Developing a GIS- and QRA-based Hazard-Analysis-Critical-Control-Point-System (HACCP) for drinking water abstraction

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1. Background

Principles of quality assurance for drinking water supplies were already applied over the past years in Germany, for example the multi barrier approach, that includes all steps of water supply, beginning with the protection of raw water quality in the catchment area. However, European and national legislation still emphasizes the control of the "end product drinking water". Recently, the formalization of quality management programs for drinking water emerged, in particular the application of HACCP (Havelaar 1994) which comprises the identification of hazards concerning product quality and determination of so called critical control points (CCP) including all steps of the water supply chain.

In the context of this research project, a process oriented concept for risk and surveillance management based on HACCP principles of quality assurance and quality management is implemented. The establishment of critical control points and the definition of critical limits emphasizes on the process of drinking water abstraction in the catchment area and is based on (semi)-qualitative and quantitative risk assessment.

Catchment management and source water protection provide the first barrier for the protection of water quality. Once the potential hazards and their causes have been identified, the level of risk associated with each hazard must be estimated so that priorities for risk management can be defined (NHMRC 2002).

2. Combining HACCP and GIS

The characterisation of the catchment area comprises the collection of geo-ecological data, the analysis of raw water quality and the survey of potential hazards. The data management is conducted via Geographical Information Systems (GIS). Such a GIS-supported HACCP-Concept is implemented for a catchment of ground water abstraction in Germany .

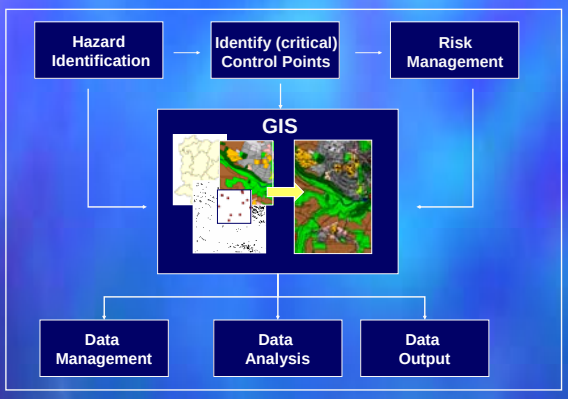

Fig. 1 : HACCP and GIS

In order to exploit full capabilities of GIS as a general-purpose tool for handling spatial data, its functionality must be extended far beyond the classical means of data storage, manipulation and visualisation. Spatial and geostatistical analysis methods, in particular interpolation techniques, emphasize the investigation of the catchment area predicting unknown values for sample point locations.

3. Characterisation of the catchment

The municipal utility Niederkassel is one of more than 6,000 water suppliers in Germany. The catchment of Niederkassel (35 km² with 36,000 supplied inhabitants) is situated in the densely populated area Cologne/ Bonn near the river Rhine in North Rhine-Westphalia. Two wells in the northern part of the catchment produce groundwater without further drinking water treatment (only deacidification, no chlorination). Agricultural activities dominate in the catchment area.

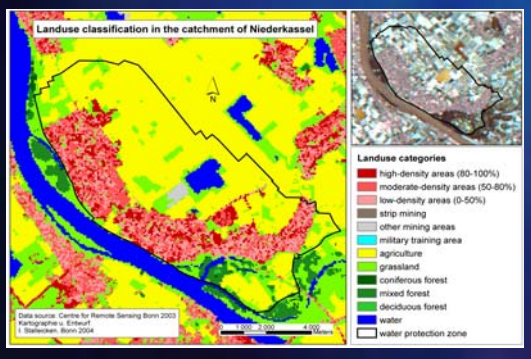

Fig. 2: Landuse classification with Landsat ETM +, 30 metres resolution

4. Risk mapping

In order to identify areas of higher or lower risk in the catchment, a semi-quantitative **risk mapping** was conducted. Fig. 3 classifies groundwater hazards after characterizing land use in the catchment.

