

April 24, 2016

Dear Dr. Bas van Wesemael

We have made the changes requested in the manuscript. The changes requested by reviewer 1 are in red and by reviewer 2 in blue. The green text are changes made in order to make the text read better and in some cases improve on our responses to the reviewers. We have not marked the deleted text for ease of reading

Below we first response to your comments and then we have added the submitted responses to reviewers 1 and 2. Note the color of the changed text in the response is not consistent with the changed text in the manuscript.

We would like to thank you and the reviewers for their time and the excellent comments

For all authors

Tammo Steenhuis and Mamaru Mogus

Response to the “Topical Editor Decision: Revision (23 Mar 2016) by Bas van Wesemael”

Dr. van Wesemael wrote:

“The authors already responded to the comments of reviewer 1. However, reviewer 2 also has some serious remarks that need to be taken into account before publication can be considered. Please respond to the specific comments and in particular to the major comments:

- Lack of justification of the work in relation to the literature.
- Details are lacking on gauging stations used by the Ethiopian authorities
- The application of the equations valid for large catchments to micro-catchments needs to be justified.”

Since we already submitted the response to reviewer 2, we will extent the responses given in the response

Comment Lack of justification of the work in relation to the literature.

Response: In the manuscript we updated the following paragraph. Where the colored text is added.

“In the Blue Nile Basin, where the construction of the Grand Ethiopian Renaissance Dam is and planning of other hydroelectric dams) are under way, determining sediment loads is becoming more urgent. At the same time concern for the environment has been increasing and it has been noted that the fish production in Lake Tana is decreasing due to increasing sediment concentrations (Vijverberg et al. 2012). Thus, the ability to predict accurately the sediment concentrations and loads to the lakes and man-made has become important in the Ethiopian highlands where they are not available.

Modeling sediment loss is fraught with difficulties that unlike runoff is not bounded by the amount of rainfall. So there is no upper bound for sediment load in the absence of data. The models most commonly used for predicting soil loss are the USLE (Wischmeier and Smith,1965) and its derivatives such as RUSLE (Renard et al., 1991) and MUSLE (Williams and Berndt, 1977) Hydrologic Engineering Center River Analysis System, (HEC-RAS, HEC 1995), Water Erosion Prediction Technology (WEPP, Nearing et al., 1989), Agricultural Non-Point Source Polution (AGNPS, Young et al.1989), Erosion Productivity Calculator (EPIC,Jones et al., 1991), Soil and Water Assessment Tool (SWAT, Arnold et al., 1998) and Chemicals, Runoff and Erosion from Agricultural Environment Systems (CREAMS, Knisel, 1980). More sophisticated models used are the Neural Differential Evolution (NDE), Artificial Adaptive Neuro-fuzzy inference system(ANFIS), and Artificial Neural Network (ANN) Models

(Masoumeh and Mehdi, 2012; Özgür, 2007). However, it is cumbersome to obtain the required data for these models especially in developing countries. The reason is that these models were originally developed for areas that have large amounts of data. For example, in the land use and land cover map, the leaf area index data that SWAT needs is not available. Similarly, the soil data in Ethiopia is very coarse and is missing basic information such as soil texture, hydraulic conductivity and other parameters that are difficult to measure in Ethiopia. Additional challenges using these models are: i) the models have been developed in regions with a semi-arid temperate climate where the runoff mechanisms are governed by Infiltration excess unlike the highland areas where saturation excess runoff is dominating (Steenhuis et al., 2009; Bayabil et al., 2010; Tilahun et al., 2013) and ii) almost all of the models need intensive data with many parameters that might be available centrally in developed countries but not in developing countries such as Ethiopia. Therefore, historically when concurrent concentration and discharge measurement were taken at irregular intervals; rating curves were often the preferred choice for predicting sediment loads (e.g., Walling, 1990) but also recently (e.g., Horowitz, 2010); Kokpinar et al., (2015); Choi and Lee, 2015; Kheirfam and Vafakhah, 2015). The abundance of papers on load rating curves in the refereed literature should be not surprising since purpose of the measurements was to determine the amount of sediment that potentially could be deposited in rivers and reservoirs. In the literature, a limited number of articles developed sediment rating curves. These few studies were carried out in Sweden (Fenn et al., 1985); Ontario Canada (Irvine and Drake, 1987), British Columbia in Canada (Sichingabula, 1998), South Australia (Sun et al, 2001) and for the Himalayan glacier in India (Arora et al., 2014). Thus, compared to the sediment load rating curves that are available throughout the world for many rivers, there are very few sediment concentration rating curves and none for a monsoon climate.”

In addition in page 1422 and 1423, we stated that a unique rating curve function cannot describe the sediment concentration pattern during the rainy period in the Ethiopian highlands. We, therefore, proposed a new sediment rating curves that include the decreasing concentrations for a given flow with the progression of the rainy season.

Comment: Details are lacking on gauging stations used by the Ethiopian authorities

Response: We have added the following information (in red) related to Figure 2 and Table 1. And included the locations in Figure 2. Finally we added text how the discharge and sediment concentrations were measured (as documented below)

“The gauging stations are located 95, 20, 26 and 40 km for the Gilgel Abay, Gumara, Rib and Megech respectively, to the lake inlet as shown in (Fig. 2. Table 1). The four gaging stations installed by the MoWIE are located right on the bridges cross section along the main asphalt road that runs from Addis Abeba to Gonder. These gaging station were installed in early 1960’s and maintained and improved during the 1990’s.”

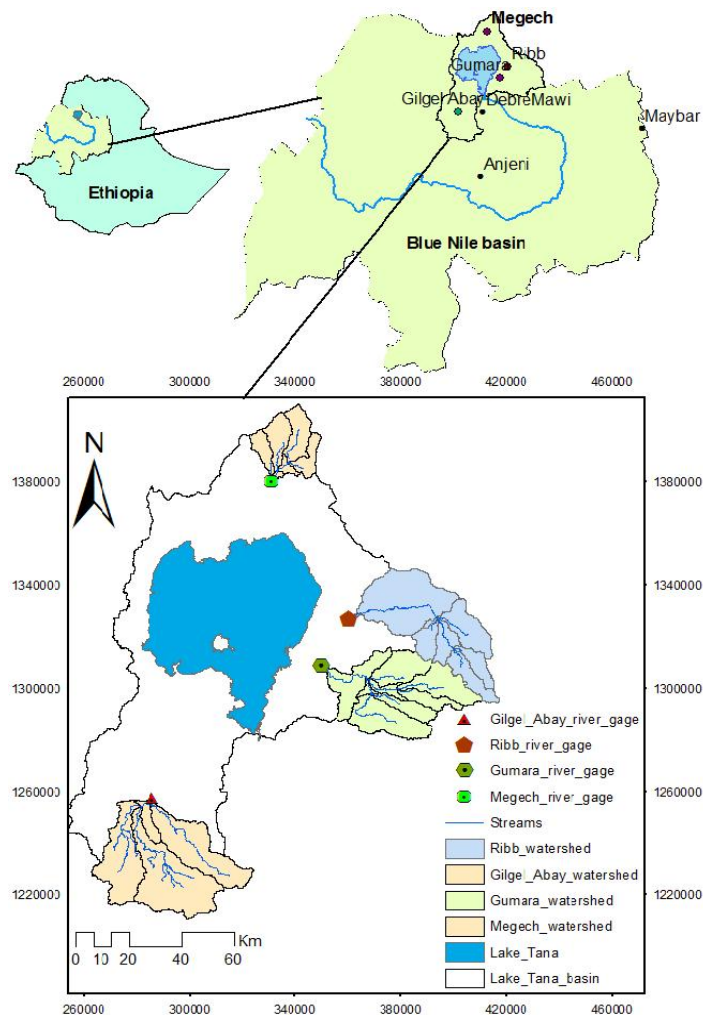


Figure 2: Location maps of the Lake Tana watersheds (Gilgel Abay, Gumara, Ribb and Megech) and 100-ha watershed 100 ha watersheds (Debre Mawi, Anjeni and Maybar) in or close to the Blue Nile Basin.

Table 1: Characteristics of the study watersheds of the Lake Tana Basin and the three 100 ha watershed in the Ethiopian highlands.

