing to participate in the survey were send final questionnaire. Responses were analysed and follow up to some of the respondents was done to gain some more information. Communication with them was carried out through e-mail. While conducting follow up via e-mail some of the respondent where asked for interview. Responses from all the respondents and interviewees were analysed.

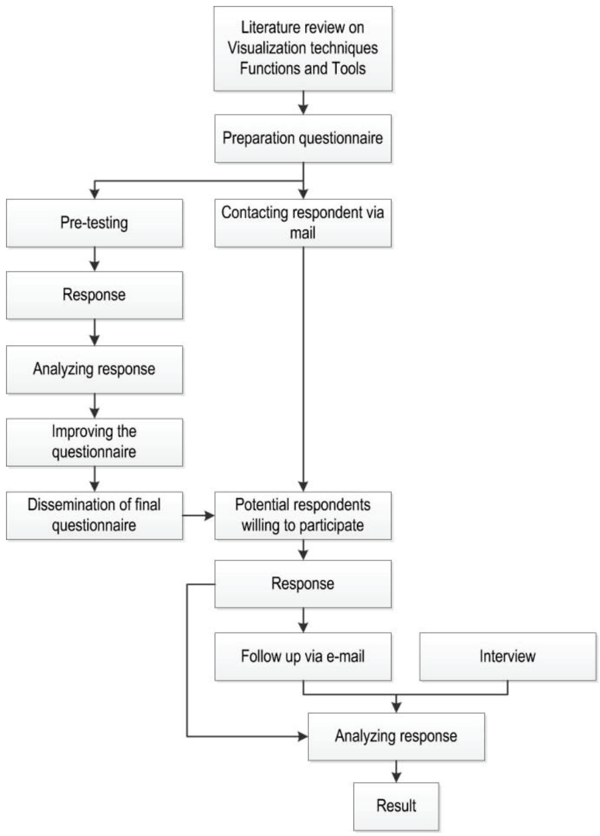


Figure 11 Methodology of online questionnaire

## 3.3. Follow-ups, interviews and demo's

After briefly studying the responses on the questionnaire, follow up through email was carried out to get further clarification on the responses. During the follow ups respondents were asked to kindly suggest any colleague or scientist that could be interested in the online survey used in this research.

Furthermore, during the follow up, a request for demo on SDSS (Map4decision) along with an interview was made to one of the respondent. With the recommendation of one of the respondent (developer of SDSS), one of the co-author and developer of SDSS (interviewee) agreed on presenting the demo along with the interview.

The interviewee provided a short demo of the Map4decision, parallel to which a semi structured interview was conducted. This was all done online through Gotomeeting (software). The main focus of the interview and demo was on the structure of the SDSS, visualization techniques, operationalization of the system, data requirements and end users of the system. Moreover interviewee also provided written documents to better understand Map4Decision. Additionally, One of the visiting scientists (environmentalist) working on SDSS in ITC was interviewed. Format of online questionnaire was used for the structured interview.

### 3.4. Analysis of the questionnaire

The mixed method is used for the analysis of the primary data. Quantitative analysis is used for close ended questions whereas qualitative analysis is used for the open ended questions. Data collected through online questionnaire survey was downloaded and edited in excel sheet. With the initial reading of the data it was found that there is a difference in preference of respondents with different professional backgrounds. So respondents were categorized according to professional background and they were assigned identification number (ID). The inferences of respondents to the open question were arranged according to question in a separate word document; it was then indicated with professional background and identification number (ID) of the respondents for the ease in analysis.

After managing the data, it was studied to find the patterns, relationship and singularities in the data. Data was categorized in four groups according to the professional background; technical background [mostly people involved in the development of decision support system (DST), authors and professors in DST and visualization], public health professionals, planners and environmentalists. Data was analysed within the same professional groups as well as between the groups. To study the preference of experts likert scale is used in the questionnaire. According to Jamieson (2004) median and mode should be used in the analysis of likert scale; however, in this this research mean is used because multiple choices were to be analysed against the likert scale along with that cross table and graphs were made for quantitative analysis. Initially, short summaries were written on the findings trying to explain the patterns and relationships found in the data.

A chapter is devoted on the analysis and finding of the questionnaire (see chapter 4).

### 3.5. Secondary data and its processing

Secondary data was collected and provided by JuFo Salus project (healthy and equal cities). Data was provided in four formats; shape file, raster, excel and portable document format (pdf). Environment data (noise), administrative data and land use data was provided in shape files; however one of the environment data (air pollution) was provided in raster format. Demographic data was provided in excel format. Index (key) that described about the attributes of the land use file was provided in pdf format.

### Administrative data

Administrative data provides the different administrative boundaries for Dortmund. The city is divided in to 12 city districts, 62 statistical districts and 170 sub statistical districts. Since demographic data was available in 62 statistical districts, it was used in this research.

### Land use data

Land use data consists of 66 different land use classes. This research tries to understand geographic extent of the environmentally deprived areas(cumulative) in the case study city; therefore, from the land use data set of 66 classes namely industrial area, commercial and industrial waste land, waste disposal, public and private green space and parks, lake and ponds, forest area, are used in the research. Hence sub set of all these necessary layers were made by using export data.

### Environment data

Environment data consist of data on noise pollution and air pollution. Noise pollution data from air, road, rail traffic as well as industry was provided in shape file. Projected coordinate system was modified from DHDN_3_Degree_gauss_Zone_2 (Gauss_Kruger) to Germany_Zone_2 (Traverse_Mercator) to solve the problem of dislocation of different noise layers. Air pollution data for nitrogen dioxide was provided in raster format. It was changed to vector by using 'raster to polygon' command in GIS.

### Demographic data

It consists of demographic data of 2011 for the 62 statistical districts. It consist of data on total population, population according to gender, migration background, inhabitant receiving social welfare benefits, birth rate and data rates. To understand the relation between environmental condition and socio economic condition of the area subset of demographic data on migration background and total population was created. Figure 12 shows the preparation of demographic layer in GIS, here density was distributed with in the residential blocks rather than whole area assuming that the all the people live in these blocks.

### Translation

The data was provided in German. Demographic and index (key) that described about the attributes of the land use file was translated in to English.

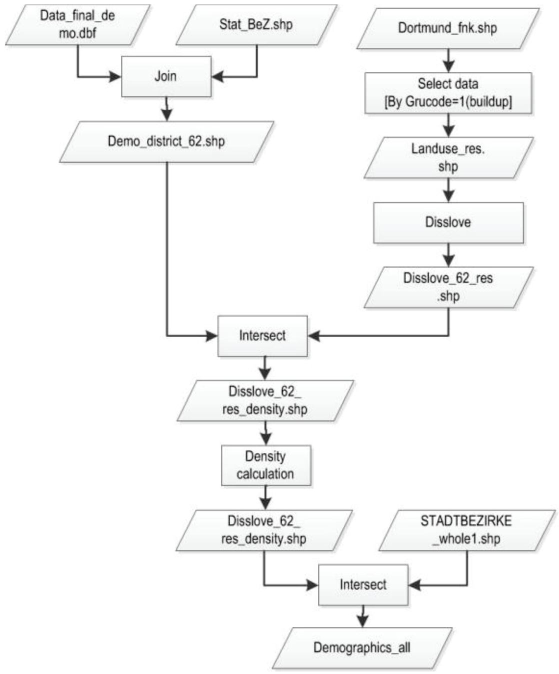


Figure 12: Preparation of demographic layer

# 4. ANALYSIS AND DISCUSSION ON RESPONSES OF THE QUESTIONNAIRE

*This chapter provides analysis on the responses collected from the online questionnaire survey on "Importance of visualization, functions and tools in understanding cumulative environmental impacts in a decision support system (DST)". Structure of this chapter follows the structure of questionnaire. For the analysis of questionnaire mixed method has been adopted however, qualitative analysis has been given more importance. This chapter starts with a classification of respondents as there are clearly different groups of respondents. Questions which are debatable quantitatively and qualitatively are discussed in the section 4.2, 4.3, 4.4. In 4.5, discussion provides information on the different functions, visualization techniques and tools that will be included in the design of SDST$_{CE}$.*

## 4.1. Respondents

There are clearly four groups of respondent's twelve professionals with technical background [mostly people involved in the development of decision support system (DST), authors and professors in DST and visualization], six public health professionals, five planners and two environmentalists. Respondents were divided in to four groups on the basis of professional background as shown in Table 1, to study the difference in their choices and preferences.

Table 1: Classification of respondents on the basis of professional background

| S. No | ID. No | Profession of Respondent | No. of Respondent | Remarks |
|---|---|---|---|---|
| 1. | ID1-ID12 | Technical group | 12 | Nine from snowball sampling |
| 2. | ID13-ID18 | Health professional | 6 | Three from snowball sampling |
| 3. | ID19-ID23 | Planners | 5 | One from snowball sampling |
| 4. | ID24-ID25 | Environmentalist | 2 | One visiting scientist in ITC |

## 4.2. First Part: General questions on experience of respondents with decision support tool (DST) and assessment of cumulative environmental impacts

This section of the questionnaire dealt with the general questions on understanding and experience of respondents with decision support tool (DST) and cumulative environmental effects. In general 76% of the respondents were aware of the DST but however only 52% of them have been using it. They have been using AirGIS, multi-criteria analysis, SWOT analysis, Map4decision, SOLAP, MapInfo, Excel, what if, Index and ArcGIS as the DST. When the data was drilled down it was found that mostly public health professionals are not aware of the decision support tool however one of them who said was aware of DST later said that he has not used it and explained that he had seen *"……a short introduction on DST and touchable"*(ID21).

In general respondents prefer to present cumulative environmental impacts in maps.79% of them said that they use maps whereas 21% said that they used graphs. Most of those that said graphs were public health professionals.

### 4.3. Second Part: Questions on techniques of visualizing cumulative environmental impacts (CEI) s

Three visual representations A) Non spatial representation B) spatial representation and C) combination of A and B were presented and the question[1] was asked which form of visual representation is more useful in understanding environmental effects of the area. Likert scale of 1(very useful) to 5(not useful) was used to capture their preference. Most of the respondent answered combination of spatial and non-spatial representation to be useful in understanding environmental effects of the area. This can be inferred from the average rating of 1.22(useful) and some of the answers that respondents gave when asked to elaborate on their choice.

*"…combination of A and B amplifies the perception of environmental effects, especially if charts and maps are dynamically integrated"* (ID3)

*"Maps provide an intuitive understanding of patterns and spatial relationships but graph conveys better qualitative information. Using a graph in combination can provide additional information that will moderate or reinforce message…."* (ID 5)

It was expected that public health professionals will prefer non-spatial representation but it was found that if available they prefer spatial representation although are used to non-spatial representation(according to their preference in question no 5).

However, in the next question[2] when the non-spatial choices A) Bar chart and B) Radar chart were presented; 57% of the respondents voted for the bar chart. Although only 48% of respondents voted for radar some of them argue that radar charts are faster and informative and explained that *"Radar chart allows quick focus on most affected areas."* (ID3), *"…… radar chart seems to me more informative"* (ID6), and *"……answer came faster with the radar chart."* (ID9). Bar charts are easier to understand where as radar are informative and fast; there seems to be trade-off between bar and radar chart.

When respondents were questioned[3] what would be easier in understanding the cumulative environmental effects, given the choice 'Individual Indicator Map' and 'Multiple Environmental Deprivation Map'; 80% of them said 'Multiple Environmental Deprivation Map'. However, according to respondents it is better to provide individual indicator maps along the multiple indicator maps. One of the respondents argued individual indicator map to be equally important and said that *"we will lose important and more precise information about each effect"* (ID1) if we ignore individual indicator maps. The two pictures were provided 'Air pollution mapping in 2D and buildings in 3D' and 'Air pollution mapping and buildings both in 3D' and respondents were asked[4] which of them is '*easier*' to understand and *'informative'* to understand. From the figure 1 it is very clear that according to respondents 'Air pollution mapping and buildings both in 3D' are informative and easier to understand. Although 'B' is clearly a favourite, 'A' scores 19% more in 'easier to understand' category. 'A' showed 3D in a detail or human scale which helps to understand the ground

[1] Question Number 6
[2] Question Number 7
[3] Question Number 8
[4] Question Number 11 and 12

truth easily whereas 'B' gives overview of the level of pollution in different sections of road. However, some of the respondents seem to have misunderstood the message that the graphics of 'B' was trying to deliver. According to them 'B' showed the level of air pollution with respect to altitude. This can be inferred from some of the responses which is provided below.

*"We can better visualize the city environment and better understand the impact of altitude due to air pollution effect."* (ID 8)

*"It can be interesting to have the information about the air pollution according to the elevation."* (ID 9)

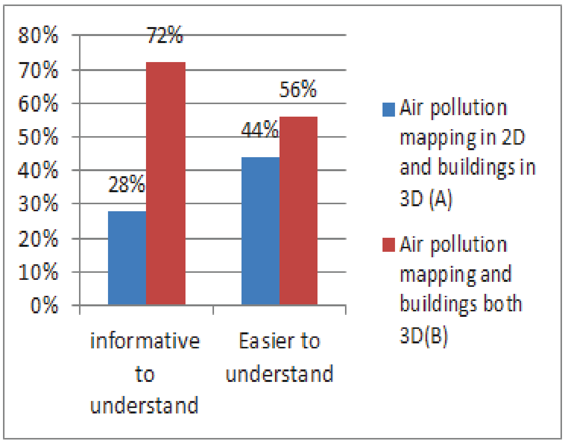


Figure 13: Comparison between 3D graphics (air pollution mapping in 2D and buildings in 3D VS air pollution mapping and buildings both in 3D)

There is a specific group of respondents with study background of engineering and architecture who think that 'Air pollution mapping in 2D and buildings in 3D' are easier to understand. One of the respondents explained that 3D maps create a perspective effect according to him *"......it falsifies the analysis"*. He further explained that *"This is one of the reasons why SOLAP don't use much 3D representations."* (ID1/technical group/engineer).

Hence after studying all these responses it can be concluded that sometimes interpretation of 3D can be difficult understand and misleading. Therefore in this research 'Air pollution mapping in 2D and buildings in 3D' will be used to keep it simple and easy to understand.

'Time series' and 'Animation' of air pollution in the city was provided and respondents were asked[5] which of them will be more useful in understanding environmental condition of the area; most of the people think that time series is more useful in understanding environmental condition of the area rather than animation. The average rating of time series is 1.33 and animation is 1.95; making time series more useful since respondents were asked to indicate the usefulness in the scale of 1 (very useful) and 5 (less useful). It may be because time series allows them to read the map. It helps them to compare between subsequent years; understand and analyse the situation but animation is fast, respondents don't have much control on it due to which it is difficult for them to understand and analysis the situation. This can be inferred from the responses, one of the respondent explained that the "*Time series are better, because we can easily compare each year with different maps. An animation is more useful in understanding a constant evolution, but we cannot compare each year*" (ID8).

### 4.4. Third Part: Potential functions and visualizing tools of DST for visualizing and analysing (CEE)s

When the question[6] was asked, what would be more useful 'Allowing stakeholders to create index map' or 'Providing stakeholders with prepared index map'; most of the respondents think that providing stakeholders with prepared index map will be useful with the average rating of 1.9(useful). Average rating

[5] Question Number 13
[6] Question Number 17

for 'allowing stakeholders to create index map' is 2.48 (fairly useful). This may be because respondents think that it will be complex and too technical. However, the fact that involving stakeholders in index making is important is undeniable. Moreover, one of the respondents explained that that *"when you let them make the index map themselves they know how it is made and feel ownership towards what they are doing."*(ID25). If the indexes are to be made for all the possible combination there will be large number of index maps depending up on the availability of raw data so if they are allowed to make the index themselves it will be more flexible meaning that they will be able to select the indicators and create index depending upon their requirements.

When respondents were asked[7] to select their preference between A) side by side comparison of maps and B) overlay of maps; 59% of respondents prefer overlay rather than side by side comparison of maps. In general side by side comparison of indicators is preferred if there are few indicators (2 to 3) but if there are more, in such a case overlay is preferred.

Most of the planners and technical group prefer overlay of maps. It may also be due to professional background. Planners and technical group have been working in GIS and SOLAP where overlay is a simple function due to which they find overlay easy. We can infer this from some of the explanations given by the respondents while they were asked to elaborate on their choice. Some of them explained that overlay will help in *"hypothesize the cumulative environmental effects"* (ID19/planner), *"…easily identifying hot spots"* (ID20/ planner), and overlay *"…would be more precise in assessment of cumulative effects "*(ID23/planner). Additionally, one of the respondents explains that *"overlay is better if several indicators are to be analysed but side by side comparison is preferred if there are only 2-3 indicators"*(ID1/ technical group). However, most of the public health and environmentalist prefer side by side comparison of maps, they think that it's easier to interpret and analyse the data. This can be concluded from the responses; one of the respondents explained that while using side by side comparison *"…I can choose my information..."* (ID20/public health).

When the question[8] was asked, will "Weighting" provide flexibility in creating a multiple environmental deprivation map (MEDM); in general respondents think that it will provide flexibility and also will help in creating an explicit map that will support in decision making. 55% replied 'Yes', 15% replied 'No' and 30% replied 'I don't know'. To weight the pollutants expert knowledge on pollution is crucial however; it is not enough we also need to understand population size that is being affected. This can be inferred from the responses given by the respondents while they were asked to elaborate on their choice.