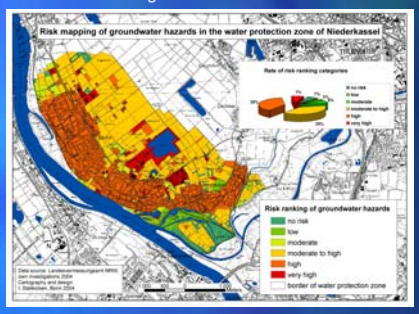

Fig. 3: Risk mapping of groundwater hazards

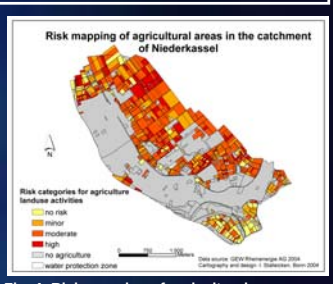

Fig. 4: Risk mapping of agricultural areas

Fig. 4 categorizes groundwater risks from agricultural activities depending on the type of cultivation, crop rotation and nitrate eluviation, for example specialized crops (strawberries, cabbage, fruit trees) are high risk areas, root crops are lower risk areas.

5. Hazard Identification

Table 1: Identification of groundwater hazards in the catchment of Niederkassel

Potential hazard	Cause	Localisation	Likelihood	Severity
Agricultural pollution: nitrate	Use of inorganic and organic fertilisers in the catchment area	Agricultural areas of water protection zone	almost certain	moderate
Agricultural pollution: pesticides	Use of pesticides in the catchment area	Agricultural areas of water protection zone	almost certain	minor
Recharge by river rhine	Infiltration of surface water (river Rhine) into the aquifer because of high level of the river rhine and rising ground water levels	Water protection zone III	moderate	minor
Oil pipeline	Leakage of mineral oil from active oil pipeline	Wells and northern water protection zone I	rare	major
Microbiological contamination: sheep	Grazing sheep near the wells	Water protection zone I	unlikely	minor
Ingress of chemicals into the groundwater	Ingress of chemicals from private gardens into the groundwater	Private gardens	unlikely	minor
Gravel mining: microbiological and chemical contamination	Leaching chemicals and pathogens into the groundwater because of gravel mining	Gravel mining water protection zone III	rare	moderate
Ingress of contaminants: drains	Leakage from drains cause ingress of contaminants	Drains in the water protection zone	rare	moderate
Ingress of hydrocarbon fuels into the groundwater	Leaching of hydrocarbon fuels into groundwater from tanks and filling stations	Filling stations	rare	moderate

Recharge by river Rhine

Fig. 5 shows the groundwater flow in the catchment of Niederkassel depending on the local groundwater level. In this example **Spline interpolation** is used to minimize overall surface curvature, resulting in a smooth surface.

This method is best suitable for gently varying surfaces, such as elevation, water table heights or pollution concentrations (McCoy, Johnston 2002).

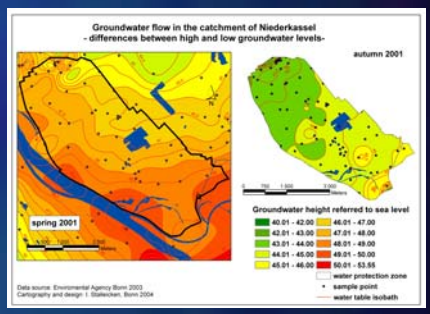

Fig. 5: Groundwater flow in the catchment of Niederkassel

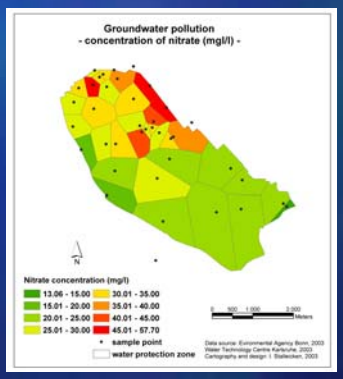

Fig. 6: Groundwater nitrate contamination in the catchment of Niederkassel

Groundwater nitrate contamination

Interpolation methods require a sufficient quantity of observations to model spatial autocorrelation of the population (Thayer 2003). When the number of observations is insufficient to use interpolation, **Thiessen polygons** can be created so that every location within a polygon is the closest to the sample point in the polygon. In Fig. 6 Thiessen polygons are built to have a general impression about the nitrate groundwater pollution. By assigning weights to each observation (weights which are proportional to the area of the polygon), the spatially arithmetic mean of the sample can be calculated (26.36 mg/l in 2002).

The development of an adapted GIS-based HACCP-system for a concrete drinking water abstraction will allow important insights for its applicability in Germany and initiates the German perspective of the world-wide discussion of HACCP for drinking water supply.

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