Reply to comments of Hongkai Gao

We thank Hongkai Gao for his very constructive comments; they were very helpful to improve our manuscript. Our responses to the comments are provided in bold (below each comment).

General comments

This manuscript is very interesting for me. The writing is clear and concise. The authors applied a new modelling framework (Savenije, 2010) to do runoff production area classification by topography information. Slope was used as criteria to do the classification.

The model structure is simple but reasonable. The number of free parameters is also limited to 7, which dramatically reduces the equaifinality. Although the model did not apply the normally used curve in soil reservoir to represent the distribution of water storage capacity (Zhao, 1992), the results are also excellent, which is intriguing for me.

The authors cooperated topographic information and soil texture information into the model. The average slope gradient and slope length are parameterized into the conceptual model by semi-empirical relations. The porosity and field capacity of soil are used to determine the storage capacity. All the functions are clear and reasonable for me. But there are still several things needs to be clarified.

1. Following the comments from Prof. Merz and Anonymous Referee #1, I also think a benchmark model is necessary in this paper to illustrate the better performance or transferability of this modelling approach than traditional lumped models which neglect the heterogeneity of catchments. Not only hydrograph, but also the flow duration curve shall be shown to illustrate the model performance on flow frequency simulation.

We agree to use a benchmark model as an alternative to compare the results with our topography driven model. From the recommendation of Anonymous Referee #1, we chose the lumped model with lumped input data (Flex$_B$) by Fenicia et al. (2008) as a benchmark model to assess the benefits and performance of topography-driven semi-distributed modelling of this paper. This comparison will be shown in the revised version of the paper.

We thank Hongkai Gao for his suggestion to show the flow duration curve to illustrate the model performance on flow frequency simulation. Accordingly, we have shown the calibration and validation results for the flow duration curve of the model in Figs.1C and 2C. These will be included in the revised version of the paper.

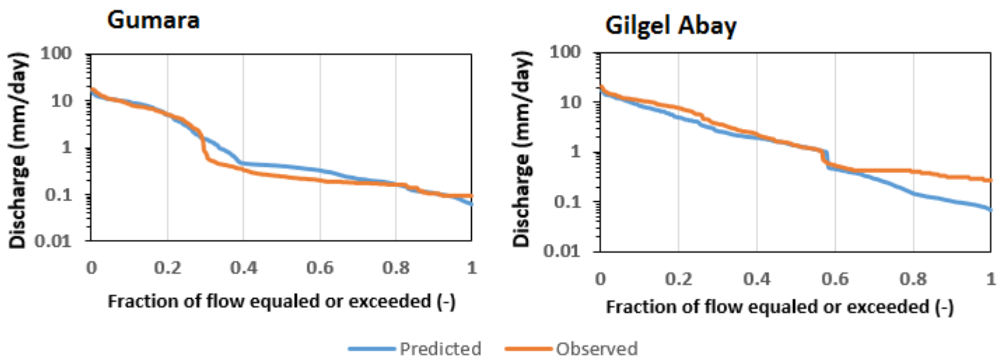

Fig. 1C. Predicted and observed results of the flow duration curve for Gumara and Gilgel Abay catchments for the calibration period

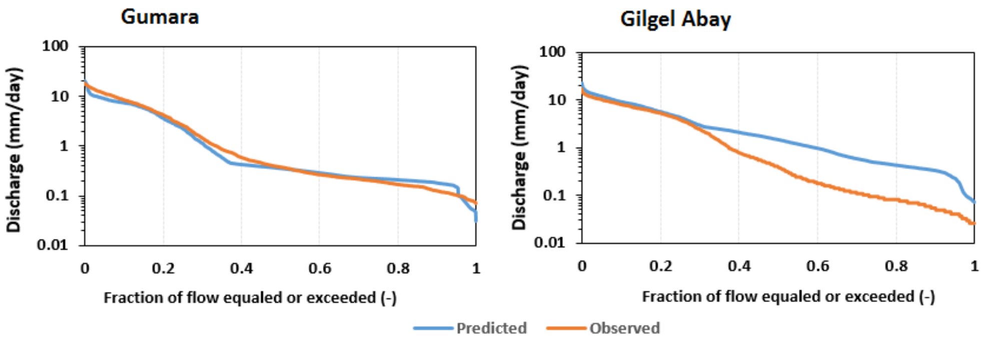

Fig.2C. Predicted and observed results of the flow duration curve for Gumara and Gilgel Abay catchments for the validation period

