Detailed response to interactive comments by Anonymous Referee #2 on: "Transport and retention of phosphorus in surface water in an urban slum area" by P. M. Nyenje et al., hessd-10-10277-2013

GENERAL COMMENTS

RC 2.1 This manuscript presents an interesting case study about P transport in the channels of a slum area in Kampala, Uganda. The authors made a great effort working in a challenging area were data are scarce and research presents difficulties for monitoring and sampling. These types of studies contribute to the development of the society with some clear applied objectives and they have to be reflected in the scientific literature. Nevertheless in spite of the good methodological description and the suitability of the techniques applied, this work presents some weak points that make difficult to publish it in this journal. Anyway I think it would be totally suitable for publication as a case study in other scientific publication.

Reply: The authors would like to thank Referee #2 for his/her constructive comments. We have taken note of each of the comment and our corresponding comments are listed below. There were major weaknesses in the first version of the manuscript whereby most of our interpretations were not supported by data. We have now provided more data (e.g. saturation indices and other rainfall events) and we hope that our explanations will clarify most of the issues raised.

MAJOR COMMENTS

RC 2.2 The authors highlighted that "studies on P transport in streams and/or channels draining unsewered informal settlements (or slums), where most P discharge are associated with untreated or poorly treated domestic wastewater discharge from on-site sanitation, have not been published" but they donot present what are going to be the challenges or scientific interest of this study compared with others when there is a different source of P. Also they referred in the discussion to published studies in this topic of Chua et al. (2009) and Katukiza et al. (2012). If they want to show the novelty of this study they must do a much better search and discussion of previous works.

Reply Thank you for this comment. We do acknowledge that one of the major weaknesses of our work was the limited reference to what others have done. This makes it difficult for the reader to compare our work with findings already available literature. The study by Chua et al. (1999) was also carried out in a tropical urban environment and provides some unique comparable findings about the presence of the first-flush effect. There are also many other studies which we can use to compare our results (e.g. Kansiime and Nalubega, 1999). However, the study by Katukiza et al. (2012) only provides a review of sanitation technologies in urban slum areas. In the revised version, we addressed the shortcoming of the original manuscript by discussing our findings in relation to previous works, despite the limited literature on this kind of study, especially in sub-Saharan Africa. In the introduction, for example, we added the following paragraph.

"Whereas a lot of research has been done on P transport in surface water, little

has been done in urban informal settlements especially in SSA. Most research is carried out in agricultural and forested watersheds and in temperate systems (e.g. Evans et al., 2004; Rodríguez-Blanco et al., 2013; Blanco et al., 2010), with very few studies in tropical urban informal systems. However, these two systems could have contrasting mechanisms controlling P transport due to differences in climate, land use and geology. Hence, the fate of P in urban tropical catchments with informal settlements remains unknown (Nyenje et al., 2010). Chua et al. (2009) presented a case study of P transport in a tropical environment but they only focused on P transport dynamics during high and low flows and did not provide insights into the chemical processes regulating P transport. Informal catchments are rapidly evolving in urban areas in SSA and so is the amount of wastewater and P discharged in the environment. There is therefore a strong need to understand and manage the transport of P in these catchments."

Likewise, in the discussion section, we compared our work with that of Kansiime and Nalubega (1999) who carried out a similar kind of work in a similar kind of environment.
"Currently, there are few published studies on P transport in urban informal settlements in SSA with which we can compare our results with regard to P transport. One study by Kansiime and Nalubega (1999), however, did try to investigate the removal of P by sediment in Nakivubo channel/swamp, which had received wastewater from Kampala city, Uganda for over 30 years. This study, on the contrary, suggested that the precipitation of CaCO3 was not a very important process for P retention because of the low Ca content (60 mg/Kg) and the low Ca-bound P (10% of TP) in the sediment. The retention of P was instead attributed to precipitation of vivianite because of the low Fe:P molar ratios (1 - 3). However, this study did not carry out geochemical speciation of phosphate phases in the overlying water to confirm if there was a strong likelihood for vivianite to precipitate. In our study, Fe:P ratios in the sediment were generally high (> 3.6; Table 3) and the overlying water was undersaturated with respect to Fe phosphates. In addition, the sediment Ca content was very high (> 2000 mg/Kg; Table 1) while at the same time Ca-bound P contributed over 50% of total sediment P. This implies that in our study there were indeed interactions between Ca and P. These findings show that P retention processes in surface water in urban informal settlements can vary significantly depending on the location."

