AN IT BASED APPROACH TO ASSESSING SOME OF THE ISSUES LINKED TO PROBLEMATIC SOILS

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Abstract. *This paper presents a new methodology whereby the cumulative factors associated with the issues that may arise during construction on problematic soils may be addressed. In particular a computer based methodology is presented, which enables various factors of relevance to be considered in a methodical fashion.*

The new methodology makes use of a Geographical Information System (GIS) as the fundamental building block upon which the approach is based. Extensions of the basic GIS approach to include a combination of i) underground conditions, ii) structural performance and iii) economic and social factors are considered. The work makes use of classical GIS type "layers of information", superimposed on one another, to identify areas of major concern.

The approaches considered to overcome the many challenges encountered when tackling such multi-disciplinary problems are presented. Data which adequately describe three dimensional underground structures and forms need to be manipulated, in conjunction with geographical space and layout, which in turn need to be combined with economic impact and social inclusion information. An insight will be given of the range and types of data fields that need to be accommodated in such an approach, with solutions that can be achieved via neural networks and self learning techniques highlighted.

1 INTRODUCTION

Due to the growing population of the world and ever increasing economic activities, mega infrastructures are being built around the globe for residence, commercial, industrial and for the exploitation of natural resources. These mega infrastructure developments are tightly linked with socio-economic aspects. These integrated engineering-socio-economic challenges highlight the importance of proper planning and design of infrastructure developments by considering all important factors from different disciplines.

Various aspects of structural integrity and life performance of engineering works are based on a number of factors, from which soil properties and behaviour is one key component. Geotechnical engineering related researches have been playing an important role in understanding the behaviour of different soil types under different conditions and the impact they have on structures throughout their life span. Problematic soils, be they expansive soils, collapsible soils, dispersive soils or unsaturated soils can cause significant challenges during both engineering construction and performance throughout the lifespan of a structure. These soils and associated problems have extensively been studied and engineering solutions have been developed to deal with problems that may arise.

In this paper, a new framework is proposed to deal with such soils, their impact on construction, life time performance and associated socio-economic impacts in case of a distress or failure under an integrated framework. The framework forms the basis for the development of an integrated multi-criteria Spatial Decision Support System **(SDSS)**. The architecture of the IT-based system is designed for the purpose of an informed risk based decision support mechanism, which incorporates the key factors involved. These factors are related to geotechnical engineering, a socio-economic domain and the environmental conditions of the area. The framework comprises Geographical Information Systems **(GIS)**, intelligent computing techniques and relational Geo-databases. The conceptual framework also suggests an inventory of important factors from geotechnical, socio-economical and environmental aspects to be incorporated in the analytical framework.

Design of the system facilitates the incorporation of 3D underground modelling for better understanding of the ground condition and its effects. This also gives an opportunity to study the impact of emerging technologies related to the exploitation of ground source energy resources such as underground coal gasification, shale gas and even tradition coal mining activities. The system will be able to model the complexities between multidimensional and inter-linked parameters/factors related to how engineering and infrastructure developments and emerging technologies, constructed on problematic soils can be affected on the base of an integrated technical and socio-economical platform.

2 CONCEPTUAL FRAMEWORK AND KEY COMPONENTS

As stated above, the proposed conceptual framework combines the strengths of GIS, SDSS and analytical techniques (both empirical and intelligent computing) in an integrated manner. The framework takes the form of a spatial decision support system and facilitates the overall decision making process while confronting semi-structured decision problems related to socio-economic upheaval caused by the distress to infrastructures. It provides a mean to incorporate all important domains and key parameters related to the problems discussed above, covering a wide range from geo-technical to socio-economic domains. Figure 1 explains the conceptual framework of the proposed spatial decision support system, its different components, sub-components and interfaces.

The framework suggests an inventory of important factors from different domains that are to be incorporated in the geo-database component. In the model base component it is shown how conventional GIS mapping and analytical techniques can be combined with the neural network and genetic algorithm to understand and explain the complex relationship in a data centric approach. The knowledge base component presents known empirical models that can be used to answer some of the questions and how local and existing domain knowledge can be important in facilitating the overall decision making process. The graphical user interface component explains how the decision maker interacts with the system and uses the capabilities of different parts of the overall framework.

After presenting the conceptual framework of the proposed spatial decision support system, the following sections highlight its important components, how they work, aided with examples and diagrams. The architecture is generic in nature and depends on the availability of several datasets of the study area. These datasets are highlighted in section 3.1 of the paper. Modelling techniques are also discussed and suggested for the framework in section 3.2 aided with some scenarios.