Watersheds	Drainage Area (km ²)	Mean Annual Rainfall(mm)	Rating curve (Eq.1) by MoWIE load rating curve(RC) constants	
			a	b
Lake Tana watersheds			a	b
Gilgel Abay	1665	1912	4	1.65
Ribb	1288	1213	30	1.59
Gumara	1274	1540	17.5	1.48
Megech	500	1455	15.1	1.35
100 ha Watersheds				
Debre Mawi	0.91	890	-	-
Anjeni	1.3	1658	-	-
Maybar	1.1	1320	-	-

Finally we revised the paragraph on page 1426-1427, starting from Line 25

“Irregular measured discharge and sediment concentration data by Ministry of Water Irrigation and Electricity (MoWIE) for the major four rivers in Lake Tana basin were available for the period from 1964 to 2008. The discharge was measured bridge cross-section using velocity-area method using. The stream flow velocity was estimated for the dry phase low flows by wading into the river and using cable during the rainy phase.”

We have not added the following map but if it is helpful we could do that.



Comment: The application of the equations valid for large catchments to micro-catchments needs to be justified.”

Response: In order to validate the applicability of the concentration rating curve equation we selected two size ranges of watersheds consisting the 100 ha watersheds and the Lake Tana watersheds ranging from 500 km² to about 1600 km². The justification is given in the paragraph below

“Since the traditional method of determining rating curves for sediment loads assume that the sediment concentrations are a unique function of the discharge, this method cannot be used in environmental applications for predicting sediment concentrations when the sediment concentration decreases throughout the season for a given amount of discharge. The objective of this paper is, therefore, to develop a realistic method in determining the decreasing sediment concentration with the progression of the monsoon using the limited data common in most of the tropics. The study is carried out in the Ethiopian highlands. Two groups of watershed sizes were selected to test how well the concentration rating curve performed. These consisted of four major rivers and their watersheds in the Lake Tana basin and three small well-monitored 100 ha watersheds the Blue Nile basin”

In the discussion at the end we discuss all watershed and draw conclusion based on the results of the four large watersheds and the three small watersheds

Response to comments of Reviewer 1

We thank the reviewer for the positive and encouraging evaluation of the discussion paper. We appreciate the many detailed and helpful comments allowing us to make the text better readable. We implemented all suggested changes. Below we first repeat the comment of the reviewer and follow that with our response in blue.

Comment: My main concern is the P_T parameter. I could not understand from the manuscript how this parameter was determined (page 1428, line 12). The P_T is crucial for determining the stage within the rainy season and selecting the discharges to determine the end members of the 'a' parameters. The approach is illustrated in Figure 1, but this does not indicate how the parameters are determined from the data.

Response: Experimental data showed that the sediment concentration for a given amount of rainfall is greater in the beginning in the rainy phase than later on. The high concentration initially is caused by rill formation in the plowed land (Zegeye et al. 2010; Tilahun et al. (2013a, b). We assume that the sediment transport capacity of the runoff water determine the sediment concentration in the runoff. Once the rills are formed they increase in size and after the most intense storms have passed in late July the rills become stable. The sediment concentration in the water is then determined by the cohesion of the soil. The amount of effective rainfall to the point when the rills are stable (or when the most intensive storms have passed is called P_T . It is impossible to calculate when this occurs exactly. Past modeling by Tilahun et al. (2013a, b) showed that P_T was around 500 mm. For the rating curve determination fitted the value of P_T so that the best fit was obtained. The value of P_T was in the expected range and only slightly dependent on location.

Based on the above explanation we changed the text as follows:

“where a_s is sediment source limiting factor, a_t is the sediment transport limiting factor, P_e is the cumulative effective rainfall (mm) at a particular day, P_T is the threshold cumulative rainfall up to what point the a_c parameter linearly decreases with cumulative rainfall, P_e , and after which the sediment concentration remains at the source limit.

When P_e is equal to and greater than P_T , the ratio becomes one, which indicates that the sediment concentration is equal the source limit. The “ a_t ” and “ a_s ” parameters depend on a number of factors such as slope length, particle size and disposability. In addition, “ a_s ” parameter varies with the cohesion of the soil (Yu et al., 1997). The threshold value was found in other simulations to be around 600 mm (Tilahun et al., 2013 a,b). The values of all three parameters are therefore difficult to predict a priori and need to be calibrated. As we will see hereafter they follow in a relatively narrow range indicating that they have physical meaning”

Comment: Page 1421, line 11: Please avoid abbreviations such as ‘GERD’ if you do not use them later on in the text.

Response: We removed the abbreviation ‘GERD’ from the manuscript.

Comment: Page 1422 Line 3-5. Is there a connection between the two approaches mentioned: models and rating curves? Please discuss in a couple of sentences which models use rating curves.

Response: Based on the comments we added the following paragraph to explain connections between models and rating curves. The paragraph explained below was included in the revised manuscript page 1422 starting in between line 5 and 6.

“There is a connection between models and rating curves in sediment studies in the Ethiopian highland. Rating curves have been used to validate models. Previous simulations to predict sediment load in the Lake Tana basin such as Easton et al. (2010) and Setegn et al. (2009b), sediment load rating curves were used to generate the observed sediment load data and validate the models. Our intent is to improve the prediction of sediment concentration by developing better rating curves so that sediment concentration data can be generated from observed flow. In addition, these improved rating curves can be used as a model to predict sediment concentration and load”.

Comment: Page 1423 line 6-8: There are two arguments mixed up in this sentence: percentage of freshly plowed land and wetness and cohesiveness of the soil. The first is

determined by the timing in the crop calendar, while the second depends on the cumulative rainfall. Please separate these two issues.

Response: We agree that our explaining the statement was poor. We improve the statements by separating in two the text by separating in to two sentences as follows:

“...the progression of the rainy monsoon phase, the value of a_c is a function of the portion of the area of newly plowed land and takes the highest value in the beginning of the rainy season when in the unconsolidated soil rills form and the soil removed is transported by runoff. Then a_c value decreases linearly with effective cumulative precipitation, P_e to the threshold value, P_T when the value of a_c becomes constant.”

Comment: Page 1423 Line 15 . . . increases.

Response: In the revised manuscript we corrected it. Thanks.

Comment: Page 1423 Line 24 word missingand aims to test how.....

Response: Corrected as proposed. We added “concentration rating curve” following the word ‘how’

Comment: Page 1423 Line 24 is not a range of scales optimistic? There are only two size groups of catchments (100’s km² and 100 ha). This is hardly ‘a range of scales’.

Response: We include in the manuscripts as proposed: it was corrected as substituting “range of scales” by “two groups of watershed sizes”

Comment: Page 1424 Line 7 (see also page 1423 line 7) please be consistent in the spelling ‘plowed ‘or ‘ploughed’

Response: We used the word “plowed” consistently in the manuscript.

Comment: Page 1424 Line 19. Is P_e the cumulative effective rainfall or the daily effective rainfall? How is P_e determined (only explained on page 1427, line 26)? I can understand the threshold for the beginning of the rainy season, but have some difficulties with the end of the rainy season. Over which time period does the P_e has to 0 to reach the end of the rainy season?

Response: P_e is the cumulative daily effective rainfall starting from the beginning of the rainy season to the end. It is obtained by subtracting the daily observed precipitation from potential evaporation and then summing the daily values starting at the beginning of the rainy phase. When the P_e become equal to maximum effective rainfall threshold (P_T), source limiting become a limiting factor in the rating curves and P_e will not be used as an input in equation 4a after this period. The end of the rainy period is not important as the threshold usually occurs before that.

Therefore based on the above explanation we changed that paragraph as follows as follows:

“Therefore, the sediment concentrations were calculated separately during the rainy monsoon phase and during the dry phase. Since the start of the rainy phase varies from year to year and from one location to another, we will use the cumulative effective rainfall, P_e , to replace the “time” parameter and is determined by summing the daily effective rainfall which is equal to precipitation minus the potential evaporation for that day. The rainy phase starts when the cumulative effective rainfall, P_e is greater than 40 mm (from observation) and setting each time when P_e is negative to zero. As we will see later in most of the Lake Tana basin this occurs in the beginning of July, but it begins in mid of May in Gilgel Abay because the rainy phase starts earlier in a southern direction. Mainly in all of the watersheds the rainy phase in ends the beginning of October.

Comment: Page 1427 line 9-12. Please rephrase the sentence. There is some confusion between the years selected and the installation period of the SWC measures.

Response: We corrected as per the comment and included the rephrased sentences in the manuscript as:

“The Megech data was only available and the analysis was made for 1990–2007. The analysis for the Anjeni was made for 1996 and for Anjeni 1994 when the watershed were stabilized from the soil and water conservation practices that were installed in the mid of 1980’s.”

Comment: Page 1430: line 1occurs.....

Response: Corrected as proposed and included in the manuscript.

