Responses to Reviewer's Comments

Manuscript: Reducing the basin vulnerability by land management practices under past and future climate: a case study of the Nam Ou River Basin, Lao PDR
Authors: M. Maharjan, M. S. Babel, S. Maskey
Journal: HESS
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We are thankful to the Anonymous Reviewers for their valuable comments on, and suggestions for the paper. Below we provide our responses and revisions made in the manuscript to address the issues they have raised. The changes/improvements in the revised manuscript are shown in RED in this document to facilitate the review process.

Comment 1: The question (main objective) addressed by the manuscript is interesting and framed appropriately to be within the scope of HESS, but there is some confusion regarding what vulnerability means. Vulnerability should be clearly defined in the context of soil erosion and sediment yield to make the main objective less ambiguous.

Response 1: Thank you for pointing this out. We agree that it will be more appropriate to define vulnerability in terms of soil erosion and sediment yield to make the main objective of the study clearer.

Revision in the manuscript:
We have added— in the Introduction section—the definition of basin vulnerability, as assessed in this research. Basin vulnerability, in this study, is related to soil erosion and sediment yield.

An uncontrolled or excessive amount of sediment yield or soil erosion may occur in a river basin because of poor soil textures, high rainfall intensities, steep land slope, land use changes and various other factors. This can, in turn, cause fluctuations in the ecological balance of the natural state of the river basin. When these instabilities become too high, they are likely to have an adverse impact on the natural state of the river and the whole basin itself. Thus, basin vulnerability is one of the main concerns of this research. In this study, the basin vulnerability is defined in terms of the adverse changes in the functionality of the river basin due to increase in soil erosion or sediment yield. The level of basin vulnerability may differ from place to place, according to the type of topography and other basin parameters associated with sediment yield in the basin. A detailed theory of sediment yield helps in providing relevant information when formulating quantitative models for landscape evolution and sediment mass balance and for estimating sediment load and erosion intensities in any basin (Walling, 1994). An extensive study of the characteristics of the basin and possible basin vulnerability is the basis for relevant adaptation strategies, adopting which helps to make the basin less prone to high sediment yield.

Comment 2: Additionally, the authors fail to explain the significance of soil erosion and why a high susceptibility to soil erosion within the Ou River Basin should be a concern. Mentions of planned hydroelectric projects are made throughout the manuscript that could serve as a starting point for highlighting the significance of soil erosion and the manuscript in general.

Response 2: Thank you for your comment. We agree that the explanation of soil erosion and why high soil erosion should be a concern for the Nam Ou River Basin is required to be mentioned. We have added points that address the comment and have revised the manuscript accordingly.

Revision in the manuscript:
The revised text in the relevant section of the revised manuscript as a response to this comment reads thus:

The Nam Ou River Basin has been categorized as highly vulnerable to soil erosion (Fuchs, 2004). Chaplot (2007) also showed that interrill soil erosion is relatively higher on the sloping lands in the northern part of Laos. The study has shown that one of the major sediment contributing sources in the Lower Mekong Basin is the Northern Laos, which includes the Nam Ou River Basin (Lu, 1998). And although the Nam Ou Basin has been ranked as a soil erosion risk zone in Lower Mekong, there is plans for additional infrastructure development in the near future, which will render the basin more vulnerable in terms of soil erosion and ecological imbalance. Under a 20–year development plan, the water resources of the Nam Ou River Basin are going to be used extensively for electricity generation (Hoanh et al., 2010). An increase in reservoirs or dams might result in higher sedimentation in the reservoir, and the infrastructure will trap most of the suspended sediment. This will not only reduce the life of the reservoirs but also decrease the flux of sediment and nutrient to the downstream areas (Mekong River Commission, 2003). This may, in turn, cause geomorphological changes such as bank erosion and bed degradation, fragmentation of the river’s ecosystem and disturbance in the local biodiversity of the river basin. While coping with changing climate and future anthropogenic activities, there is a high possibility of susceptibility to soil erosion and disturbance in the natural ecosystem. A previous study carried out in this basin showed that there is a definite impact of climate change on the sediment yield of the basin in the future, but the change is not always unidirectional when different general circulation models (GCMs) and GHGES and are considered (Shrestha et al., 2013). The study also demonstrated the necessity for managing high sediment yield caused due to both, human interference and climate change. Hence, this study was conducted to observe the vulnerability of the basin in terms of the amount of sediment yield and to evaluate relevant land management practices to assess their impact in reducing the sediment yield of the critical sub-basins.

Added references in the revised manuscript:

Chaplot, V., Khampaseuth, X., Valentin, C., and Bissonnais, Y. Le.: Interrill erosion in the sloping lands of northern Laos subjected to shifting cultivation, Earth, 428, 415–428, 2007.

Lu, H.: Comparative analysis of the hydrological characteristics in Lancang Mekong River basin, International symposium of flooding in South Asia, Bangladesh, 1998.

Mekong River Commission: MRC Work Programme, Mekong River commission, Vientiane, 2003.

