AUTHOR'S RESPONSE

Author's response comments in red.

Referee Comment #1

General comments:

This review paper presents a comprehensive overview of studies applying the R/USLE all over the world and provides information on how different studies have adapted the equations to calculate the factors of the USLE to local conditions. In addition, studies dealing with limitations of the USLE and future developments of the approach are mentioned. The authors explain that they provided this review to serve as a reference for other researchers working with the USLE.

In general, a review of the USLE is well placed in HESS. The authors have done a very diligent work by summarizing many publications applying the USLE. In addition the manuscript provides some helpful hints, as for example the advice to be careful with the units of the USLE-factors used in different studies (i.e. for the K-factor in Chapter 2.2). However, my major objection is, that the manuscript provides only an overview of existing studies and that a critical examination of the approaches presented in the manuscript is missing. Thus, I cannot see a significant own contribution of the authors besides the summary of existing studies on the application of the USLE. The manuscript should thus be thoroughly revised and provide a critical analysis of the approaches presented to gain new insight in the topic. Further comments for revision of the manuscript are given in the following:

- The introduction is very general. It should be worked out, why this review of the USLE is necessary and what is its benefit in relation to other reviews. In addition, the objectives are not clear and included at various locations in the introduction. Thus, the introduction should clearly motivate this review, leading to focused objectives at the end of the introduction (see also specific comments).

Response #1: Previous reviews of soil erosion models were discussed and included a brief mention of the USLE and RUSLE as it has been integrated into other models (page 2, line 8 to 11; page 3: line 2 to 5), but there has not previously been a comprehensive review focussed specifically on covering the RUSLE and all of its components. A review of the related Modified Universal Soil Loss Equation (MUSLE) has been published previously by Sadeghi et al. (2014), and a review of rainfall erosivity has also been done by Nearing et al. (2017). The scope of this paper is to review the entirety of the R/USLE and its all sub-factors and provide a starting point for newer soil erosion modellers to get a handle on the R/USLE depending on their location and data availability, which has not been published previously.

To improve the manuscript, we propose to make the significance and objectives of the review clearer at the beginning of paper, with more critical analysis added in the next iteration of the paper given the comments of referee #1 and referee #2.

- The authors promise, that they will provide guidance which equation is most appropriate for a range of different geoclimatic regions (Page 2, line 17 – 18). However, the advices are very general and the studies presented in Chapter 2 seem to be randomly picked. For example, Chapter 2.1 provides a comprehensive overview of 19 studies that have derived approaches to estimate R-factors for different regions or have applied these approaches (Table 3). Furthermore, the authors summarize various studies using approaches to calculate R-factors in regions other than those for which they were developed. Following this, a simple calculation example is provided (Page 6, line 8 – 16 and Figure 1): In this example, 2

equations developed for Portugal and 1 equation developed for New Zealand are applied to a watershed in New Zealand (Figure 1). As expected, the equations developed for Portugal do not match the seasonal variation in New Zealand. The authors conclude that it is important to understand the regional applicability of rainfall erosivity equations (Page 6, line 17-18). Although many studies were reviewed, the main result of Chapter 2.1 is a very general statement drawn on the basis of a simple example. If such examples are provided, they should cover a much larger number of approaches and data of different regions to derive useful conclusions to guide other users of the USLE. It would be much more important to analyze, if approaches for R-factors could be transferred to regions with similar climate characteristics for which no detailed data is available and what criteria should be applied to do this.

Response #2: Portions of Section 2.1 discuss which datasets and equations are appropriate for locations with annual, monthly, daily, and sub-daily rainfall data (Page 5, line 8+). The studies in Table 3 were chosen due to their scope (global, regional, national) and the fact that their equations had been cited by several other studies in different regions (e.g. the equation by El-Swaify et al. (1987) originally developed in Thailand but also applied in the Philippines and Sri Lanka). Additionally, some equations were chosen because of their utility in predicting intra-annual soil erosion rates (Shamshad et al., 2008; Irvem et al., 2007; Ferreira and Panagopolous, 2014). Page 5 line 33 to page 6 line 7 discusses why estimating seasonal erosion rates is important, especially for areas with high temporal variability of rainfall.