*"Weighting helps to create a map that is explicit and helps in decision making"* (ID11).

*"Estimation of environmental health risks depends on exposure classification and sample size"*(ID15)

*"Weighting is complicated for decision makers but may work for experts"*(ID21).

Moreover, the respondents were asked[9] which weighting system will be easier and flexible for decision makers, given the two choices A) slider bars and B) weighting by manually inputting the numbers. 91% of respondents think that allowing slider bars will be easier and flexible for the decision makers. Some of them explained that providing slider bars make *"….relations between exposures well illustrated"*(ID15) and *"more*

[7] Question Number 18
[8] Question Number 19
[9] Question Number 20

*intuitive"* (ID19). Spontaneous results will help in understanding different situation and also will encourage discussion among the decision makers. However, one of the respondent argued that *"Sliders are not efficient gadgets to enter data"*(ID1) because it's hard to exactly fix the value and sometimes input values are not displayed. If this problem can be fixed and provide a slider bars that displays the input value as the slider bar moves; slider bar seems to be an interesting tool.

When the question was asked[10], if pop-up windows are provided along with maps how useful will they be in understanding the environmental condition of the area. Most of the respondents think that additional information along with maps will be useful with the average rating of 1.95. They think that such information could be helpful in reinforcing hypothesis, enhancing information and could be helpful for professionals to share their ideas. However, they were very concerned about the distraction that pop-up windows could create. There was a clear difference between respondents (technical group/DST developers) and others. DST developers are quite confident about the use pop-up window in SDST. This can be inferred from the responses that respondent provided when they were asked to elaborate their choice.

*"Pop-up windows could underpin your hypothesis. If there are too many pop-ups, it could become confusing. I suppose it depends on the conciseness of information given in the window"* (ID15/ public health professional)

*"Pop-up windows are extremely useful. We have implemented it as contextual warnings in our projects….. "* and added that *".....very important for epidemiologists"* (ID1/ technical group/ DST developer).

*"The supplementary information is always useful to get more detailed insight to a problem. It allows getting information when needed and avoiding unnecessary information….."* (ID6/ technical group/ DST developer)

*"Well done additional information for sure might help. But if it just overloads the map with unnecessary information or if it provides information the user isn't familiar with it might deflect somebodies attention from the main point"* (ID12/ planner)

It is important that the pop-up window are used carefully; it should not overload map with unnecessary information. Extra care should be taken so that users are not intimidated by information overload. According to Al-Kodmany (2001) delivering knowledge or sharing information become easier and effective if a media (paper-pen, pictures, and models) is used so in this research pop-up window could be used as one of the media. It can be used by decision makers to share, support and reinforce their understanding with others.

## 4.5. Conclusion

There are definitely some patterns and singularities in the responses. Since there were open ended questions, respondents had their say as the result a lot of things was not black or white. However, preference stated by responds will be addressed while drawing conceptual design of $SDST_{CE}$.

One of the important findings of the questionnaire is that preference depends on professional and study background; sometimes if not always. Mostly public health professionals are not aware of the decision support tool. Additionally, public health professionals prefer to present cumulative environmental effects

[10] Question Number 21

by using graphs whereas respondents from technical group, health professionals and environmentalist prefer maps. However, it was found that if available health professionals prefer spatial representation, it can be inferred from their preference in question no.5. Most of the planners and individuals from technical group prefer overlay of maps rather than side by side comparison. They mostly work in software's such as GIS where overlay is a simple function due which they find it easier.

Statistics may be one of the very important criteria for steeling decision but while trying to understand behind the numbers it was realized that combination of different functions and visualization is comprehensive and is necessity rather than compromise. Therefore, for the visualization of cumulative environmental effects combination of 1) spatial and non-spatial representation 2) a set of individual indicator map and a multiple environmental deprivation map will provide the users of SDST a wider range of choice. To reduce the complexity in understanding 3D this research will use 'Air pollution mapping in 2D and buildings in 3D' in the design of SDST. Furthermore, bar charts are easier to understand and provides detail information whereas radar are fast in gathering information; there seems to be trade-off between bar and radar chart. Following the preference of respondents, literature review and review of existing case studies it can be inferred that providing different choices is better; it will encourage discussion between the end users. Quantitatively difference in the preference between bar chat and radar chat is very less hence; both the chart will be used in the design of the SDST. According to respondents 'time series' allows better comparison, analysis and understanding of information compared to animation, hence will be included in the design of the SDST.

While discussing on functions, index making will be one of the most important function in the SDST. Stakeholders should be allowed to create index map. It will provide flexibility in generating index depending upon stakeholder's requirement and availability of data. Moreover it will create the feeling of ownership in stakeholders and encourages them to devote. Similarly, while discussing on tools, slider bar seems to be an interesting tool for weighing the indicators; providing a slider bars that displays the input value as the slider bar moves will be more interesting. Pop-up window is a useful source of additional information that can be used along the maps in the SDST. It is important that it is used cautiously; it should not overload map with unnecessary information. Extra care should be taken so that users are not overwhelmed by information overload. It can be used by decision makers to share, support and reinforce their understanding with each other's.

Hence, questionnaire helped to collect information on expert's preference and idea on different visualization techniques, functions, methods and tools to be included in $SDST_{CE}$. Their suggestion were very helpful particularly the suggestions from technical group. They were very clear about the advantages and disadvantages of different visualization techniques, functions and tools.

# 5. CONCEPTUAL DESIGN OF $SDST_{CE}$

*This chapter provides the conceptual design of spatial decision support tool for understanding cumulative environmental exposure. It mostly presents an ideal conceptual design for the data rich condition, which will be used as the basis for the development of the tool.*

## 5.1. Conceptual Design

The main objective of conceptual design of $SDST_{CE}$ is to provide a framework for the development of a prototype which will provide information on cumulative environmental state and exposure. It is used to identify, clarify and organize systems requirement. It will provide information on the guiding principles of the tool, targeted user group, major components, required inputs and outputs, unit of analysis, assumptions, different functions and its operationalization. It will also provide a possible sequence of interaction between the system and users. Therefore, in very simple words, it is a blueprint that can be utilized for the development of $SDST_{CE}$ (prototype).It is drawn on the basis of literature review, reviews on existing DST and analysis of questionnaire by applying ROMC design approach and the use case design approach.

## 5.2. $SDST_{CE}$

Spatial decision support tool for cumulative environmental exposure ($SDST_{CE}$) aims to understand the geographical extent of multiple environmental stressors in the area. As already discussed in chapter 1, a large portion of world's population is residing in urban areas and are being affected by the degrading environmental condition; as a matter of fact people are being affected by multiple environmental stressors. Health of people is being affected due to these circumstances. Policies have been implemented to check on environmental conditions and for sure there have been some positive changes; however, tangible outcomes are important to acknowledge the effort.

$SDST_{CE}$ will be used in the first phase of the decision making (intelligent phase) since it is more important to understand the problem rather than find the solution (Couclelis, 1991). It will be used to understand the geographic extend of cumulative environmental exposure due to multiple environmental stressors. Additionally, it will be able to show level of exposure and health condition of the population in the exposed area. It will be able to show the effect of political implementation and change in environmental condition by using spatial temporal data.

$SDST_{CE}$ is a generic tool that will function according to availability of data. It will mostly focus on different functions, methods, visualization techniques and tools in assessing and analysing the cumulative environmental exposure. The objectives of $SDST_{CE}$ are explained in detail in the following section.

## 5.3. Objective of $SDST_{CE}$

The main goal of this tool is to provide the end users with an overview of cumulative environmental condition of the city; show them the level of exposure and health condition of the population. The main objective of the tool is decomposed in to eight sub objectives.

### Sub objective

1. To understand the geographic extent of cumulative environmental exposure.
2. To allow exposure analysis.
3. To allow spatial temporal comparison of data.
4. To allow thematic comparison (comparison between two individual maps; most probably of same domain) of data.
5. To allow comparison between individual indicator map and index map.
6. To allow visualization of spatial distribution of individual environmental pollutants.
7. To provide different visualization techniques for the data analysis.
8. To provide interactive Maps and Graphs.

## 5.4. Potential users of SDST $_{CE}$

The probable end users of the SDST$_{CE}$ are urban planners, public health experts, environmentalist, decision makers and non-profit organization. They have a vital role in improving the environmental and health condition of the city. Moreover, Crawford et al. (2010) suggests health professionals together with urban planners are becoming mindful of the effects of environmental condition on the human health. Therefore, it is important to have a common understanding of the environmental problems of the city for well-targeted interventions since environmental problems are responsible for as much as 24% of the total burden of diseaseWHO (2013).

## 5.5. Guiding principles for the design of SDST$_{CE}$

From the literature review, reviews on existing DST and analysis of questionnaire it can be concluded that the SDST should be 1) Easy to use, 2) Easy to understand, 3) Fast, 4) Flexible, 5) Interactive

1. **Easy to use:** It can be explained as having clear structure. As discussed in section **Error! Reference source not found.**, start to finish should be properly guided, so that users can easily perform the task. It should reduce the physical and mental effort of users while working on SDST. Use of tab is one of the efficient ways of structuring the functions of SDST as understood from the review of existing SDSS (see section 2.3.3 and **Error! Reference source not found.**).

2. **Easy to understand:** Tool might be easy to use but users might not find outputs easy to understand. Output or information should be easy to understand. It helps user to stay focused and saves time. Visual communication has a huge impact while delivering information effectively. Different visualization techniques such as maps, graphs and 3D's should be used in combination; to make information easier to understand.

3. **Fast:** It is important for the end users to maintain the focus when exploring or validating any hypothesis and for that SDST$_{CE}$ needs to be easy to use as well as fast. To allow the fast operation tools such as 'drill-in', 'drill up', 'drill across', swap (Bédard et al., 2003) should be used in the SDST$_{CE.}$

These tools should be able to show different levels of data in both maps and graphs. 'Drill-in' should show detail inside the maps and graphs for example it should show the individual indicators and the weighting used to create multiple environmental deprivation index. The Figure 14 shows the drill-in operation on total population affected by noise pollution. 'Drill-up' should show more general level in the data through maps and graphs for example multiple environmental deprivation index instead of individual indicators. 'Drill-across' should show another theme at the same level of detail; for example, it should show the individual indicator map and multiple environmental deprivation index map in the same scale. 'Swap' should interchange between graphs for example bar chart or radar chart.

4. **Flexible:** $SDST_{CE}$ is a tool that will work as a common platform where analyst, decision makers from different profession will work together to understand the cumulative environmental condition. In such a condition different stakeholders will have their own ideals and knowledge based on which they might want to weight the indicators. In such a situation weighting might be done number of times. Slider bar is an efficient and user friendly tool which allows easy iterative calculation, increasing the flexibility of the tool.

5. **Interactive:** Maps and graphs should be synchronized such that they respond to the changes instantaneously as changed are made in input.

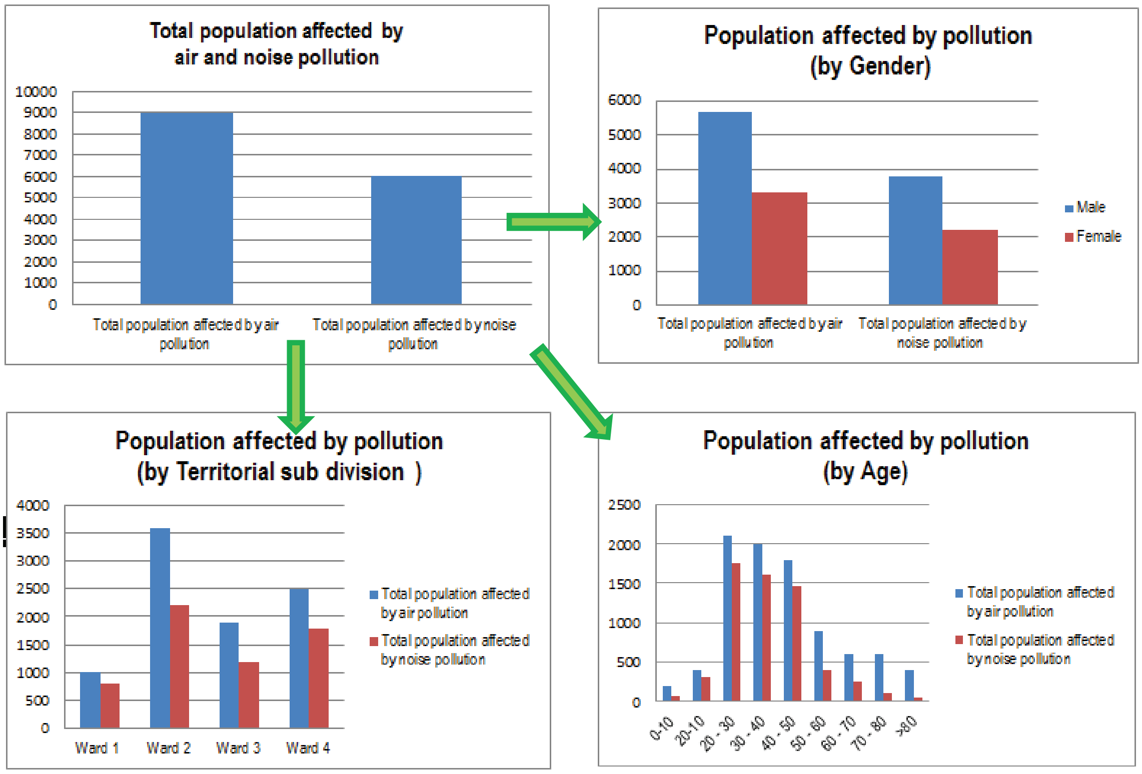


Figure 14: Figure illustrating drill-in operation in graph (own source)

### 5.6. Architecture of $SDST_{CE}$

Figure 15 shows the architecture for special decision support tool ($SDST_{CE}$) for mapping cumulative environmental health effects. In general $SDST_{CE}$ is a data intensive tool; it requires data on environmental factors, health of the citizens and social economic and other demographic data of the citizens. Ideally data required for the mapping of environmental effects of the city depends up on the major environmental problems in the city. This research tries to design a conceptual framework of SDST for data rich condition which will be addressed as ideal SDST (iSDST). It consists of data base management, model management, and dialog management. ROMC design approach (see section 2.2.5) is used for identifying different components of the ideal SDST such as functions, methods, tools, aids and visualization.

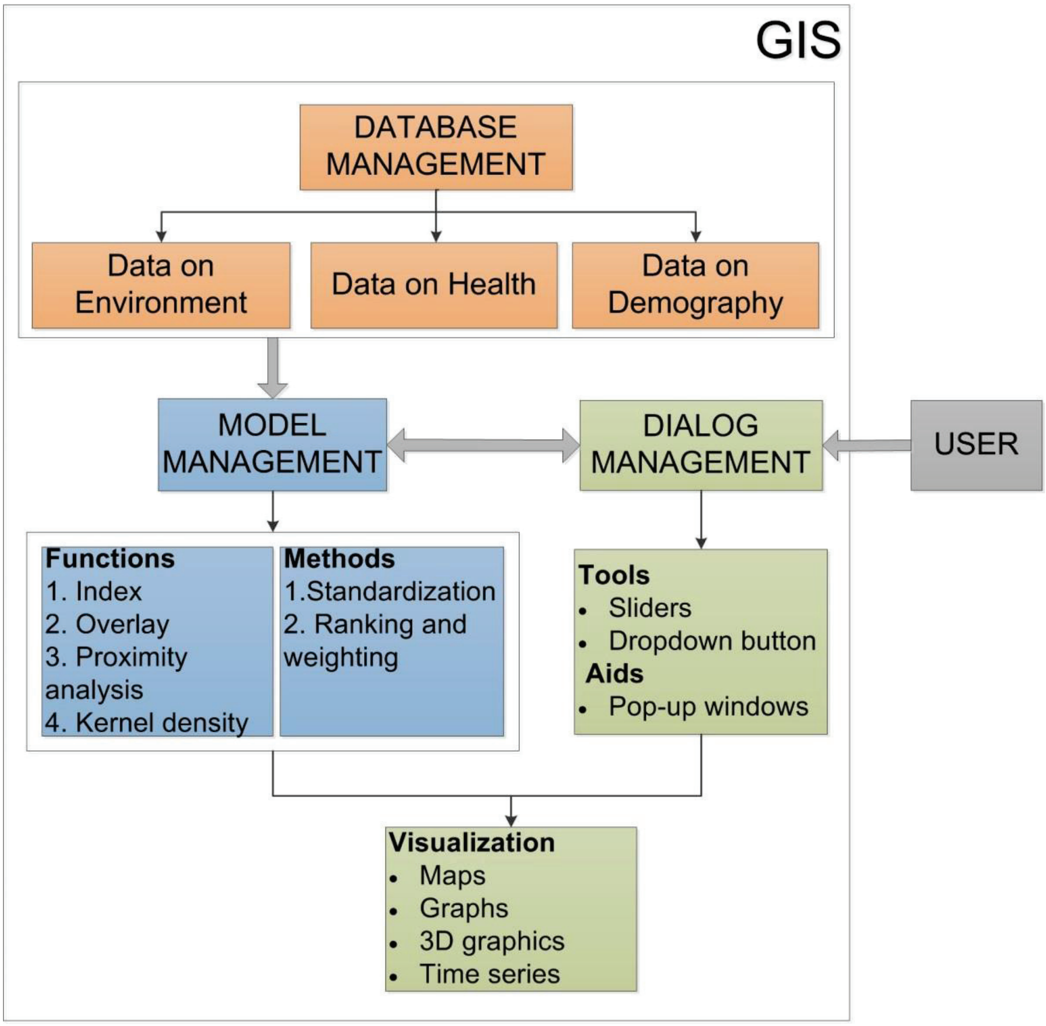


Figure 15: Framework for ideal SDST (iSDST) [Source: Adapted from (Sugumaran & Degroote, 2011)]