Comment 3: I do not have any experience with downscaling GCM output and cannot comment on the appropriateness of the methodology employed to that regard, but I do have expertise in SWAT model calibration/validation, use, and the incorporation of different land management practices into SWAT simulations that I can comment on. Conceptually, the approach utilized seems appropriate for the objectives outlined at the end of the introduction, but there are aspects of the SWAT modeling that draw some concern.
Details regarding why SWAT modeling was conducted at a spatial resolution of 250 meters remains unclear; along with aspects of SWAT calibration (time-step used in computing goodness-of-fit indicators (GOFI) is not provided; GOFI values for calibration of sediment yield are vague; warm-up/calibration/validation time-periods seem too short for projections made so far into the future; and more GOFIs can be provided). The temporal scale at which SWAT was calibrated and inclusion of more GOFIs will provide insight on how to classify the degree of model calibration (see Moriasi et al. 2007).

Response 3: Thank you for your comment. This study is the extension of the work of Shrestha et al. (2013) for the second phase of the PRoACC project (as acknowledged in the manuscript). Therefore, we have used the same SWAT model set up in order to evaluate the impact of land management practices to reduce the basin vulnerability due to sediment yield in the Nam Ou River Basin. Similarly, the same resolution of DEM i.e., 250 m is reused in this study. The DEM was obtained from the Secretariat of the Mekong River Commission Phnom Penh (MRC). The DEM is produced by MRC, based on topographical maps.

Regarding the second part of your comment, the time step used in the computation of GOFI in SWAT calibration is a daily time step. The daily sediment load was only calibrated for the period of 1996-2002 but not validated due to limited data. The sediment data was not continuous and there were only 176 measurements within 7 years. As a result, GOFIs for sediment are not as good as for discharge. However, this is generally the case because availability of sediment data is scarcer than for discharge. Therefore, for the given data, we still think that this calibrated model can be used to fulfill the objectives of this study.

Moriasi et al. (2007) recommended three goodness of fit indicators (GOFIs) namely, Nash Sutcliffe Efficiency (NS), Percent Bias (PBIAS) and Ratio of the root mean square error to the standard deviation of measured data (RSR) for the evaluation of model's performance. Therefore, in the revised version, we added one more GOFI (i.e. RSR) to evaluate the performance of the SWAT model and to give a clearer picture. Generally, model simulation can be evaluated as satisfactory if $NS > 0.50$ and $RSR < 0.70$, and if PBIAS ± 25% for discharge and PBIAS ± 55% for sediment. Moriasi et al. (2007) found that most of the evaluation is done on daily and/or monthly time steps (Santhi et al., 2001; Van Liew et al., 2003; Singh et al., 2004) and some on annual time steps (Gupta et al., 1999; Reyes et al., 2004); one evaluation used weekly time steps (Narasimhan et al., 2005). Usually, model simulations are poorer for shorter time steps than for longer time steps. For an instance, Yuan et al. (2001) reported the R^2 value of 0.5 for event comparison of simulated and observed sediment yields, and the R^2 value of 0.7 for monthly comparison. The NS values were 0.395 and 0.656 for daily and monthly, respectively, for the DRAINMOD-DUFLOW calibration in their study by Fernandez et al. (2005). Since the time step in this paper is a daily time step, the range of the three GOFIs (computed using monthly calibration) for a satisfactory result might be difficult to obtain, given the lack of good and complete data sets for sediment yield.

Revision in the manuscript:
The following revisions have been made in various sections of the revised manuscript:

- Daily discharge was calibrated for the period of 1992–1999 and validated for 2000–2003. A warm-up period of two years was retained in order to minimize the error from the estimation of initial state variables (Zhang et al., 2007). The daily sediment yield was calibrated for the period of 1996–2002.

- The performance of the model was evaluated using the coefficient of determinant (R^2), Nash-Sutcliffe coefficient (NS) (Nash and Sutcliffe, 1970), Percent Bias (PBIAS) and Ratio of the root mean square error to the standard deviation of measured data (RSR) as recommended by Moriasi et al., (2007). Generally, model simulation is considered satisfactory if NS > 0.50 and RSR < 0.70, and if PBIAS ± 25% for discharge and PBIAS ± 55% for sediment. Moriasi et al. (2007) found that most of the evaluations are done in daily and/or monthly time steps (Santhi et al., 2001; Van Liew et al., 2003; Singh et al., 2004) and some in annual time steps (Gupta et al., 1999; Reyes et al., 2004); one used weekly time steps (Narasimhan et al., 2005). Usually, model simulations are poorer for shorter time steps than for longer time steps. For an instance, Yuan et al. (2001) reported the R^2 value of 0.5 for event comparison of predicted and observed sediment yields, and the R^2 value of 0.7 for monthly comparison. The NS values were 0.395 and 0.656 for daily and monthly, respectively for the DRAINMOD-DUFLOW calibration in their study by Fernandez et al. (2005).

The comparison of daily simulated discharge with daily observed values gives $R^2 = 0.64$, NS = 0.64, PBIAS = 5.12% and RSR = 0.58 and validation gives $R^2 = 0.74$, NS = 0.72, PBIAS = -14.25% and RSR = 0.53. The performance of the calibration for discharge was reasonable. Though the model could capture the runoff volume well, it was unable to capture peak discharge, except for 1998 and 1999. The error in peak discharge can be attributed to observed precipitation and discharge data during high flows. Rossi et al. (2009) discussed in their study of the Lower Mekong River Basin about possible error accumulation during measurement at gauging station during high flow seasons. This can lead to less reliability in the observed data for the model's validation, mainly along the study area in the Mekong's tributaries.