The warning of regional applicability is due to R/USLE studies commonly pointing to rainfall erosivity equations derived in different regions but not justifying why those equations were chosen for their study area. The purpose of testing the different R-factors is to illustrate how the derived rainfall erosivity using the same input data can vary and encourages future users of R/USLE to do the same sensitivity testing in their area. To improve the manuscript, this point will be made clearer and the importance of sensitivity testing will be outlined.

The example from New Zealand is from a more general case study that will form a paper in the future, and we will include a little more guidance from other outcomes, along with summary outcomes from an application in the Philippines in the edited manuscript. In the Philippine case study, the sensitivity testing of the R-factors produced values that were significantly different from each other even though most of the equations were produced near to the Philippines.

To further improve the manuscript, we also propose adding a summary paragraph at the end of each section (rainfall, soil, etc) to critically discuss which datasets and equations are appropriate for general climate types such as hot arid areas, cold arid areas, tropical, and temperate.

- In Chapter 2.2 only studies for the US are presented. It would be interesting, how studies in other regions deal with K-factors?

Response #3: Very true, most studies outside the US use the K-factor equations in Table 4. As mentioned before, a follow-up paper includes a discussion of a New Zealand case study and includes some values from a previous NZ study for K-factor but no equation associated with it (e.g. has a value for loam, clay loam, etc). To improve this review's manuscript, this NZ application and K-factor example will be included.

- Chapter 3 is about limitations of the R/USLE. As before, only existing studies dealing with the limitations of the USLE are summarized and a critical analysis of the limitations is missing (see also specific comments). The topic of validation of estimated soil loss rates by using the

USLE is mentioned only briefly. In my opinion, it is one of the major limitations of the USLE that it is so difficult to validate the estimated soil loss rates. This topic should be discussed in more detail.

Response #4: Referee #2 also made a similar comment about how the uncertainty associated with soil erosion models and USLE is a big limitation and should be spelled out earlier in the paper, possibly the introduction. To improve the manuscript, the uncertainty and lack of validation data limitation of USLE will be mentioned in the introduction and then more critical discussion will be in Section 3. Possible proxies for soil erosion measurements will be mentioned (e.g. water quality data, total suspended sediment loads, comparison to soil erosion rates of similar land cover, etc.) and the paper will also point to global/regional/national studies that have published their soil erosion rates so that future modellers can compare their results with those studies.

- In Chapter 4 again only studies are summarized which are dealing with further developments of the USLE, but again, a critical analysis is missing.

Response #5: The follow-up paper mentioned before discusses the inclusion of other techniques to estimate gully erosion and mass wasting, and that discussion will be incorporated into this review paper instead. The discussion covers the Compound Topographic Index (CTI) for gully erosion, the advantages/disadvantages to using it, and possible ways it can be combined with the RUSLE. Summary critical analysis of this and other recommended further developments (monthly or seasonal erosion and consistency in units) will be added.

- The conclusions are very general.
- The abstract is very brief. It should be thoroughly revised according to the revision of the manuscript.

Response #6: We propose to include more critical analysis and results in the revised conclusions and abstracts.

Specific comments:

Response #7: In general, most of these specific comments will be incorporated in the next iteration of this paper.

- Page 1, line 22 – Page 2, line 5: The introductory part on soil erosion is very long and not specific for the USLE. It should be shortened and focused.

Response #8: Noted.

- Page 2, line 6 – 13: In this section, a few review papers on erosion models are presented. It is not clear, why these reviews have been selected. I suggest to focus on previous reviews of the USLE and to work out, why the additional review presented in this paper is necessary and what will be the benefit of it.

Response #8: As previously discussed in Response #1, previous soil erosion reviews have covered soil erosion models in general and have mentioned USLE, but not discussed it in depth. One review paper of rainfall erosivity has been previously published, but there are no published reviews focusing only on the R/USLE, its components, and previous applications.

- Page 2, line 15 – 19: I suggest to move this section to the objectives at the end of the introduction.

Response #9: Noted, will be included as part of objectives.

- Page 2, line 28 – 29: move to objectives at the end of the introduction. In addition, it should be made clear, which limitations of the USLE are analyzed.

Response #10: Noted, will be included as part of objectives.

- Page 2, line 30 – 34: redundant to the section above. Include the information not yet provided in line 19 – 27 into this section.

Response #11: Noted.