### 5.6.1. Data base management

On the basis of environmental problems and health issues as discussed in section **Error! Reference source not found.** data required for mapping cumulative environmental health should be loaded in the data base. Basically three types of data should be included in the data base; spatial, temporal and descriptive. Spatial and temporal data will be used for exploration and analysis; it can be used together with descriptive data to unpin the hypothesis (Cook et al., 1995; MacDougall, 1992; Wise et al., 1998)

Data base management should be loaded with multidimensional data; environmental, health and demographic data are each individual dimensions. Environmental data is broadly divided in to two types pathogenic and salutogenic. For example pathogenic factors are air pollution [Particulate matter ($PM_{10}$, $PM_{2.5}$), Nitrogen oxide ($NO_2$), Ground level ozone ($O_3$), Sulphur dioxide ($SO_2$)] and noise pollution [road,

rail, air traffic and industrial noise]. Similarly salutogenic factors are green spaces, water bodies and open activity area.
Health data should contain records on different categories of hospital visit such as diseases, accident or death at hospital. However death outside the hospital should not be neglected to get the real picture. Records on diseases, accidents and death most preferably should be listed according to "International classification of diseases, injuries and causes of death" (Bédard et al., 2003; Elbir, 2004)

#### 5.6.1.1. Spatial resolution

Pollution mostly (air and noise) are very dynamic, within or between the wards; pollution may vary drastically. Air pollution levels are recorded by monitoring stations, which are not evenly distributed in many cases. Air pollution model such as dispersion models are used to calculate the spatial distribution of pollution. Air and noise pollution are mostly classified into 5-7 indexes depending up on the country or city of study (air pollution index). Additionally, environmental pollution has been studied in different spatial resolution; continental level, national level, regional, municipal, district and ward. In many cases other social, economic and demographic data are available in smaller spatial units such as wards and census tract. Therefore, in many cases spatial resolution is determined by the availability of data. In empirical science more the disaggregation of data the better it is. Therefore, when studying environment and health effect it is better to work in smaller units for the correlation study of exposure and effects. Moreover, using smaller unit of analysis helps avoid the problem of data normalization and MAUP.

#### 5.6.1.2. Multidimensional data structure

The $SDST_{CE}$ should use multidimensional data structure (Caron, 1998) cited in (Rivest et al., 2001) for the rapid and iterative data exploration and analysis. The multidimensional approach is based on concepts, dimensions and measures. Concepts are the main themes of analysis. Dimensions and dimensional member represent different aspects of the concepts which are used for the analysis, whereas measures are the numerical values of respective dimensions being analysed.

Users will be able to query information on different levels of the hierarchical data structure. Hence, the result of any query depends upon the selection of the set of dimensions, dimensional member or the measure. Therefore, the result can be considered as the dependent variable and dimensions, dimensional member or the measure as the independent variables. Table 2 provides the hierarchical structure of concepts, dimensions, dimensional member and measure. While studying Table 2 it is important to bear in mind that the examples used under the headings (Concepts, Dimensions, Dimensional member, Measure) can be changed according to the availability of data.

Table 2: Multidimensional data structure of $SDST_{CE}$

| Concepts | Dimensions | Dimensional Member | Measures |
|---|---|---|---|
| Cumulative environmental effects (Environmental data) | MEDIx ideal<br>MEDIx air<br>MEDIx noise | | |
| Individual environmental effects (Environmental data) | Air pollution | $PM_{2.5}$,$NO_2$,$So_2$ | |
| | Noise pollution | Air traffic noise<br>Road traffic noise<br>Rail Traffic noise<br>Industrial noise | Low <=55 dB<br>Medium>55<=65 dB<br>high >65>=75 dB |
| Health | Disease | Asthma | Ordinal values |

| | | | |
|---|---|---|---|
| | Hospitalization<br>Death | Sleep loss<br>Hypertension<br>Respiratory disease<br>Cardiovascular disease | |
| Demographics | Population | Population by gender | Male and female |
| | | Population by age | 0-10,10-20,20-30…>80 |
| Spatial resolution | Territorial sub division | Municipality<br>Districts<br>wards | Nominal or ordinal value |
| Level of pollutants | Air pollutants | Example : $No_2$ | Very low 0-25µg/m$^3$<br>low 25-50µg/m$^3$<br>Medium 50-75µg/m$^3$<br>High 75-100µg/m$^3$<br>Very high >100µg/m$^3$ |
| Temporal resolution | Time | Year | 2000-2014 |
| | | Month | January-December |

#### 5.6.2. Model base management

Model consists of functions and methods. In this research, functions are the arrangement used to create knowledge building outputs (for example index maps) from the existing products (for example individual indicator maps) through the single or chain of action. There are four functions under model base management; index making, kernel density, proximity analysis and overlay. Index making will be used to assess cumulative environmental effects; additionally, kernel density and proximity analysis will help in exploring and analysing the exposure to cumulative environmental stressors.

Methods are the steps that will be used in accomplishing different functions. Index making requires methods such as standardization, ranking and weighting as discussed in section 2.1.6.

#### 5.6.3. Dialogue base management

Dialog management mainly consists of tools, aids and visualization techniques. Tools are the communication techniques which will help to accomplish different functions and methods. On the basis of review of different SDSS and questionnaire it is realized that dropdown menus and slider bars are most useful and user-friendly tools. To make operationalization of SDST easy slider bars, dropdown menus are proposed. Similarly 'Aids' are the element that guides and supports the user by providing information such as pop-up windows.

Visualization techniques are applied for representation of spatial distribution of environmental condition. Maps (individual indicator maps and cumulative environmental maps), graphs, 3D, time series have been proposed as the effective visualization technique on the basis of literature, reviews of existing SDSS and questionnaires. Visualization should be interactive meaning that maps and graphs should respond to the changes simultaneously.

### 5.7. Use cases

Use case describes the possible sequence of interactions between the system and actors in order to achieve stated objectives. Moreover, it describes rational along with prerequisites of the function such as data required, criteria's, operationalization and the final goal. Use case titles briefly describe the capabilities of

$SDST_{CE}$. To exemplify the sequence of interaction between the $SDST_{CE}$ and users, few use cases are listed below.

Use case title 1: *User should be able to assess cumulative environmental exposure by index making.*
Use case title 2: *User should be able to carry out proximity analysis.*
Use case title 3: *User should be able to carry out kernel density.*
Use case title 4: *User should be able to assess population affected by individual environmental pollutants.*
Use case title 5: *User should be able to assess population affected by cumulative environmental pollutants.*
Use case title 6: *User should be able to assess population affected due to different level of pollution for example in case of noise pollution 50DB, 60DB, 70DB.*
Use case title 7: *User should be able to assess people affected by individual and cumulative environmental pollution in different spatial units (district, wards or census tract etc.)*

## 5.8. Use cases of functions

The main functions of the $SDST_{CE}$ are index making, proximity analysis and kernel density. This section will deal with use case title 1 to 3.

### 5.8.1. Use case 1: Index making

In this research index making is a function. There are different indicators of environmental pollution such as $NO_2$, $PM_{10}$. Maps showing the spatial distribution of these indicators are termed as individual indicator maps. Since this research is interested in cumulative effects of multiple environmental stressors as already discussed in 2.1.4.2, index is one of the methods that can be employed in calculating single measure that shows cumulative effect of multiple environmental stressors. In this research it will be termed as "multiple environmental deprivation index" (MEDIx).

#### 5.8.1.1. Indicators and criteria's

To create multiple environmental deprivation index (MEDIx) the first thing to do is selection of indicators. Environmental indicators are selected on the basis of degree of adverse effect to human beings as discussed in 3.6. Second thing to do is draw criteria. Table 1 exemplifies different indicator and criteria's for it. While defining the criterion for the MEDIx; one should bear in mind that it shows the areas which are deprived with multiple environmental factors. Moreover, in an ideal condition it will portray the area which is deprived with salutogenic factors and have more of pathogenic factors. For pathogenic factors numerical value should be used while defining the criteria whereas proximity/distance in the case of salutogenic factors. Additionally, all the salutogenic factors which are in proximity might not be easily accessible so keeping this in mind threshold distance should be used (see section **Error! Reference source not found.**). Therefore, in general criteria for pathogenic factors is drawn as 'higher the better' and for salutogenic factors 'farther the better'.

Table 3: Indicators and criteria's

| Environmental domain | Environmental factors | Indicators | Criteria's |
|---|---|---|---|
| Pathogenic | Air pollution | Particulate matter (PM10 ,PM2.5)<br>Nitrogen oxide (No2)<br>Ground level ozone (O3)<br>Sulphur dioxide (So2)<br>Benzene, | Higher the better (numerical values) or benefit criteria |

| | | | |
|---|---|---|---|
| | Noise pollution | Road traffic noise<br>Air traffic noise<br>Rail traffic noise<br>Industrial noise | Higher the better (numerical values) or benefit criteria |
| Salutogenic | Water bodies | | Farther the better (Goal standardization) |
| | Green space | | Farther the better (Goal standardization) |

#### 5.8.1.2. Accepted criteria's

An accepted criterion describes the conditions that are required to be fulfilled in order to successfully accomplish any operation. While making index user must select two or more indicators then standardize, rank the indicators.

#### 5.8.1.3. Operationalization

Database management system (DBMS) should have stimulated indicator data. For the study of cumulative environmental effects stakeholders need to make multiple environmental deprivation index; for making index users/ stakeholders will have to go through three main steps. Figure 16 shows the steps involved in index making.

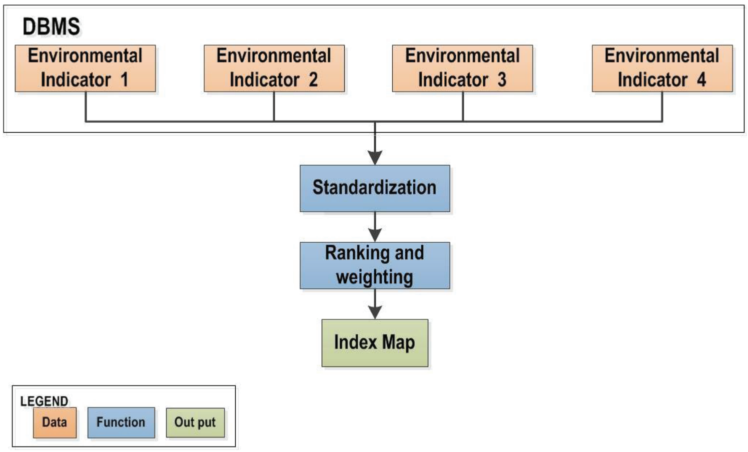


Figure 16: Operationalization for index making

**Step 1: Selection of indicator**

The first work to be carried out while creating an index is selection of relevant indicators and drawing criteria for it. Stakeholders should be allowed to add as many indicators as possible. For the ease of adding indicators they should be able to select the indicators by using dropdown button.

**Step2: Standardization**

After the selection of indicators, it should be standardized so as to create comparable indicators. For the scope of this research maximum and goal standardization will be used. One of the advantages of maximum standardization is that the standardized values are proportional to the original value. Additionally, goal standardization will allow threshold values. Depending upon the nature of criterion stakeholder's should be able to select 'benefit criteria' or 'cost criteria'.

**Step3: Ranking**

After standardization of indicators ranking of each individual indicator should be carried out. Since the tool is designed for experts, this research will use rank sum method. It is simple and easy to understand, ease to repeat the process and less time consuming. Once the ranking of indicators is carried out, the ordinal values must be converted to cardinal values in order to operate further. As discussed in 2.1.6.2, Equation 7 will be used to calculate the normalized weight.

After carrying out all the above steps, users will be able to create multiple environmental deprivation index. Once the index is created users should be able to change the weight if required. Slider bars will be used for changing the weight of indicators. It will allow spontaneous results which will help in understanding different situation as the rank order of the indicator changes and this will also encourage discussion among the stakeholders. It is important that the slider bar displays the input value as the slider bar moves.

**Step 4: Multiple environmental deprivation index**

Once the individual indicator maps are selected and methods (standardization, ranking and weighing) are carried out multiple environmental deprivation index is produced. Multiple environmental deprivation index highly depends up on data availability. Figure 17 shows the ideal condition. Depending up on the availability of data some of them can be removed or other can be added. Figure 18 shows the specific case condition when only four types of noise data are available.

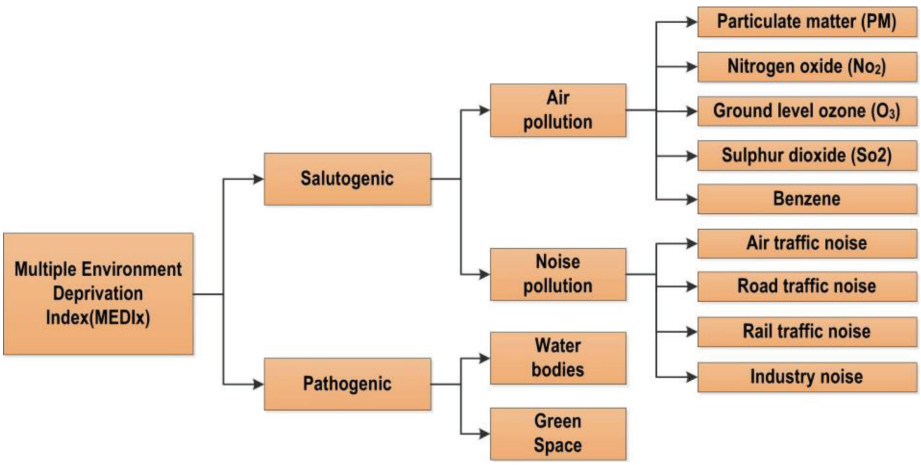


Figure 17: Multiple environmental deprivation index for an ideal case[source: Adapted from (J. R. Pearce et al., 2010)]

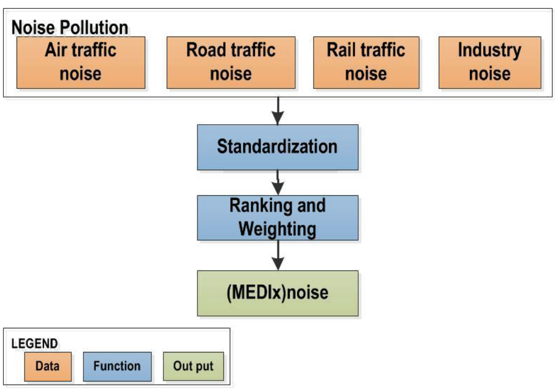


Figure 18: Multiple environmental deprivation index for a specific case (noise pollution)

#### 5.8.1.4. Visualization of Output

Final output of the multiple environmental deprivation index will be a map. It will show the cumulative environmental exposure of the area. Index for different time period can be created to show the change in environmental condition by using time series. Additionally, individual indicator maps, graphs, 3D's should be provided; which will allow in better analysis and understanding of the environmental condition of the area.

### 5.8.2. Use case 2: Proximity analysis

Proximity analysis follows Tobler's first law of geography "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). This function will provide basic idea on the correlation of environmental condition and health.

#### 5.8.2.1. Data

For the proximity analysis it will require geo-referenced point features on health as the input feature. Health data should contain records on different categories of hospital visit such as diseases, accident or death according to "International classification of diseases, injuries and causes of death". In the proximity analysis as a point of reference, geo-referenced features of polluting line feature such as rivers and road networks should be used. Generally, distance is directly used for the analysis in the proximity analysis but in this research distance will be represented by other measures such as levels of noise and air pollution (for example: 55 dB, 65 dB, 75 dB). Since spatial component is very important, a base layer for the identification of location should be used.

#### 5.8.2.2. Operationalization

Taking in consideration principle of $SDST_{CE}$ end users of the tool should be able to go through proximity analysis very easily. Figure 19 shows the operationalization of proximity analysis; where end user tries to study the effect of cumulative noise pollution on human health for example sleep-loss.

For example-the null hypothesis is "human health is not affected by level of pollution." To study this end user will have to select; MEDIx (noise) +different level of noise pollution from the hierarchical data structure as presented in Table 2. If there is a positive correlation between number of people with health outcomes for example sleep-loss and level of noise; it can be concluded that human health is affected by level of noise pollution.

