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Identification of nitrate long term trends in Loire-Brittany river district (France) in connection with hydrogeological contexts, agricultural practices and water table level variations

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The European Union (EU) has adopted directives requiring that Member States take measures to reach a "good" chemical status of water resources by the year 2015 (Water Framework Directive: WFD). Alongside, the Nitrates Directives (91/676/EEC) aims at controlling nitrogen pollution and requires Member States to identify groundwaters that contain more than 50 mg NO3 L-1 or could exceed this limit if preventive measures are not taken. In order to achieve these environmental objectives in the Loire-Brittany river basin, or to justify the non achievement of these objectives, a large dataset of nitrate concentrations (117.056 raw data distributed on 7.341 time-series) and water table level time-series (1.371.655 data distributed on 511 piezometers) is analysed from 1945 to 2007. The 156.700 sq km Loire-Brittany river basin shows various hydrogeological contexts, ranging from sedimentary aquifers to basement ones, with a few volcanic-rock aquifers. The knowledge of the evolution of agricultural practices is important in such a study and, even if this information is not locally available, agricultural practices have globally changed since the 1991 Nitrates Directives. The detailed dataset available for the Loire-Brittany basin aquifers is used to evaluate tools and to propose efficient methodologies for identifying and quantifying past and current trends in nitrate concentrations. Therefore, the challenge of this study is to propose a global and integrated approach which allows nitrate trend identifications for the whole Loire-Brittany river basin.

The temporal piezometric behaviour of each aquifer is defined using geostatistical analyse of water table level time-series. This method requires the calculation of an experimental temporal variogram that can be fitted with a theoretical model valid for a large time range. Identification of contrasted behaviours (short term, annual or pluriannual water table fluctuations) allows a systematic classification of the Loire-Brittany superficial aquifers. The nitrate dataset shows too many irregularities to employ traditional time-series approaches such as linear regression trend tests. The non-parametric Mann-Kendall (MK) test is a robust statistical trend detection test that does not require verification of the normality of the dataset (Aguilar et al, 2007). Moreover, this test seems appropriate since it is less sensitive to missing or outlier data than a simple linear regression test. As the MK test can only detect monotonic trends, and as already done by Stuart et al., (2007) and Broers and Van der Grift (2004), the trend analyses are decennially partitioned in order to identify possible trend reversals for the studied period for each observation point. The trend identification is then spatialized by the use of the Kendall Regional (KR) test on homogenous zones characterized by their geology, their agricultural practices and their piezometric behaviour. The KR test, previously used by Frans and Helsel (2005) in the Columbia Basin Ground Water context, is quite similar to the MK test and consists of the creation of virtual regional boreholes using networks of boreholes located in the homogenous zones. This test allows the identification of regional monotonic trends, even in the zones where nitrate time-series are too small to detect significant trend per observation point.

The MK test results show significant upward trends in nitrate concentrations in the Loire-Brittany superficial aquifers when the test is computed on the 1945-2007 period. However, the decennial MK test shows different behaviours at smaller time scale. Some zones are characterized by a constant and significant increase in nitrate concentrations since 1945 (North-East of Brittany, North of Beauce) whereas others show a trend reversal (South of Brittany, Callovo-Oxfordian marls between Le Mans and Alençon, under covered Jurassic limestone around Poitiers). Furthermore, some rare zones show an increase in nitrate concentrations that follow a significant

downward trend period (Orléans). In the nineties, a transition period may have occurred with a higher proportion of upward than downward trends (82 % against 7 % respectively) for the 1980-1990 period and a lower proportion of upward than downward trends for the 2000-2007 period (37 % against 51 % respectively). Combined with the analyse of the current groundwater nitrate concentrations, the KR test reveals zones where trends in nitrate concentrations have been significantly raising with high nitrate current mean values (> 50 mg NO3 L-1). On the other hand, some zones show a significant regional downward trend since 1995 and low current nitrate concentrations (< 20 mg NO3 L-1). Causes of trend reversals cannot be determined by the MK and KR statistical trend analyses, but the cross analyse of nitrate and water table level time-series gives a hint of a positive correlation between these two variables. Evolution of nitrate concentrations in superficial aquifers may thus depend on a combined effect of changes in both agricultural practices and evolution of water table levels linked with climatic context.

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