Comment: Page 1430: line 14 Rephrase 'and in addition not very well'

Response: Thank you for the correction. It is corrected as per the comment and included in the manuscript as:

"For the Lake Tana watersheds, the sediment concentrations are under predicted by the MoWIE load rating curve and indicated low prediction performance (Fig. 4)"

Comment: Page 1430: Line 16 Delete the second 'of'

Response: Corrected as proposed and included in the manuscript.

Comment: P1430-1431 Sections 4.1.3 and 4.2. Please change the order of Figs. 5 and 6, as you refer to Fig. 6 first and Fig. 5 later

Response: Thanks for the comment and the Figures are relabeled as "Fig. 6" into "Fig. 5" and vice versa and included the in the manuscript.

Comment: Page 1431 line 21 and line 24 . . . concentrations . . .

Response: Corrected based on the proposed comment and included in the manuscript.

Comment: Page 1432 line 2 Delete 'in the Ethiopian highlands'

Response: Thanks for the comment we deleted and corrected in the manuscript.

Comment: Page 1432 Line 12 'loads and discharge' Singular or plural, please be consistent.

Response: We corrected by removing the letter "s" from "loads"

Comment: Page 1432 Line 21 Please give the parameter in brackets that describes 'the amount.....of the rainfall'

Response: Comment corrected as proposed by adding the parameter name and symbol in brackets as "The amount of cumulative effective rainfall (P_e)"

Comment: Page 1432 Line 26 Please check the spelling of 'gauge' or 'gage' (used earlier in the text)

Response: Thanks for the comment. We accepted the Comment accepted and corrected by using the word "gage" instead of "gauge"

Comment: Page 1433 line 4 Watersheds.....

Response: Corrected as proposed and included in the manuscript.

Comment: Page 1433 Line 10after land is plowed (or ploughed see earlier remark) and rills are formed.

Response: Corrected as proposed. The word "plowed" were used in the corrected manuscript.

Comment: Page 1433 Line 16gentle slope.....

Response: Thank you for the comment. The correction was included in the manuscript.

Comment: Page 1433 Line 17coefficient compared to the Maybar...

Response: We corrected as proposed and included in the manuscript.

Comment: Page 1433 Line 20the other four watersheds.....

Response:. We corrected as proposed and include in the manuscript.

Comment: Page 1433 Line 23Gumara has the greatest value.....

Response:. We corrected as proposed and include in the manuscript.

Comment: Page 1433 Line 24-25 unclear sentence. Please break up: first mention human activities, and specify them in a separate sentence.

Response: Thanks for the comment. We addressed the comment by separating the statement "This can be related to the human activities in the river for irrigation and sediment taken out from the banks" as:

“This can be related to several factors mainly increasing population and activities for natural resource competition. This includes pumping water for irrigating cash crops during the dry monsoon phase from the river. In addition, sand is being mined from the river bed.”

Comment: Page 1434 Line 2sediment concentrations.....

Response: Corrected as proposed. Thanks for the comment.

Comment: Page 1434 Line 2observation while developing.....

Response: It was corrected as proposed and included in the corrected manuscript.

Comment: Page 1434 Line 4improves the prediction of the sediment.....

Response: The statement was corrected based on the proposed comment and included in the manuscript.

Comment: Page 1434 Line 10 Part of the sentence (and more importantly the clue of the paper) is missing after ‘might have’

Response: Thanks, we added the following phrase based on the given comment to complete the sentences:

"Although more research has to be done, there is an indication that the coefficients in the newly developed concentration rating curve can be related to landscape characteristics. Therefore might have physical meaning which would help to generate the parameters from the physical catchment characteristics for the ungagged catchments for predicting concentrations and load in the upper Blue Nile Basin."

References Added to the Manuscript

Easton, Z.M., Fuka, D.R., White, E.D., Collick, A.S., Biruk, A.B., McCartney, M., Awulachew, S.B., Ahmed, A.A., and Steenhuis, T.S. A multi basin SWAT model analysis of runoff and sedimentation in the Blue Nile, Ethiopia, Hydrological and Earth System Science, 14: pp.1827-1841, doi:10.5194/hess-14-1827-2010, 2010.

Setegn, S.G., Srinivasan, R., Dargahi, B., and Melesse, A. M. Spatial delineation of soil erosion vulnerability in the Lake Tana Basin, Ethiopia, *Hydrological Processes*, 23(26), 3738-3750. DOI: 10.1002/hyp.7476, 2009.

Response to comments of Reviewer 2

We are delighted with the response reviewer 2. We appreciate the many detailed and helpful comments. It has allowed us to improve the manuscript significantly. We implemented all suggested changes. Below, we first wrote the direct copy of the comment from the reviewer and follow that with our response in “blue”. The “red” color is for words that we inserted in the text of the original manuscript.

General comments

Comment: The study indicates the importance of local calibration of empirical models for estimating sediment load and concentration. However, the research question is not clearly indicated and the discussion is very shallow. Overall with major modification the article can be accepted.

Response: The main research question was whether the existing sediment rating curves developed by the Ministry of Water Resources and Electricity (MoWIE) of Ethiopia could be used to describe sediment concentrations which depend on saturation of watersheds (i.e. ratio of cumulative effective rainfall with the maximum threshold effective precipitation). Sediment concentration in the highlands of Ethiopia decreases with the progress of the rainy phase of monsoon and with increment of discharge. We agree with the reviewer that the research question on last paragraph of page 1423 was not well formulated and reworded it as follows:

"Since the traditional method of determining rating curves for sediment loads assume that the sediment concentrations are a unique function of the discharge, this method cannot be used in environmental applications for predicting sediment concentrations when the sediment concentration decreases throughout the season for a given amount of discharge. The objective of this paper was, therefore, to develop a realistic method to determine the decreasing sediment concentration with the progression of the monsoon using the limited data common in most of the tropics. The study is carried out in the Blue Nile basin, in the Ethiopian highlands, where four major rivers and their watersheds were selected to test how well the relation performs for a range of scales."

Comment: Introduction: It is not properly address what is lacking from the previous scientific studies. It looks like the study was conducted because you have sediment-discharge data.

Response: We agree and we added the following text to indicate what previous scientific studies were carried [on page 21, line 10](#)

“In the Blue Nile Basin in the Ethiopian highlands, where the construction of the Grand Ethiopian Renaissance Dam is underway near the border of Sudan and other **planned** hydroelectric dams upstream of it, determining sediment loads is becoming more urgent. At the same time, concern for the environment has been increasing and it has been noted that the fish production in Lake Tana is decreasing due to increasing sediment concentrations (Vijverberg et al., 2012). Thus, the ability to predict accurately the sediment concentration and load to the lakes and man-made reservoir has become important **and these are not available in the Ethiopian highlands.**”

We added the following to the end of the paragraph that follows the above paragraph.

“.....However, it is cumbersome to obtain the required data for these models especially in developing countries. Therefore, **previously** when concurrent concentration and discharge measurement are taken at irregular intervals; rating curves are often the preferred choice for predicting sediment loads **in the past (e.g., Walling, 1990) and more recently (e.g., Horowitz, 2010); Kokpinar et al., (2015); Choi and Lee, 2015; Kheirfam and Vafakhah, 2015).** The abundance of papers on load rating curves in the literature should be not surprising since purpose of the measurements was to determine the amount of sediment that potentially could be deposited in rivers and reservoirs. In the published refereed literature, a limited number of articles developed sediment rating curves. These few studies were carried out in Sweden (Fenn et al., 1985); Ontario Canada (Irvine and Drake, 1987), British Columbia in Canada (Sichingabula, 1998), South Australia (Sun et al, 2001) and for the Himalayan glacier in India (Arora et al., 2014).Thus, compared to the sediment load rating curves that are available throughout

the world for many rivers, there are very few sediment concentration rating curves and none for a monsoon climate.”

In addition in page 1422 and 1423, we stated that a unique rating curve function cannot describe the sediment concentration pattern during the rainy period in the Ethiopian highlands. There were attempts by other authors but we learned from field studies that the observed sediment concentrations in streams and rivers are decreasing for the same discharge with the progression of the rainy monsoon phase. We, therefore, proposed a new sediment rating curves.

Moreover, we do believe that any new models should be site specific and, these can be achieved through the experimental observations in the watershed that can serve as the building blocks of models. Two main steps needs to be carried out in developing models (such as new rating curves) are: i) developing an experimental set up to understand the process of the system, in our case the sediment trends in the rainy season in relation to effective rainfall and ii) designing the model (empirical or physical) based on the process observed and the data collected for calibration. As a result, we have understood from the data collected in 100ha experimental watersheds and inferred the trends in sediment concentration during the rainy season and then develop the rating curve (as model) and calibrate the parameters.