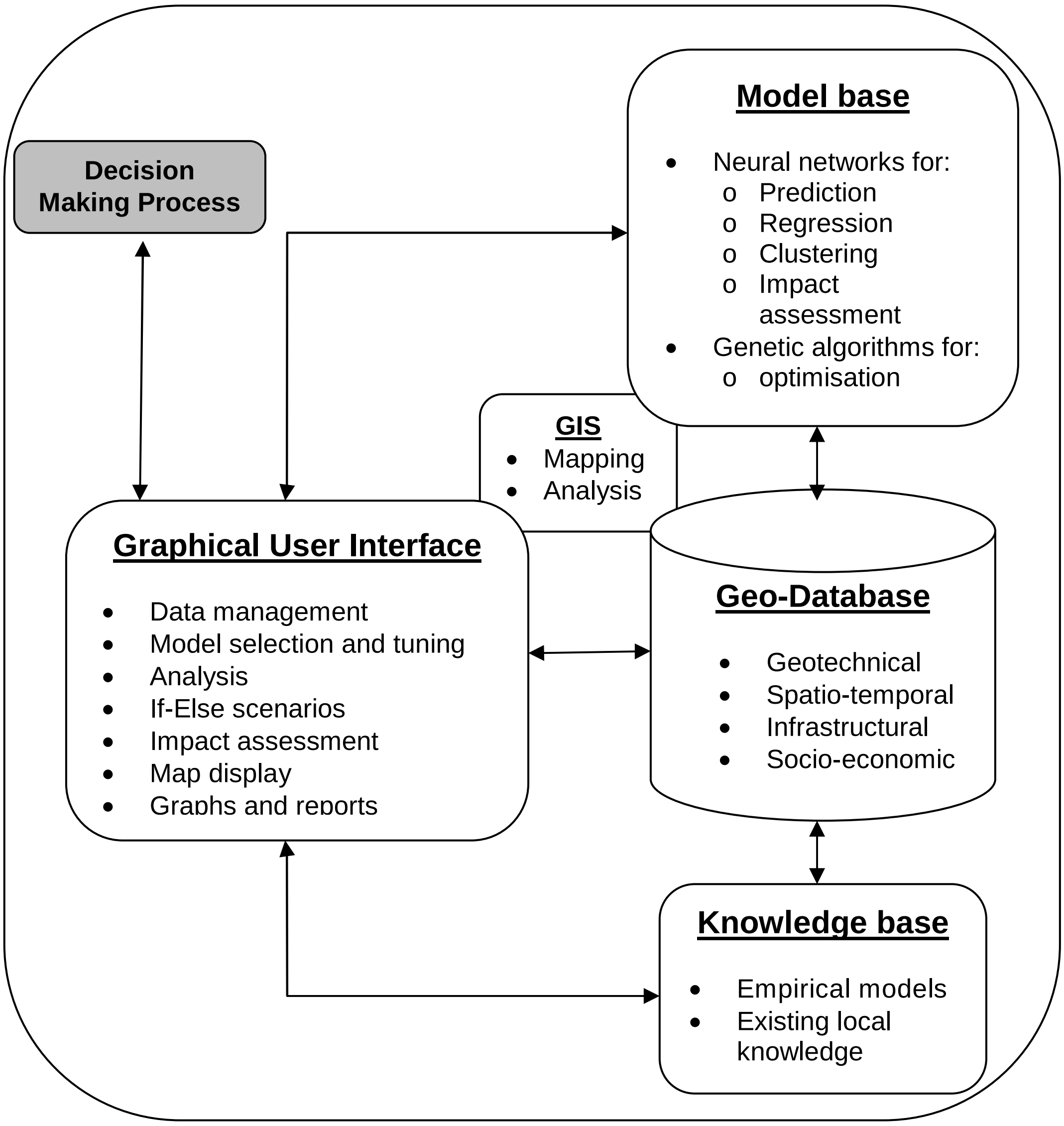


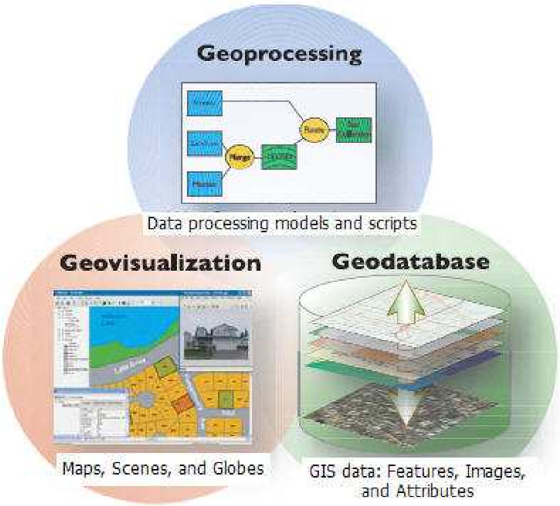
Figure 1: Proposed Framework of the Spatial Decision Support System.

2.1 GIS (Geographical Information Systems)

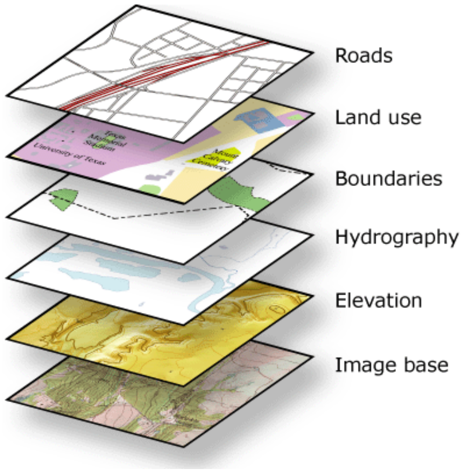
Geographical information systems are software tools used to input, store, manage, retrieve, manipulate, query, analyze and visualize geographically referenced data. GIS systems are widely used covering a range of applications in different disciplines such as earth sciences, health science, social sciences, natural resource management, information sciences, transportation and mobility.

A complete GIS is conceived as a combination of the hardware (server, desktop, mobile devices, data capturing devices), software (commercial, open source, tailor made GIS packages), data (spatial and attribute data like maps, reports, satellite images, RADAR and LIDAR data, weather station data GPS data), methods (overlay, neighbourhood analysis, spatial statistics, multi criteria analysis, analytical hierarchy process) and people (GIS users: data editors, analysts, decision makers). A typical GIS architecture has 2 structural components i.e. Geoprocessing, Geovisualisation and Geo-database as shown in Figure 2(a). The Geo-database consists of several spatial layers with linked attributes. Geovisualisation provides different views of the data as maps, tables and charts etc. Different themes are presented as separate layers called thematic layers as shown in Figure 2(b), and are analyzed together using the overlay analysis.

The Geo-processing component provides GIS analysis and modelling techniques to be applied to one or more spatial layers in the Geo-database.



(a)



(b)

Figure 2: (a) key parts of a GIS[1] and (b) thematic layers and overlay[2].

Several studies highlight the application of GIS and remote sensing in geotechnical engineering. In a study conducted by Wan-Mohamad and Abdul-Ghani (2011)[3], the use of GIS was described in geotechnical engineering for the purpose of processing and viewing information. In a case study in Malaysia, they incorporated soil types and strength at various depths in the form of a GIS for efficient utilization of such available information. Mhaske and Choudhury (2004)[4] also presented work on the use of GIS to produce a soil liquefaction susceptibility map of Mumbai, India for earthquake events.

