HESS-2016-120, Reply by the authors to reviewer #1.

Dear Dr Editor,

We addressed all technical corrections for Anonymous Referee#1 as requested. We thank Anonymous Referee#1 for his positive and critical appreciation of our manuscript. Please find below a detailed revision report, along with the revised manuscript for your consideration. We have highlighted (yellow colour) the sections in the manuscript which have been amended or re-written.

General Comments

Ouedraogo and Vanclooster (2016) provide an interesting meta-analysis of groundwater nitrate studies across Africa. They build a simple multiple linear regression model to explore the potential factors affecting observed groundwater nitrate concentrations. The paper is interesting and within the scope of HESS. The novel contribution is the first synthesis of nitrate data across Africa. Unfortunately, the use of English through the paper is regularly strange and difficult to understand. I have included a few examples in the technical corrections but there are many more. It is suggested the paper is fully reviewed by a native English speaker prior to publication.

The issue of bias in the observed nitrate datasets analysed is not discussed in detail. It should be acknowledged explicitly in the text that a number of studies analysed have been investigating specific groundwater quality issues and thus the dataset may be biased towards higher concentrations. If possible, the number of studies that address specific groundwater nitrate contamination issues should be quantified against the number of more general groundwater hydrochemistry studies. I assume there will also be bias towards studies on aquifers which are productive and used for water supplies and this should also be noted.

Response:

We thank Anonymous Referee#1 for his constructive general comments. The English language was checked, but will further be improved through the HESS editing process (providing systematic language checking for all manuscripts). We agree with the Reviewer that bias in the dataset may be present. This issue was already addressed in the manuscript, but was not enough emphasized. We acknowledge that this bias may be due to multiples reasons, as stated by the reviewer. In our conclusion of the manuscript, we state that the main weakness or the major constraints of the modelling at the pan African scale, lies in the unavailability of a homogeneous data set on nitrate contamination, particularly the lack and uneven distribution of nitrate measurement points. Results from this analysis should not be over-interpreted. Whilst the data provide a useful preliminary assessment of the nitrate contamination in groundwater at the African scale, there are clear limitations. Unsurprisingly there are no consistent measurement datasets that can be explored at a continental scale; at larger scales, much of this information is also patchy, both spatially and temporally. Non-traditional data sources such as

literature data (for example meta-analysis) may therefore be useful substitutes for some traditional measurement data. The data used in this study are derived predominantly from literature. The data come from different sources (reviewed journal article, book of articles or other grey literature) and the methods (such as isotopic analysis) used to collected and produce the results of each study are not the same. They should therefore not be treated as traditional nitrate measurements.

We fully agree with the Reviewer that certain studies address specific groundwater nitrate contamination to water supply, others address groundwater nitrate contamination to strong irrigation areas, others again couple the two issues (water supply and irrigation), or again others studies address the nitrate pollution in mining zones, etc. The different nature of these studies constitute a possible bias. In spite of potential problems caused by possible sampling bias, the data set was used to explain the environmental/physical factors that contribute to the nitrate pollution at the African scale. Despite the issue of possible bias and uncertainties notified by the Reviewer, we are very optimistic about the robustness of the model for predicting contamination at the continental scale. The model that was obtained used population density, depth to shallow groundwater, aquifer type and recharge as explanatory variables. This is consistent with a study from UNEP/DEWA, (2014) in 11 countries across Africa that stated:

- "The level of protection at the wellhead strongly influences the quality of the well water. This is a vital aspect in protecting groundwater quality. Sanitation must not be delinked from Groundwater Protection".
- "Recharge from multiple sources influences groundwater microbial and chemical water quality".
- "The magnitude of contamination is also strongly affected by the population density and socio-economic setting".
- "Groundwater pollution and vulnerability issues are affecting all developing countries with increasing urbanization".

The study presented here is designed to give a continent-wide view of groundwater contamination by nitrates and to encourage the development of more qualitative national and sub-national qualitative model and assessments to support the development of groundwater-based adaptation strategies to current and future climate variability. Inevitably these results can be improved. They should be viewed as a first attempt to provide quantitative statistical modelling of nitrate contamination in groundwater for Africa and provides furthermore, a strong basis for future studies when homogeneous data without bias will be available at the African scale. Some elements of this discussion will be better emphasized in the revised manuscript (See P11 L391-402)

##: A large number of datasets discussed in the paper are given as available "on request" from the author. Please provide these datasets as supplementary information.

Response: We thank for this suggestion. We will upload an excel file data set as supplementary information.