Comment: Some of the citations are out dated.

Response: Yes we understand some of the citations are old. However, we were referring the original authors for the rating curves or the models as they were the founders of the method or authors of the methods or the models. Partly, we tried to improve or make the references as indicated in the above comment and as it could be seen from the new citations and added references.

Comment: Methods: What kind of instruments was used by MoWIE for sediment sampling, what was its accuracy?

Response: While we were collecting the data from MoWIE, we managed to discuss how the samples were analyzed. Based on the information we received:

Flow rate or discharge was measured while sediment samples were taken. Discharge was measured by measuring the stage, cross-section of the channel and flow velocity at the gaging station. At the same time, grab sampling river water from the gaging station (Lake Tana watersheds) was conducted for sediment concentration analysis. This was done by collecting the water samples using standard plastic bottles and transporting it to the laboratory for sediment concentration analysis. The sediment concentration was determined by using gravimetric analysis.

Comment: Indicate the coordinate of the study area in Figure 2. Use different symbols for the gauging stations at the catchment and at the small plots.

Response: Thanks for the comment. We corrected the figures based on the comment as indicated below and included in the manuscript.

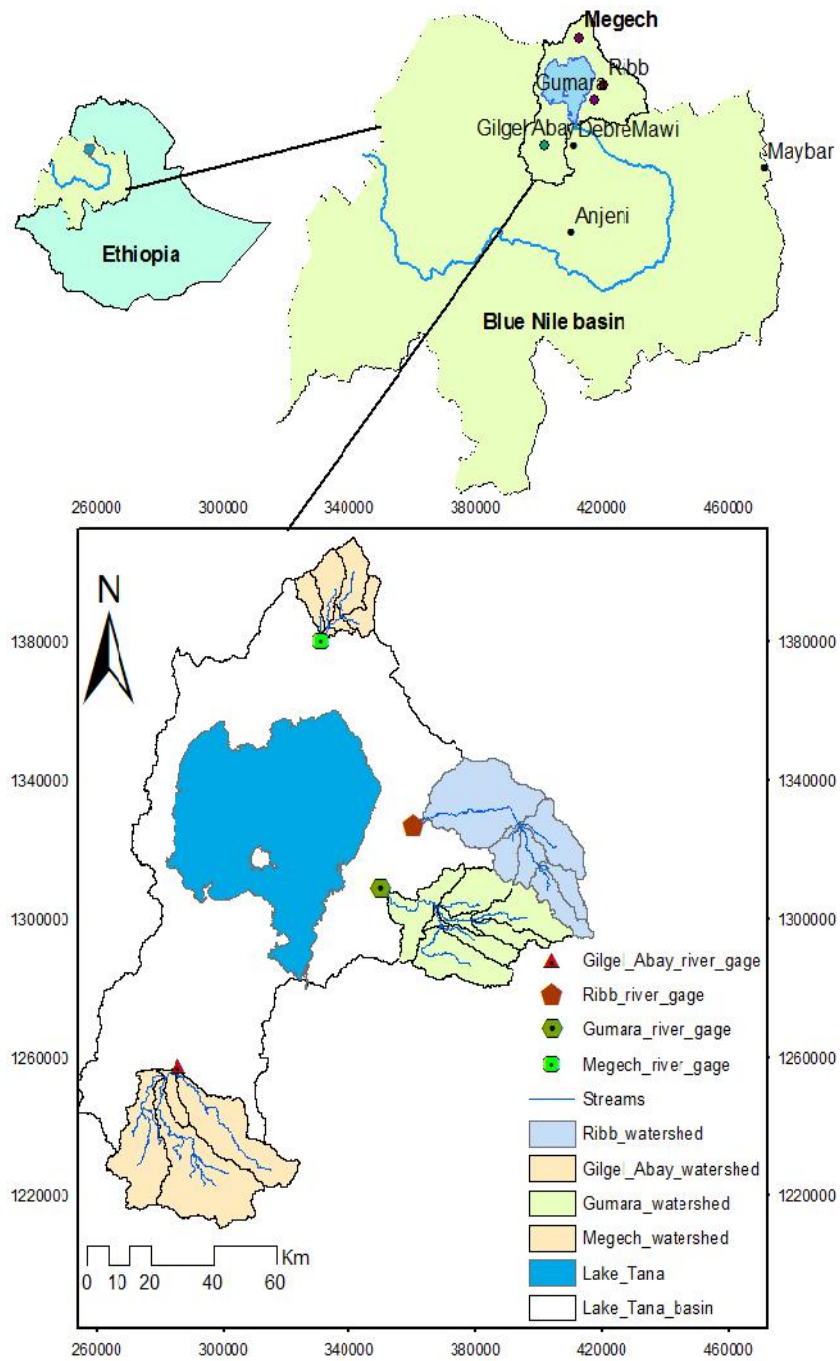
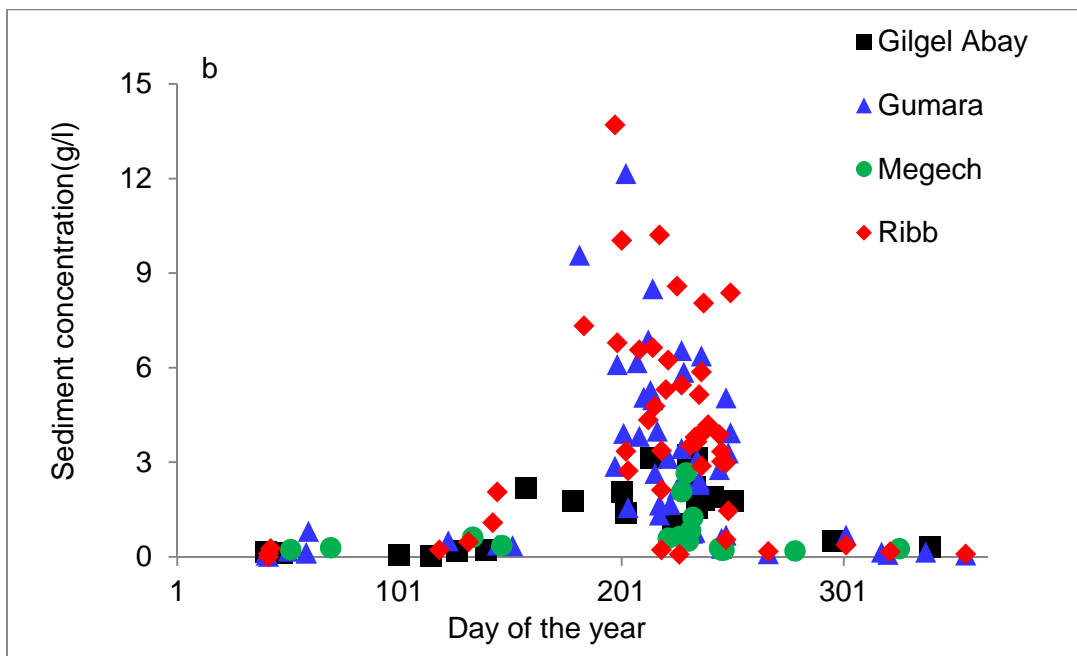
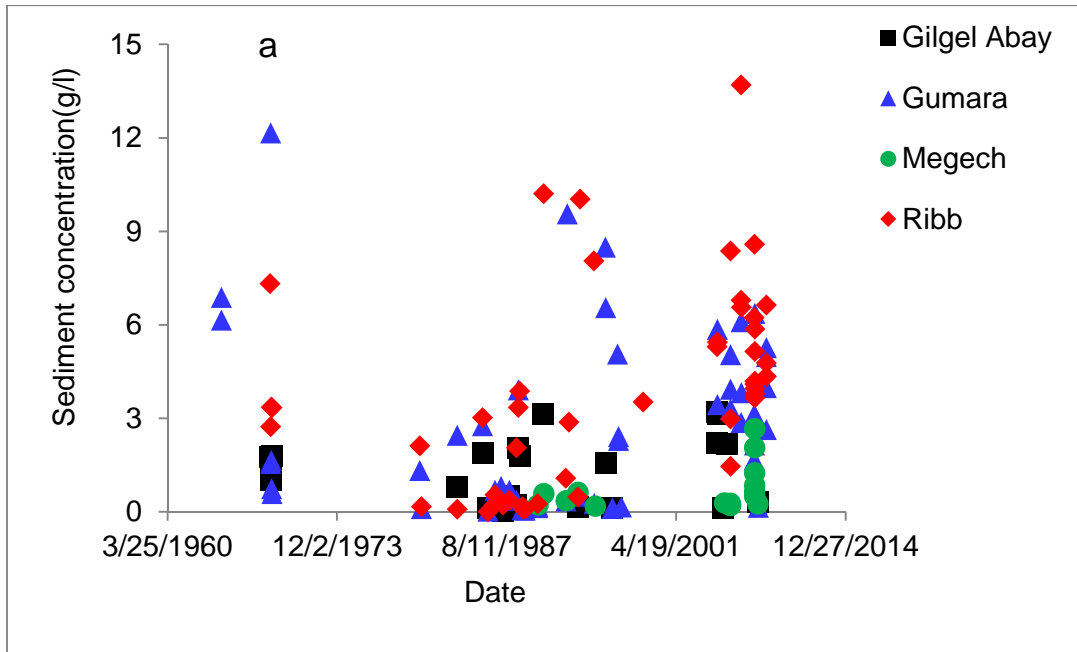