Similarly, the simulated daily sediment yield matches the observed values for calibration with R^2 and NS = 0.19, PBIAS = 4.18 % and RSR = 0.9. The calibration results showed R^2 and NS to be less than 0.5 and RSR > 0.7. However, the PBIAS value was 4.18%, which shows that the observed and simulated sediment loads have good balance in terms of volume. The poor performance of calibration for sediment yield is mainly attributed to missing data and fewer records. Other reasons are the uncertainty and/or inaccuracy in the derivation of the topographic (LS) factor (Babel et al., 2011) and estimation of the parameters of the sediment erosion model (MUSLE). According to the Sediment Parameter and Calibration Guidance for Hydrological Simulation Program Fortran (HSPF), sediment calibration always involves many steps, in estimating a model's parameters, in finding adjusted values for better simulation results of sediment sources in a watershed, and in calculating sediment delivery ratios. Calibration parameters for sediment erosion are generally more sensitive than other hydrological variables. The sediment parameters are changed to increase agreement between simulated and observed sediment loss and storm event sediment removal. However, observed sediment loss is often not available, and the sediment calibration parameters are not as distinctly separated between those that affect sediment and those that control storm sediment loss. In fact, annual sediment losses are often the result of only a few major storms during the year. Potter and Hiatt (2009) reported that lower values of goodness of fit indicators might be the consequence of limited data available in their study area, Laguna de Santa Rosa watershed in North California. Bieger et al. (2012) also mentioned in their study that lower R^2 values for sediment calibration might be due to inadequate input data, insufficient representation of the spatial variability of rainfall, uncertainties prevailing in the model's structure as well as in observed sediment data. Similarly, Jain et al. (2010) also pointed out that possible human errors in the collection of data of observed rainfall, runoff and sediment yield data might be liable for poor calibration results of sediment yield. All these studies highlight the need for a qualitative assessment of sediment data at any watershed, since the results largely depend on data availability, the location of measuring stations, the time step and the accuracy of data sets.

Added references in the revised manuscript:

Fernandez, G. P., Chescheir, G. M., Skaggs, R. W. and Amatya, D. M.: Development and testing of watershed-scale models for poorly drained soils, Trans. ASAE, 48 (2), 639-652, 2005.

Gupta, H. V., Sorooshian, S. and Yapo, P. O.: Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration, J. Hydrologic Eng, 4 (2), 135-143, 1999.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., and Veith, T. L.: Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, Transactions of the ASABE, 50, 885-900, 2007.

Narasimhan, B., Srinivasan, R., Arnold, J. G. and Luzio, M. Di.: Estimation of long-term soil moisture using a distributed parameter hydrologic model and verification using remotely sensed data, Trans. ASAE, 48 (3), 1101-1113, 2005.

Potter, C. and Haitt, S.: Modeling river flows and sediment dynamics for the Laguna de Santa Rosa watershed in Northern California, J. Soil Water Conserv., 64, 389-393, 2009.

Reyes, M. R., Skaggs, R. W. and Bengtson, R. L.: GLEAMSSWT with nutrients, Trans. ASAE, 47 (1), 129-132, 2004.

Santhi, C., Arnold, J. G., Williams, J. R., Dugas, W. A., Srinivasan, R. and Hauck, L. M.: Validation of the SWAT model on a large river basin with point and nonpoint sources, J. American Water Resources Assoc., 37 (5), 1169-1188, 2001.

Singh, J., Knapp, H. V. and Demissie, M.: Hydrologic modeling of the Iroquois River watershed using HSPF and SWAT, ISWS CR 2004-08. Champaign, Ill.: Illinois State Water Survey, Available at: www.sws.uiuc.edu/pubdoc/CR/ISWSCR2004-08.pdf. 2004, 2004.
Van Liew, M. W., Arnold, J. G. and Garbrecht, J. D.: Hydrologic simulation on agricultural watersheds: Choosing between two models, Trans. ASAE, 46 (6), 1539-1551, 2003.

Yuan, Y., Bingner, R. L. and Rebich, R. A.: Evaluation of AnnAGNPS on Mississippi Delta MSEA watersheds, Trans. ASAE, 44 (5), 1183-1190, 2001.

Comment 4: Additionally, the land use that was utilized in SWAT simulations (Figure 2) contains vague class names (e.g. "deciduous" and "mosaic") and contains the class "clouds" that does not belong in a SWAT simulation.

Response 4: The land use map for this study was obtained from the Mekong River Commission (MRC). Because MRC has proper ground truth data, it has highly detailed classification of land use with corresponding properties of these land uses. MRC used MODIS satellite imagery to develop this land use map (shown below). The names of land use classifications defined in the manuscript come from the classification obtained from MRC. Here, "Deciduous" stands for deciduous forest, and "Mixed mosaic" for the mosaic of mixed forests containing evergreen and deciduous forests. Similarly, "Evergreen mosaic" refers to the Evergreen forest mosaic. "Crop mosaics" are of two types: one is where the cropping area is less than 30% and the other is where the cropping area is higher than 30%. From the landuse classification of MRC, the landuse mentioned as "Clouds" in the manuscript refers to No data. This has been incorporated in SWAT by using the properties of dominant land use in the specific sub-basin where No data type land use was found. We have changed the land use class name to "No data" rather than "Clouds". This classification of land use by MRC under "No data" land use class can be verified from the MRC data portal link: http://ffw.mrcmekong.org/landuse.htm# . A new landuse map has been added in the revised manuscript with the proper modifications in landuse class names.