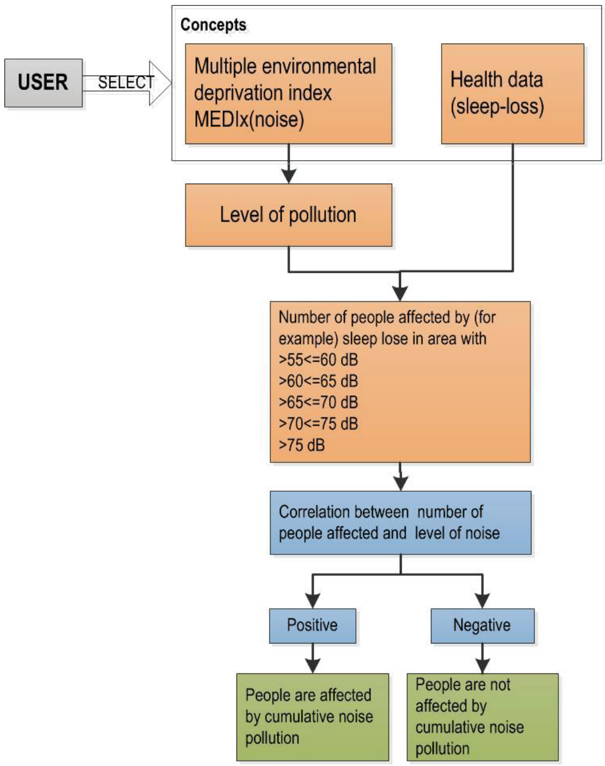


Figure 19: Operationalization of proximity analysis

Table 4: Accepted criteria and the output for proximity analysis

| Functions | Accepted criteria | Visualization of Output |
|---|---|---|
| Proximity analysis | While doing proximity analysis point data and level of pollution at which user want to make analysis must be selected. | Map and graph. |

#### 5.8.3. Use case 3: Kernel density

According to ArcGIs Resource Center (2011a) kernel density is the method used to calculate the magnitude of concentration per unit area from any point or polyline. In this research kernel density will be used to calculate the magnitude of concentration of health outbreaks in the city; it may be around the polluting facilities such as industries, gas station or along the polluting rivers and transport network. Output will be a raster; it will show the gradient of very affected to less affected area. It will help end users in constructing the hypothesis. Along with raster map pop-up window will help to strengthen the hypothesis on the concentration of health out breaks rather than coming to the conclusion. Figure 20 illustrates the operationalization of kernel density.

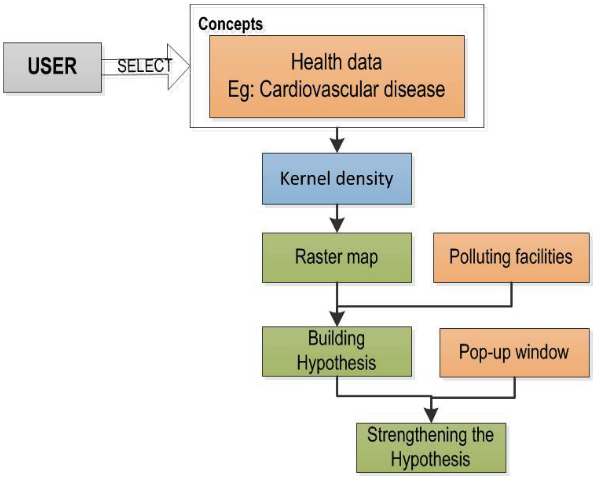


Figure 20: Operationalization of kernel density

##### 5.8.3.1. Data

For the calculation of kernel density it will require geo-referenced point features on health as the input feature. Health data should contain records on different categories of hospital visit such as diseases, accident or death according to "International classification of diseases, injuries and causes of death". As a point of reference for the calculation, geo-reference point feature of polluting facilities along with that line feature such as rivers and road networks will be required. Since spatial component is very important, a base layer for the identification of location is very important.

Table 5: Accepted criteria and the output for kernel density

| Functions | Accepted criteria | Visualization of Output |
|---|---|---|
| Kernel density | While doing kernel density point feature of health outbreaks must be selected. | Output will be a raster; it will show the gradient of very affected to less affected area. |

### 5.9. Exposure analysis

After the multiple environmental deprivations index is produced end users should be able to explore, analyse and understand cumulative environmental exposure. $SDST_{CE}$ should be able to answer questions regarding different 'concepts' and 'dimensions' such as pollution (air, noise etc.), level of pollution (50dB, 60dB, 70dB etc.) and unit of spatial resolution (district, wards or census tract etc.) as discussed in Table 2. Following are some of the capabilities of $SDST_{CE}$.

Use case title 4: *User should be able to assess population affected by individual environmental pollutants.*
Use case title 5: *User should be able to assess population affected by cumulative environmental pollutants.*
Use case title 6: *User should be able to assess population affected due to different level of pollution for example in case of noise pollution 50DB, 60DB, 70DB.*
Use case title 7: *User should be able to assess people affected by individual and cumulative environmental pollution in different spatial units (district, wards or census tract etc.)*

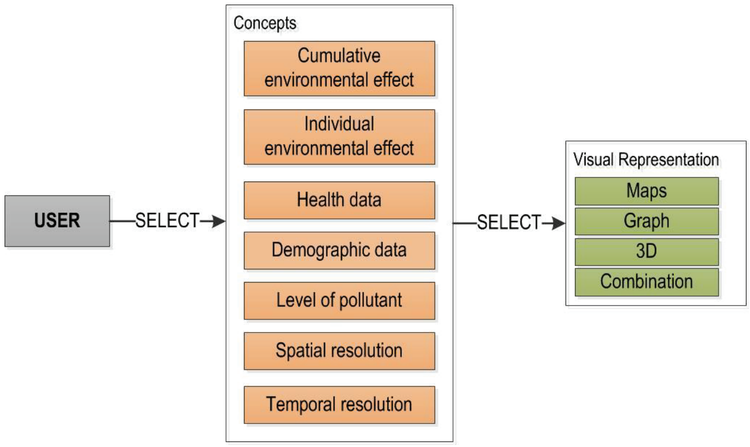


Figure 21: Operationalization of use cases

Following the principle of the $SDST_{CE}$; operationalization of exposure analysis should be 'easy to use', 'fast', 'easy to understand', 'flexible' and 'interactive'. For the exploration and analysis of data it needs to be retrieved. Information can be retried by selecting desired concepts and dimensions; following are the examples showing the information retrieval for use case title 4 to 7. User should be able to assess above use cases easily with in few mouse clicks. Figure 19 shows the operationalization of above use case titles.

Use case title 4: "Population"+ "PM2.5/PM10/No2/So2"
Use case title 5: "Population"+ MEDIx air
Use case title 6: "Population"+ "PM2.5/PM10/No2/So2" + "50-75 $\mu g/m^3$"
Use case title 7: "Population" + "air pollution"+ ward no 20

Since the $SDST_{CE}$ is designed with multidimensional data structure, may more information can be retrieved. $SDST_{CE}$ should be capable of providing information on individual or a combination of questions. Questions can be formulated as, what is the number of population affected by cumulative environmental condition of >75dB in ward 23. Once the set of dimensions are selected (for example MEDIx noise +>75dB of noise+ ward 23) then the output will be visualized in map, graph or 3D.

# 6. DEVELOPMENT OF SDST$_{CE}$ EnL

*This chapter discusses on the test wise development of a small section of SDST$_{CE}$, which is termed as SDST$_{CE}$ EnL. This research uses secondary data of the city of Dortmund for the development of the tool. The first section of the chapter introduces the case study city and discuss on its environmental problems in the city. The second section will discuss on the development of the SDST$_{CE}$ EnL. The final section will discuss on the results produced by the tool.*

## 6.1. Case study area : The city of Dortmund

The city of Dortmund is located in the western part of Germany. It is a one of the largest and most populated German cities with a population of 572,087 (2012). In the late 19th century Dortmund was a major European centre for coal and iron production. Since, 1980's Dortmund is facing economic transformation due to closing down of coal mining and steel production companies. Therefore, the city is facing a high rate of unemployment (13.3%) due to which a large number of people are receiving social welfare. During the industrialization, large number of people migrated to Dortmund; almost 30% of people are of migration background.

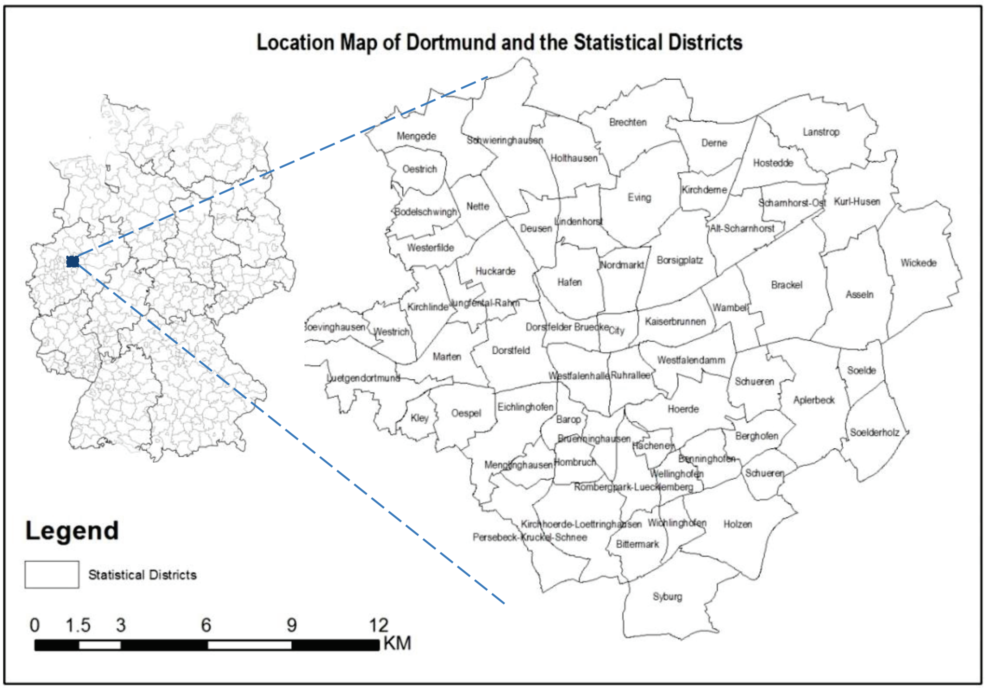


Figure 22: Location map of case study area (Dortmund)

The city of Dortmund is divided in to 12 city districts, 62 statistical districts and 170 statistical sub districts. The data for 62 statistical districts will be used in this research.

According to Bezirksregierung Arnsberg (2011) many German cities are struggling with air pollution, which is affecting the health of people. Dortmund is also facing the environmental problem. Especially air pollution due to road traffic and rail traffic are the major cause and contributing factor for particular matter and nitrogen dioxide which is considered to be most harmful. In some part of the city (mostly by the side of road) level of $NO_2$ and $PM_{10}$ exceeds the threshold level. According to LANUV (2009) road section exceeding the limit value of $NO_2$ and $PM_{10}$ are also affected by night noise disturbances.

Moreover, comparative studies to demonstrate the interrelation between noise and air pollution together with that impact on human beings have been conducted in the case of Dortmund.

Hadnagy et al. (1996) compared three cities; Borken, Duisburg and Dortmund and found that concentration of particular matter is comparatively high in Dortmund and suggested that it may be due to the coal mining industry and coke plants. Respectively Dortmund has more environmental health effects such as paranasal sinusitis, chronic bronchitis compared to other two cities. They suggested that permanent exposure to increased levels of airborne particles may lead to health effects. Schikowski et al. (2005) determined an association between long term exposure to air pollution ($PM_{10}$ and $NO_2$) and living near a major road focusing the respiratory health of woman in Dortmund.

Kreisel (1984) used an empirically derived environmental index to understand the environment of Dortmund. In the study the term environment was not limited to natural (physical, chemical and biological) factors; social factors such as open spaces that positively affect the health of the human beings was also included. The author concluded that the neighbourhood with high environmental burden corresponds to the economically poorer neighbourhoods of the city. Additionally, according to Dortmund (2013) municipality of Dortmund reveals through its statistics that there are significant disparities in life expectancy in various districts of the municipalities due to the environmental condition. Köckler and Flacke (2013)discussed that there exist combined environmental factors such as noise, storage of explosive goods and green areas in some part of the Dortmund. Furthermore, the authors pointed out that the area with high percentage of population with migration background is exposed to such environmental condition.

Therefore, Dortmund is gearing up to reduce the environmental health burden and disparities. The city of Dortmund belongs to the healthy city network. It is trying to decrease all sorts of pollution such as air, noise, vibration, radiation etc. Dortmund is part of the "Clean Air Plan Ruhr Area". It includes various measures to reduce the pollution in the area. Some of such measure are "Environmental Zone Ruhr Area"(see Figure 23) and it is also trying to reduce noise pollution through "Noise Mapping"(Dortmund.de, 1995).

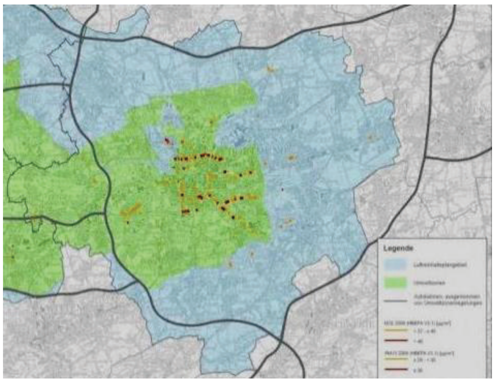

Figure 23: Map Showing Environmental Zone (in green colour) in Dortmund [source:Bezirksregierung Arnsberg (2011)

## 6.2. Environmental state in Dortmund

The city of Dortmund is moving towards modern hi-tech industrial development and has excellent traffic infrastructure ensuring a good inter and extra city connections. While talking about the roadways, A40 and A42 are the main arterial road that runs from the centre of the city. Dortmund is connected by railways and airways to other cities in Europe. However, the other side of these facilities is that the city is struggling with externalities such as environmental pollutants.

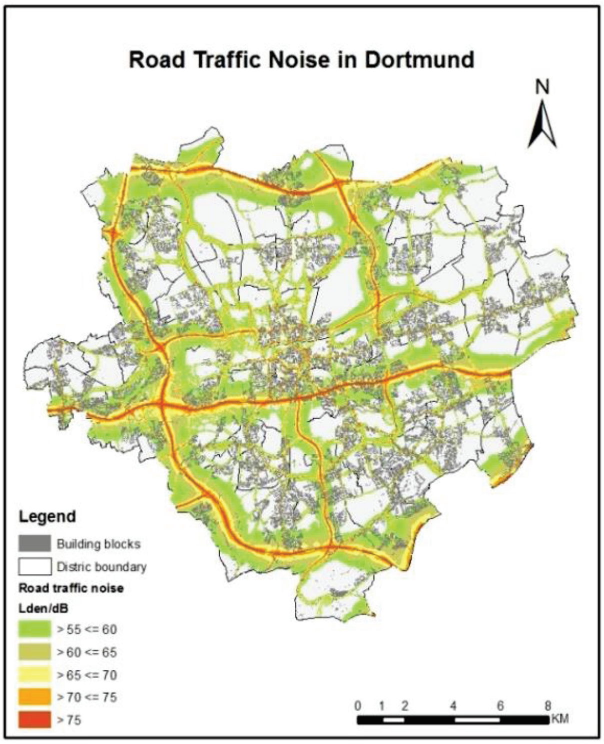


Figure 24: Road traffic noise in Dortmund
Source: Jufo Salus, modified by author

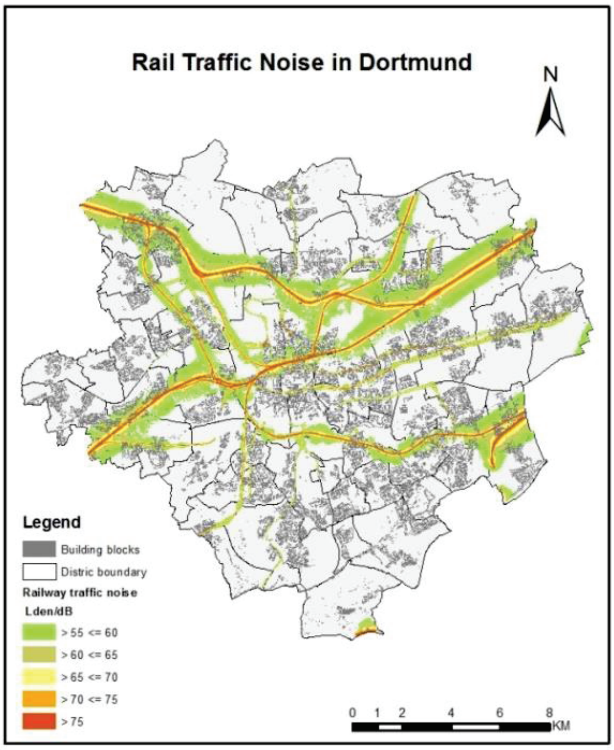


Figure 25: Rail traffic noise in Dortmund
Source: Jufo Salus, modified by author

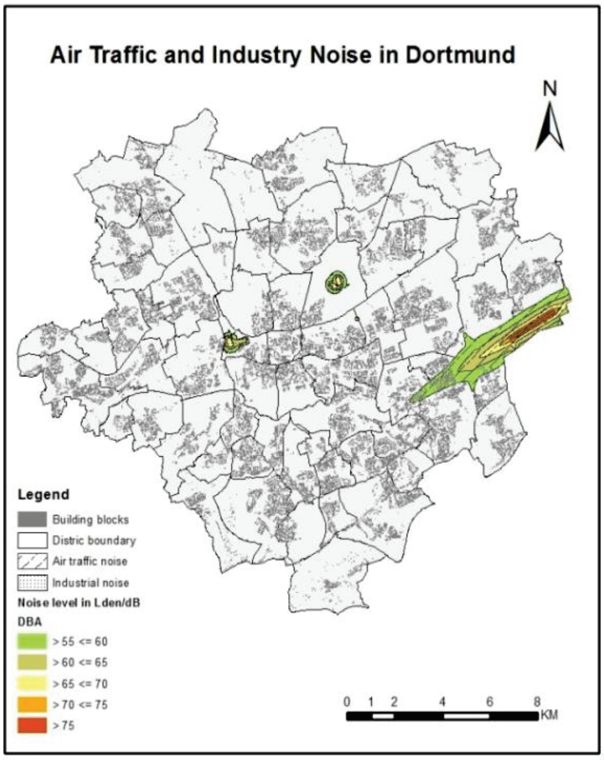


Figure 26: Air traffic and industrial noise in Dortmund
Source: Jufo Salus, modified by author