2.2 SDSS (Spatial Decision Support Systems)

Spatial decision support systems are useful in decision making processes in situations, where the presence of semi-structured spatial decision problems make it difficult for the decision makers to make effective decisions. The idea of a decision making continuum from structured decisions to unstructured decisions have been defined in the litherature[5]. Structured problems are repetitive and can be modelled and programmed whereas un-structured problems are complex and are solved entirely by human beings from the core of their intuition and choice. A semi-structured spatial problem falls in the middle of this decision continuum and are solved by the interaction of decision makers and the decision support systems. Spatial decision support systems (SDSS) bring together the strengths and benefits of GIS and Decision Support Systems to help the decision maker or a group of decision makers in solving a complex and semi-structured spatial problem. SDSS are bespoke software, designed and developed to address a particular domain of problems. SDSS facilitate the decision making process with higher effectiveness and efficiency. Malczewski (1999)[5] suggested different components of an SDSS and their functions. These components are mainly divided into the following three categories:

- Database and management
- Model base and management
- Dialogue generation and management

Ferdinando, et al. (2009)[6] developed a system ARIES (Artificial intelligence for Eco systems) which helps discover, understand, and quantify environmental assets, and what factors influence their value according to explicit needs and priorities. ARIES has different modules covering various spatial dynamics of carbon sequestration and storage, flood regulation, coastal flood regulation, aesthetic views and open space proximity, freshwater supply and sediment regulation. Researchers have used GIS and geotechnical information for informed risk based decision making. In another study Freyre et al. (2010)[7] used GIS and developed an online decision support system for geological risk evaluation i.e. ground fracturing.