2. The model structure is not very clear for me, although it is mentioned in the text and shown in Figure 2 and Figure 3. I suggest the authors show the inter-link between different runoff production areas in one figure, which could be clearer and easier to follow.

We agree to work further on the model structure to make it clearer, and the clarifications are shown below.

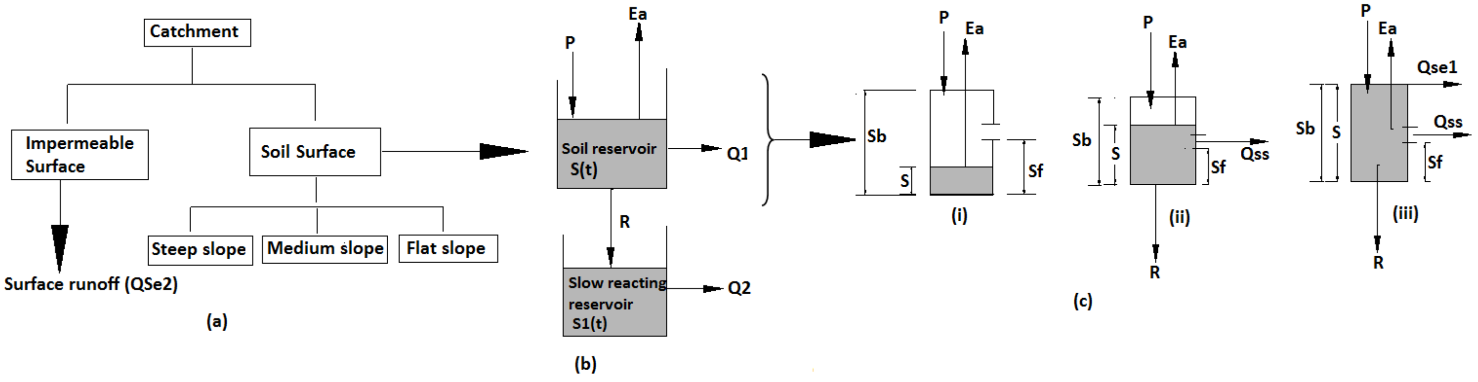

Fig.3C. The modeling approach showing (a) divisions of a catchment into different runoff production areas of, (b) conceptual model configuration of the soil surface at an outlet of a catchment and (c) Inflows and outflows for the soil reservoir when the soil water storage capacity is (i) below field storage capacity, (ii) greater than field storage capacity and (iii) greater than the maximum soil water storage (after Krasnostein and Oldham, 2004).

As shown in Fig.3C, in this modeling approach, the catchment is first split into soil surface and impermeable surface (these are areas with little or no soil cover and bedrock outcropping in the catchment as well as soils with well-developed tillage pans). The runoff from the presumed impermeable areas is modeled as infiltration excess (Hortonian flow) runoff and is represented as Qse2. The other component of the catchment, recognized as the soil surface, is further divided into three using topographic criteria, considering topography as a proxy for the variability of most of the catchment characteristics. The catchment buckets (reservoirs) and the runoff process of the soil reservoir (the upper soil layer) for each of these divisions are depicted in Fig.3C (b) and (c). The slow reacting reservoir (or the ground water reservoir) is set to be common to all of the three divisions as it looks quit inconsistent to separate the groundwater system in the catchment. The total runoff at an outlet of the catchment is:

Total discharge = surface runoff from impermeable part (Qse2) + surface runoff from each of the steep, medium and flat slope catchment divisions (Qse1)+ subsurface runoff from each of the steep, medium and flat slope catchment divisions (Qss) + base flow from the slow reacting reservoir (Q2)

Details of the mathematical equations and meaning of the different abbreviations in Fig.3C are shown in the discussion paper.
These clarifications will be included in the revised version of the paper.