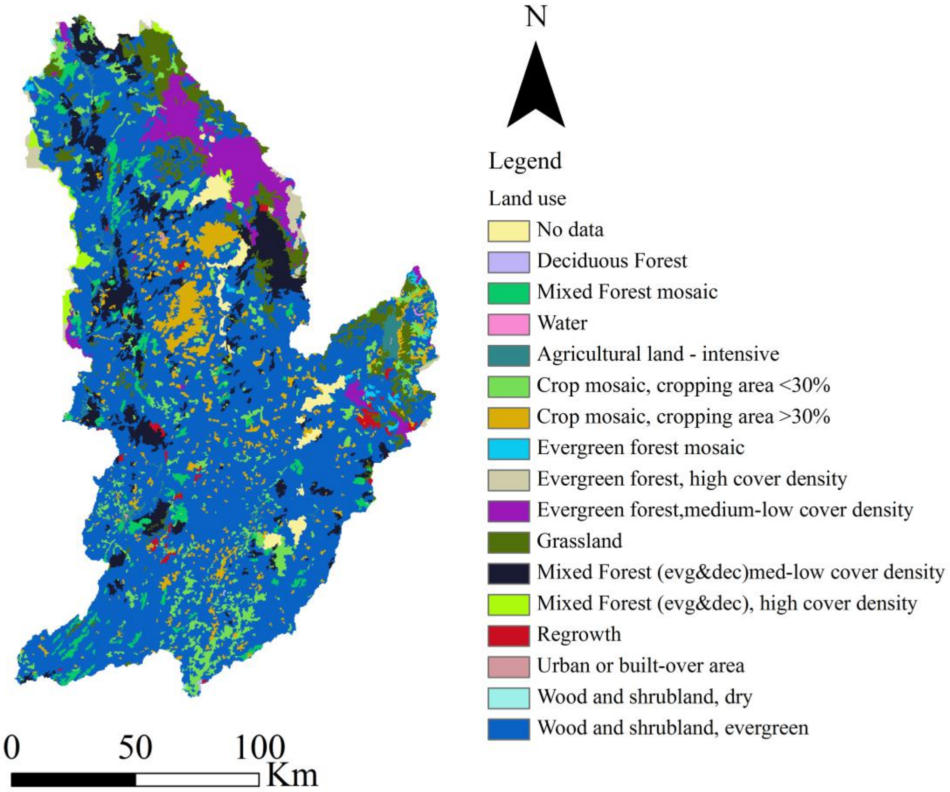

Figure 2: Existing land use

Comment 5: Furthermore, more details are needed regarding how the erosion control practices were incorporated into SWAT simulations because it seems like the incorporation only involved changing MUSLE parameters without specification of how these values were determined.

Response 5: The assessment of management practices was done based on the parameters that are sensitive to sediment yield in the basin. The topography of the Nam Ou River Basin is generally steep and have high slope. The steep slope of the basin is one of the causes for high sediment yield. The high slope lands are more susceptible to soil erosion with high rainfall amount and intensities. Therefore, land management practices that are capable of reducing the steep slope and slope length of the river sub-basins are taken into account as the potential management practices in reducing sediment yield. The management practices such as terracing, strip-cropping, vegetative field strips are evaluated in this study, which remarkably reduced the amount of sediment yield from the vulnerable sub-basins. Different MUSLE parameters which are linked with the mentioned management practices are calculated and used in model simulation under land management practices. A more detailed explanation of how these MUSLE parameters are defined is now incorporated in the revised manuscript

Revision in the manuscript:
These additional descriptions are added in the relevant section of the revised manuscript:

In Case 1 (C1), vegetative filter strip (VFS) was applied in those areas of the basin which have higher sediment yield, based on the defined threshold values. Vegetative filter strips were placed on those vulnerable areas which are only wood and shrub land as well as croplands. The effect of the filter strip is to filter the runoff and trap the sediment in a given plot (Bracmort et al., 2006). In this study, the function of the vegetative filter strip model in SWAT was to remove the sediment by reducing runoff velocity due to its cover and enhance infiltration in the VFS area (Barfield et al., 1998). The appropriate parameters for representing vegetative filter strips in SWAT are: the ratio of the field area to filter strip area (ha^2/ha^2) (FILTER_RATIO), the fraction of HRU that drains to the most concentrated ten percent of the filter strips area (ha^2/ha^2) (FILTER_CON) and the fraction of flow within the most concentrated ten percent of the filter strip that is fully channelized (FILTER_CH). In this study, assigned values for these parameters were 50 for FILTER_RATIO, 0.5 for FILTER_CON and 0 for FILTER_CH. Ten percent of a filter strip can receive runoff from 0.25 to 0.75 from the entire field. Thus, 0.5 was assumed to be FILTER_CON value in this study.