- Page 3, line 10 – 13: The objectives of the study mentioned at various locations in the introduction should be summarized at the end of the introduction (see comments above).

Response #12: Noted, and agreed that these repeated points will be summarised at the end of the introduction section as clear objectives.

- Page 3, line 19 – 26: In my opinion, this information fits better in the introduction.

Response #13: Noted, and will be incorporated into the introduction.

- Page 4, line 1 – 5: some additional objectives are mentioned in this section → should be moved to a focused section presenting the objectives at the end of the introduction.

Response #14: Pursuant to previous comments, these will be incorporated into the objectives section.

- Page 3, Chapter 2: Some general information on the USLE should be provided, i.e. that it was developed from soil loss rates on plot experiments.

Response #15: Noted, we propose including some general information about how USLE was formulated, including mention of the unit plot.

- Page 11, line 6: the information on the R/USLE unit plot is also essential for the other factors. It should be mentioned in the preface of Chapter 2, i.e. page 3, line 19 - 26.

Response #16: Noted, and will be incorporated into Section 2.

- Page 20, line 2 – 10: in this paragraph it is stated, that the application of the USLE outside the US may lead to over or under-prediction of actual soil loss. This statement implies that the application of the USLE in the US leads to correct prediction of soil loss. This is not true. Over or under-prediction of actual soil loss rates is also due to the simplicity of the approach. Furthermore, it is stated that the USLE also may lead to uncertainties in predicted soil loss if it is applied to larger scales than the plot scale. Again, this statement implies that predictions for the plot scale are correct, which is not true.

Response #17: Agreed, and the wording of this section will be changed to make it more clear that the uncertainties associated with USLE are not just dependent on the study site application but also on the simplified approach vs the complex interactions associated with soil loss.

- Page 21, line 26 – 29: redundant to Chapter 2.3

Response #18: All technical corrections are noted and will be changed in the next iteration of this paper.

Referee Comment #2

1. Scope

The paper provides a thorough introduction into the USLE model family, a group of empirical long term soil erosion models. This paper is of interest to the HESSD community, as the various USLE variants described in this paper are among the most used erosion models overall.

2. Summary

The paper gives an introduction into the motivation and method of using USLE models and describes the conceptual background for all individual factors needed to calculate the annual soil loss amounts with USLE models. This is being done by referring to different case studies as well as widely cited papers of variations of USLE models developed to adapt the model to other regions of the world and improve the model family. The calculation formulas of the USLE factors from those papers are provided in tabular form as well, giving a quick overview of these different approaches. The paper also discusses the limitations of USLE models and points at needed future improvements.

3. General evaluation

Scientific significance

The paper provides a good overview of the topic and goes in depth into the history and motivation of the various USLE models. This is especially helpful for someone just starting with soil erosion modelling. Although mentioned briefly, it is missing a contextualization of USLE models versus other soil erosion modelling approaches.

Response #19: Please see Response #1 regarding the place of USLE in other soil erosion models and reviews. To improve the manuscript, we propose emphasising the place of USLE within the soil erosion modelling space will be emphasised and the reader will be directed to more general erosion reviews.

Scientific quality

While providing a useful overview over widely used USLE models and their respective equations as well as discussing the limitations, it could do a better service of evaluating each of the different approaches as well as USLE models performances in general. What is completely missing is any form of information regarding a validation of model results with measurements. Also the connection to surface runoff and sediment transport is missing completely, a very important part of the whole soil erosion process chain and an obvious weak point of the USLE model family. Related to that, the whole sediment delivery ratio (SDR) concept is absent, while being a necessity for most applications of USLE models that go beyond plot scale. Also the paper needs stronger precision and less vagueness in some terms, especially since the target audiences of the paper are newcomers to erosion modelling.

Response #20: Please see Response #4 regarding validation of soil erosion results using proxies. We propose to add a discussion about the importance of data validation, how sediment data collection is expensive, therefore there is a need to compile global and national databases of sediment data/soil erosion measurements, which is a good point for future work. SDR was mentioned in some of the papers that were cited in this review, and will be now be included as a discussion point in Section 4.1 about representing other types of erosion, and possibly in the LS-factor discussion instead some LS-factor approaches use flow accumulation.