Figure 2. Location maps of the **Lake Tana watersheds** (Gilgel Abay, Gumara, Ribb and Megech) and 100-ha watershed 100 ha watersheds (Debre Mawi, Anjeni and Maybar) in or close to the Blue Nile Basin.

Comment: Results: Use different symbols for the graphs in case the printing is in Black and White. Use proper scale for the Y and X axis at the 1:1 graphs

Response: Thanks for the comment. We corrected as proposed and included in the manuscript. Some of the graphs in which the symbols have been changed are presented below.



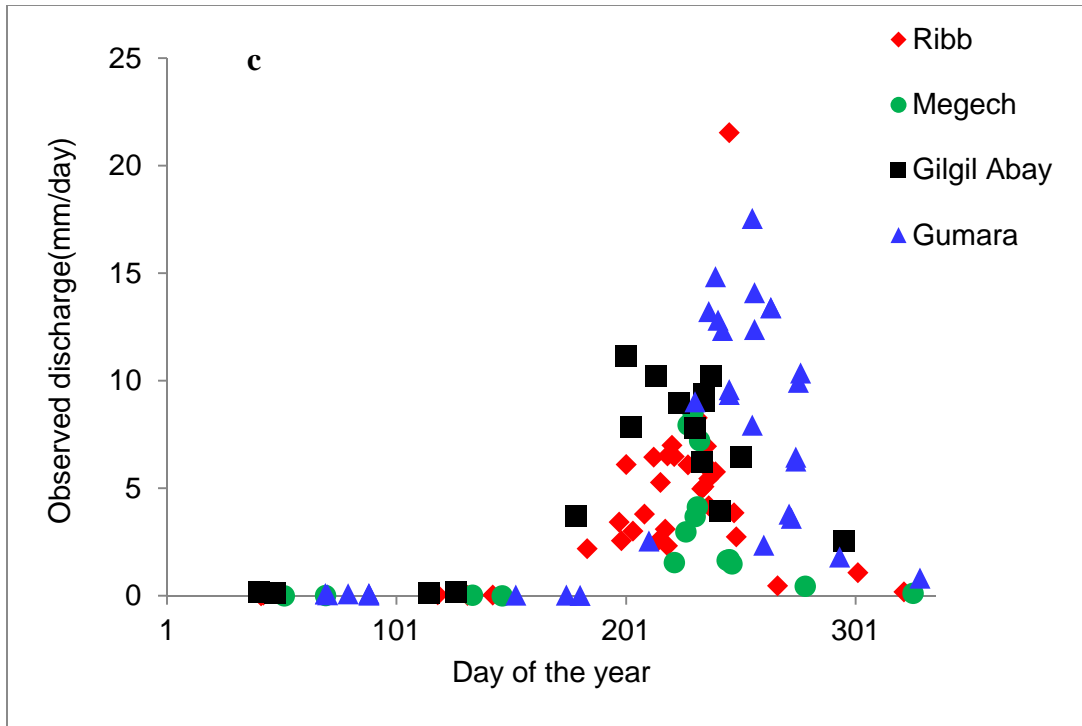
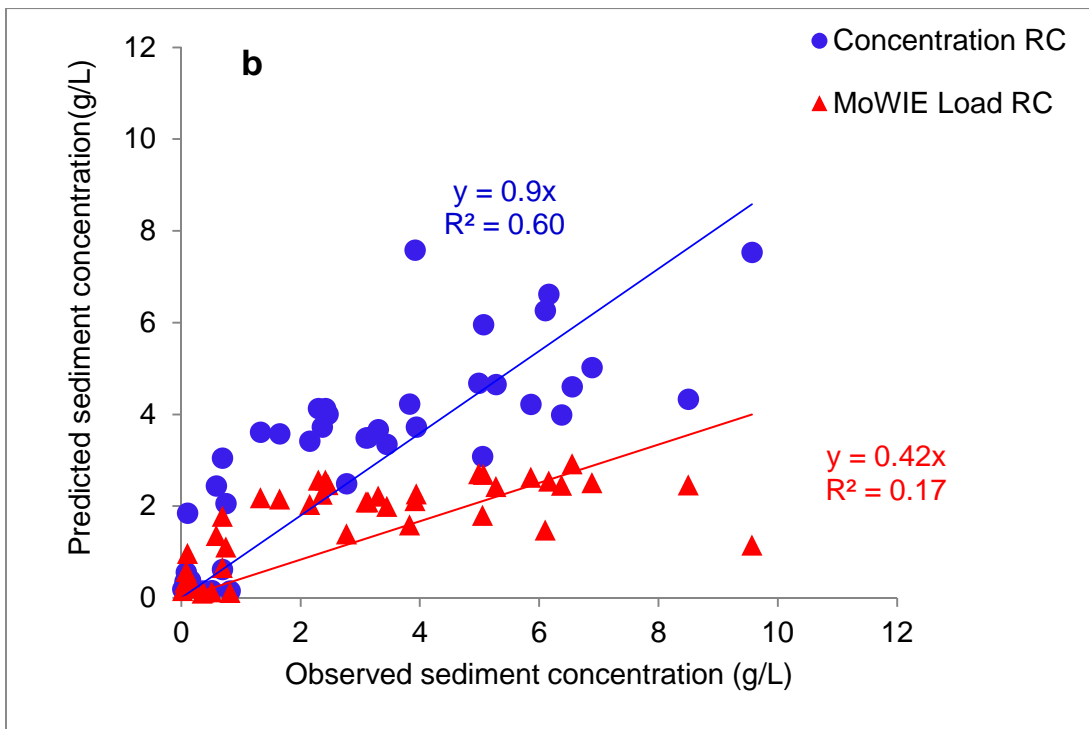
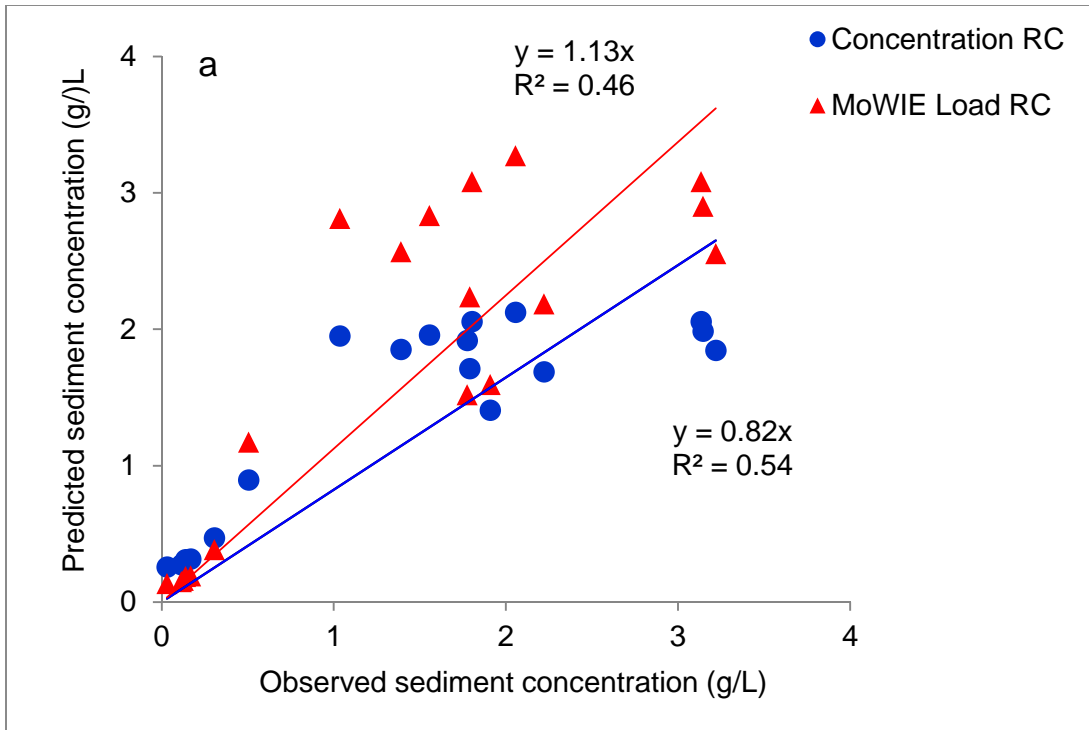


Figure 3 Observed sediment concentration and discharge for the four Lake Tana watersheds: Gilgel Abay, Gumara, Megech and Ribb. **a.** sediment concentration vs date of sampling **b.** sediment concentration as a function of day of sampling independent of the year, and **c.** observed discharge plotted vs sampling day.



