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Citation: GODFREY, S. ... et al, 2003. Static risk mapping using a Geographic Information System. IN: Harvey, P. (ed). Towards the millennium development goals - Actions for water and environmental sanitation: Proceedings of the 29th WEDC International Conference, Abuja, Nigeria, 22-26 September 2003, pp. 107-110.

Additional Information:

- This is a conference paper.

Metadata Record: https://dspace.lboro.ac.uk/2134/30013

Version: Published

Publisher: © WEDC, Loughborough University

29th WEDC International Conference Abuja, Nigeria, 2003

TOWARDS THE MILLENNIUM DEVELOPMENT GOALS

Static risk mapping using a Geographic Information System

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Water safety plans (WSPs) are risk management tools designed to assure the safety of drinking water. This paper outlines the development of a Geographic Information System (GIS) to assess and manage risk data which supports the development of the WSP. Findings presented in the paper are based on research undertaken by the Water. Engineering and Development Centre (WEDC) in collaboration with the National Water and Sewerage Corporation (NWSC) and Makerere University in Kampala, Uganda. The research was funded by the Department for International Development (DFID) with the development of the static risk maps being developed between January 2002 and June 2003.

Materials and Methods

This paper focuses on the development of *static* risk maps as opposed to *variable* risk maps for the Kampala water supply network, Uganda. The objective of the paper is to outline the stages of development of a static risk map in a GIS format. See figure 1 for detail of the 4 stages of GIS development. For the purpose of this paper *Geographic Information Systems (GIS)* are defined as computer based facility for storing, analysing and representing geo referenced data. The data sets required for the development of GIS risk maps are two fold:

1. Static Data – Baseline data on the physical state of the infrastructure to reach performance targets and its potential vulnerability to hazard events. This includes pipe attributes (age/material/diameter/length) to define the inherent risk associated with both the infrastructure type and its location
2. Variable Data - Monitoring data related to increased hazardous events and the extent of impact on the pipe network. This include data on pipeline failures (breakage/leakage/discontinuity) (Godfrey, *et al*, 2002)

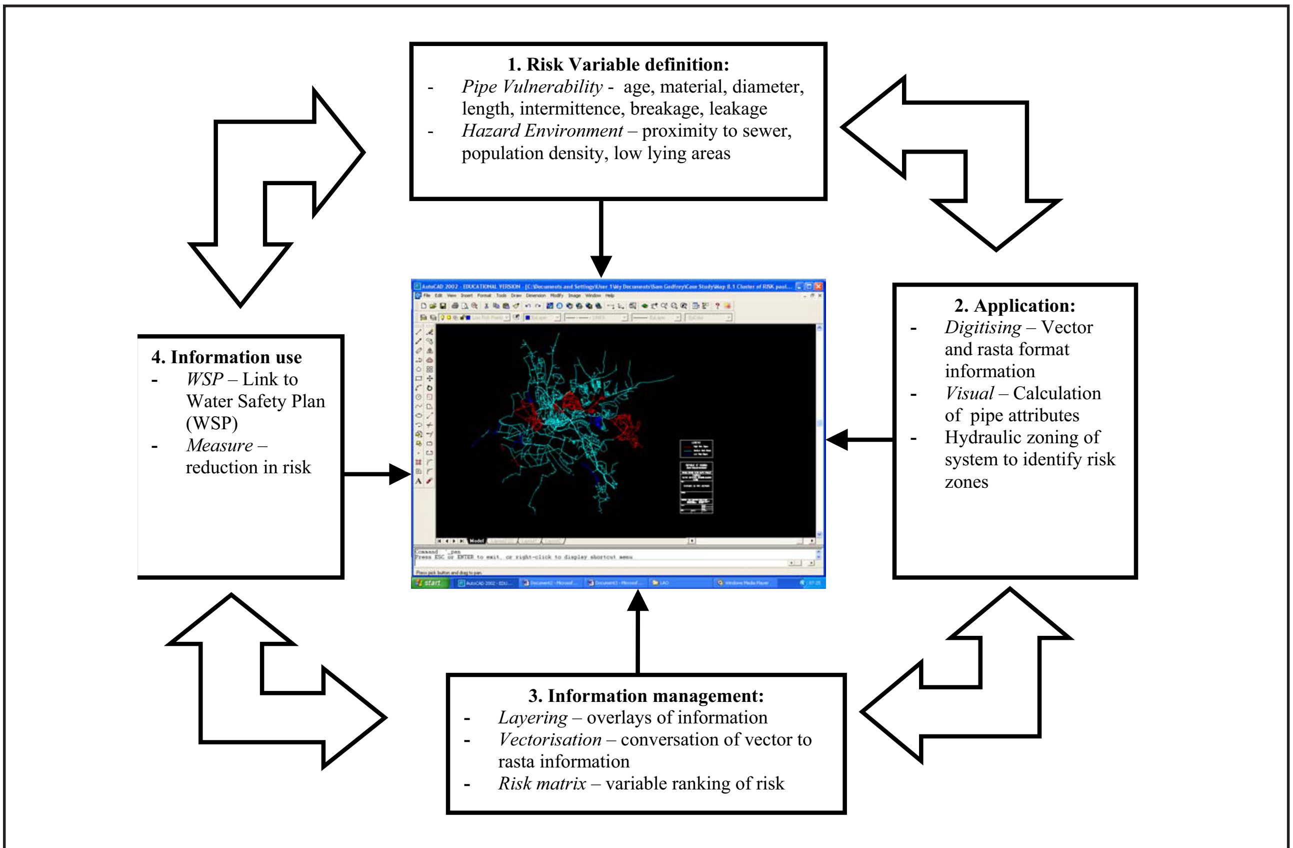

Figure 1. Stages of development of GIS static risk maps

This paper will focus on the development of *static risk maps* . The topic of *variable risk maps* will be the subject of future papers.