The proposed spatial decision support system will include some of these parameters along with others aspects in an integrated format. Figure 3 elaborates the key characteristics of a spatial decision support system:

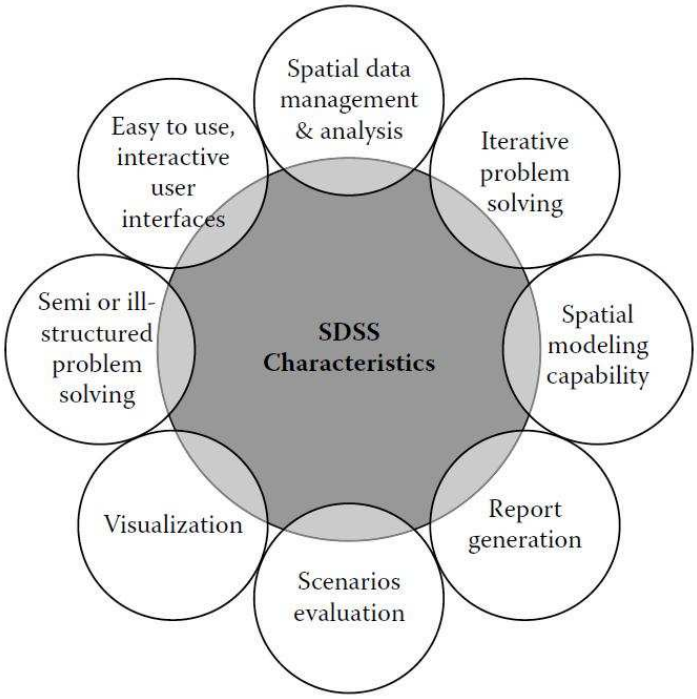


Figure 3: Components of SDSS[8].

2.3 Artificial intelligence based modelling component

Artificial intelligence covers a wide range of computing techniques that help to explain complex processes which are otherwise very difficult to be explained mathematically. These techniques are widely used in interdisciplinary cross cutting research themes to overcome some of the deficiencies of conventional empirical modelling techniques. These intelligent computing techniques are data exploratory in nature and tend to extract hidden knowledge out of the bulk of data (spatial and non-spatial). These techniques include but are not limited to Artificial Neural Network (ANN), fuzzy logic and genetic algorithms.

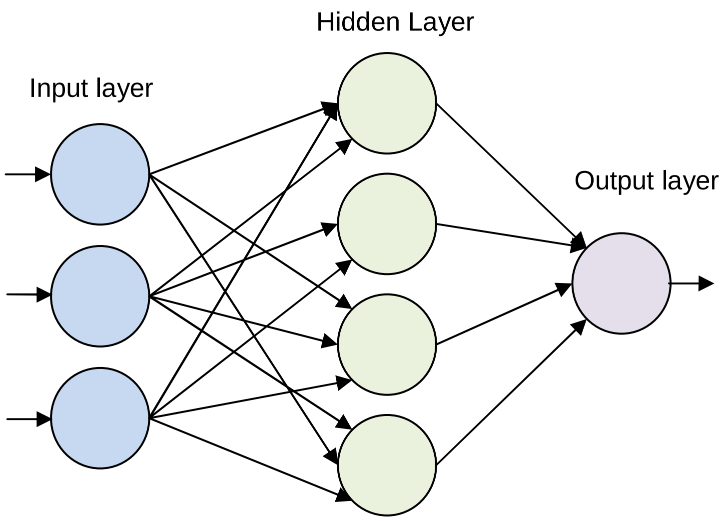


Figure 4: Basic structure of Artificial Neural Network (ANN).

There are different types of Artificial Neural Networks and a variety of usage in different application areas. The general structure of most neural networks is shown in Figure 4. The input and out of the training data is provided at the input and output layer of the neural network. A learning algorithm is used to train the Black Box (the middle layer) to formulate the input output mapping function. The number of hidden layers and number of neurons in different layers can be varied and depends on the application. Genetic algorithms can be used to find the most suitable architecture of the network to suit a particular application area.