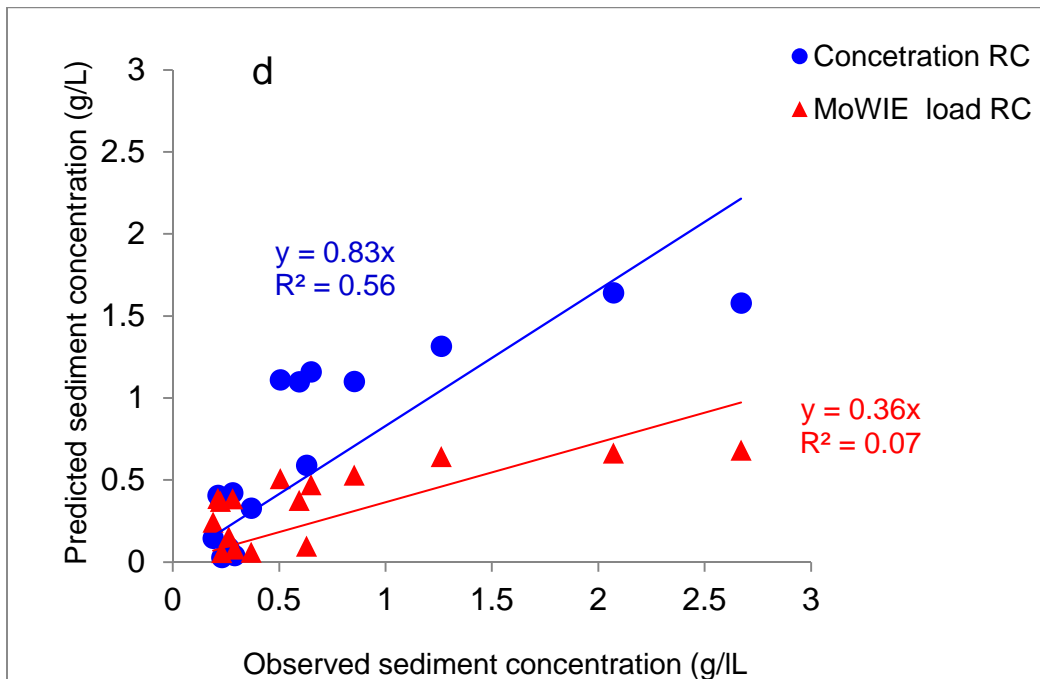
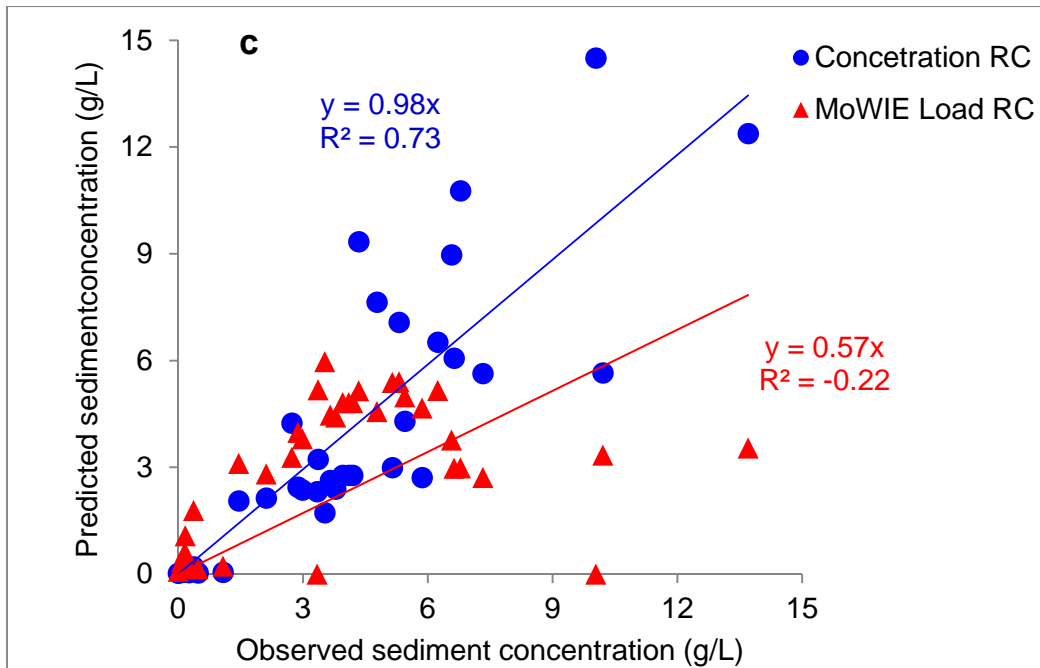
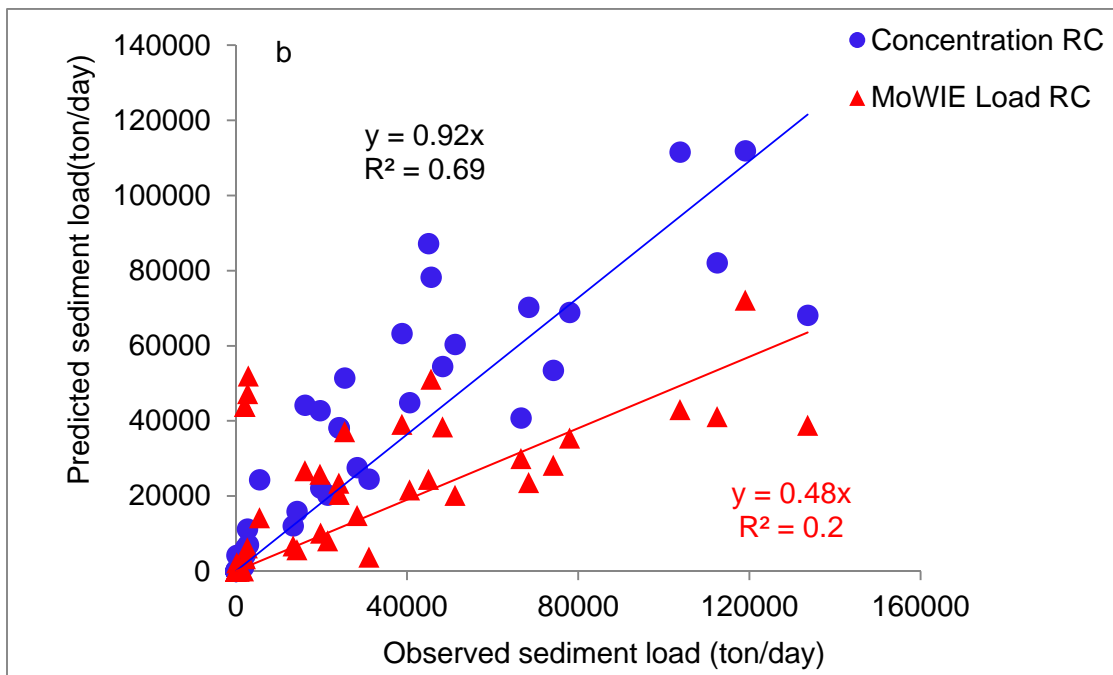
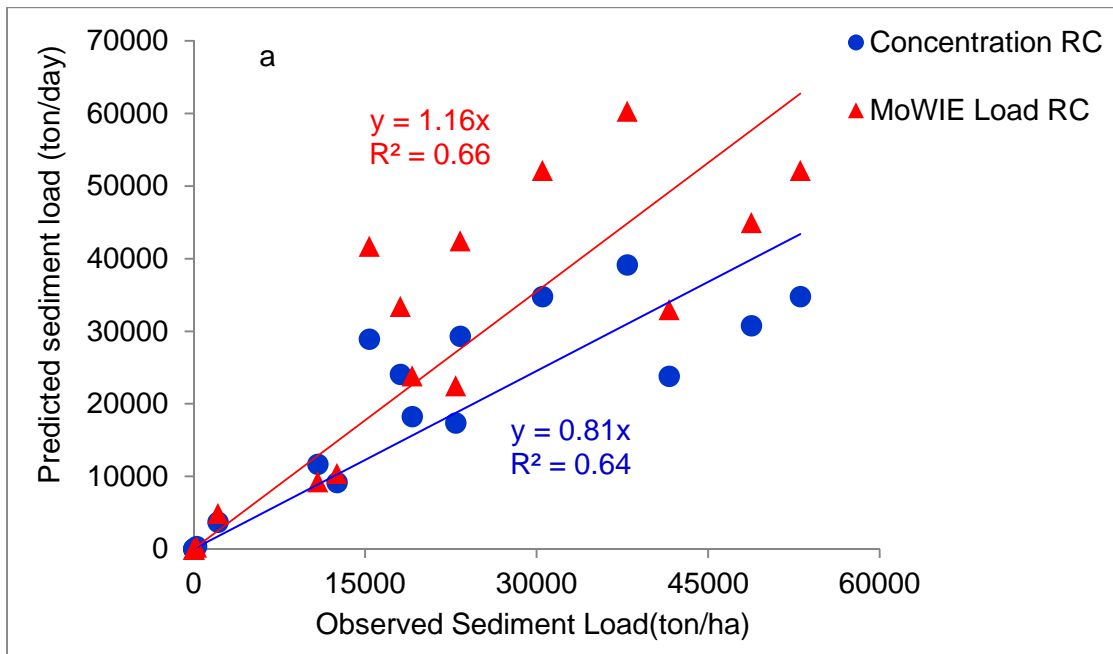