3. Please show the slope map, classification map obtained by topography criteria, and the soil map, from which we can easily see the heterogeneity among different catchments.

Fig.4C shows the slope map of the Gilgel Abay and Gumara catchments (the study catchments) and the three slope categories (steeply, medium and flat slope surfaces).

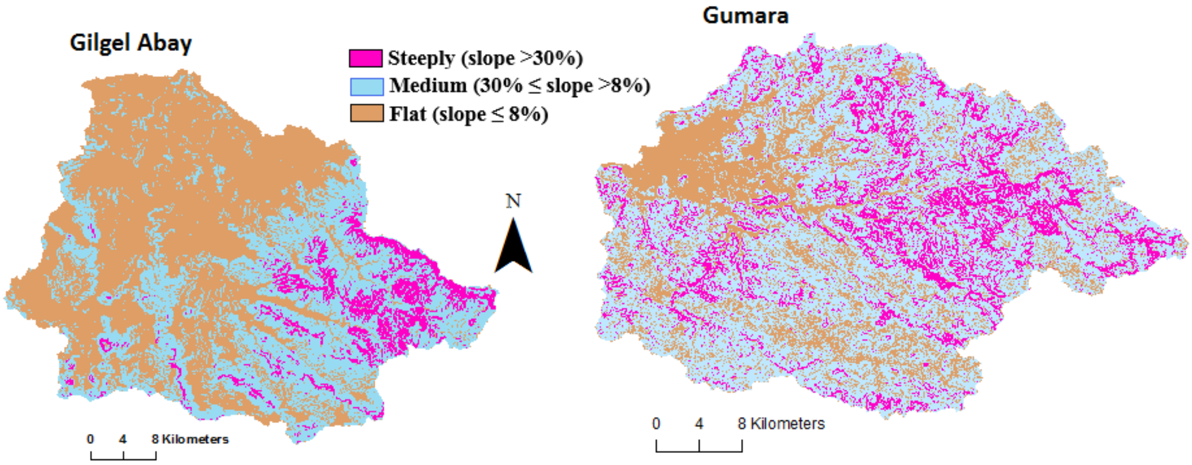

Fig.4C. the three slope categories for the Gilgel Abay and Gumara catchments

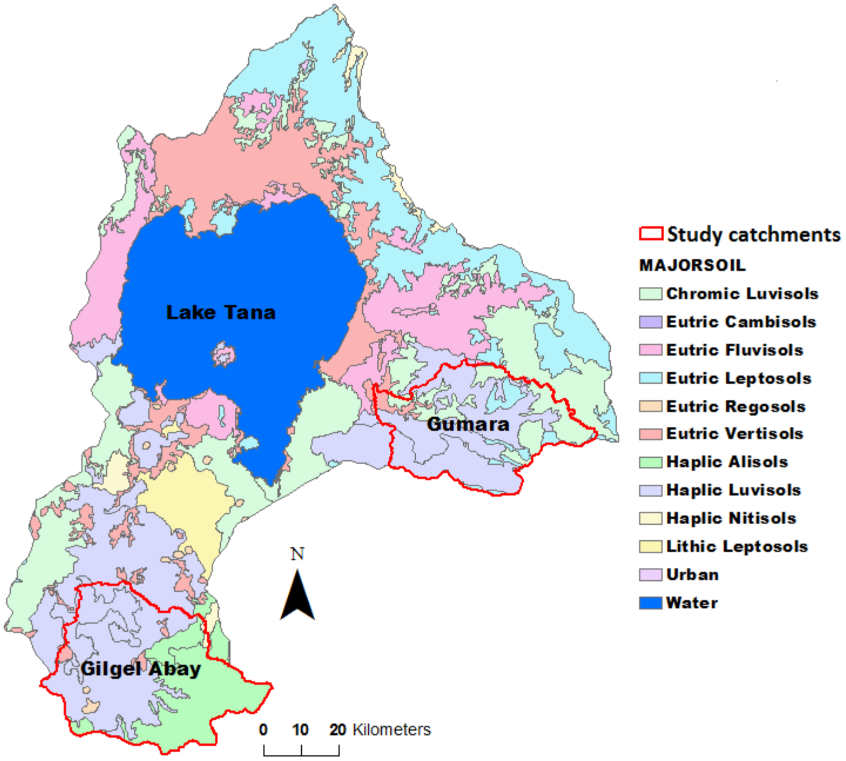

Fig.5C. Major soil types in the Lake Tana basin and the study catchments

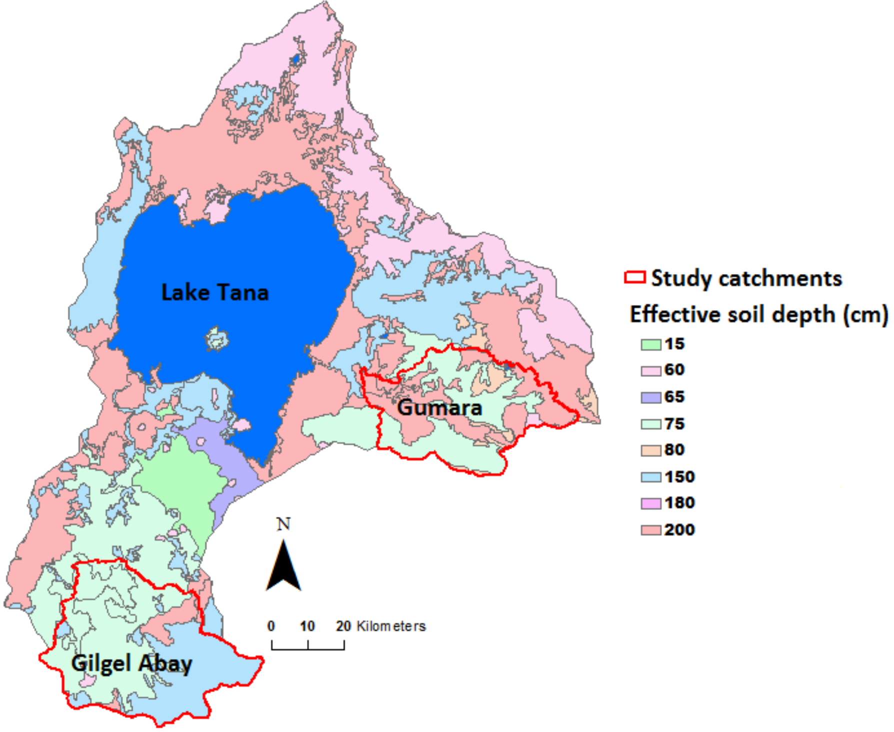

Fig.6C. Soil depth in the Lake Tana basin and the study catchments

(source for both figures: BCEOM: Abay River Basin Integrated Development Master Plan, Land Resources Development – Reconnaissance Soils Survey, Ministry of Water Resources, Addis Ababa).

4. In Section 6.3, for the transferability test, I think the authors should do more discussion to clarify why this modelling approach can get good transferability. The authors could refer our newly published paper (Gao et al., 2014) about the application of the FLEX-Topo modelling approach in the Heihe river basin in China, in which paper the model performance comparison and transferability with several benchmark models are test.

We agree with Hongkai Gao suggestions to do more discussions to clarify why this modelling approach can get good transferability. Accordingly, we will make the following additional discussions that starts in Section 6.3, page 5307, line 28 in the discussion paper, next to the following sentence in the discussion paper, for the revised version of the paper.