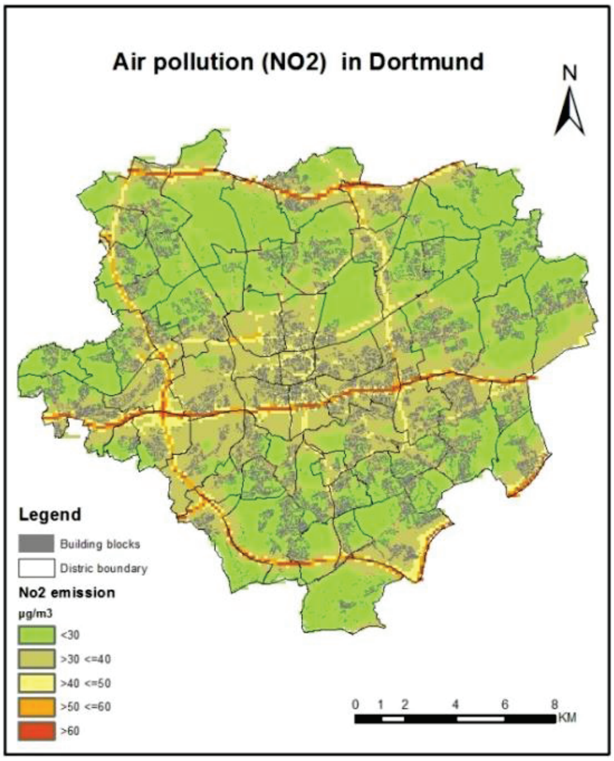


Figure 27: Air pollution (NO2) in Dortmund
Source: Jufo Salus, modified by author

The main environmental stressors in the city of Dortmund are $NO_2$, $PM_{10}$ and noise pollution from various sources such as road, rail, airport and industries (LANUV, 2009). On the basis of environmental issues that Dortmund has been facing, the above discussed environmental stressors were taken into consideration while developing the $SDST_{CE}$ EnL; however, this research could not look into PM10 due to the lack of the data.

Figure 24, Figure 25, Figure 26 illustrates the spatial extent of noise due to road, rail, industries and air traffic. Similarly, Figure 27 shows the spatial extent of $NO_2$. These maps clearly provide information on individual environmental stressors that the city is facing; however, it is important to understand the cumulative environmental state due to the multiple environmental stressors. Therefore, Figure 29 (A) tries to illustrate the spatial extent of the number of individual environmental stressors in a single map by using the overlay technique in the GIS; however, from figure 26 (B) it can be realized that it is not easy to understand the cumulative environmental state by using the overlap of multiple environmental stressors. It is challenging to find out the hotspots due to multiple environmental stressors. It is even more of a problem if the socio-economic or other data are to be studied in combination to these multiple stressors. Since visualization offers a method for seeing the unseen (Al-Kodmany, 2001) and is the key for communicating ideas; this research suggests the methods to visualise the multiple environmental stressors which is operationalized through a spatial decision support tool.

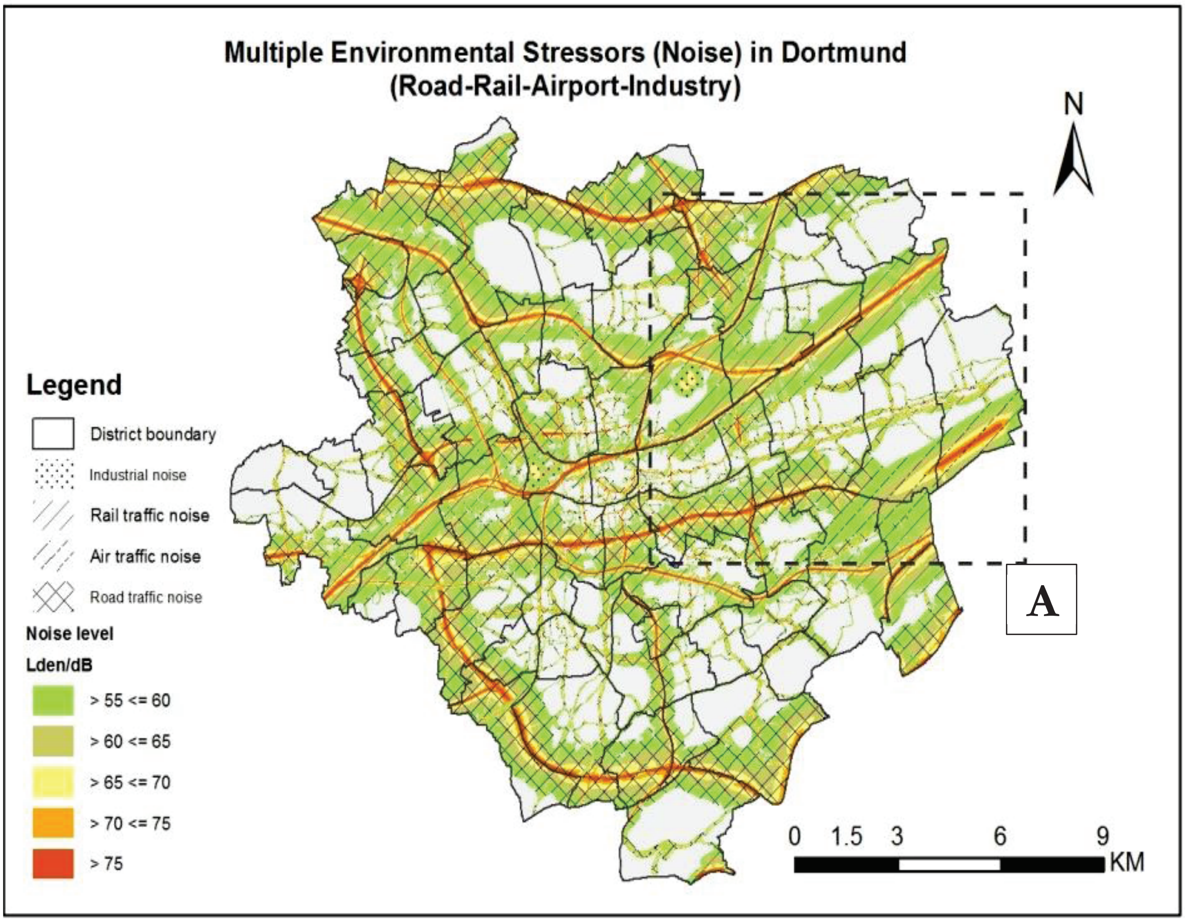


Figure 28: Multiple environmental stressors

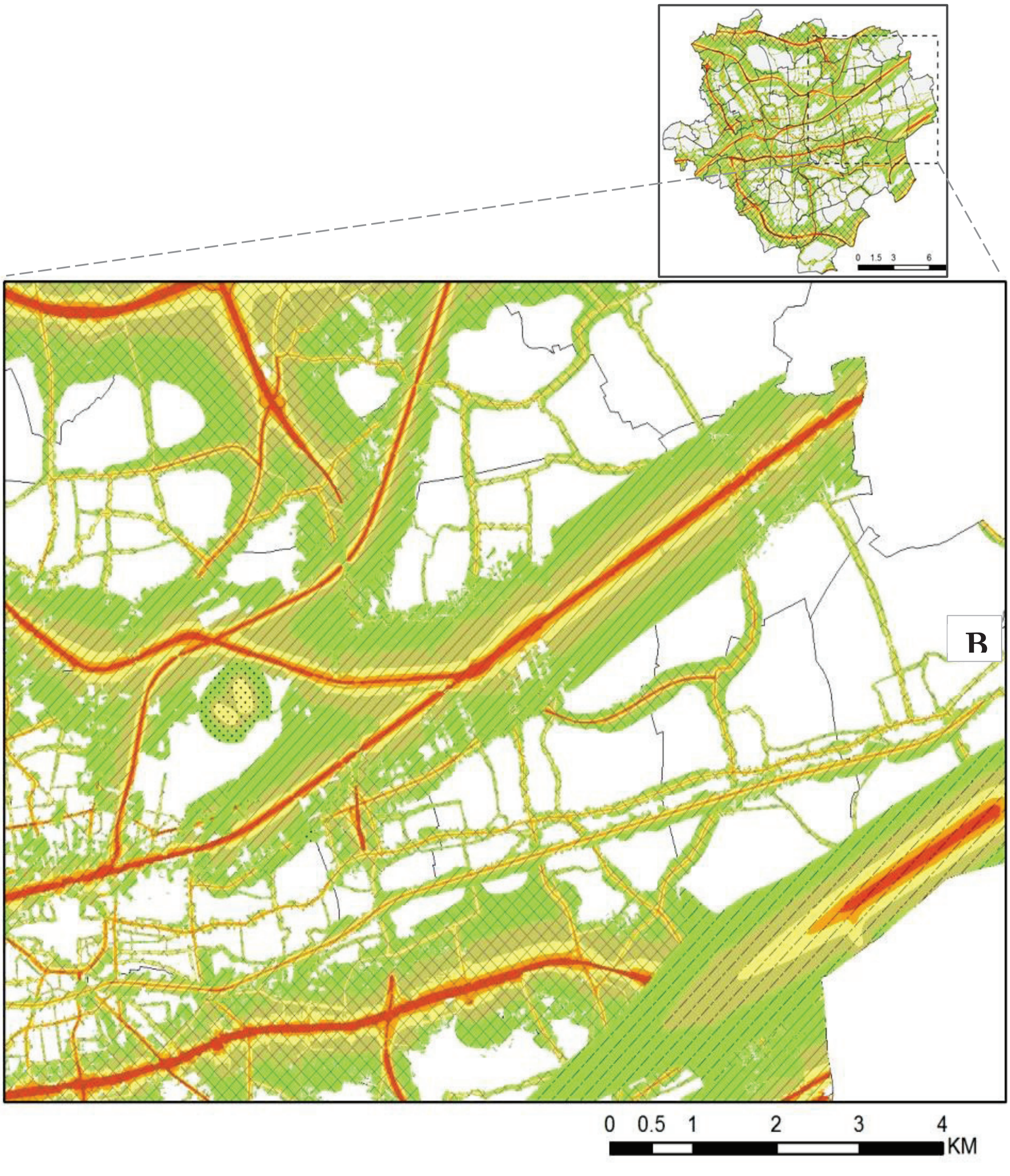


Figure 29: Multiple environmental stressors (Zoom in to section A)

### 6.3. Building of SDST $_{CE}$ EnL

Although this research provides conceptual design of the SDST$_{CE}$; however, it does not develop the overall tool. This research develops a small section of the SDST$_{CE}$ as a test wise development to illustrate the operation of an entry level prototype. It is termed as 'SDST$_{CE}$ EnL'. It demonstrates the interactive tool that allows easy and fast assessment of functions and produces interactive maps and graphs.

Scenario 360 in community Viz is used to create the SDST$_{CE}$ EnL. In order to avoid the technical complication community Viz platform is used. GIS environment of community Viz was used to visualize the geographic information.

Figure 30 illustrates the conceptual framework of SDST$_{CE}$ EnL; Slider bars are used as a tool to input the values and output is realized through Maps and graphs whereas, overlay is used for the comparison between data.

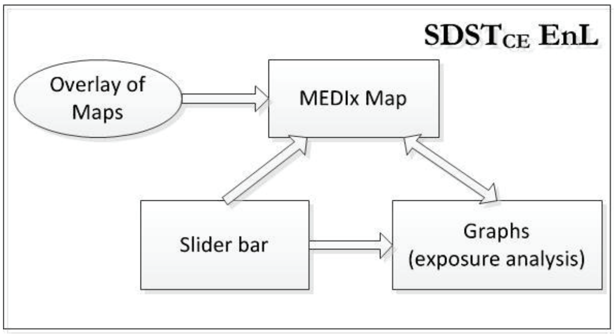


Figure 30: Conceptual framework of SDST$_{CE}$ EnL

#### 6.3.1. Objectives of SDST$_{CE}$ EnL

The 'SDST$_{CE}$ EnL' addresses only the few sub objectives of SDST$_{CE}$ as listed below since it is a test wise development of the conceptual design of SDST$_{CE}$.

1. To understand the geographic extent of cumulative environmental exposure.
2. To allow exposure analysis
3. To provide interactive Maps and Graphs.

#### 6.3.2. Architecture of SDST CE EnL

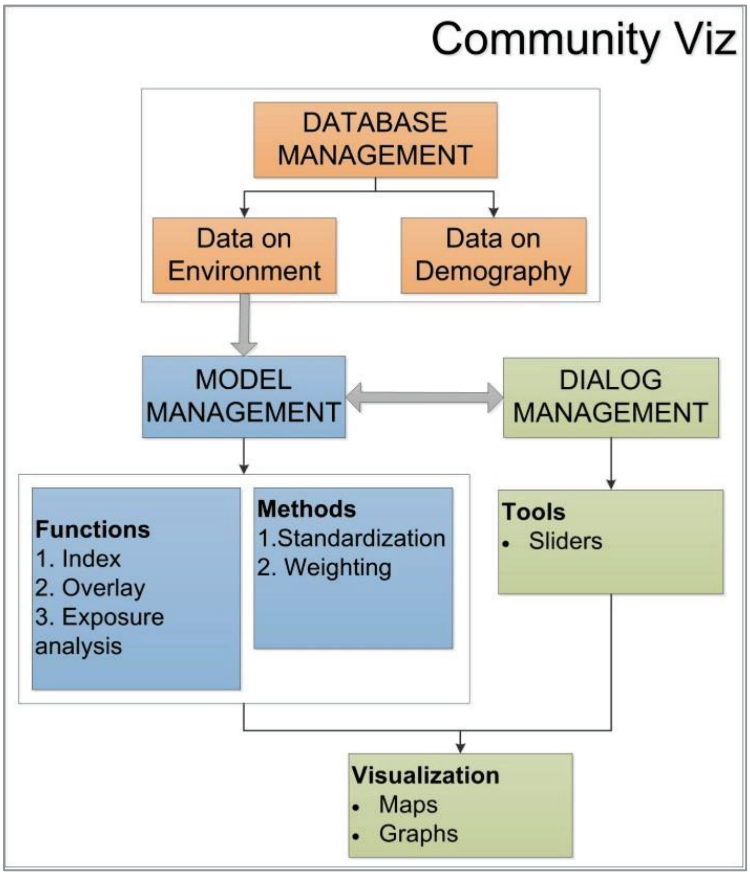


Figure 31: Architecture of SDST$_{CE}$ EnL.

#### 6.3.2.1. Data base management

On the basis of environmental problems in the city of Dortmund as discussed in 6.1 data required for the mapping of cumulative environmental state and exposure are loaded in the database. Spatial data for only one year is available due to which spatial temporal exploration is not possible. Table 6 shows the data used in the development of SDST$_{CE}$ EnL.

Table 6: Data used for making MEDIx

| S.No | Data | | Remarks |
|---|---|---|---|
| 1 | Pathogenic factors | NO2(air pollution) | Air pollution presented in $\mu g/m^3$ |
| | | Road traffic noise<br>Rail traffic noise<br>Air traffic noise<br>Industrial noise | All Noise pollution presented by the average level Lden (unit in dB) |
| 2 | Salutogentic factors | Green space | Public and private green spaces and parks |
| | | Water bodies | Lakes and ponds (natural and standing water, ponds in the park) |
| 3 | Demographics | Total population | |
| | | Total migration | People migrated to Germany after 1949 or being born in Germany or having at least one parent with the background of migration |
| | | Unemployed population | |

#### 6.3.2.2. Model and base management

SDST$_{CE}$ EnL will test on three functions. Index is used for the understanding of the cumulative environmental condition. Exposure analysis is used for assessing the area and people exposed to the multiple environmental stressors. In the case of Dortmund exposure to environmental stressors are assessed for the last quantile. By taking the advantage of GIS environment in community Viz the overlay technique is used to check the people exposed to the environmental stressor or people residing in environmentally deprived area.