In Case 2 (C2), contour strip cropping was applied in the wood and shrubland areas of the vulnerable sub-basins. This scenario is based on the principle that contour strip cropping will help to increase surface roughness and that will, in turn, reduce sediment yield. In this study, sugarcane was considered as an alternative crop, grown alternatively with the existing crops or any other vegetation. The cover and management factor for sugarcane lies between 0.13–0.4. For this study, 0.15 was taken as STRIP_C (cover factor for the stripped cropped field value) for sugarcane as the strip crop. STRIP_P (the USLE support factor for the stripped cropped field) was chosen considering that the practice would be contour strip cropping. The STRIP_P value was defined on the basis of HRU's slope and the management practices considered for the vulnerable areas (Table 3 in the revised manuscript).

In Case 3 (C3), strip cropping in the form of contour farm terraced field was applied in HRUs. This case was evaluated to analyze the effects of strip cropping in terraced field conditions with P_{USLE} factor from Case 2. The STRIP_P values were defined according to land slope (%) and contour strip cropping was applied in terracing condition (Table 3).

In Case 4 (C4) and Case 5 (C5), terracing was simulated using the USLE topographic factor (LS_{USLE}), reduced by 25 and 50% respectively in order to reduce the sediment yield in the sub-basins. Terracing is generally effective for steeply sloping areas. It reduces the slope length as well as the slope of the HRUs. The appropriate parameters for representing the effects of terracing are: the average slope length in HRUs (TERR_SL), the USLE Support Practice factor (TERR_P), and the curve number (TERR_CN). Initially, the existing slope length and land slope in percentage were used to determine the LS_{USLE} factor. Then, according to the considered cases, LS_{USLE} was reduced by 25% and 50% (respectively) in order to determine the new slope length and land slope (Wischmeier and Smith, 1978).

Table 3: Support Practice factor P for cultivated lands (Wischmeier and Smith, 1978)

Land slope %	**Contouring**	**Contour, strip cropping and irrigated furrows**	**Terracing**
1-2	0.60	0.30	0.12
3-8	0.50	0.25	0.10
9-12	0.60	0.30	0.12
13-16	0.70	0.35	0.14
17-20	0.80	0.40	0.16
21-25	0.90	0.45	0.18

[The graph plot between the topographic factor (LS_{USLE}), land slope and slope length (Wischmeier and Smith, 1978) as shown in ***Figure I*** *in this response file, was used first to find out LS_{USLE} at present condition and then reducing it by 25 and 50 % respectively for the new land slope % and slope length.]*

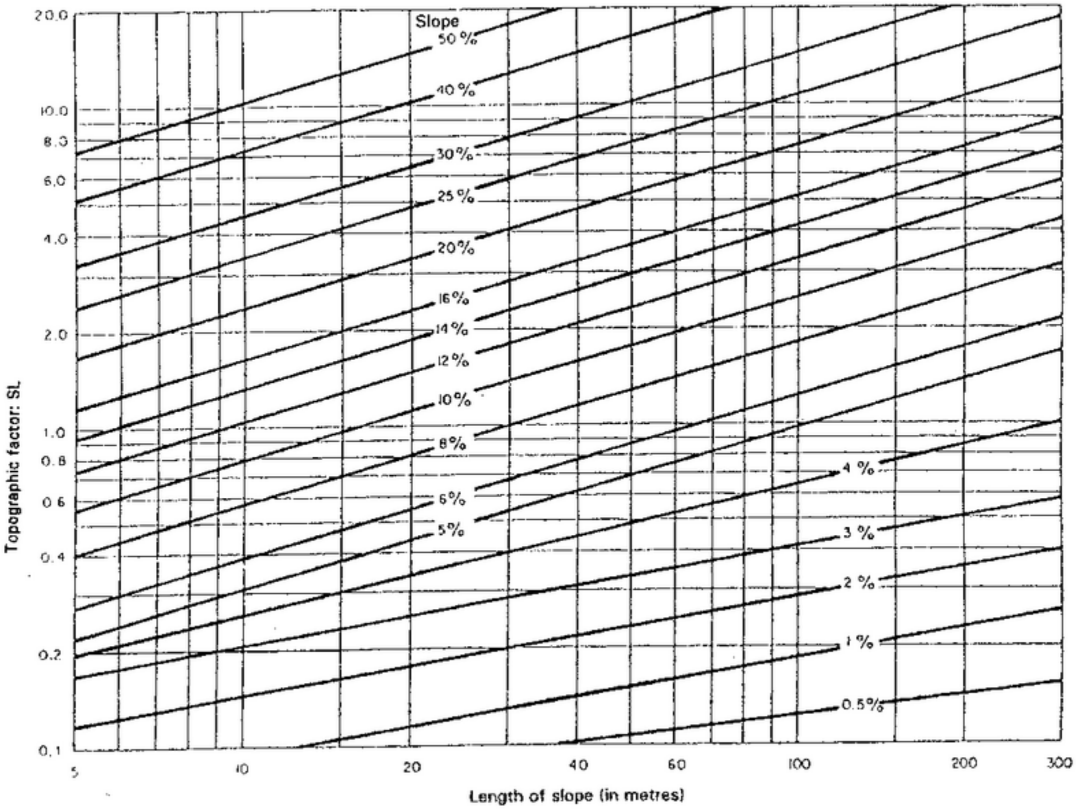

Figure I. Graph showing the topographic factor along with land slope % and length of slope in meters (Wischmeier and Smith, 1978) (This figure will not be added in the revised manuscript)

Added references in the revised manuscript:

Barfield, B. J.; Blevins, R. L., Fogle, A.W., Madison, C. E., Inamdar, S., Carey, D. I. and Evangelou, V. P.: Water quality impacts of natural filter strips in karst areas, Transactions of the ASAE, 41 (2), 371-381, 1998.