In general, transferability results showed good performance of the daily runoff model in the two study catchments and an average performance in the test catchment (Dirma catchment). This can be explained by the fact that emphasis was made to incorporate more knowledge available from observation and experiments in the model parameterization to increase model realism. We based strongly on the soil storage characterization of the soil reservoir in the rainfall-runoff process and representation of the maximum storage of the unsaturated reservoir at the catchment scale, which is closely linked to rooting depth and soil structure and strongly depends on the ecosystem. Transferability of the model has benefited from this in that we were able to derive most of the input data from the test catchments. The consideration of topography driven landscape heterogeneity analysis and catchment information extraction for the model is another reason for the better performance of the model transferability. From a comparison of four model structures on the Upper Heihe in China, Gao et al. (2014) also confirmed that topography-driven model reflects the catchment heterogeneity in a more realistic way.

Minor comments:

1. Perhaps I have missed something, do the different hydrological components have isolated groundwater or they share the same groundwater reservoir?

They share the same groundwater reservoir since it looks quit inconsistent to separate the groundwater system in these relatively small catchments and we preferred all the three slope based classified catchments to share the same groundwater reservoir.

2. Equation 12. Why the saturated hydraulic conductivity of deep soil layer (Ks,e) is not a free parameter in Table 2? How did the authors determine the Ks,e?

It can be a free parameter. But the authors' interest is to reduce the number of parameters in the model formulation and use more knowledge available from observation and data as much as possible to reduce the equaifinality and increase chance of model transferability. In this perspective, we preferred to estimate the saturated hydraulic conductivity of deep soil layer (Ks,e) by identifying the likely aquifer formation of the study area (colluvial mantle on top of the igneous rock) and using ranges of conductivities given by Domenico and Schwartz (1990) for the different aquifers.

3. Equation 23 and 24. Where is i in these equations?

We thank Hongkai Gao for this remark. Equations 22, 23 and 24 are updated to show i in the equations as follows. The corrections will also be incorporated in the revised version of the paper.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (Q_{\mathrm{obs,i}} - Q_{\mathrm{sim,i}})^2}{n}} \qquad (22)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Q_{\mathrm{sim,i}} - Q_{\mathrm{obs,i}})^2}{\sum_{i=1}^{n} (\mathrm{Q}_{\mathrm{obs,i}} - \overline{Q_{\mathrm{obs}}})^2} \qquad (23)$$

$$R^2 = \left[\frac{\sum_{i=1}^{n} (\mathrm{Q}_{\mathrm{sim,i}} - \overline{Q}_{sim})(\mathrm{Q}_{\mathrm{obs,i}} - \overline{Q}_{obs})}{\sqrt{\sum_{i=1}^{n} (\mathrm{Q}_{\mathrm{sim,i}} - \overline{Q}_{sim})^2} \sqrt{\sum_{i=1}^{n} (\mathrm{Q}_{\mathrm{obs,i}} - \overline{Q}_{obs})^2}} \right]^2 \qquad (24)$$

4. Table 1. Is ‘flat’ more suitable than ‘level’?

We think that the two words are synonymous.

5. Table 1. Are field capacity and porosity parameters or input data? If they are input data, how did you get these information in catchment scales? Please clarify this point.

Field capacity and porosity are input data. As we tried to explain in Section 4.2, page 5299 in the discussion paper, the porosity and field capacity of the soils were derived from the soil texture based on the work of McWorter and Sunada (1977). We determined the dominant soil textures of the study catchments (Table 1) from soil map of the Abay River Basin integrated master plan study BCEOM (1998a). Average values of the porosity and field capacity of the soils were considered at catchment scale from the ranges of values recommended by McWorter and Sunada (1977) based on the relevant soil texture in each catchment category.

6. Table 2. Why lambda is a parameter? To my point view, you can determine the proportion of impermeable surface by soil map. Is it possible?

We agree with Hongkai Gao’s idea of the possibility of determining the proportion of impermeable surface from the soil map. However, currently the available soil map of the study areas is not with such details. The available soil maps (Fig.5C and 6C above) do not differentiate the impermeable portions of the catchments, making difficult to know the impermeable surfaces from such maps.

References

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