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Nitrogen and phosphorus modelled in freshwater eutrophication: The director's cut

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Abstract

Existing spatially-explicit freshwater eutrophication indicators focus on phosphorus as the sole contributor to the impacts, although nitrogen may be a limiting factor too. We developed Fate Factors (FFs) for both dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP), distinguishing emissions from soil and emissions to freshwater. The fate processes modelled include nutrient attenuation from land to stream, in the river network, in reservoirs and lakes, and associated with water consumption. FFs were calculated at a river basin resolution with a global coverage. Preliminary emission-weighted global average FFs are (in days) FF_soil_DIN = 117; FF_river_DIN =251; FF_soil_DIP = 21; FF_river_DIP = 241. The present fate model is consistent with recent advances in marine eutrophication impacts assessment and complements such an approach.

Keywords: *Freshwater eutrophication; Nutrient; LCIA; Global; Spatially-explicit.*

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1. Introduction

Most Life Cycle Impact Assessment (LCIA) methods to date estimate freshwater eutrophication impacts from phosphorus (P) emissions only (Helmes et al. 2012, Struijs et al. 2009). This baseline assumption is not representative of the numerous freshwater systems across the world where eutrophication is nitrogen (N) limited or N and P co-limited (e.g. Lake Taupo in New Zealand (Pearson et al. 2016), rivers in Ireland (Elsaholi and Kelly-Quinn, 2013), lakes in Canada (Ogbebo et al., 2009)). As a result, for freshwater eutrophication impacts assessment, there is a need to account for the contribution of N to freshwater eutrophication as well, in those cases (Payen and Ledgard 2017).

A comparison of eutrophication impact assessment indicators showed that farm inputs are an important determinant of the impacts, but the fate modelling (transport, attenuation) and the sensitivity of the receiving compartment are also crucial (Payen and Ledgard 2017). Given the globalization of current product chains and the ubiquity of the emission sources within, it is paramount to have both site-specificity and global coverage embedded in the characterisation factors for freshwater eutrophication.

The objective of this work was to develop Fate Factors (FFs) for both N and P nutrients, at a worldwide river basin resolution.

2. Material and methods

The proposed FF model work accounts for the attenuation processes of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) in soil, rivers and lakes. The method discriminates two emission routes: diffuse emission from soils ($FF_{\_soil}$) and point emission to freshwater ($FF_{\_river}$). The model input parameters used, correspond to the removal coefficients developed in the Global Nutrient Export from WaterShed 2 (NEWS2-DIN and NEWS2-DIP) models suite (Mayorga et al. 2010) and water residence time in lakes from the extensive HydroLAKES database (Messager et al. 2016). The resulting FFs represent the persistence of the fraction of the original DIN or DIP emissions in the freshwater system. The fate processes modelled include nutrient attenuation (i) from land to stream, (ii) in the river network, (iii) in reservoirs and (iv) associated with water consumption (Mayorga et al. 2010). A missing component in Global NEWS2 is nutrient attenuation in lakes. For that, we used the water residence time of 1,420,891 lakes across the world (Messager et al. 2016) to estimate N and P attenuation, using Nixon et al. (1996) empirical relationships. These express the fraction of N or P inputs that are exported, as a function of the water residence time in lake and estuaries.

FFs are modelled at an individual river basin resolution and are also aggregated at a country and global scales using an emission-based weighting scheme. Emissions per individual river basin were obtained from the NEWS2 models.

All calculations were performed using a GIS software package (ArcGIS Pro v.2.0).