Artificial neural networks have been used to solve soil related problems. Park (2011)[9] adopted artificial neural networks to estimate the permeability coefficient of soils using six variables including natural water content, specific gravity and grain size etc. In another study Park and Lee (2011)[10] evaluated the compression index of soils using an artificial neural technique. Khozaghi and Choobbast (2007)[11] used ANN to predict liquefaction hazard mapping.

3 PROPOSED DATASETS AND ANALYSIS

This section identifies and highlights some important datasets and key indicators to be included in the framework.

3.1 Key datasets

In order to supplement the proposed framework of the spatial decision support system, an example list of effective parameters and indicators are suggested here.

Geo-Technical & Geo-Engineering Parameters • Soil data, e.g. o Compressibility o Strength o Permeability o Soil characteristics e.g. salinity, texture, organic content, Ph, plasticity index etc o 3D soil profile • Water table data • Subsurface 3D information e.g. geology, hydro geological, faults etc	**Spatio-Temporal Parameters** • Landuse, land-cover mapping (LULC) • Annual rainfall • Thematic layers of existing infrastructure e.g. roads, railway network, airports, bridges, dams, industrial and commercial structures etc
Infrastructural & Engineering Information • Design parameters • Structural load on unit area • Layout • Mining information o Conventional mines o UCG o CO_2 sequestration o Shale gas	**Socio-Economic Parameters** • Population density and structure • Income levels • Education levels • Multiple deprivation • Soil capital • Access to civic facilities • Community safety • Dominant economic activities

Table 1: Key datasets identified for the framework.

3.2 Modelling processes

For modelling different processes involved in the decision making involved in the whole process the following important considerations have been identified in the current research:

- **Site suitability analysis:** For a particular development based on structural engineering requirements and design parameters, soil stability of the area, structure lifetime concerns from soil underneath, underground geological stability and mining activity underneath and in surrounding areas. Also a socio-economic impact assessment is considered as one aspect of site suitability analysis. There are a number of GIS modelling techniques available for the site suitability analysis and have been used in different application areas. Some useful important GIS modelling and analysis techniques are suggested to be included in the proposed framework i.e. AHP (Analytical Hierarchy Process), SAW (Simple Additive Weighting), overlay analysis and buffer analysis. Some important 3D GIS analytical techniques like terrain analysis, cut and fill and interpolation can also be included in the framework to aid the overall analysis process.

- **Impact assessment:** Economic outcome of the project and anticipated socio-economic dependency of the community on the structure and its linked activities during and after construction. In case of a structural distress due to soil instability caused by either natural or anthropogenic activity. This includes an estimation of the population under threat, surrounding structures that may be affected, socio-economic upheaval. To model the complexities of such processes, the capabilities of GIS and artificial intelligence techniques i.e. ANN (artificial neural networks) are combined together in the framework. GIS analytical capabilities of the framework will be able to answer the questions related to time and space. The artificially intelligent data exploratory techniques learn from past experience and can predict the unknown values based on a suitable network learning technique. These techniques help in overcoming some of the difficulties in conventional empirical modelling techniques i.e. multivariate analysis, nonlinear complex relationship between indicators and assumptions for simplicity of the models.

4 CASE STUDY

Recent studies have postulated that untapped coal reserves in the South Wales area may have the potential to be explored for underground coal gasification (UCG)[12]. A geographical map of the area is presented in figure 5.