Specific Comments

##: Title: I suggest "statistical modelling" is included in the title somewhere to better reflect the contents of the paper

Response: We thank Anonymous Referee#1 for this suggestion. The title was changed to incorporate the contents of the paper. The new title proposed is: "**A meta-analysis and statistical model of nitrates in groundwater at the African scale**". (See P1 L1).

##: P3L78 – I would be inclined to add a subheading in here for the section on methods for assessing groundwater vulnerability.

Response: We thank the Reviewer for this suggestion. However, we suggest to keep this section in the introduction part. In HESS papers, the literature review is very often an integral part of the introduction. We prefer to keep this traditional structure.

##: Table 2 – It would be helpful to add another column showing for each study whether this is a peer reviewed journal article, book or other grey literature. As per the general comments, it would be helpful to detail for each study whether the study is addressing a nitrate contamination issue or is a more general hydro geochemical study. This could be in the form of another column in the table.

Response: We thank the Reviewer for this suggestion. However, we think that adding an additional column decreases the readability and is redundant of the information the reader can retrieve in the reference list that is an integral part of our manuscript (Table 2 in P30-35).

##: P8L282-286 – I do not agree that increasing nitrate concentrations are observed with increasing recharge. If anything, they appear to decrease – is this due to dilution of nitrate in recharge?

Response: We agree with the Reviewer: the nitrate decreases with recharge. This may be due to dilution effect into aquifers during recharge periods. We checked and corrected these errors in the manuscript. (See P8 L290-293).The dilution role for recharge factor was discussed in addition. (See also P13 L474-479).

##: P10 L357 – The probability plot in figure 10 shows a close to normal distribution but the points do not fall exactly on the straight line. The text should be changed to say that the distribution is close to normal.

Response: We corrected the sentence to take account that the distribution is close to normal distribution. (See P10 L363).

##: L11 L414-422 The issues of lag in nitrate transport through the unsaturated zone and denitrification are not well explained and should be re-written taking into account recent work on nitrate in the unsaturated zone. "Also, given the larger travel times associated with the recharge of deep groundwater systems, there is an enhanced opportunity for denitrification" – Do you mean there is more opportunity for denitrification in the unsaturated zone? Or in the saturated zones of deep confined aquifers? The evidence for unsaturated zone denitrification is limited (Kinniburgh et al., 1994; Rivett et al., 2008) and I do not think this should be used to explain why deeper aquifers have lower nitrate concentrations. There is a substantial body of literature showing evidence for nitrate accumulation in the unsaturated zone (Ascott et al., 2016; Wang et al., 2016; Worrall et al., 2015)– it may be that nitrate concentrations are lower in deeper aquifers because recharge from periods of high fertiliser use have not reached the water table yet.

Response: We agree with these remarks on the denitrification process. We rewrote the L430-457 in P 12 to include recent work on this issue.

Indeed, according to Close (2010), nitrate is negatively charged and thus electrostatically repelled by media in unsaturated zone that usually have a negative charge, such as clay minerals. This means that nitrate is less likely to be sorbed within the unsaturated zone. Moreover, according to Rivett et al., (2008), denitrification, which is generally facilitated by the absence of oxygen, is considered to be the dominant nitrate attenuation process in the subsurface system. Denitrification was found to be relatively limited in unsaturated zone (Kinniburgh et al., 1994; Rivett et al., 2008), while it is the principle process responsible for reduction of nitrate in groundwater (Aljazzar, 2010, Stevenson and Cole, 1999; Thayalakumaran et al., 2004), in particular in reduced groundwater (Burow et al.,2013). Boy-Roura et al.,(2013), for instance found low nitrate concentrations (below 50 mg/L) in those areas where denitrification processes have been identified. An indicator of the presence of denitrification processes contributed as such to explain nitrate contamination in the Osona region (NE Spain) (Boy-Roura et al., 2013). In our study, an indicator of the presence of denitrification processes in the groundwater system was not available and could not be included in the model.

Technical Corrections

##: P2L41 – remove "However,"

Response: The word "However" was removed in the revision manuscript. (See P2 L42).

##: P2L59 – change "no comprehensive and synthetic study" to "no comprehensive synthesis of"

Response: We changed "no comprehensive and synthetic study" to "no comprehensive synthesis of". (See P2 L60-61).