#### 6.3.2.3. Dialog base management

As discussed in conceptual design, slider bars are user-friendly tools hence it has been used in the development of SDST$_{CE}$ EnL. Slider bars are used to change the weight provided to the different factors whereas maps and graphs are the outputs used to convey the results.

### 6.3.3. Index making

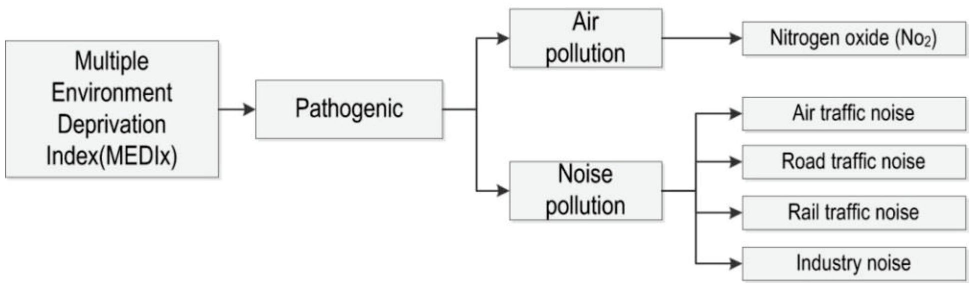


Figure 32: Multiple environmental deprivation index (MEDIx) with only pathogenic factors

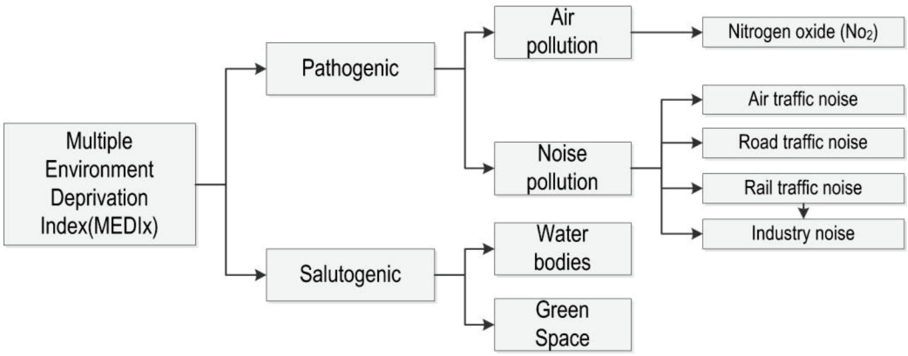


Figure 33: Multiple environmental deprivation index (MEDIx) with both salutogenic and pathogenic factors

The $SDST_{CE}$ EnL is basically developed to test two types of multiple environmental deprivations index (MEDIx); Figure 32 shows the MEDIx that takes in to consideration only pathogenic factors and Figure 33 shows the MEDIx that takes in to consideration both the pathogenic and salutogenic factors. The conceptual framework presented in figure 29 is operationalized through $SDST_{CE}$ EnL. Table 7 shows the criterions used in the development of MEDIx.

In case of pathogenic factors, maximum standardization (see section 2.1.6.1) was used taking the numeric values (i.e area with high amount of pollution is given high score); whereas in case of salutogenic factors, goal standardization is used. A distance of 200 meters is used as the threshold as quarter of mile is considered as the walk able distance to parks (see section 2.1.3).

Table 7: Indicators and criteria's used in the development of $SDST_{CE}$ EnL

| Environmental domain | Environmental factors | Indicators | Criteria's |
|---|---|---|---|
| Pathogenic | Air pollution | Nitrogen oxide (No2) | Maximum standardization(benefit criteria) |
| | Noise pollution | Road traffic noise<br>Rail traffic noise<br>Air traffic noise<br>Industrial noise | Maximum standardization(benefit criteria) |
| Salutogenic | Water bodies | | Goal standardization |
| | Green space | | Goal standardization |

#### 6.3.4. Interactive Graphs

For the development of interactive graphs, formula is established in the community viz.
For the calculation of area exposed to MEDIx, only area in fifth quantile is considered.
Exposed area = Sum of area in last quantile of MEDIx

Similarly, for the calculation of population exposed to MEDIx, only area in fifth quantile is used.
Population =Development density * Area
Population exposed = Sum of population in last quantile of MEDIx

## 6.4. SDST$_{CE}$ EnL

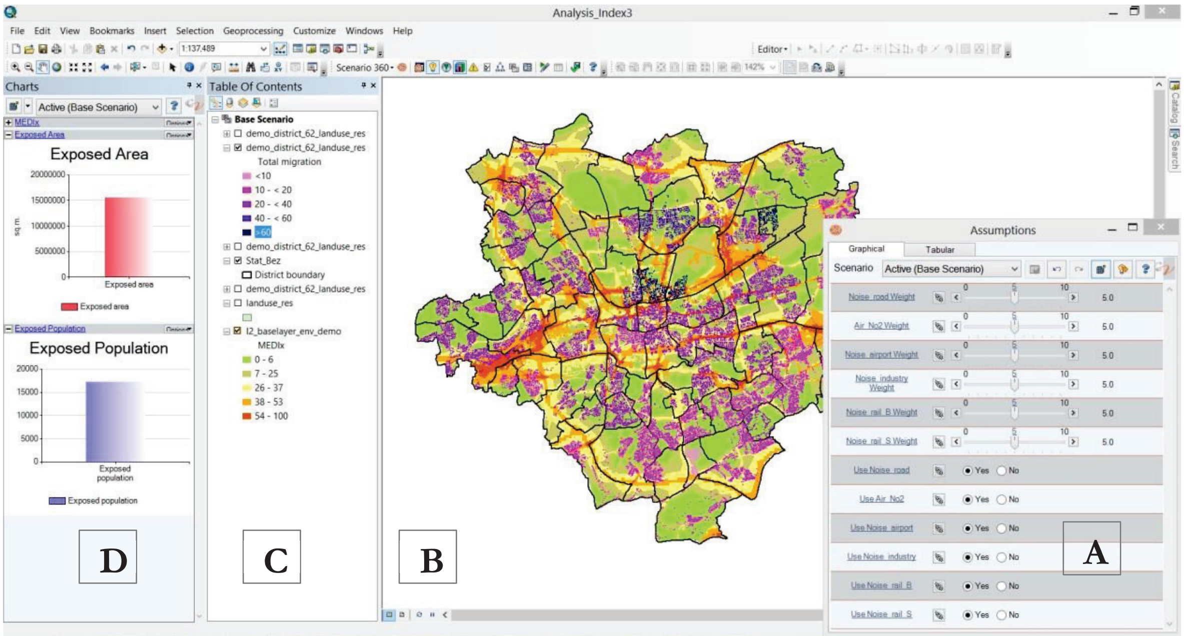


Figure 34: Screen short of SDST$_{CE}$ EnL within community Viz showing the use of overlay technique (overlay of migrated population)

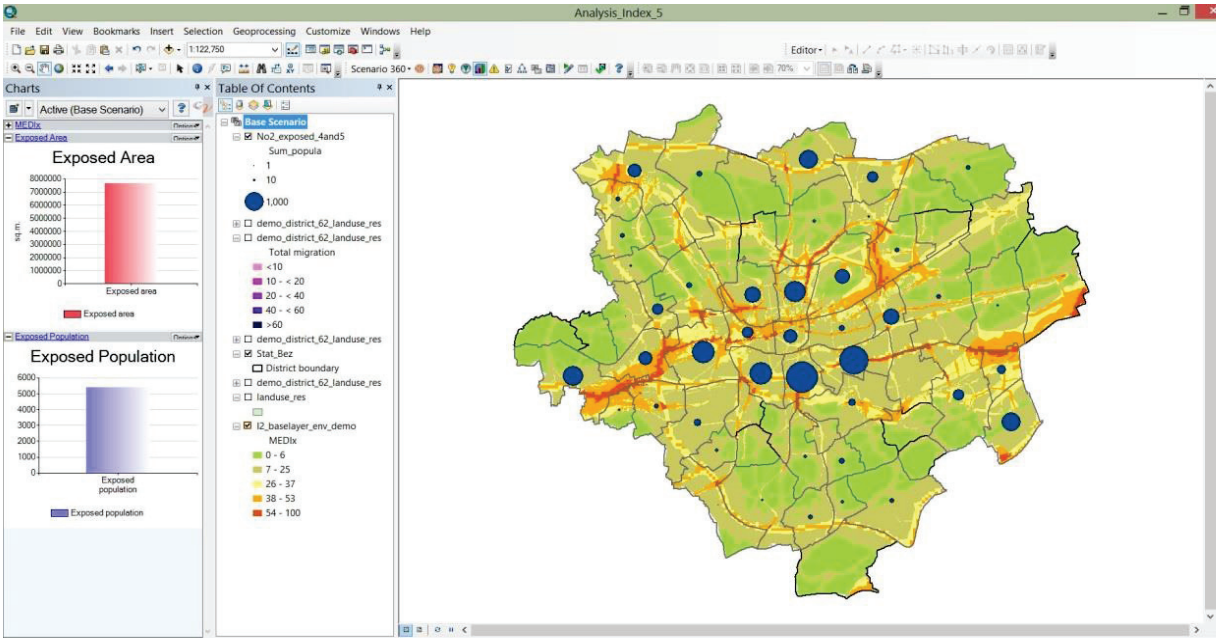


Figure 35: Screen short of SDST$_{CE}$ EnL within community Viz showing the use of overlay technique (overlay of exposed population)

Figure 34 and Figure 35 shows the screen shot of SDST$_{CE}$ EnL in the Community Viz interface. In Figure 35, 'A' is the slider bar. It is mainly used to change the weight of the environmental factors used to create the MEDIx. Environmental factors are scored between 1 to 10; 1 represents low value and 10 represents high value. 'B' is the map area where the maps can be visualized. 'C' is the table of contain which helps to track different layers available in the tool. Simple overlay (overlapping of different layers) technique can be used to visualize and compare different data. In Figure 35, map showing the location of migrated population is overlaid on the MEDIx map. Similarly, in Figure 36 map with propositional symbol showing the number of people exposed to multiple environmental stressors in each ward is overlaid on the MEDIx map. This function will provide flexibility to the users in switching on and off the layers as per the requirement. 'D' shows the graphs; it is used to present the result of exposure analysis. The Slider bar, the map and the graphs are interconnected and are interactive, meaning that change in the weightage of the environmental factors in the slider bar will result changes in the map and the graphs.

## 6.5. Results

The multiple environmental deprivation index (MEDIx) provides scores from zero to hundred. Figure 36 shows the map of multiple environmental deprivation. In the figure green colour shows value approximate to zero (the first quantile) and is characterized as an environmentally better area whereas red colour shows value approximate to 100 (the fifth quantile) and is characterized as poor or the environmentally deprived area with high combined environmental stressors.

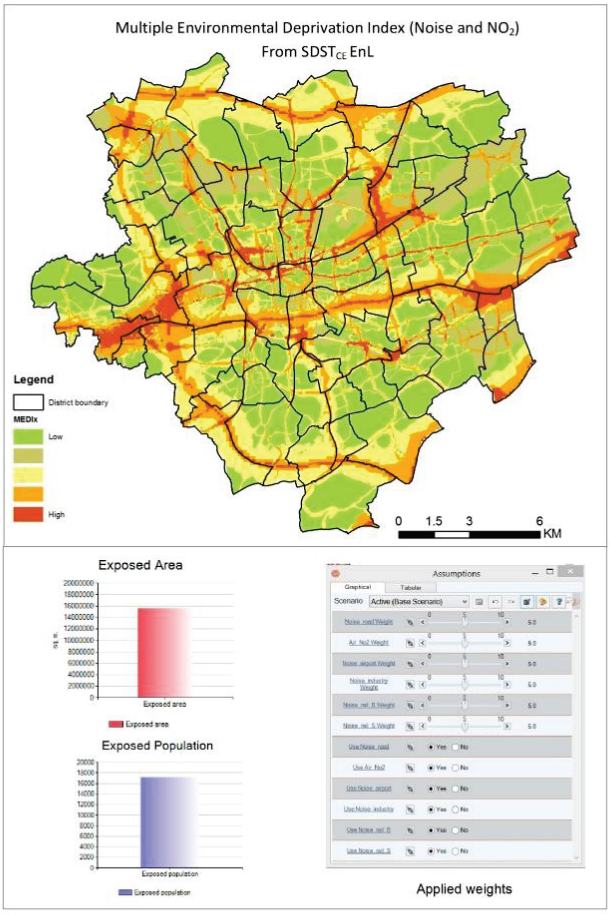


Figure 36: Input and Outputs of $SDST_{CE}$ EnL (equal weight to all the factors)

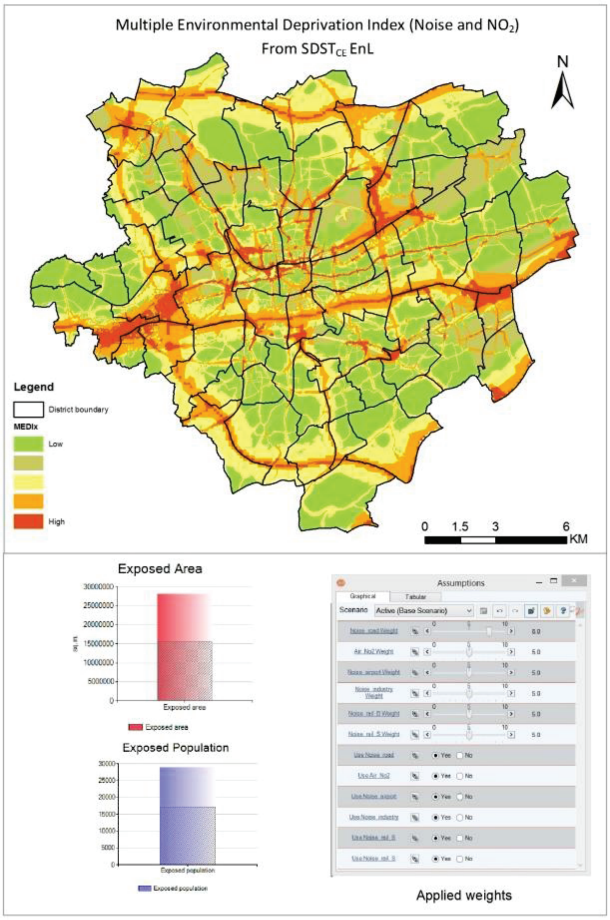


Figure 37: Input and Outputs of $SDST_{CE}$ EnL (high weight to $NO_2$)

The $SDST_{CE}$ EnL creates an index that captures co-exposure to several environmental stressors. Weighting of environmental factors are used in this research; the effect of one environmental stress may be more than the other hence the method of weighing provided in this research is to reflect the experts point of view regarding the significance of pollutants considering risk to human health.

After developing MEDIx, weighting was changed several times to recognise the variation in the environmental state and the population exposure in the area. Table 8,
Table 9, Table 10 and

Table 11 shows the weight applied to each factors and the respective outputs (area and the population exposed) to the cumulative environmental condition due to multiple stressors.

In figure 34, all the factors (Air_$NO_2$, Noise_road, Noise_rail, Noise_airport, Noise_industry) are provided equal weight (that is 50%); the area exposed in this condition is 15.5 sq.km and 17,170 population is exposed. When weight of one of the factor Air_$NO_2$ is increased to 8; the area exposed in this condition is 28.10 sq.km and 28,873 population is exposed. Similarly, when the weight of Air_$NO_2$ was decreased the exposed area and population both decreased (see Figure 39). When salutogenic factors were considered in the index, it was realized that the area and population exposed to the multiple environmental deprivation was increased.

From Figure 36, Figure 37, Figure 39 and Figure 38, it can be clearly seen that area along the road and railway together with the area around the airport area are mostly exposed to the multiple environmental stressors. From above results it can be drawn that the decrease in environmental stressors can have a positive impact on the environment of the city.