RC 2.3 The main problem of this work is that (a) if they want to present a new perspective concerning P transport in the slum areas they must include a more complete dataset that ensure that this study is not merely a local situation non-exportable to other similar environments. (b) If the objective is to present a case study with international impact the analysis and results are not enough outstanding and rigorous to be published in its present form.

Reply: The main objective of our study was to provide insights into the possible mechanisms controlling P transport in unsewered urban catchments in sub-Saharan Africa. We do acknowledge that the data we provided was not sufficient and that the analysis was not rigorous enough. We have now provided more data in order to augment our findings. We have hourly data (for all the events) on saturation indices of all the events we sampled. This data is useful in understanding the chemical processes controlling P transport either by dissolution or precipitation. From this data, we also calculated the metal and nutrient molar ratios in the bed sediment, which are useful in understanding the processes responsible for the retention of phosphorus in the sediment. But more important, we have included data on two more rainfall events that we collected at two more locations upstream of the catchment outlet. With this data, we have tried to address the problem of spatial and temporal representation of our data. We therefore revised the manuscript accordingly to address the shortcomings that were present in the first version of the manuscript.

RC 2.4 (a) The data are not representative because of the limitation in space and time of the monitoring activity. Only two high flow events were sampled, probably incomplete as the authors explained (maybe they didn't sampled with enough density during the peak), the maximum monitoring time extends for 3-5 months and only in two channels (that was not discussed why they were selected). The period of monitoring is short and therefore, would throw partial results. With this limited dataset, it seems difficult to extrapolate these conclusions to another region or even in the study area it would be not sure that the other channels in Kampala can show a similar pattern.

Reply: We have included two more rainfall events, which we sampled at two locations upstream of the catchment outlet. Therefore, our data is now representative in space and time and we think that our interpretations and conclusions can now be extrapolated to other regions.

We have therefore revised the entire manuscript and the discussion section and we believe that our revised manuscript is much more improved. For example, we now have four high flow events and from all these events, it is clear that there was a flushing of PP and TP. We also have a large set of data on saturation indices (collected hourly for 24 hours), which provides insights into the processes affecting P transport in the channels. For all samples collected, for example, surface water was near saturation with respect to calcite implying that it likely regulated P by co-precipitation.

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RC 2.5 (b) The analysis of the results and some of the assumptions that the authors made are not rigorous for a manuscript that pretend to present a new perspective in the study of P in urban areas. It is based on too many uncertain facts not quantified and that can be applied or not depending if the results need them or not to match. Some examples are: The arbitrary definition of old and recent. The concept of shallow-deep sediments was not accompanied by any study of this and it lacks of geological meaning. The authors proposed that 0-30 cm means that sediments area recent and deeper than 30 cm are old, in areas with storm events, 60 cm of sediments can be easily deposit in one single event.

Reply: With the new data we have included in the revised manuscript (see our reply to RC 2.3 and 2.4), we believe that our interpretations are much better. The entire discussion has been revised accordingly and our paper provides a much clearer perspective of P transport in unsewered urban areas with informal settlements.

<u>Regarding the concept of shallow and deep sediment:</u>
The shallow sediments here referred to surface sediment (usually between 0 - 30 cm thick; e.g. Hooda et al., 2000; Cooke et al., 1992) . This

sediment layer was loose and readily interacted with the water column as suggested by Gale et al., 1994. The deep layer sediment was, however, more consolidated and indicated sediments deposited much earlier. In fact, to collect the deep layer sediment, we had to use an auger. Therefore, these two types of sediments were presented in the context of trying to identify the differences (in any) between the P processes that took place with recently deposited sediment and sediment deposited much earlier. Probably, this was not clear in the first version of the manuscript. It has now been clarified in the revised manuscript. In relation to this, we revised the text description sediment sampling (in the methodology) as follows:

"We collected both surface and deep layer bed sediments at locations B1, B7 and B4 (see Fig. 1). The surface layer sediment (herein called shallow sediment) is where most P interactions between the water column and bed sediment occur (Hooda et al., 2000), whereas deep layer sediments represent older deposits that can give insights into earlier interactions that took place. Shallow sediment was loose and was sampled at depths of 0 - 30 cm using a 1m long multi-sampler with a 40 cm internal diameter (Eijkelkamp, The Netherlands). Deep layer sediments were more consolidated and were sampled at depths of 30 - 60 cm using a hand auger. In the tertiary channel (B4, Fig. 1), only the shallow sediment was sampled because the channel was lined and the sediment layer was thin (< 10 cm)."

