**Designing vulnerable zones of nitrogen and phosphorus transfers to control water pollution in China**

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It has been reported that 31% of the rivers and six of nine major coastal bays in China have suffered from eutrophication, caused by elevated concentrations of nitrogen (N) and phosphorus (P). In addition, >60% of the monitored drinking water wells are severely contaminated, classified as level IV (I-V, where V is the worst) or worse1,2. Transfers of N and P from agriculture are the main contributors to the poor water quality2.

China has recently introduced water protection policies to address nutrient transfers to vulnerable watercourses, such as the 2015 Water-Pollution-Prevention-Control-Action -Plan. However, this policy focuses on the management of industrial effluents and includes only two mitigation strategies related to agriculture: (i) relocation of livestock farms outside the highly populated regions, and (ii) reduction of chemical fertilizer use to increase recycling of manure in crop production. These actions have been implemented without identifying the key regions that are vulnerable for NO3- and P leaching from agriculture to groundwater and surface waters. As a result, such policies may not have the desired effect in reducing N and P contamination in waters.

**Designation and Role of Nutrient Vulnerable Zones in China**

Nutrient Vulnerable Zones (NVZs) to control N and P use have the potential to reduce water pollution and increase the effectiveness of policies to protect water quality. However, such zones do not exist for Chinese water systems yet. NVZs have been introduced in United States (US) and European Union (EU) where significant contamination of water bodies by N and P from agricultural sources has occurred. The Nitrates Directive was implemented in the EU in 1991 and Clean Water Act was introduced in the US in 1972. All EU member states have to designate NVZs (<https://water.jrc.ec.europa.eu/arcgis/apps/webappviewer/index.html?id=efab8e6ac9a840a086b63eed76094b3b>), defined as areas of land draining to waters that are affected by NO3- pollution or that could be affected if action is not taken to decrease NO3-leaching. In these NVZs, a number of key actions have to be taken to reduce NO3- leaching. As a result, nitrate leaching reduced by 16% between 2000 and 2008, and thereby water quality in NVZs is improving in the EU 3, and eutrophication of surface waters has been be prevented. The Clean Water Act in the US aims to reduce both N and P transfers to watercourses. Different states are required to submit a list of polluted and threatened watercourses and establish priority actions to reduce N and P pollution of surface water bodies4.

We argue for a need to design NVZs for Chinese agricultural systems. The criteria for the design of such nutrient vulnerable zones (for N and P losses to water) should include the following elements: (i) Information about the current eutrophication status of waters, based on monitoring data of NO3- and P concentrations in surface waters and groundwater; (ii) A comprehensive evaluation of the risks of NO3- and P leaching to groundwater from agriculture at regional levels; (iii) A comprehensive evaluation of the risk of N and P runoff to surface waters, and (iv) Risk analysis of nutrient losses to water from manure management. The regions where N and P concentrations are already excessive should be termed Vulnerable Zones, where immediate policies and actions should be implemented. Regions with high risk of N and P losses should be deemed as potential Vulnerable Zones, where further monitoring of N and P in the watercourses needed.

Designation of the NVZs is possible for China because of the existing information and knowledge. We combined existing information to support our views on the potential of designing the NVZs for China (Fig 1). We used the most recent monitoring data for NO3- concentrations in groundwater1,2 and surface waters2, and a comprehensive evaluation of the risks of NO3- and P leaching and runoff in more than 2000 counties in 20125 toshow the extent of N and P Vulnerable Zones (NPVZs) in agricultural land in China (Fig 1). This illustrative example shows that the total area of NPVZs cover around 68 million ha arable land (51% of the agricultural land), of which 20% is potential NPVZs.

**Implications for Research, Policy and Practice**

We demonstrated an approach to designate NPVZs in China using existing data, and we provide an illustrative example in Fig 1. However, this is a first example with designations of NPVZs based on limited data and broad assumptions, so more research is needed to improve the quality of NPVZs designation, by quantifying surface water and groundwater contamination (and water table depth) at the regional level, and aggregating smaller areas of NPVZs into larger NPVZs to facilitate more efficient control and monitoring of action programs. Furthermore, NPVZs could become part of the recently implemented water protection policies, so that effective measures are targeted at the regions with highest N and/or P pollution.

Scientists also need to develop an action program for each NPVZ, including measures to reduce N and P leaching and runoff, e.g. by determining maximum N and P application rates for specific crops based on balanced fertilization to avoid over-fertilization. A coordinated program of national field experiments will be needed to quantify optimal nutrient application rates, also allowing for nutrients and their availability in manures, depending on crop type, soil type, climate and yield level.

Policy makers and scientists should work together to develop a cost-effective monitoring and reporting system. Standard methods for measuring water quality, and NO3- and P leaching and runoff concentration should be developed and widely applied to monitor the effectiveness of the nitrate action programs in NPVZs. A system to control and enforce the implementation of the mandatory measures should be developed, e.g. by recording the use of fertilizers and manure to assist nutrient management planning. Guidelines for farmers to apply the measures and to implement best available N and P management practices have to be developed, and a knowledge communication program designed to train farmers and extension officers.

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Figure 1. An illustrative example of nitrogen (N) and phosphorus (P) Vulnerable Zones (NPVZs) in China.

*Note: Map was made based on existing data about: i) current surface and ground water contamination****1,2****; ii) N and P leaching and runoff risk per hectare of agricultural land at the county level* ***6****; iii) N and P runoff risk per hectare of agricultural land at the county level* ***6****.*