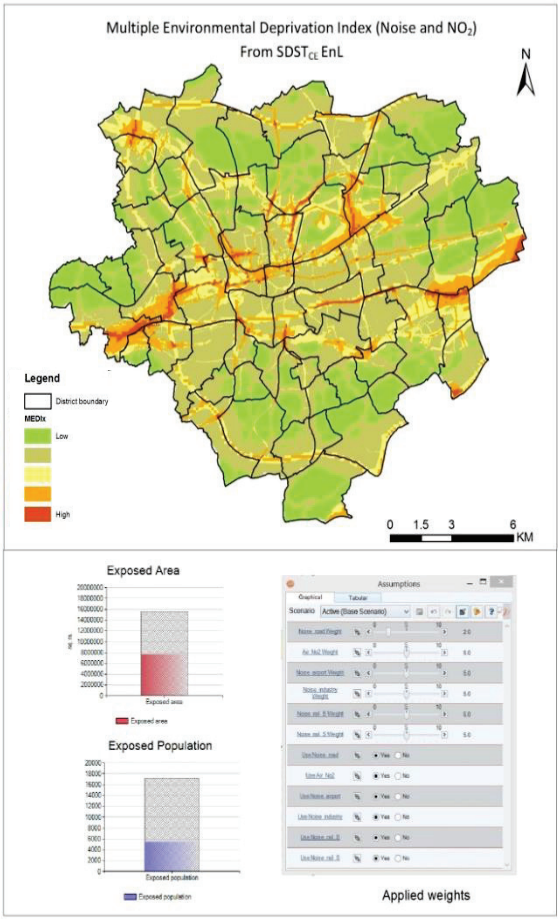


Figure 39: Input and Outputs of $SDST_{CE}$ EnL (low weight to $NO_2$)

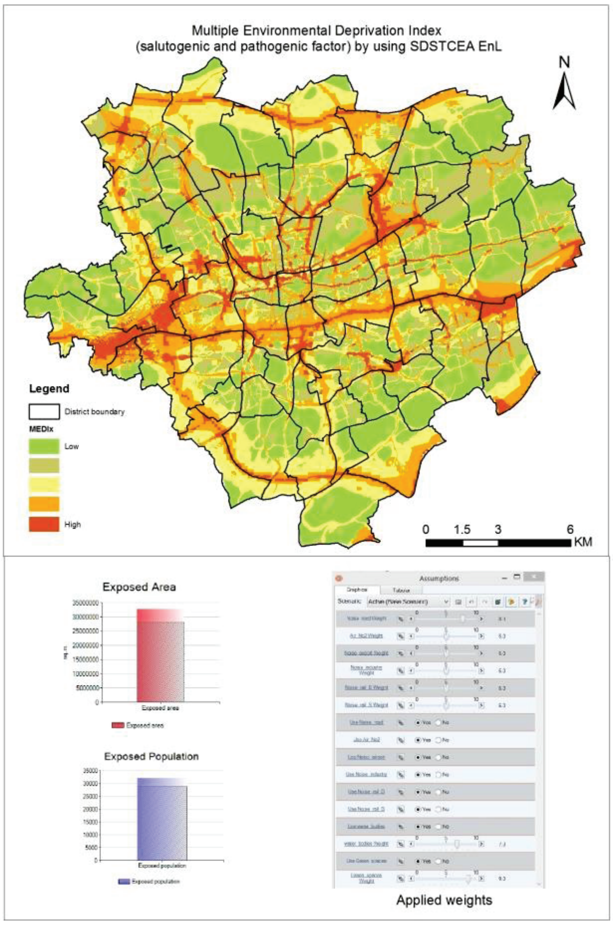


Figure 38: Input and Outputs of $SDST_{CE}$ EnL (including both pathogenic and salutogenic factors)

Table 8: Index including only pathogenic factors (equal weight to all the factors)

| Relate to | Index | Factors | Weight in % | Total exposed area in last quantile of MEDIx (sq.km) | Total population exposed |
|---|---|---|---|---|---|
| Figure 37 | MEDIx | Air_$NO_2$ | 50 | 15.5 | 17,170 |
| | | Noise_road | 50 | | |
| | | Noise_rail | 50 | | |
| | | Noise_airport | 50 | | |
| | | Noise_industry | 50 | | |

Table 9: Index including only pathogenic factors (high weight to $NO_2$)

| Relate to | Index | Factors | Weight in % | Total exposed area in last quantile of MEDIx area(sq.km) | Total population exposed |
|---|---|---|---|---|---|
| Figure 37 | MEDIx | Air_$NO_2$ | 80 | 28.10 | 28,873 |
| | | Noise_road | 50 | | |
| | | Noise_rail | 50 | | |
| | | Noise_airport | 50 | | |
| | | Noise_industry | 50 | | |

Table 10: Index including only pathogenic factors (low weight to NO2)

| Relate to | Index | Factors | Weight in % | Total exposed area in last quantile of MEDIx area(sq.km) | Total population exposed |
|---|---|---|---|---|---|
| Figure 37 | MEDIx | Air_$NO_2$ | 20 | 7.63 | 5,389 |
| | | Noise_road | 50 | | |
| | | Noise_rail | 50 | | |
| | | Noise_airport | 50 | | |
| | | Noise_industry | 50 | | |

Table 11: Index including both pathogenic and salutogenic factors

| Relate to | Index | Factors | Weight in % | Total exposed area in last quantile of MEDIx area(sq.km) | Total population exposed |
|---|---|---|---|---|---|
| Figure 37 | MEDIx | Air_$NO_2$ | 80 | 32.66 | 32,094 |
| | | Noise_road | 50 | | |
| | | Noise_rail | 50 | | |
| | | Noise_airport | 50 | | |
| | | Noise_industry | 50 | | |
| | | Green space | 70 | | |
| | | Water bodies | 90 | | |

### 6.5.1. Understanding relation between social economic and environmental condition in the city of Dortmund by using $SDST_{CE}$ EnL

Figure 40 uses overlay techique in $SDST_{CE}$ EnL to illustrates the population exposed to the $NO_2$ above 40 μg/m³. Similarly, Figure 41 shows the population exposed to road noise above 55 dB in the district level. These figures clearly illustrates that the area along the road and railway together with area around the airport are mostly exposed to the multiple environmental stressors. These figures clearly illustrates that the central and the western districs of the city are exposed to enviromental stressors.That means high evel of multiple environmental stressors exist mainly in environmental zone.

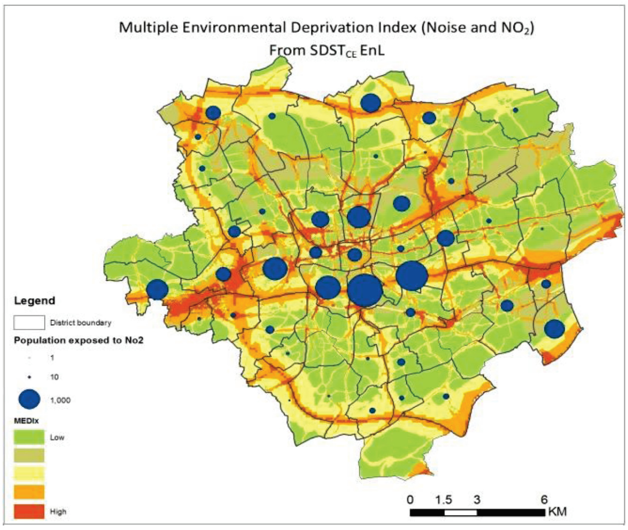


Figure 40: Overlay of population exposed to $NO_2$ above 40μg/m³ on the MEDIx map

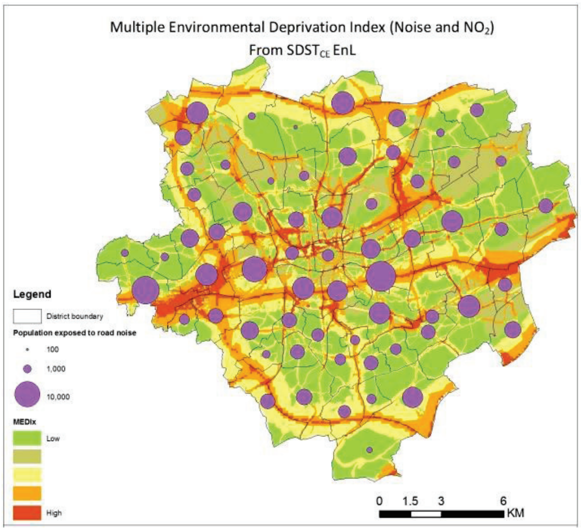


Figure 41: Overlay of population exposed to road noise above 55dB on the MEDIx map

There is a high correlation between migration and unemployment in the city of Dortmund. The central districts of the city is resided with high number of migrants. In this research data on migration is used to study the relation between socio-economic and environmental condition in the city.

In Figure 42, data on migration is overlaid on the MEDIx. Due to the road and railway networks running from the central of the city; central statistical districts are mostly exposed to multiple environmental stressors which is also true in the case of western statistical districts of the city. These disticts are stuggling with high unemployment, has high number of migrants and the life expectancy is also comparativly low.

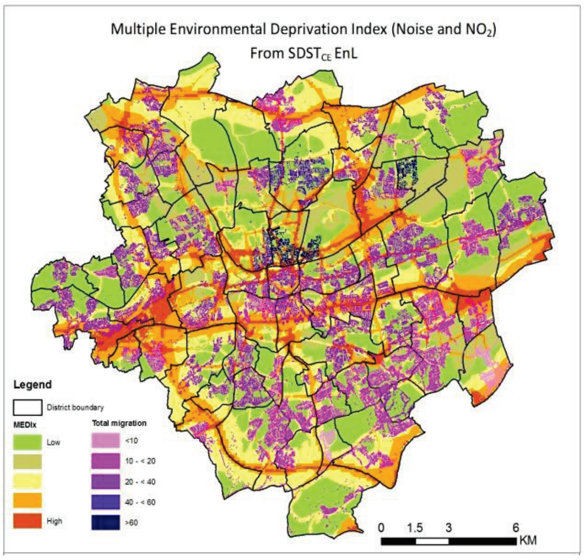


Figure 42: Overlay of migrated population on the MEDIx map

# 7. CONCULSION AND RECOMMENDATIONS

*This chapter discusses on the research findings with respect to research objectives. The first section of the chapter will discuss on conclusion . The second section will provide recommendations and future directions.*

## 7.1. Conclusion

The main objective of the study was to design the Spatial Decision Support Tools (SDST) for understanding the cumulative environmental condition of the area.

The conceptual design of spatial decision support tools for understanding the cumulative environmental exposure (SDSTCE) has been proposed. The conceptual design of SDSTCE if implemented can generate a generic tool that can be used in any city regardless of its geographic location and the environmental problems. However, the results produced will be data dependent since it addresses multiple environmental factors. It will be able to show the difference of considering or avoiding the environmental factors in the calculation. This will ultimately unfold different situations that can be anticipated in the real world, if different environmental stressors are addressed.

The probable end users of the $SDST_{CE}$ are urban planners, public health experts, environmentalist, decision makers and non-profit organization. $SDST_{CE}$ will be used in the first phase of the decision making (intelligent phase). The multidimensional data structure is proposed for easy and fast data query so that the line of thought of the end users is not broken. It will be able to provide the end users with individual as well as cumulative environmental condition of the area with respect to different spatial and temporal resolution. Furthermore, it will be able to show distribution of health outbreaks in the same manner.

The ROMC design approach and the use case approach were used for the design of the $SDST_{CE}$. These approaches provided a good structure for the design of the tool. However, it was realized that although the main focus of the research was to design the tool, it would have been better to break the design process into phases and used prototyping so that the rough idea of the functionality of the tool could be approximated with the proposed functions and tools rather than a complete programming of the system. Such a development process could have provided an opportunity to understand the end user's perspective on the tool.

It was found that stakeholders are one of the main components behind the success of the SDST. Hence, for the success of the tool stakeholders were involved in the selection of different components of the $SDST_{CE}$ through the questionnaire. An online expert questionnaire was developed by using the graphical representation from different existing visualization techniques; due to which it was difficult to express the exact situation (Cumulative environmental condition) on which question was to be posed. Hence, the questionnaire could be better designed by using a set of data for case study area or any other as per the requirement. Involving stakeholders (experts from different professional backgrounds) through online questionnaire was challenging and time consuming, although it is one the best choice when a large number of expert opinion is to be collected. Therefore, a socio-technical methods (O'Neill, 2001) where experts could be involved directly so that the researcher can interact and understand their views should be used to draw the components of the SDST.

It was found that the index making is one of the most useful methods that can be used to understand the cumulative environmental condition due to multiple environmental stressors. This research proposes that the index making should be allowed to the stakeholders. From the literature and expert questionnaire it was found that the combination of different functions and visualization techniques make the tool comprehensive. Hence this research proposes combination of 1) spatial and non-spatial representation 2) individual indicator map and a multiple environmental deprivation map for the visual analysis of cumulative environmental state and the exposure. Furthermore, 3D and time series provide better understanding of the situation.

The conceptual design of $SDST_{CE}$ was partly realized through $SDST_{CE}$ EnL which was operationalized in Community Viz. Although it was an entry level prototype it clearly illustrated how the cumulative environmental exposure due to multiple environmental stressors could be assessed and visualized. Furthermore, it clearly demonstrated the interactive tool. The functions such as overlay technique demonstrated the comparison of different data which could be of great importance to different professionals and decision makers in planning better and healthier cites.

It was found that air pollution, such as $NO_2$ and $PM_{10}$ together with noise pollution from road, rail, air traffic and industry are the most prominent environmental stressors in the case study city of Dortmund. Central districts and the area along the road, railways as well as the area around airways airport are found mostly exposed to $NO_2$ of above 40 $\mu g/m^3$ and composite noise pollution of above 55dB. Hence, can be concluded that the cumulative environmental exposure along the road, railway and around the airport are high.

## 7.2. Recommendations

This research is the first attempt to design a spatial decision support tool for understanding cumulative environmental exposure. Due to the lack of temporal data, only spatial dimension of cumulative environmental exposure was considered in $SDST_{CE}$ EnL. Furthermore, due to the lack of health data, health effects were not considered in $SDST_{CE}$ EnL. With these limitations in the research the following recommendations are presented for further research directions.

- This research focuses on the intelligent phase; the future research could be done on design and choice phase.
- The design of the $SDST_{CE}$ does not consider animation and overlay of 3D built-up area on the cumulative environmental stressors; the future step could be to incorporate these visualization techniques for more insights into the environmental condition of the area.
- Decision makers from government and non-profit organization were not involved during the questionnaire. They could be involved as they are one of the potential contributors in elevating environmental issues in the cities.
- Due to the time limitation the $SDST_{CE}$ EnL was not tested involving the end users. Testing could be carried out to improve tool as well as to measure the success of the tool.
- Along with air, noise, green spaces and water bodies, facilities such as industries, landfilled sides, and heat island effects could be considered in studying multiple environmental deprivation to provide a larger picture on the environmental condition of the area.

- Although relation between cumulative environmental exposure and socio economic condition was checked in the case of Dortmund through overlay and visual analysis, correlation cannot be proved by using this tool.
- Although the design of $SDST_{CE}$ provides the capability of locating health outcomes in the area and help the experts to draw the hypothesis, causality between environment and health cannot explained.
- Introducing the statistical analysis in the tool could be the future direction for more concrete results.

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# APPENDIX

**Questionnaire: Importance of Visualization, Functions and Tools in Understanding Cumulative Environmental Effects in Decision Support System (DST)**

**Introduction**

My research is on the design and development of a "Spatial decision support tool for mapping cumulative environmental health impact". **Decision support tools (DST)** in general are computer based tools that can help decision makers to explore, understand, analysis and visualize the underlying factors of a specific problem. When such a tool takes into consideration spatial factors then it is referred as a spatial decision support tool.

This research aims to develop a spatial decision support tool (SDST) which will focus on visualization techniques, functions and tools for better understanding cumulative environmental effects. **Cumulative environmental effects (CEE) s** may be defined as combined impact of individual environmental stressors such as air pollution, noise pollution etc.

**Visualization techniques** are applied for representation of spatial distribution in different forms such as maps, graphs, 3D or animation whereas **functions** are the methods used to assess the effects and **tools** are the communication techniques which help to accomplish different methods.

This questionnaire aims to understand effectiveness of different visualization techniques, methods and tools in analyzing cumulative environmental effects through the lens of different stakeholders. This questionnaire consists of 5 different visualization techniques. It contains simple to complex and combination of different visualization technique for comprehensive information. Each of the visualization techniques is explained with text in order to clarify its purpose.
There are three parts in questionnaire. **First part** is about general questions on Decision Support Tools (DST). **Second part** is on visualization techniques and **third part** is on functions and tools in DST.

***I would be very grateful if you could take some time to complete this questionnaire and assist me in addressing some (if not all) of the questions.***

**Identification of respondents:**
Name of the respondent: ……………………………………………….
Profession of the respondent: …………………………………………..
Institution: ……………………………………………………………...
Email address: ………………………………………………………….

**First Part:** General questions on experience of respondents with decision support tool (DST) and assessment of cumulative environmental effects

1. Are you aware of decision support tool(DST)? (It may be that you might not have used it but have seen others use it or and about it.)

   **A. Yes** **B. No**

   If yes, could you please name it?

   ……………………………………………………………………………………………………….

2. Have you been using decision support tool?

   **B. Yes** **B. No**

   If yes, could you please name the one that you have been using?

   ………………………………………………………………………………………………………

3. Could you please name some of the methods used to assess cumulative environmental effects? ………………………………………………………………………………………………………

4. How do you visualize cumulative environmental effects?

   A. Maps B. Graphs C. any other

   Please specify if any other ………………………………………………………………………………………………………

**Second Part:** Questions on techniques of visualizing cumulative environmental effects (CEE) s

There are some visualization techniques given in the following pages. This questionnaire tries to make a comparison between different visualization techniques. To comprehend these figures, graphs and maps, some texts are also provided along with it.