3. Results and discussion

Four sets of FFs were obtained corresponding to two emission routes (nutrient emitted from soil and emitted to river) and two nutrients (DIN and DIP), namely $FF_{\_soil\_DIN}$; $FF_{\_river\_DIN}$; $FF_{\_soil\_DIP}$ and $FF_{\_river\_DIP}$. Among 6,081 river basins in the world, preliminary FFs show 4 and 7 orders of magnitude variation for DIN and DIP emissions from soil, and 2 and 3 orders of magnitude variation for DIN and DIP emissions to river. Figure 1 shows $FF_{\_river\_DIN}$ at the river basin scale. Preliminary results of emission-weighted global average FFs show (in days) $FF_{\_soil\_DIN\ Global} = 117$; $FF_{\_river\_DIN\ Global} = 251$; $FF_{\_soil\_DIP\ Global} = 21$; $FF_{\_river\_DIP\ Global} = 241$.

A comparison of these results with FFs for P developed by Helmes et al. (2012) of $FF_{\_river\_DIP} = 130$ days shows that we obtained higher FFs (241 days). This difference may not only be due to differences in the model used, but also to a different FFs aggregation rule, as Helmes et al. (2012) used human population density whereas we have used DIN and DIP emissions per river basin.

A comparison with European FFs for P emitted to river available in ReCiPe 2008 (Struijs et al. 2009) (111 days) and Helmes et al. 2012 (40 days) shows that we obtained values within that range, i.e. $FF_{\_river\_DIP\ Europe} = 68$ days.

The only comparison possible regarding FFs for N emitted to river, is with European values from ReCiPe 2008 (Struijs et al. 2009) (110 days) which shows that we obtained lower values with $FF_{\_river\_DIN\ Europe} = 74$ days.

When comparing FFs for P emission from soil with P emission to river, we obtained values that are 11 times higher for direct emission to water, which is in the range of previous work with factors ranging from 7 (Potting et al. 2005), 18 (Struijs et al. 2011), and 20 (Huijbregts and Seppälä 2001).

The main limitation of this work is the use of lake water residence time as a proxy for nutrient residence time in lakes. Future work will investigate the use of an empirical relationship based on a larger dataset specific for lakes and rivers. A sensitivity analysis on the parameters (exported fraction and water residence time) still have to be performed.

Another limitation, is the resolution imposed by the NEWS2 model not distinguishing fate within river basin sections or at smaller spatial units. This can be an issue for large river basins, where significant differences in nutrient attenuation rates per river section or spatial unit may bias the FF estimation. Higher spatial resolution modelling is currently under testing in New Zealand.