##: P2L63 – Define UN SDGs on first use

Response: UN SDGs is the United Nations (UN) Sustainable Development Goals (SDGs). Furthermore, according UN, (2014), transboundary water cooperation is a focus of target 6.5, which states "by 2030 implement integrated water resources management at all levels, including through transboundary cooperation as appropriate". According to Saruchera and Lautze, (2015), transboundary water cooperation has emerged as an important issue in the post-2015 United Nations (UN) Sustainable Development Goals (SDGs). (See P2 L63-67).

##: P2L67 – change "non-homogeneity" to "heterogeneity"

Response: We substituted "non-homogeneity" by "heterogeneity" term. (See P2 L70).

##: P9 L320 – do not need to explain how p-values work.

Response: We eliminated the sentence that explains how p-values work in the manuscript. (See P9 L326).

##: Subscript for 3 in NO3 not used consistently.

Response: We checked it by replacing by NO_3 (see P2 L35).

##: Figure 3 legend reports nitrate concentrations to 2 decimal places. This is not necessary – just report whole numbers.

Response: We built a new figure without any decimal. We retained just whole numbers (see figure 3, P40 or figure in below).

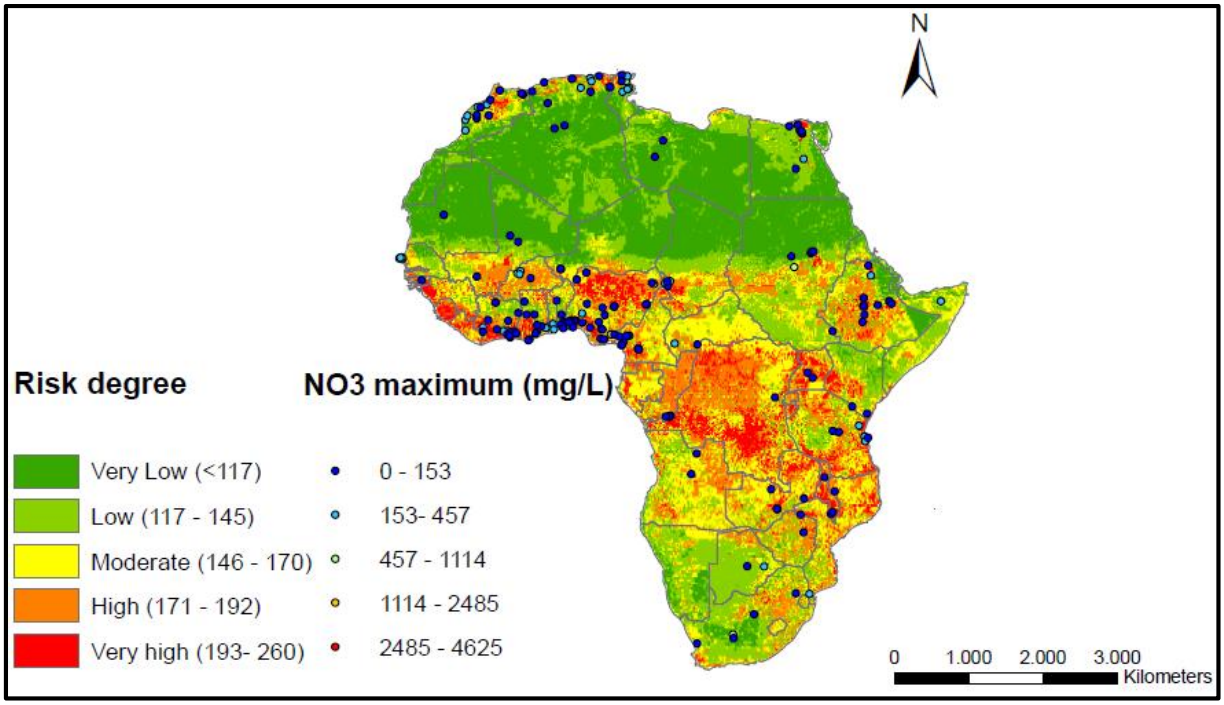

Figure 3 in the manuscript.

##: P12 L426 – Humps – do you mean groundwater mounding?

Response: This error was replaced by "hand pumps". (See P13 L468).

##: Figure 8 looks stretched horizontally – please correct this. Please label each sub-figure (a), (b), (c) and (d) and refer to them in both the figure legend and text

Response: We corrected and used the labels (a), (b), (c) and (d) for respectively groundwater depth classes, recharge classes, population density classes and nitrogen application rate classes. This figure was also adjusted and centred to eliminate the horizontal stretching. (See figure 8 in the manuscript, P43).
Moreover, in the text, we use the label for each figure. (See P8, L283, L290, L296 and L304).

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