Figure 4. Predicted versus observed sediment concentration using concentration rating curve and MoWIE load rating curve for the Lake Tana watersheds (a) Gilgel Abay, (b) Gumara, (c) Ribb, (d) Megech



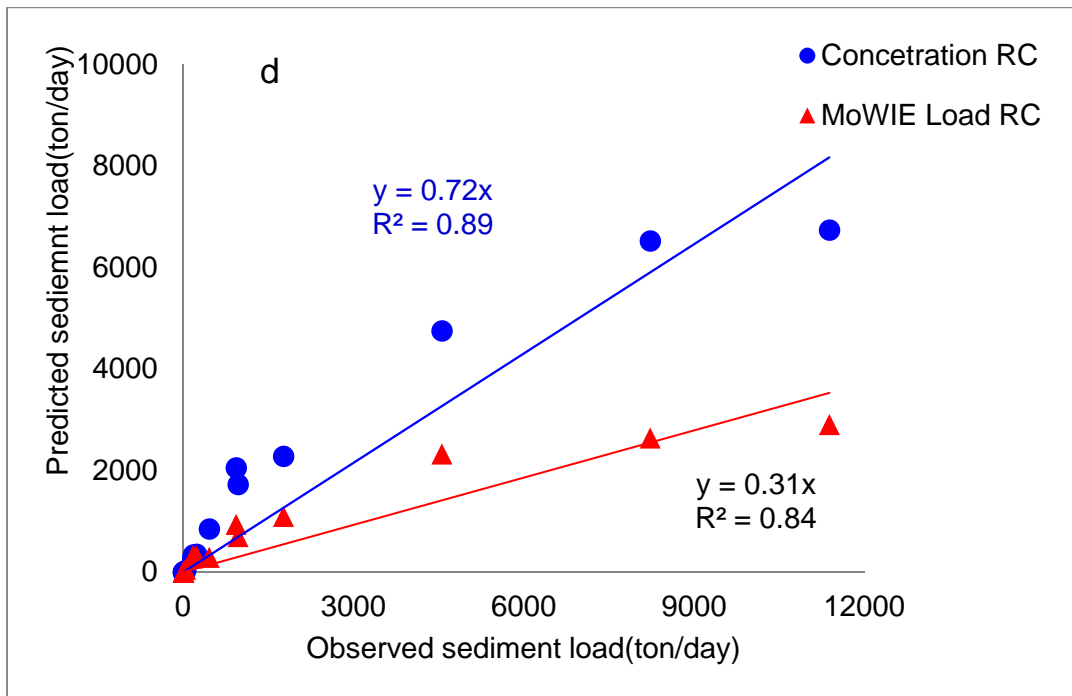
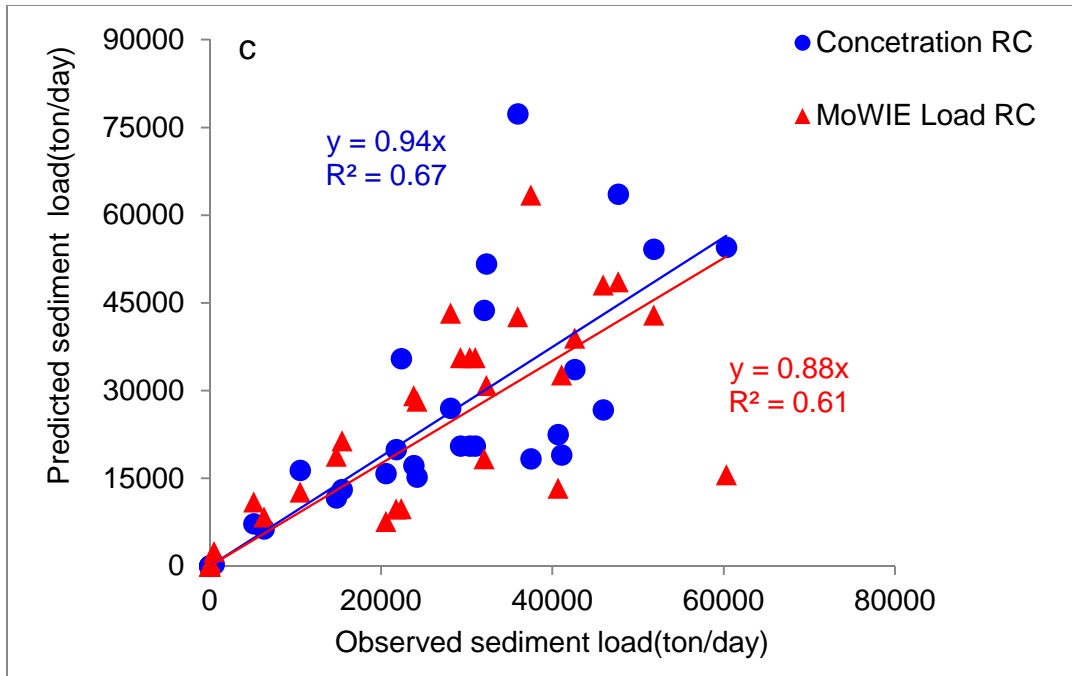


Figure 5. Predicted versus observed sediment load using concentration rating curve and MoWIE load rating curve for the Lake Tana watersheds (a) Gilgel Abay, (b) Gumara, (c) Ribb, (d) Megech

Comment: Figure 2: I couldn't see the logic behind the fitting of the Load/concentration rating curves from catchment based ($> 500 \text{ km}^2$) to micro-watershed ($0.1\text{-}11 \text{ km}^2$). These catchments are expected to have different morphologic and fluid transport mechanisms. So can we say that the correlation happens by chance?

Response: Our result of good correlation for the new rating curves at various scales did not happen by chance. It is telling that there is some similarity in response by the two groups of watershed sizes (100's km^2 and 100 ha). The similarity can be explained as follows:

Such similarities exist because the watersheds behave similarly when they dry out and wet up. When they dry up, all upland watersheds will be plowed and vegetation cover is poor. At this time, sediment is available that can be transported within the watersheds. After the watershed has been wetted up after the end of P_T , sediment in the watershed is limited as the soil is saturated and becoming more cohesive and vegetation cover improves. The only difference between these two scale watersheds is that there is sediment from the channels of large sized watersheds by base flow. The alluvial sediment deposits in the channels are high in the larger rivers so that the coefficient a_b introduced in our new rating curves for larger sizes. In smaller size watersheds, a_b is zero describing the base flow is clean from sediment during dry period.