Presentation quality

The paper is structured well, but is lacking in visual descriptions of concepts and equations and instead relies too heavily on tabular listing of equations. Especially a visualization of the many (linear and non-linear) equations could make each concept behind it more understandable.

Response #21: Only a few of the cited equations have published graphs of their equations, and the next iteration can include some of these graphs lifted from their paper with proper citation. Some maps of the output will also be included to show how the different equations produce different sub-factors that affected the soil loss estimates.

4. Specific comments

Response #22: These specific comments will be incorporated in the next iteration of the paper as they are very constructive. Issues around wording require more clarification and precision from the authors. More critical analysis will be added.

p. 1, l. 8-10: two minor things, USLE is not necessary the best tool to understand the driving forces behind erosion, due to its dependency on empirical relations and lack of physical based approaches. Also "effectively manage" is a little presumptuous compared to the little effect some measures actually have when applied (or the little amount of measures that are being enforced in general).

Response #23: True, although RUSLE modelling can give management an idea of what kind of management interventions prevent soil erosion (e.g. bare soil vs contouring vs mulching). In the more general case study paper, scenario analysis was done for the Philippines case study showing decreases in potential soil loss when conservation technologies were applied in agricultural areas. We propose adding some of these output maps showing the difference in soil loss due to the conservation technologies.

p. 1, l. 23: rather small study cited for such a broad statement. Better or more citations?

Response #24: Noted, will add further citations.

p. 2, l. 4-5: "advances in technology" too unspecific.

Response #25: Will be more specific (e.g. GIS programmes for spatial analysis, increases in desktop computing power, etc) in next iteration of paper.

p. 2, l. 9 + 13: redundant citation.

Response #26: Noted.

p. 2, l. 19: average over what precisely, space, time?

Response #27: Space and time as the soil loss is in estimates of tons hectare^{-1} year^{-1}

p.2, l. 6: contradicting statement regarding sediment transport.

Response #28: The statement reads "Soil erosion models aid land management by helping understand sediment transport and its effects on a landscape". The model outputs help elucidate driving forces/possible causes of soil erosion, sediment transport, and the potential degrading effects on landscape. We are unclear as to where the contradiction is in this statement, and would appreciate further clarity from the Reviewer.

p. 3, l. 10: "things"?! precision please.

Response #29: “Things” refers to choices in sub-equations, caveats associated with RUSLE, limitations, etc. We propose clarifying this in the manuscript by replacing “things” with “factors such as sub-equations, limitations,” etc.

p. 3, l. 11: None of the models are being extensively reviewed in this paper, it should be included like the others if this paper is supposed to be providing a complete overview. Also event scale, and the problems with modeling over long-term averages, need to be discussed in regards to the actual processes of erosion.

Response #30: This review mainly focuses on USLE and RUSLE, since the event-based MUSLE has already been extensively reviewed by Sadeghi et al. (2014). To improve the manuscript, some of the issues associated with modelling over long-term averages and event-based erosion events will be discussed.

p. 3, l. 19: As the name suggests (“Universal”), the model in theory was developed for every type of soil, but parameterized for the United States. A noteworthy difference.

Response #31: True, and I verbally made a point about this in an oral presentation in December 2018 entitled “Parameterisation of the Revised Universal Soil Loss Equation (RUSLE) for New Zealand Data and Conditions” to discuss the regional limitations of the RUSLE. Will be incorporated into this chapter because it is an important limitation.

p. 3, l. 20: Context of citation should be not in regards to location, but scale.

Response #32: Sentence will be reworded for clarity.

p. 3, l. 22: first (?) mention of uncertainties with SE models. This needs a more general and honest introduction on its own instead of solely being mentioned at the limitations chapter.

Response #33: This issue has been raised by RC#1 and the uncertainty of soil erosion models will be emphasised and placed in the introduction since this limitation came up many times in the papers reviewed.

p. 3, l. 22-26: Focus solely on one issue with data (length of data measurements) and is missing more important issues like time step interval length, spatial scale and the amount of variables needed.

Response #34: Although these issues are outlined in each of the factor sections, these lines will be expanded to include those other issues.

p. 5, l. 13-18: noteworthy issue, but should be outside the R-Factor chapter due to its more general nature.

Response #35: Inconsistencies in units is brought up later on in the limitations section.

p. 5, l. 23-32: This paragraph reads more like an anecdotal narration of model appliances without any classification or judgement.