In our study, it is not possible to have 60 cm deposited in one rainfall event. If we are to consider 10 heavy storms in a year, this would give 6 m of sediment deposited, which may not be possible in a catchment as small as 25 km^2 and where the channel width was only about 3 m.

RC 2.6 The explanations concerning why first flush effect are not detected. This could be one of the main findings of this study but the interpretation is based on personal observations and a topographical explanation that is not demonstrated with quantitative data (for example with a DEM construction and flow accumulation study). The discharge of the pit latrine content is an original idea but is not accompanied by any quantification of the effect to check if it has the potential to change the chemistry and the P content.

Reply: We generally observed that the peak concentrations of TP, PP and SS during rain events were realized after the peak discharge. Even with the two added events at the two upstream locations, this phenomenon was observed, which might suggest that first-flush effects were not present. However, our data was not intense enough during peak flows for us to conclude that first-flush effects were present or not. We have therefore recommended that future studies carry out more intense sampling during high flow events in order to have a complete understanding of the first-flush effects in these types of catchments and their causes.

Here below is our revised discussion about the presence of first-flush effects:

"First-flush effects for PP and SS have been reported in many studies investigating P transport during storm events (e.g. Stutter et al., 2008; Zhang et al., 2007). They occur when the rising limb of a hydrograph contains higher concentrations of pollutant than the falling limb (Deletic, 1998). Results from our study, however, seem to suggest that PP and TP did not exhibit first-flush effects.

This is because the concentration peaks of PP and SS were most of the times realised after the peak events (see Fig. 3 to Fig. 6), implying that the falling limb contained higher concentrations of pollutants that the rising limb. We attribute this phenonemon to the poor on-site sanitation systems in the catchment where wastewater, especially from pit latrines, is normally released into drainage channels after rain events (particularly when increased flows are observed) as a cheap way of emptying the latrines (see description study area). Chua et al. (2007) investigated a tropical catchment with proportions of rural and urban landuse similar to the catchment we studied, and they also observed that the first-flush effects were generally weak for TP and PP. However, our sample collection was not frequent enough during peak flows and it is therefore not possible to confirm whether the first-flush effects for PP were present or not."

2.7 Some of the observations that the authors made about the results are not evident for me when I check the figures. Figures 3 and 4 presents many different peaks, some of them are considered interesting and therefore analyzed, but others are simply ignored.

Reply: In the first version of the manuscript, Figures 3 and 4 presented P trends during high and low flows. In the revised version, we have added 4 more figures on P trends during rain events (From Fig. 3 to Fig. 6) and in all these events, the different discharge and concentrations peaks and trends are now properly described and analysed. During rain event 2, in particular, we had two subsequent rainfall events which produced two peak discharges. In the revised manuscript, these peaks were analysed as follows:

Under the results section:
"During the second event (28 - 29 July 2010; 14.8 mm, intensity of 6.5 mm/h), two smaller peak discharges of 1.3 and 1.4 m^3/s *were produced. Consequently, two peak concentrations of TP and PP were produced (Fig. 3c). The first concentration peak had 3.0 mg/L for TP and 2.4 mg/L for PP whereas the second had 2.1 mg/L for TP and 1.5 mg/L for PP."*

Under the discussion section:
"During the second event (Fig. 3c), there were two discharge peaks at B1 which resulted in two concentration peaks of TP and PP, with the later peak lower than the former probably due to flushing effects."

RC 2.8 In page 10, lines 9-11 it is stated that ": : :deeper sediments contained less Ca-bound P than shallow sediment whereas Fe-bound P was approximately equal in both deep and shallow sediments (Figs. 5 and 7)".

Reply: This statement was ambiguous and has been removed. Consequently, the entire discussion has been revised and our interpretations are now sound and clearer.

RC 2.9 In figure 5, I do not see actually the differences that are commented, B1 shallow and deep are almost identical and the difference with B2 is barely representative to be commented as evident.

Reply: Indeed, the difference between the P fractions in the surface and deep layer sediments was not significant. Therefore this phrase has been removed.

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