**Note:**

*The figure, graphs, maps presented in questionnaire does not represent the real data of the research. They are taken from literature and sources are provided below each the figure.*

*In some of the questions figure, graphs, maps presented in questionnaire needs to be compared with each other in order to rank your preference so please go through all different visualization techniques before getting started.*

Spatial versus non spatial visualization techniques

1. Which form of visual representation is more effective in understanding environmental effects in the area? Please indicate in the scale of 1(Most effective) to 5 (Not effective)

   **A. Non spatial representations (Example: Bar chart, Pie chart)**
   **B. Spatial representation (Example: Maps)**
   **C. Combination of A and B**

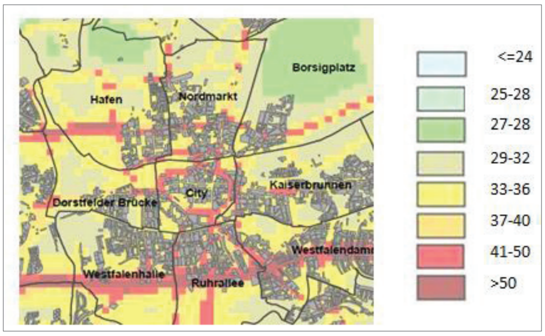
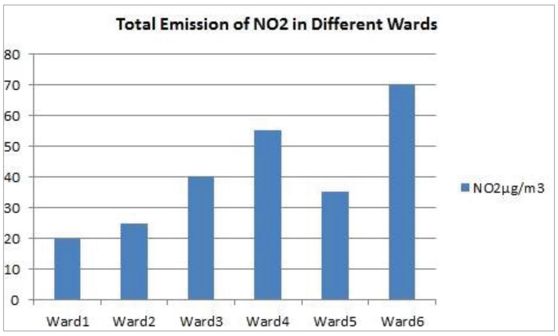
| Spatial Represntation | Non spatial representations |
|---|---|
|  |  |





Figure 43: Figure showing spatial versus non spatial visualization techniques (Q)

Visualization of cumulative environmental effects (CEE) s in aggregated non spatial form

2. The bar chart and the radar chart given below show air pollution and noise pollution in six different wards. Which of the chart is easier to understand the degree of environmental exposure in different wards?

   **A. Bar chart**
   **B. Radar chart**

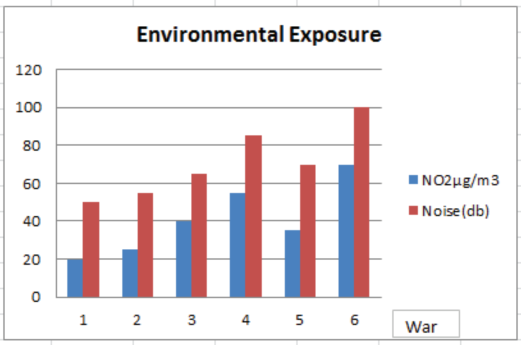
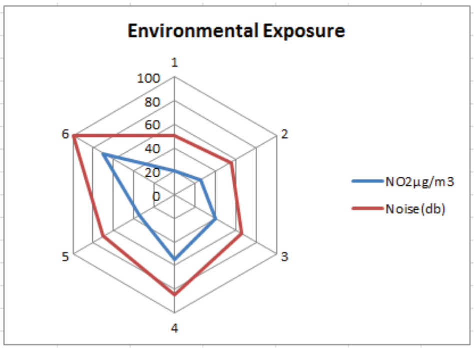
| Bar chart | Radar chart |
|---|---|
|  |  |





Figure 44: Figure showing spatial versus non spatial visualization techniques (Q)

Disaggregated map versus Aggregated maps

3. *'Individual Indicator Map' represents single environmental indicators such as air pollution, noise pollution in an area. Whereas Multiple Environmental Deprivation Map (MEDM) represents cumulative analysis of multiple environmental indicator.*

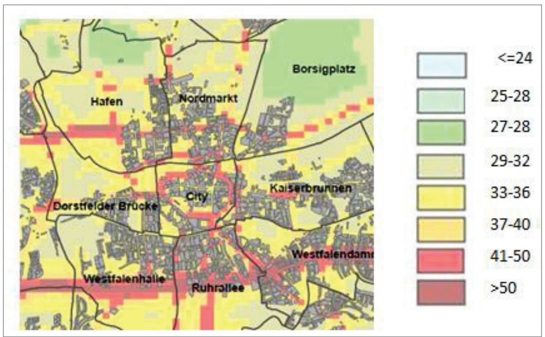
Q. What would be easier in understanding the cumulative environmental impact?

A. A set of combination of Individual Indicator Map
B. Multiple Environmental Deprivation Map

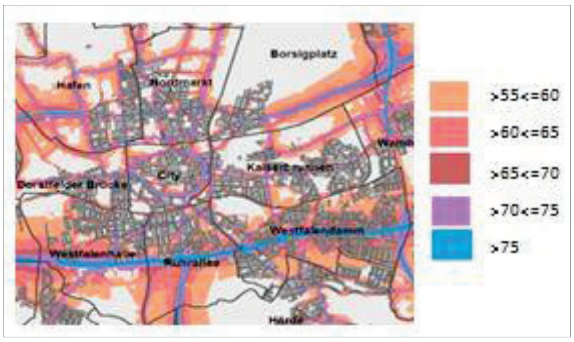
Q. What would be informative in understanding the cumulative environmental impact?

A. A set of combination of Individual Indicator Map
B. Multiple Environmental Deprivation Map

A. Individual Indicator Map

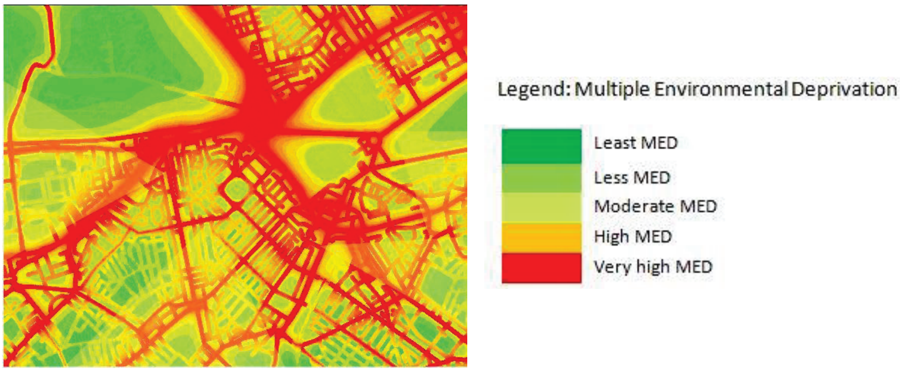



Total Emission of $No_2$ in Different Wards




Noise Pollution due to Road Traffic in Different Wards

**B.** Multiple Environmental Deprivation Map




Multiple Environmental Deprivation Maps

Figure 45: Figure showing disaggregated map versus aggregated maps

Pollution map in 2D and 3D

The picture below shows Nitrogen dioxide ($No_2$) mapping in 2D form and in 3D environment of the city. Which of these maps do you think will be more informative in understanding the spatial distribution of environmental indicators such as nitrogen dioxide ($No_2$) in the city? Please indicate in the scale of 1(Very informative) to 5(not informative)

**A.** $No_2$ Mapped in 2D
**B.** $No_2$ Mapped in 3D Environment

$No_2$ Mapped in 2D

$No_2$ Mapped in 3D Environment

Figure 46: Figure showing pollution map of the city in 2D versus 3D environment form (Q)

<u>2D pollution map versus 3D pollution map</u>

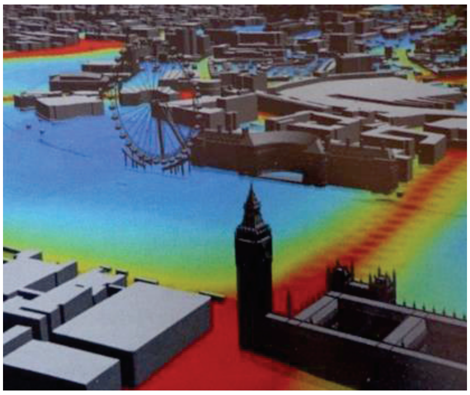
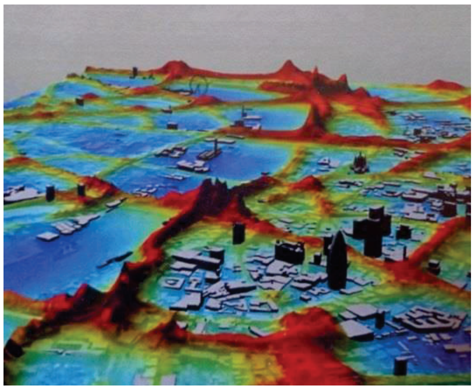
4. The graphics provided below shows air pollution mapping of the city. Red to blue shows high to low concentration of air pollution.

Q1. Which of the picture is easier in understanding the condition of air pollution in the city?

**A. Air pollution mapping in 2D and buildings in 3D**
**B. Air pollution mapping in 3D and building also in 3D**

Q2. Which of the picture is more informative in understanding the condition of air pollution in the city?

**A. Air pollution mapping in 2D and buildings in 3D**
**B. Air pollution mapping in 3D and building also in 3D**

| **A. Air pollution mapping in 2D and buildings in 3D** | **B. Air pollution mapping in 3D and building also in 3D** |
|---|---|
| <br>Figure 47: Figure showing air pollution mapping in 2D and buildings in 3D environment (Q) | <br>Figure 48: Figure showing air pollution mapping in and 3 building both in 3D (Q) |

Time Series versus Animation of Air Pollution

5. If a 'Time series' and an 'Animation' is provided for a time period that shows the state of environmental condition (for example nitrogen dioxide). Which of the following techniques will be more useful in understanding environmental condition of the area? Please indicate on a scale of 1 (very useful) to 5 (not useful).
    a) Time series

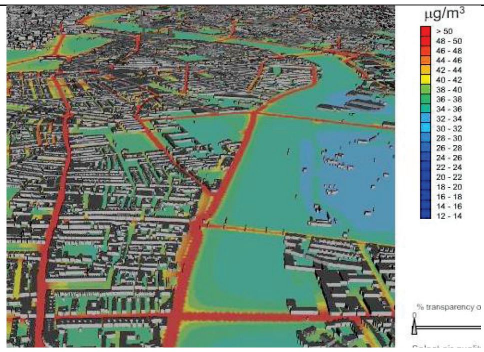
| | |
|---|---|
|  Figure 1: Nitrogen dioxide mapping in 2004 |  Figure 2: Nitrogen dioxide mapping in 2006 |
|  Figure 3: Nitrogen dioxide mapping in 2008 |   Figure 4: Nitrogen dioxide mapping in 2010 |

Figure 49: Figure showing time series of air pollution (Q)

Environment Research Group King's College of London (2013)

    b) Animation
    Link for the animation: http://youtu.be/DOJQ8sJlpV4

**6.** In a 3D environment of the city, where 3D created represents different individual or multiple socio-economic condition of the city; if it is overlaid on a Multiple Environmental Deprivation Map (MEDM). Do you think such overlay will help decision makers in better understanding the spatial differences of environmental distribution in the city?

**A. Yes** **B. No** **C. I don't know**

If 'Yes' or 'No' could you please elaborate your choice?

…………………………………………………………………………………………………….

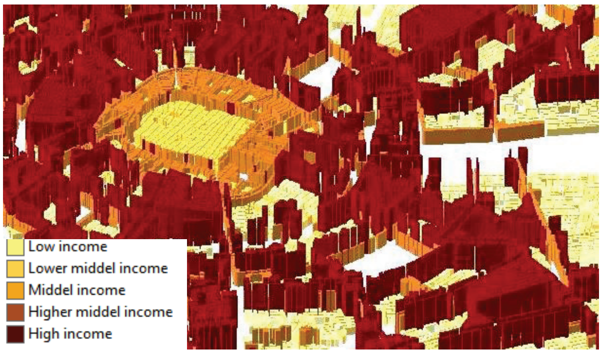



Figure 9: 3D environment showing Multiple Deprivation of the city (Q)

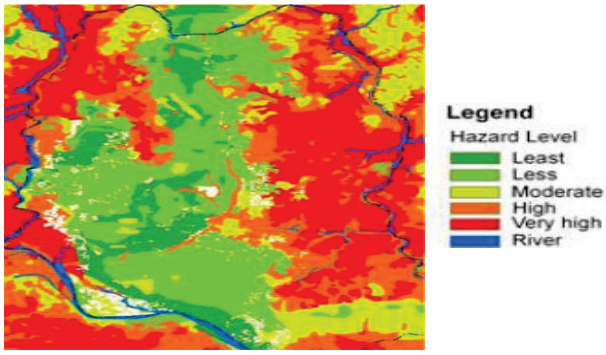



Figure10: Figure showing multiple environmental deprivation maps (Q)

**Third Part:** Potential functions and visualizing tools of DST for visualizing and analysing (CEE)s

Functions are the methods which help to assess complex queries such as cumulative environmental effects in the city. Creating an index map is a function. Whereas tools are the technique which helps to accomplish different methods.

This part of the questionnaire will be on potential functions and visualizing tools of DST for visualizing and analyzing cumulative environmental effects (CEE) s.

7. The figure below is an example of the Kernel density. It shows the magnitude of concentration per unit area form any point. In the figure below it is trying to show the magnitude of concentration of disease (small red dots) per unit area from the gas station (big yellow star at the center), such mapping of disease helps in hypothesis formulation rather than coming to the conclusion.

   How useful do you think such a map will be in understanding human exposure to environmental pollutants? Please indicate its usefulness in a scale of 1(very useful) to 5(not useful).

Figure: Figure showing Kernel density (Q)

8. In general two types of maps can be used to understand the cumulative environmental effects.

i. **Static maps** are the normal maps which are prepared beforehand.
ii. **Adaptive maps** are interactive in nature meaning that it changes with the change in underlying values and criterions of the map.

Which map do you think will be more useful in understanding the cumulative environmental effects? Please indicate in the scale of 1(very useful) to 5(not useful).

A. **Static maps** B. **Adaptive maps**

9. In case following condition (i and ii) are provided i.e.

i. Different individual environmental and social indicator maps are provided.
ii. A function to create an index map is provided. (Such a function will provide a flexibility of creating index map as per the requirement of the analysis by providing the possibility of combining one or more maps).

In the course of collaborative decision making, what do you think will be more useful? Please indicate in a scale of 1(very useful) to 5 (not useful).

**A. Allowing stakeholders to create index map**
**B. Providing stakeholders with prepared index map**

***15. Overlay*** *is a technique in which maps are overlapped over each other and the transparency of upper map is increased so that relation between different factors of the maps that are overlaid can be visualized and analysed.*

Q. What would you prefer?
**A. Side by side comparison of maps**
**B. Overlay of maps**

Could you please elaborate on your choice?

………………………………………………………………………………………………………..………

***16. Weighting*** *is a method in which one gives score to the criteria's (for example air pollution, noise pollution, heat stress) with respect to its importance. In this method decision makers will use their expertise on the topic for weighting. It is a subjective method so it highly depends upon once knowledge of experts and stakeholders.*

Q. If decision makers are provided with a provision of weighting different criteria's. Do you think such a function will provide flexibility in creating a multiple environmental deprivation map (MEDM) that better pictures the cumulative environmental stressors of the area?
**A. Yes** **B. No** **C. I don't know**

**17.** Which weighting system will be easier and flexible for decision makers?

**A. Slider bars (allow to adjust scores between lowest and highest endpoints)**
**B. Weighting by manually inputting the numbers**

Could you please elaborate your choice?
……………………………………………………………………………………………………….

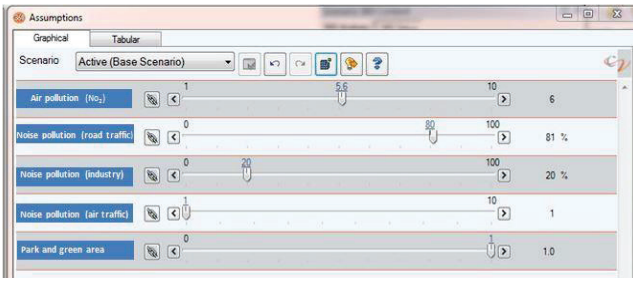


Figure 50: Figure showing slider bar (Q)

*18. A Pop up window allow the decision makers to get some detail information about certain feature in the map such as road, gas station, industry which might be the cause of pollution. Such a window may help in drawing a hypothesis. For example 'Industry "A" is the cause of health hazard in the area.'*

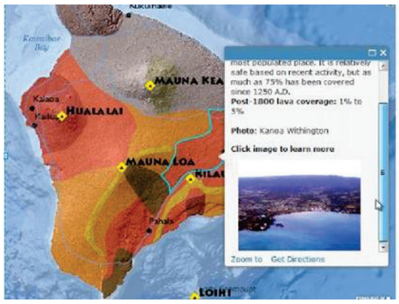


Figure 51: Figure showing pop up window (Q)

Q. Do you think pop-up windows along with map could be helpful in understanding the environmental condition of the area?

**A. Yes** **B. No**

Could you please elaborate your choose?

……………………………………………………………………………………………………….

**19.** Suggestion on any other visualization techniques, methods and tools to understand cumulative environmental effects would be very much appreciated.

……………………………………………………………………………………………………….

***You have successfully completed the questionnaire. Thank you for your support.***

For any further questions please contact n.thapashrestha@student.utwente.nl