Wischmeier, W. H. and Smith, D. D.: Predicting Rainfall Erosion Losses. In *USDA Agric. Handbook*; Agricultural Research Service, Washington, DC, USA, 537, 58, 1978.

Comment 6: Outside of concerns regarding SWAT simulations, I found the classification scheme used for depicting the vulnerability of a sub-basin to erosion interesting, but the scheme originates from a conference preceding and I wonder if there are other similar classification schemes in the peer-reviewed literature that could be used.

Response 6: Many studies have classified the river basins into different vulnerable sub-basins based on the amount of soil erosion or sediment yield rate. In this paper, we have referred to Chakraborti (1991) which has classified sub-basins into five different categories: very low zone (sediment yield rate < 2 t ha^{-1} yr^{-1}), low zone (3–9 t ha^{-1} yr^{-1}), medium zone (9–15 t ha^{-1} yr^{-1}), high zone (15–21 t ha^{-1} yr^{-1}) and very high zone (> 21 t ha^{-1} yr^{-1}). There are some other studies which have used similar classification schemes but different range of values. Tamene et al. (2005) classified the range of soil loss as 0-5 t ha^{-1} yr^{-1} (very low), 5–15 t ha^{-1} yr^{-1} (low), 15–30 t ha^{-1} yr^{-1} (medium), 30–50 t ha^{-1} yr^{-1} (high) and >50 t ha^{-1} yr^{-1} (very high). Similarly, Singh et al. (1992) ranked each watershed from very severe to slight soil loss zone with the classification given as slight (0–5 t ha^{-1} yr^{-1}), moderate (5–10 t ha^{-1} yr^{-1}), high (10–20 t ha^{-1} yr^{-1}), very high (20– 40 t ha^{-1} yr^{-1}), severe (40–80 t ha^{-1} yr^{-1}) and very severe (>80 t ha^{-1} yr^{-1}). However, the classification range is dependent to topography and amount of soil erosion rates in the study area. The minimum and maximum rate of sediment yield is generally used to define the threshold values of different levels of vulnerability in the sub-basins. In this paper, the maximum amount of sediment yield in the sub-basins is 53 t ha^{-1} yr^{-1} and minimum of 0.1 t ha^{-1} yr^{-1}. Therefore, based on the maximum amount of sediment yield, the threshold range of sediment yield are: 0–2 t ha^{-1} yr^{-1} (slight), 2–6 t ha^{-1} yr^{-1} (moderate), 6–10 t ha^{-1} yr^{-1} (high), 10–20 t ha^{-1} yr^{-1} (very high) and > 20 t ha^{-1} yr^{-1} (severe). We have added citations from peer reviewed journals in the updated version of the manuscript.

Revision in the manuscript:
These additional descriptions are added in the relevant section of the revised manuscript:

Critical sub-basins are generally identified on the basis of their average and maximum amount of annual sediment yield in the basin. The threshold criteria for classifying critical areas of basins in terms of sediment yield vary from basin to basin and also depend on the purpose of classification. Topography also plays important role in classification schemes. Considering the sediment yield rate, Chakraborti (1991) defined the classification range as very low (when sediment yield rate < 2 t ha^{-1} yr^{-1}), low (3–9 t ha^{-1} yr^{-1}), moderate (9–15 t ha^{-1} yr^{-1}), high (15–21 t ha^{-1} yr^{-1}) and very high (> 21 t ha^{-1} yr^{-1}). Similarly, Tamene et al. (2005) classified the range of soil loss as 0-5 t ha^{-1} yr^{-1} (very low), 5–15 t ha^{-1} yr^{-1} (low), 15–30 t ha^{-1} yr^{-1} (medium), 30–50 t ha^{-1} yr^{-1} (high) and >50 t ha^{-1} yr^{-1} (very high). Singh et al. (1992) ranked each sub-basin based on soil loss zone as slight (0–5 t ha^{-1} yr^{-1}), moderate (5–10 t ha^{-1} yr^{-1}), high (10–20 t ha^{-1} yr^{-1}), very high (20– 40 t ha^{-1} yr^{-1}), severe (40–80 t ha^{-1} yr^{-1}) and very severe (>80 t ha^{-1} yr^{-1}). In this paper, the classification of vulnerable sub-basins is carried out based on the range of sediment yield in different sub-basins. The ranges are defined based on the maximum amount of sediment yield in the sub-basins of the study area. In Nam Ou River Basin, the maximum amount of sediment yield among all the sub-basins is observed to be 53 t ha^{-1} yr^{-1} and minimum of 0.1 t ha^{-1} yr^{-1}. Thus, the threshold of sediment yield for different categories is defined as 0–2 t ha^{-1} yr^{-1} (slight), 2–6 t ha^{-1} yr^{-1} (moderate), 6–10 t ha^{-1} yr^{-1} (high), 10–20 t ha^{-1} yr^{-1} (very high) and > 20 t ha^{-1} yr^{-1} (severe). The areas falling under high, very high and severe zones were categorized as critical sub-basins in terms of sediment yield. The critical sub-basins were then assessed with different land management practices to reduce the vulnerability of the basin in terms of sediment yield.