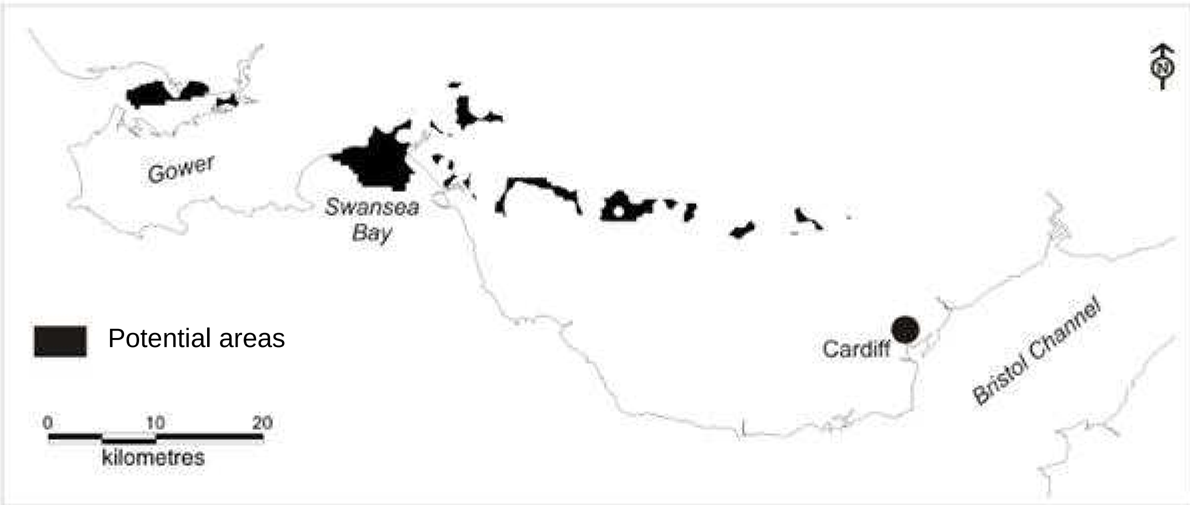


Figure 5: Map showing potential areas for underground coal gasification in South Wales, UK (adopted from Turner et al. 2008)[12].

To demonstrate the use of the approach proposed here, a hypothetical site is selected for a case study, within the potential area illustrated above. The general layout is shown in figure 6. The structural behaviour of an existing bridge is considered using the framework described. This bridge is on highway “M”, crossing river “A”. The highway connects two populated areas and forms part of a highway network. It has been assumed that for the UCG project considered, water is pumped out of the ground, which causes new conditions to be imposed on the soil system which may result in ground deformation. These issues can be considered along with the associated technical and socio-economical impacts.

The framework is used to answer questions such as:

1. How many buildings in the surrounding areas need to be considered?
2. What is the size of population that may be affected?
3. How many people essentially use the bridge to daily commute?
4. The traffic impact on alternate should maintenance work be needed?
5. The economic impact in the region?
6. The social impact on the local community for further UCG projects in the area?

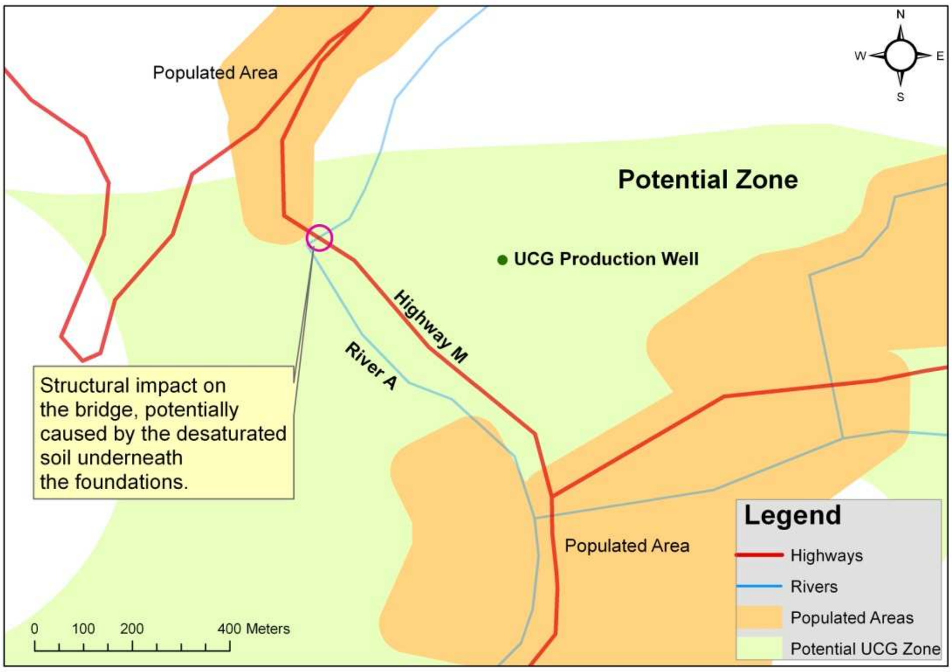


Figure 6: Study area.

5 CONCLUSIONS

In this paper the design of a GIS based framework for site suitability and risk based informed decision has been presented. The framework incorporates a variety of potential parameters and indicators for the overall decision making process. The study also focuses on the identification of GIS based empirical modelling techniques aided with the use of computational intelligence i.e. artificial neural networks for modelling the complexities.

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