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Assessment of groundwater contamination by nitrate leaching from intensive vegetable cultivation using geographical information system

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Abstract

This study employed the Geographical Information System (GIS) technology to investigate nitrate contamination of groundwater by agrochemical fertilizers in the Kakamigahara Heights, Gifu Prefecture, central Japan. Thematic information and chemical data of groundwater from the Heights were analyzed in a GIS environment to study the extent and variation of nitrate contamination and to establish spatial relationships with responsible land use types. The high and correlated concentrations of Ca^{2+}, Mg^{2+}, SO_4^{2-}, and NO_3^- reflected the polluted nature of the unconfined highly permeable Kakamigahara aquifer. Ninety percent of the water samples showed nitrate concentrations above the human affected value (3 mg/l NO_3^-), while more than 30% have exceeded the maximum acceptable level (44 mg/l NO_3^-) according to Japan regulations. The spatial analyses indicated that groundwater contamination by nitrate is closely associated with one specific land use class, the ''vegetable fields''. The nitrate concentration of groundwater under vegetable fields was significantly higher than that under urban land or paddy fields. Most of the unacceptable nitrate levels were encountered in boreholes assigned to ''vegetable fields'' but a few were also found in boreholes allotted to ''urban'' class. Therefore, the vegetable fields were considered the principal source of nitrate contamination of groundwater in the Kakamigahara. However, contamination from urban sources is also possible.

Keywords: GIS; Nitrate contamination; Land use; Vegetable cultivation; Kakamigahara; Gifu, Japan

1. Introduction

Many regions all over the globe are entirely depending on groundwater resources for the various uses. Contamination by different pollutants might render groundwater unsuitable for consumption and put human and animal life as well as the whole environment at great risk. Nitrate is the most frequently introduced pollutant into groundwater systems (Spalding and Exner, 1993). Groundwater contamination by nitrate is a globally growing problem due to the population growth and increase of demand for food supplies. It usually originates from diffuse sources, such as intensive agriculture and unsewered sanitation in densely populated regions, or point sources such as irrigation of land by sewage effluent (Keeney, 1986; Bouchard et al., 1992; Eckhardt and Stackelberg, 1995; McLay et al., 2001). The adverse health effects of high nitrate levels in drinking water are well documented (Walton, 1951; Fan et al., 1987; Gangolli et al., 1994; Ward et al., 1994; Fan and Steinberg, 1996). The most well known are methemoglobinemia, gastric cancer, and non-Hodgkin's lymphoma. Groundwater with nitrate concentration exceeding the threshold of 3 mg/l NO_3^--N or 13 mg/l NO_3^- is considered contaminated due to human activities (the so-called human affected value; Burkart and Kolpin, 1993; Eckhardt and Stackelberg, 1995). However, the maximum acceptable concentration of nitrate for potable water according to the World Health Organization (WHO) is 11.3 mg/l NO_3^--N or 50 mg/l NO_3^-. To protect the valuable groundwater resources, several approaches were developed to predict and estimate nitrate contamination from different sources. One approach is applying solute leaching models (Addiscott and Wagenet, 1985), which are difficult to calibrate and their boundary conditions cannot be easily satisfied in complex land use systems and nonuniform strata (McLay et al.,

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