Added references in the revised manuscript:

Chakraborti, A.K.: Sediment yield prediction and prioritisation of watersheds using remote sensing data, *Proc. 12th Asian Conference on Remote Sensing*, Singapore, pp. Q-3-1- Q-3-6, 1991.

Singh, G., Babu, R., Narain, P., Bhushan, L.S., and Abrol, I.P.: Soil erosion rates in India, Journal of Soil Water Conservation, 47 (1), 97-99, 1992.

Tamene, L.: Reservoir siltation in the drylands of northern Ethiopia: causes, source areas and management option, PhD Thesis, University Bonn, 2005.

Comment 7: Finally, the authors mention the large degree of uncertainty in the GCM projections and SWAT parameterization, but no qualitative or quantitative description of the uncertainty is provided; thus the uncertainty should be a focus of discussion to build confidence in the results.

Response 7: We, authors agree with the necessity for more discussion on the uncertainty in GCM projections and SWAT parameterization for confidence in the results presented. We have revised the manuscript accordingly.

Revision in the manuscript:
We have added the additional explanation on uncertainties in GCM projections in Section 4.2 of the original manuscript which now reads thus:

In this paper, the uncertainty in predicting sediment yield under three GCMs reflects in the projection results, which are outlined in Table 4. For instance, the changes in annual sediment yield under B1 during the 2020s are remarkably different under the three GCMs: HADCM3, MIHR and IPCM4. HADCM3 shows the highest increment, of 4.28 % in the sediment yield. The sediment yield reduces to 1.86% under MIHR and to 8.2 % under IPCM4. This contrast among changes in prediction due to the three GCMs highlights the presence of uncertainty linked with the use of GCMs. This uncertainty of projection of sediment yield using three GCMs with similar GHGES is enormously higher in the further future periods, the 2055s and the 2090s. Even the projections of sediment yield in the future periods vary among different GHGES for the same GCM. Under A2 scenario, an increase of 9.3 % in sediment yield is projected under HADCM3, but this reduces to 4.28 % under B1 and 1.49 % under A1B during the 2020s. During the 2090s and A2 scenario, the highest uncertainty range is observed in projection of sediment yield: percentage change in sediment yield increases by 85 % under HADCM3 whereas IPCM4 projects a decrease of 15 %. Such variations prove that the projection of sediment yield is uncertain and dependent on the GCMs and GHGES used. The results also show that uncertainties exist in the projection of sediment yield among different GCMs even for the same period, and that these uncertainties increase with time. The uncertainties due to parameters in SWAT model may have also contributed to some extent of uncertainty in the total uncertainty. But the relative contribution of model parameters and GCM uncertainties has not been assessed in this study. However, it is expected that the uncertainty due to model parameterization in SWAT would add much less uncertainty than that due to GCM projections (Prudhomme and Davies, 2009; Kingston et al., 2011).

Added references in the revised manuscript:

Prudhomme, C. and Davies, H.: Assessing uncertainties in climate change impact analyses on the river flow regimes in the UK. Part 1: baseline climate, Climatic Change, 93, 177–195, doi: 10.1007/s10584-008-9464-3, 2009.

Comment 8: Due to concerns I have regarding the proper use of SWAT and reporting of necessary results, it is difficult to determine the relevance of the conclusions made in the manuscript. Of greatest concern is the fact that no discussion or details on simulated surface water flows is provided. Surface water flows are the principal mechanism in transporting sediment and thus should not be neglected. Additionally, no discussion of how the spatial variation in precipitation or surface water flows (historical and future) could have influenced the results is provided.

Response 8: We fully agree that surface water flows are significant in the mechanism of sediment erosion and transport. Generally, the impact of high rainfall, bare soil with mostly impervious nature leads to high surface runoff. The steep slopes in the river basin also contribute in increasing soil erosion and sediment yield. Thus, changes in surface runoff is directly linked to soil erosion process and amount of sediment yield. In addition, it is also obvious that spatial variation in precipitation has significant influence on surface flows, which in turn alters the soil erosion capacity of the river basin. Thus, the spatial variation of both precipitation and runoff is to be studied in detail, in order to quantify the prediction of sediment flux in both, present and future climatic conditions. Considering these key facts, additional points have been added in the revised manuscript under the new sub-heading: “the impact of future climate on surface runoff” along with the figure. Also, the likely influences of the spatial variation of precipitation or surface flows on sediment yield are discussed in the relevant section of the revised manuscript.

Revision in the manuscript:
Further discussion on the impact of climate change on surface runoff, which now reads thus:

The impact of climate change on surface runoff:

Figure 5 (based on Revised Manuscript) shows the change in annual mean surface runoff under two GCMs (projecting extreme future climate) and three GHGES in future periods with respect to baseline period 1981-2000. The result showed that the HADCM3 projected increase in annual surface runoff whereas IPCM4 projected decrease in the future climatic conditions. This increase in surface runoff under HADCM3 can be attributed to increase in precipitation in the wet seasons as depicted in figure 3. The highest increase of 42 % of surface runoff is observed under HADCM3 and A2 scenario in the late century. The change under this condition in the early century was only 6 %. This massive change in surface runoff might be due to high precipitation in the latter period under HADCM3. In case of IPCM4, the GHGES A1B was found to be more pessimistic in the future climate resulting in decrease in surface runoff. From the results, it is witnessed that change in surface runoff is highly dependent to change in precipitation and to some extent to change in temperature. Furthermore, the intra-annual variability of precipitation will cause more variability in the surface runoff in different seasons which will have direct impact on loss of soil and sediment yield from the basin.