Stage 1: Risk Variable Definition

The approach involved the identification of the *source-pathway-receptor* relationships to identify specific risk variables that result in an increase in potential *hazardous* microbial contaminants entering the system at identified points of *vulnerability*. Conceptually, risk was therefore defined as:

RISK = HAZARD + VULNERABILITY

Where:

- Hazard = *specific biological, chemical or physical agents that cause an adverse health effect (Davison* et al, *2003).*
- *Vulnerability* = susceptibility of the infrastructure to a hazard event (Howard *et al,* 2002)

Data requirements for *hazards* can be divided into *hazardous environments* and *hazard source*. The *hazard source* would include areas of high faecal loading (i.e. areas of high population density) and *hazard environment* as areas of increased potential occurrence of hazard source (e.g. sewered zones, areas with on site sanitation or low lying areas). Low-lying areas are of particular importance due to the probability of cross contamination of water mains from on-site sanitation and/or sewers, through leaching of contaminants in water logged areas; potential for back-siphonage where intermittence and/or leaks occur.

Stage 2: Application

To model the *source* of potential hazardous contaminant, parish-level administrative boundaries were digitized as polygons from existing paper maps obtained from the Department of Surveying, Entebbe, Uganda. Using the national census figures (1991) and applying a 4.7% growth rate taken from UNDP (1999), the population for each parish was computed. By dividing this estimated population with the corresponding parish area, the population density for each parish was calculated. Based on the derived figures, the parishes were categorized by population density into high, medium, low and very low. This information was then thematically plotted onto the parish boundary layer, through colour-coded shading of the respective parish polygons.

To identify the hazardous *environments*, a digital topographic map of the study area was overlaid with the pipe network layer, highlighting the low-lying areas within the system. Similarly, the water and sewer network layers were combined to locate areas of close proximity between the two. This information was supplemented by facts gained/obtained from the system operator (OSUL) concerning known points of vulnerability such as location of exposed pipes, faulty valves, etc.

Modeling the vulnerability of the pipe infrastructure to hazard events necessitated consideration of both physical pipe attributes and historical sanitary risk data from activities by Kampala City Council (KCC). For the former, data compiled and maintained by OSUL was used, comprising length, diameter, material and age of each pipe section. This data had been compiled by on-screen measurement of pipe lengths from Universal Transverse Mercator (UTM) digital blockmaps covering the supply area, the other attributes being derived from as-built documentation.

Figure 2 opposite illustrates the various layers established to represent hazard and vulnerability in the GIS risk model.

Sanitary risk data consisted of historical records of leakage, breakage and supply intermittence. Because of an initial lack of risk data from NWSC, parish-based data from a previous urban surveillance project in Uganda was used. The data, collected by environmental health staff from KCC, was assigned scores based on the reported numbers of occurrences of leakage, breakage and discontinuity. The high-score areas were then plotted as layers on the GIS platform, providing a visual representation of the data.

In order to understand the hydraulic behaviour of the system and to identify suitable field inspection and monitoring points, network drawings were scrutinized by the WSP steering group, guided by institutional knowledge availed through the participation of NWSC and the system operator. Through this process hydraulic zones of influence, or supply zones, were identified and demarcated. These zones were digitised as a layer in the model. Within the supply zones, 182 inspection points were identified based on 12 selection criteria established through consultation between the WSP steering group and the Water Quality Control Department. The inspection points were tentatively marked on blockmaps provided by OSUL. A field assessment of these points was subsequently undertaken, during which GPS coordinates were obtained for each point. The points were then plotted as a layer on the GIS platform, in order to facilitate the relating of sanitary inspection and water quality monitoring data from these points to corresponding sections of the pipe network.

Stage 3: Information Management

Data for each of the inspection points was used to define the static vulnerability for that particular section of the Kampala network. This included the use of physical attributes of the related pipe sections (length, diameter, material, age) as well as sanitary risk data (history of leakage, breakage and supply intermittence). This vulnerability score was then combined with data on hazard environment and hazard source to comprise an additive risk score for each inspection point. These scores were plotted as point data onto the GIS platform.