Response #36: Section contextualises that monthly rainfall records can be used instead of storm records that were in the original USLE.

p. 5, l. 33-34: This paragraph makes it sound like that’s all that’s needed to go from annual to monthly time steps, that’s a bit misleading.

Response #37: The R-factor equations that estimate monthly erosivity to calculate annual erosivity have been used by some RUSLE applications to estimate monthly/seasonal soil loss by only varying the R-factor. This will be clarified and the paper will point to those studies.

p. 6, l. 19: Unacceptable figure layout.

Response #38: Unsure what this means, please clarify.

p. 11, l. 23-25: How would you test that?

Response #39: Similar to the sensitivity analysis of the R-factor equations, testing the K-factor equations to see which ones produce values similar to each other or significantly different from the others could be one way of testing their applicability. Another way would be to compare the derived K-factor values with published values from similar soils.

p. 13, l. 20: what is high resolution in this context? Raster cell size is a very important aspect of USLE applications and it's being tip toed around in most papers, so it would be nice to have specific comment to that in this review.

Response #40: High resolution will vary depending on scale, but Panagos et al. (2015a) talked about 100m resolution DEMs having an associated loss of detail regarding flow network compared to 25m resolution DEMs.

p. 13, l. 27-29: let's be honest, that's the absolute norm in my experience. And that's why raster cell size or use of a proper LS factor calculation is so important and needs to be talked about more critically.

Response #41: Agreed, and it was touched on briefly but will be further clarified here.

p. 13, l. 30: sounds good, makes sense, but does it improve the model results?

Response #42: As mentioned in previous comments, there is a follow-up paper to this one and it includes sensitivity testing for LS-factor using the method that only accounts for slope and length against a method that incorporates flow accumulation. It was found that with high resolution DEMS (15m and finer), the first method was better at the watershed scale for delineating large areas that can be marked for soil conservation measures while the second method would be better at the sub-watershed or field scale. Those results will be briefly mentioned in this section in the next iteration of the paper.

p. 19: very good and short summary of the P-factor, especially with the mention of using it for scenario analysis.

Response #43: Thank you.

p. 19, l. 13-18: Would be good to comment a bit more on the values from the cited studies from table 10 in this paragraph as well.

Response #44: Noted, will be more clear about these values and their possible effect on soil loss estimates.

p. 20, l. 1: Is there a citable metric behind the citation amount, or is this the expression of a subjective feeling of the author?

Response #45: This limitation came up in most, if not all, of the studies that were reviewed that applied the R/USLE to an area outside of the USA. To clarify, we propose citing a few of the studies and reviews that discussed the limitations of applying RUSLE outside the USA.

p. 20, l. 7: I think this is quite a significant fact which gets ignored most of the time. This should be the actual most common cited limitation…

Response #46: True, and as per the comments of Referee #1, the unit plot will be emphasised in the introduction of the RUSLE equation.

p. 20, l 11-16: I get the point and it is correct, but I think it is misleading to divert the uncertainties of the USLE modelling results to the data quality or availability, when it is the biggest reason to use the USLE in the first place, over more sophisticated models. Most uncertainties of the USLE stem from the big division between the model design and the actual processes, even when using high-resolution data.

Response #47: True, and will reword and add more critical analysis.

p. 20, l 17+: this is such an important paragraph, it should almost be part of the introduction.

Response #48: True, and will be mentioned in the introduction.

p. 21, l. 24: Grammar.

Response #49: Sentence will be revised.

p. 23, l. 15: very true and should honestly be said much earlier in my opinion.

Response #50: Noted, will be brought up earlier.

p. 24, l. 2: while the whole paragraph makes a good point, the mention of those conversion factors seems oddly specific at this section.

Response #51: This sentence was meant to reiterate making sure that units were consistent, another summary sentence will be written for this section.

5. Additional comments

While out of scope for a literature review paper, it would have been very interesting to see the actual soil loss results from each of the presented models compared in a real world or virtual example. It would be quite eye opening, especially for newcomers to erosion modelling, to see the huge variations of results between some models and compared to measurements.

Response #52: This is the scope of the follow-up paper that applies the RUSLE to New Zealand and Philippines study areas, including sensitivity testing and comparison to measured data.