Specific comments:

Comment: Page-1: Line 5-9: Need to be combined properly.

Response: Thanks for the comment and the statement was re-written included on [page 1421 line 2](#)

“In order to determine sediment loads in the absence of these measurements, models have been used. Knowing the total sediment loads from rivers is essential for evaluating the siltation of reservoirs (Ali et al., 2014) and assessment of soil erosion and nutrient loss (Walling, 1977). As a result Knowledge of sediment concentration is vital in most

environmental applications among others as it hampers fish reproduction and reduces the esthetic value of surface waters (Vijverberg et al., 2012)”

Comment: Page-1: Line 10-13: Should be rewritten.

Response: and the statement was re-written as follows and included in the manuscript on [page 1421 line 10](#).

“In the Blue Nile Basin, where the construction of the Grand Ethiopian Renaissance Dam and planning of other hydroelectric dams (upstream of it) are under way, determining sediment loads is becoming more urgent.”

Comment: Page 1: Line 19-21: The USLE and its derivatives are RUSLE and MUSLE.

Response: Thanks for the comment we corrected as proposed and included in the manuscript on [page1421 line 21](#)

“The USLE (Wischmeier and Smith,1965) and it derivatives such as RUSLE (Renard et al., 1991) and MUSLE (Williams and Berndt, 1977)”

Comment: Page 1: Line 21 – 2(Page 2): It is not clear what these area? Indicate the cons and pros of these models as it is or based on a general category y (empirical, process based, hybrids...).

Response: The statement was re-written as follows and Included in the manuscript on [page 1422, line 2](#)

“The challenges in using these models can be seen in two ways i) The models have been developed in temperate climate and arid areas where the runoff mechanism is governed by Infiltration excess unlike the highland areas where saturation excess runoff is dominating (Steenhuis et al., 2009; Bayabil et al., 2010; Tilahun et al., 2013) and ii) almost all of the models need intensive data with many parameters that might be available centrally in developed countries but not in developing countries such as Ethiopia.

Comment: Page-2: Line 5-6: What kinds of data are important for these models that are difficult to obtain in developing countries?

Response: Thank you for the comment. We included the following text in the manuscript on page 1422 line 2 to specifically to explain the data scarcity.

“This was because of these models are originally developed for areas that have large data base. For example, in the land use and land cover map, there are no leaf area index of our map that SWAT needs. Similarly, the soil data in Ethiopia is very coarse and missed basic information such as soil texture, hydraulic conductivity and other parameters that are difficult to measure here in this country.”

Therefore when we say data scarce, it is to refer those detail data that help to test the models and to scale up for larger watersheds to use the model for predicting stream flow and sediment load for the purpose we need.

Comment: page-2 Line 6-8: There is no proper transition of this section from the previous idea.

Response: Thanks for grateful comment. We corrected by adding the following paragraph between on page 1422 next to line 5 after same added paragraph for the above comments in the same position:

“There is direct link between models and rating curves in sediment studies in the Ethiopian highlands. Because of the limited data, rating curves are used to validate models (e.g. Easton et al., 2010 and Setegn et al., 2009b). Here we developed concentration rating curves so that sediment concentrations can be generated for calibration and validation from observed flow. In addition, it can be used as a model to predict sediment concentration and load.”

Comment: Page 2: What is the source of Eq.2?

Response: The source of Eq. 2 is from Eq.1 by dividing the estimated load to the corresponding discharge.

Comment: Page 9: It is not clear why you exclude the time from 1964-1967.

Response: Thanks for the comment. the sediment data for 1964-1967 was included in the data for those watersheds which have records in that period.

Comment: Page 10: Line 1: To what extent is the data "Good"?

Response: When we say the data was "Good" in addition to the daily sediment data, during the morning and afternoons. In addition storm event based data has been collected in those watersheds. As a result, the peak sediment has also added to the total daily sediment within the time period of records.

Comment: Page 10: Line 10-11: For how long you collected the rainfall data?

Response: For larger watersheds, the existing rainfall data from 1994-2008 was obtained from National Meteorological Agency Bahir Dar Branch. For micro watersheds (100 ha watersheds) the rainfall data was collected at the same time when discharge and sediment data was measured. This has been already explained in the available data section on [page 1427, line 14](#)

Comment: Page 10: Line 15-16: For the calculation of the effective precipitation on a daily basis, initial abstraction is more important than the ET.

Response: Initial abstraction would be dominant in the main rainy season especially in the beginning of the rainy season. However in order to see the variation in sediment loads in dry (where there is no initial abstraction but evaporation which highly affects the base flow) and rainy season seasons, we chose the ET as to include the loses in all season for the rating curve to calculate the effective precipitation(P_e).

Comment: Page 10: Line 6: Is there a reason for using Thiessen polygon in the study area?

Response: We used Thiessen polygon method for estimating the areal average rainfall from the watershed. We have chosen this method because it was simple and doesn't require additional information like topography and distance than the other methods.

Based on the comment, we rewrote the sentences as follows. This would be included in the manuscript on [page 1427, line16](#).

“The areal rainfall was calculated by using Thiessen-polygon method for the available rainfall stations (especially for the Lake Tana watersheds as these watersheds have **two and more than two** rainfall stations). The method **was chosen because of it was simple and doesn't require additional or more information**. Details of station weights based on the method are given in the supplementary materials (Supplement, Table A1)”

Comment: Page 10: Line 10-11: For Page 12: Line 4-6: The range of goodness of fit for the NSE should be indicated.

Response: Thank you for the comment. The “goodness of fit” of NS value in the manuscript was included on [page 1429, line 6](#) as follows:

“The Goodness of fit for model performance was rated based on Moriasi et al. (2007), as very good for $NS > 0.75$, good, if NS values was between 0.65 and 0.5, considered as satisfactory if $NS > 0.5$ and less than 0.5 was considered as poor.”

Comment: Page.... Line 13-15: What was the reason for dividing the period into three groups?

Response: It is known that there are two distinct seasons in the highland: dry and monsoonal rainy period. During the rainy period, there is a threshold at which the watersheds saturates and behave differently from the beginning of the rainy period. Since there are different behaviors in the dry, beginning and end of rainy periods, we used these periods to develop the model. (We were referring the data collection periods in developing the rating curve and we found this information from MoWIE).

Comment: Page 13: Line 1-5: The hyetograph of each watershed should be plotted on the upper axis and the Pe and PT should be indicated clearly.

Response: Thanks for the comment. Since P_e and P_T are the cumulative effective and threshold effective precipitations. It would be difficult to indicate as the hyetograph with the limited number of sediment data. We would rather choose to keep it as it was.

Comment: Page 13, Line 15-16: What do you mean by under predicting? Which one is reliable? The measured/observed or predicted?

Response: We were comparing the sediment load and sediment concentration predicted by concentration rating curve and by MoWIE load rating curve with the measured sediment load and concentrations. In this specific case, we were referring that, the MoWIE load rating curves under predicts the sediment concentration compared to concentration rating curve that we developed.

Comment: Page 13, Line 16-18: Why you include R^2 in the "Observed-Predicted" graphs?

Response: It was to indicate the strength of relationships between the observed and predicted sediment concentrations and load by using concentration and MoWIE load rating curves.

Comment: Page 13, Line 18-19: For Gilgel Abay the MoWIE curves perform better. This should be indicated clearly in this section.

Response: Comment accepted and included in the manuscript. Additional explanation was included [on page 1431 line 6](#) as follows:

“The only exception was the sediment load predictions for the Gilgel Abay (Fig. 6a) that was slightly better predicted by the MoWIE load curve than the concentration rating curves. This was due to the observation data used for calibration sediment concentrations of Gilgel Abay was available in times where the limiting factors dominated by source limiting i.e. in August (the rainfall is higher and so do the saturation extent of the watershed) and dry seasons. This likely is one reason for decreasing performance of sediment concentration rating curve. Of course, one could expect that the concentration rating curve would perform better because it has 4 fitting.

Comment: Page 14: Line 9-10: How do you measure "Good"?

Response: "Good" in this case is to indicate the rating curves performance based on Moriasi et. al., (2007) a like the above comment.

Comment: Page 15: Line 13-15: Do you think that having too much parameter means "Better" estimating capacity?

Response: No we don't believe that too much parameters will help the model to perform better and so do few parameters. However, we do believe the most sensitive parameters in the given mode or rating curve could provide better estimation. For our case the sensitive parameters were found a_t and a_s . In which the model system is mainly governed by the two sensitive parameters to govern the rating curves and adjust it or calibrate may provide better result.

Added References other than the manuscript

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