As illustrated in Figure 2, the establishment of individual layers representing each component of the risk model facilitated spatial overlay and integrated analysis of the various datasets, leading to the eventual production of an overall static risk map of the system. One of the primary outputs of the layering was the derivation of scores used to quantify each variable within a risk matrix. To achieve this a process of vectorisation was used where risk scores for individual points with in the network were related to pipe numbers. Vectorisation is commonly defined as raster to vector conversion which is the process of converting an image made up of raster cells into one described by vector data (Ormsby, 2001). To achieve this in the Kampala network, the rasta point was identified on the pipe. Outlet nodes surrounding the point were then identified and through the process of vectorisation estimated distances for risk values were computed on to the GIS platform.

Stage 4: Management tool

It is acknowledged that the process of identifying vulnerability, hazards and determining overall risk is a useful process. However, the results of these risk assessments may not be readily understood by decision makers and managers (Howard *et al,* 2002). The use of GIS is important to illustrate that risk estimates may vary over time in response to changing variable risks and remedial actions. The GIS risk maps should be periodically updated with variable risk data in order to further identify areas of increased/decreased risk. The use of water quality software databases such as SANMAN could aid the processing of variable risk data.

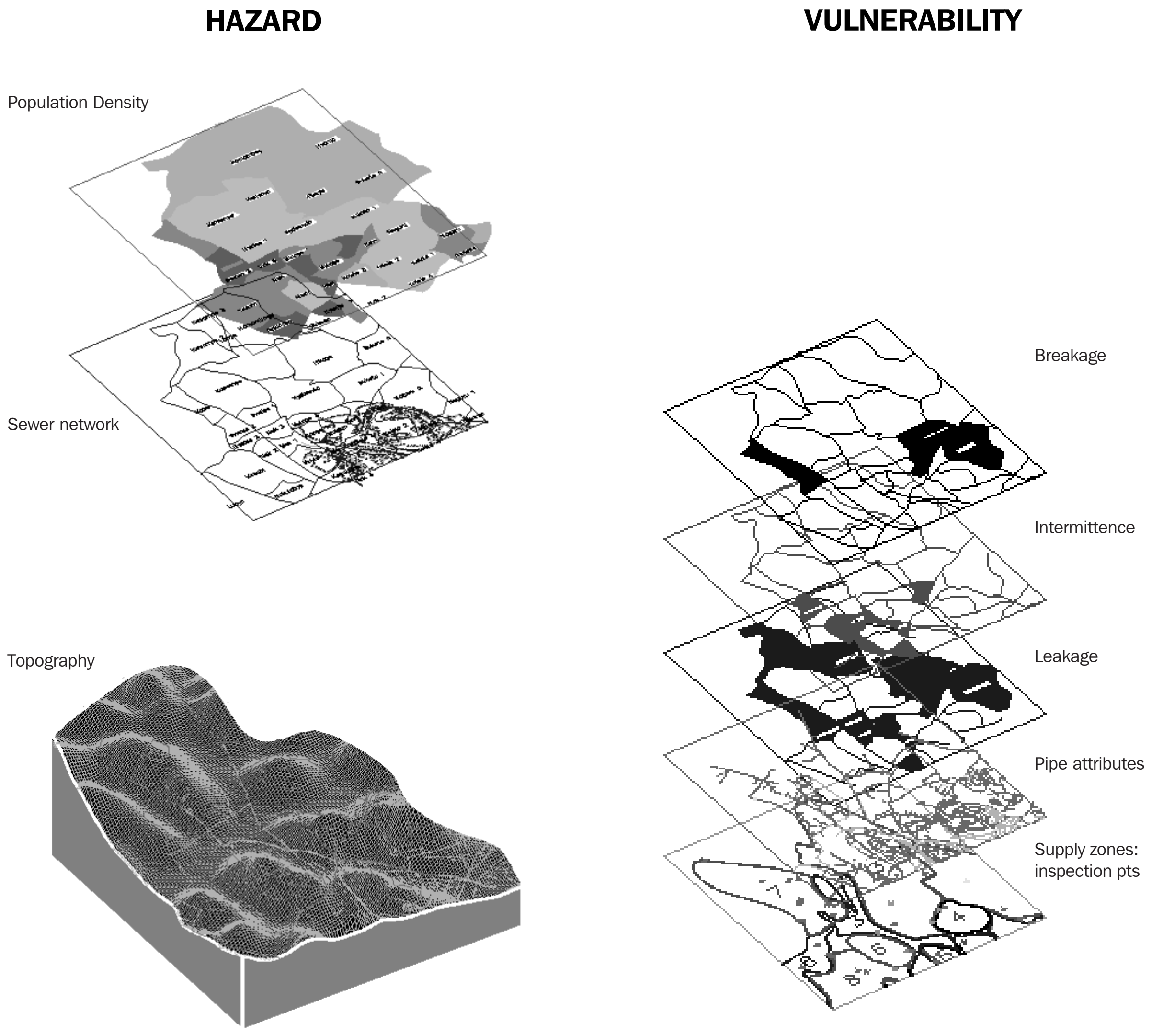

Figure 2. Layers used in GIS Model

Conclusions

The use of GIS static risk maps can greatly assist water supply operators in the assessment and management of risk. GIS is an appropriate tool to assist managers and decision makers in visualising the multi variables that make up risk. Through the use of GIS variable changes in risk can further be recorded.

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