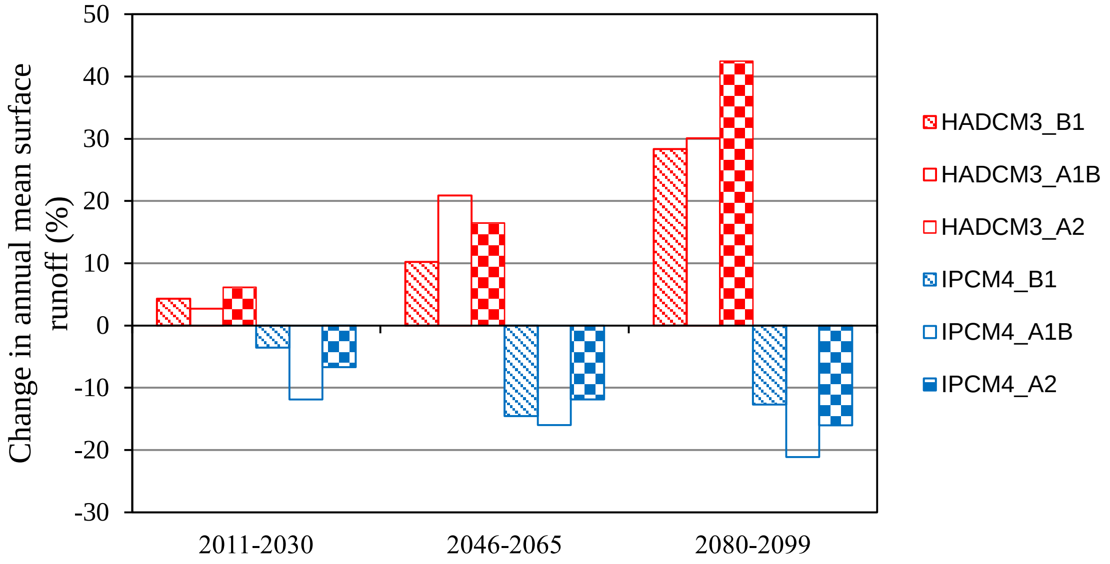

Figure 5: Change (%) in annual mean surface runoff in the future periods with respect to baseline period 1981-200 under different GCMs and GHGES (added in the revised manuscript).

Added discussion on the influence of changes in precipitation and surface runoff in the results of this study in Section 4.3 of the original manuscript reads thus:

Generally, it is known that increase in precipitation results in increase in surface runoff and discharge, which ultimately corresponds to increase in sediment yield. From figures 3 to 6 (in the revised manuscript), it is obvious that changes in precipitation due to a particular GCM correspond to change in surface runoff and sediment yield for the same GCM in future periods. This proves that increase/decrease in future precipitation plays a major role in projection of surface runoff and sediment yield in the same direction under same GCM. However, the intra-annual variability of runoff might not always match to the projection of intra-annual sediment yield in the same direction of change.

The spatial variation of precipitation in different sub-basins might change both magnitude and direction of change in runoff and sediment yield, which is depicted in seasonal variation. The variation in precipitation amount from one sub-basin to other during some time periods might result in overall or intra-annual change in the magnitude and direction of both runoff and sediment yield in the basin. For example: in case of the existing land management practices condition, the amount of precipitation amount during 2020s is considerably low under HADCM3 and three GHGES whereas the precipitation increased remarkably during 2090s period. This change in precipitation is likely to cause the basin more vulnerable to soil erosion or sediment yield, which is also clearly observed in the Figure 7 (of original manuscript). It is to be noted that more number of vulnerable sub-basins during 2090s are the result of substantial increase of precipitation, followed by surface runoff in those sub-basins. The fact that high precipitation makes the soil weak and easy to erode is also agreed by the results. Thus, the results are in agreement that precipitation change has high influence on sediment yield in the river basin. The changing surface runoff, as attributed by change in precipitation also becomes more influential in soil erosion and increasing sediment yield. Hence, alterations in precipitation in future climate affects surface runoff and subsequently to the sediment transport mechanism, increasing the basin vulnerability.

Comment 9: In its current form, I do not think the manuscript is publishable within HESS. The lack of information regarding simulated surface water flows and concerns over proper application of SWAT makes it difficult to assess relevance of the results and the conclusions.

Response 9: We noted that the lack of information regarding surface flows and the application of SWAT causes difficulties in assessing the relevance of the results and the conclusion. Therefore, further explanations and discussions have been added in the revised manuscript. The addition of the discussion on the impact of climate change on surface runoff gives an insight into how surface flows can influence sediment yield flux. Please refer to ***Response 8*** for this. There is also an additional description on proper application of land management practice in SWAT application. Please refer to ***Response 5***.