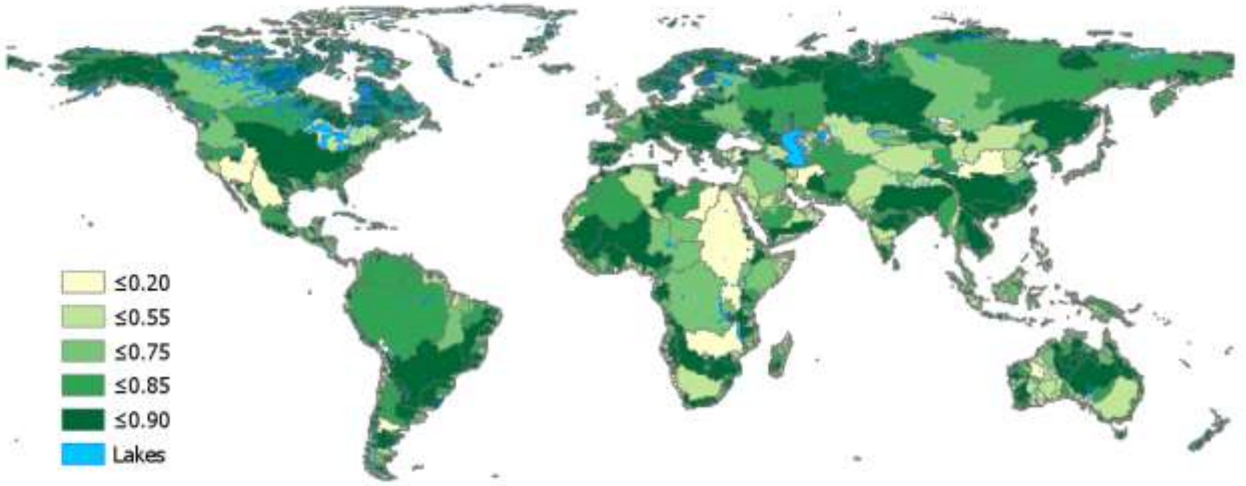

Figure 1. Fate Factors (FF) for dissolved inorganic nitrogen (DIN) emitted to river ($FF_{\_river\_DIN}$, in [yr]), calculated at the river basin scale and global coverage (green color gradient). Nutrient attenuation in 1,420,891 lakes (in blue) was accounted for in the FF model and calculations (Note the geometric scale).

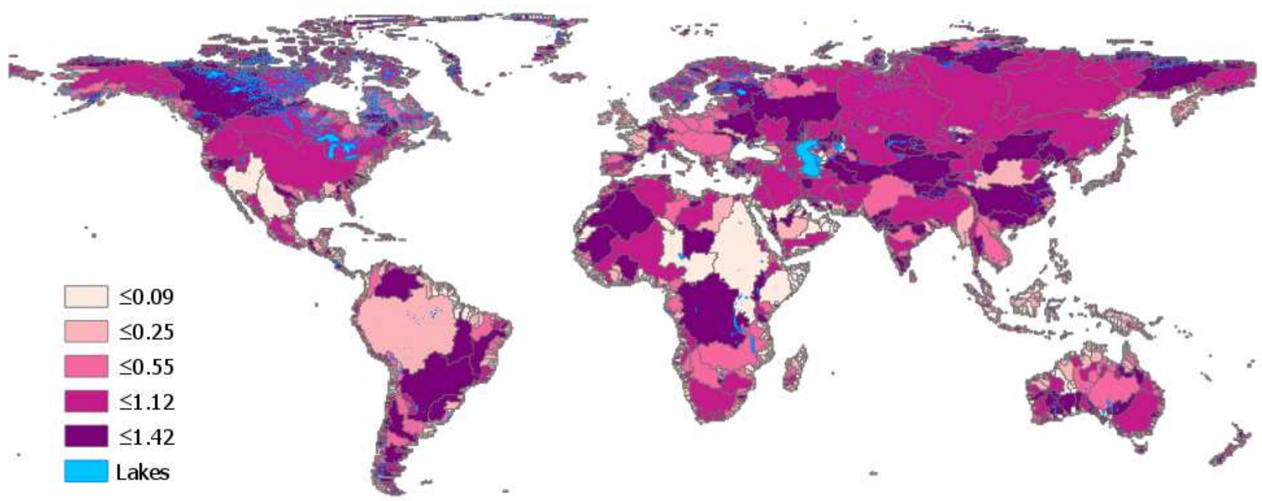

Figure 2. Fate Factors (FF) for dissolved inorganic nitrogen (DIP) emitted to river ($FF_{\_river\_DIP}$, in [yr]), calculated at the river basin scale and global coverage (purple color gradient). Nutrient attenuation in 1,420,891 lakes (in blue) was accounted for in the FF model and calculations (Note the geometric scale).

4. Conclusions

We developed spatially differentiated and globally applicable FFs, in a consistent way for both N and P emissions from soil and to river. The use of these FFs, in conjunction with a spatially-explicit inventory of DIN and DIP emissions improves the environmental relevance and discriminatory power of the assessment of freshwater eutrophication impacts for LCA applications. The method is consistent with the work on marine eutrophication impacts assessment, recently developed by Cosme and colleagues (2017, 2018) and based on the same underlying model (Global NEWS2) and spatial resolution. Future work includes application on case studies and the consideration of seasonality in nutrient limitation.

The applicability of this method at high spatial resolution is hampered by the design of LCA commercial software that does not support a regionalised impact assessment based on multiple spatially-differentiated inventory datasets. This is a limitation for the application of all recent regionalised methods.

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