Response to Decision Letter

Dear Dr. Paolo Tarolli and referee,

We are very pleased to learn from your letter about revision for our manuscript which entitled *"Dangerous degree forecast of soil and water loss on highway slopes in mountainous areas using RUSLE model".*

We greatly appreciate reviewer's thoughtful suggestions concerning improvement to our paper. These comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches.

Thank you for your consideration!

Sincerely yours,

*Corresponding Author: Shi Qi

P.S.

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Response to review's comments for nhess-2017-406-RC1

Reviewer's #1 comments:

Comment 1: This paper asks a novel and well-justified question about how to estimate soil loss on highway slopes. The authors state that most work to date on this area has been on natural slopes, and present some striking statistics about the area covered by highway slopes. However, the paper is extremely hard to read-it assumes a lot of prior knowledge about the RULSE model, does not define variables clearly and is written in long, dense and technical paragraphs. In its current draft state, it is hard to address the scientific quality of the paper in depth because it is hard to read and follow. For this reason, I would recommend major revisions to work on the communication of the paper before the content can be reviewed in detail.

Response 1: First of all, we are very grateful for your affirmation of our research work. Most important of all, we greatly appreciate your valuable suggestion concerning improvement to this paper. We have made a detailed revision of the grammar and structure of the manuscript, hoping to meet your requirements. The revised place is marked with red and details are in manuscript.

Comment 2: I have listed suggested revisions below in the approximate order in which they appear in the paper. These are a mix of medium and minor level revisions.

Response 2: Thank you for your patience and careful work! We have made correction according to your comments. Details are in the manuscript.

Comment 3: General-The English language needs work in places-at times, the language is very dense and sometimes the incorrect tense is used. Please proofread or consult a proofreader.

Response 3: Thank you for your comments! We have followed your advice to adjust it. We have had the manuscript polish with a professional assistance in writing. Details are in the manuscript.

Comment 4: The abstract is very long, this should be shortened to around 300 words.

Response 4: Thank you for your valuable advice. According to your comment, we have followed your advice to adjust it. Details are in following paragraph and MS.

Many high and steep slopes are formed by special topographic and geomorphic types and mining activities during the construction of mountain expressways. Severe soil erosion may occur under heavy rainfall conditions. Therefore, predicting soil and water loss on highway slopes is important in protecting infrastructure and human life. This work studies Xinhe Expressway, which is in the southern edge of Yunnan–Guizhou Plateau, as the research area. The revised universal soil loss equation is selected as the prediction model of the soil and water loss on the slopes. Moreover, geographic information system, remote sensing technology, field survey, runoff plot observation testing, cluster analysis, and cokriging are adopted. The partition of the prediction units of the soil and water loss on the expressway slope in the mountain area and the spatial distribution model of the linear highway rainfall are studied. In view of the particularity of the expressway slope in the mountain area, the model parameter factor is modified and the risk of soil and water loss along the mountain expressway is simulated and predicted under 20- and 1-year rainfall return periods. The results are as follows. (1) Considering natural watershed as the prediction unit of slope soil erosion can represent the actual situation of the soil and water loss of each slope. The spatial location of the soil erosion unit is realized. (2) An analysis of the actual observation data shows that the overall average absolute error of the monitoring area is 33.24 $t\cdot km^{-2}\cdot a^{-1}$, the overall average relative error is 33.96%, and the overall root mean square error is between 20.95 and 65.64, all of which are within acceptable limits. The Nash efficiency coefficient is 0.67, which shows that the prediction accuracy of the model satisfies the requirements. (3) Under the condition of 1-year rainfall, we find through risk classification that the percentage of prediction units with no risk of erosion is 78%. Results show that soil erosion risk is low and therefore does not affect road traffic safety. Under the 20-year rainfall condition, the percentage of units with high risk and extremely high risk is 7.11% and mainly distributed on the K109+500–K110+500 and K133–K139+800 sections. The prediction results can help adjust the layout of the water and soil conservation measures in these units.

Comment 5: The introduction assumes a large amount of prior knowledge about the RULSE model and the parameters that go into it. Please give more background. Imagine the audience was a highway manager, please state more clearly what the implications of previous research are in practical terms.

Response 5: Valuable suggestions! Thank you for your comments. We have followed your advice to adjust it. Details are in following paragraph and manuscript.

Water and soil erosion caused by engineering construction is an important form after agricultural cultivation and forestry deforestation, the amount of soil erosion produced by the embankment slope occupies a large proportion in the whole project. It is not only related to the feasibility and cost of the project, but also has aroused great interest and attention. Yang (2001) investigated the behavior of soil erosion on the slope of a railway embankment during construction by comparing artificial and natural rainfalls on the special Qinhuangdao–Shenyang line of passenger trains. The results showed that the main type of soil erosion in the study area was gully erosion, which caused more soil erosion than surface erosion did; in addition, the principal factor causing soil erosion on the slope was the amount of precipitation and the width of the embankment. Wang (2005) established several experimental standardized spots for soil loss collection on the side slopes of the Xiaogan–Xiang fan freeway under construction and installed an on-the-spot auto-recorder of rainfall. The data collected were used for the revision of the main parameters R (rainfall and runoff) and *K* (erodibility of soil) of the USLE, which is widely applied to forecast soil loss quantity in plowlands and predict the soil loss quantities of different types of soil on side slopes disturbed by engineering treatment (Wang et al., 2005). It can not only be applied to the prediction of disturbed soil loss in expressway construction, but also improve the prediction accuracy. It provides scientific support for relevant units or personnel to take reasonable preventive measures.

Comment 6: Paragraph starting on line 57. Many of the sentences need a citation to existing peer review or grey literature.

Response 6: Thank you for your comments! We have followed your advice to adjust it. Details are in following paragraph and manuscript.

The slope is the most fragile part of an expressway in a mountain area (Yuan et al., 2017; Mori et al., 2017). During the rainy season, soil erosion is easily caused by rainwash and leads to a worrisome extent of damage (Figure 2). At present, China's highway industry is still in a period of rapid development. By the end of 2014, the total mileages of highway network exceeds 4,400,000 kilometers, and the expressway's mileage is 112,000 kilometers (Zhou et al., 2016). According to statistics, with the development of highway construction in China, slope areas reach 200–300 million m^2 each year. In the next 20–30 years, expressways in China will measure more than 40,000 km. For every kilometer of a highway, the corresponding bare slope area formed measures 50,000–70,000 m^2. The annual amount of soil erosion is 9,000 g/m^2, which causes 450 t of soil loss every year (Chen 2010). Compared with the soil and water loss on forestlands and farmlands, which on subgrade slopes is special. Forestlands and farmlands are generally formed after years of evolution and belong to the native landscape. Most slopes are gentle and stable (Kateb et al., 2013). Traditional soil and water conservation research focuses on slopes with 20% grade or below, but the highway subgrade slope of steep slopes is generally greater than 30% (Zhou 2010). Soil erosion on subgrade side slopes affects not only soil and water loss along the highway but also road operation safety (Gong and Yang 2016; Jiang et al., 2017). Therefore, soil erosion on the side slopes of mountain expressways must be studied to control soil erosion, improve the ecological environment of expressways, and realize sustainable land utilization (Wang et al., 2005; Yang and Wang 2006).

Reference:

Yuan, C., Yu, Q. H., You, Y. H., Guo, L.: Deformation mechanism of an expressway embankment in warm and high ice content permafrost regions. Applied Thermal Engineering 121: 1032-1039, 2017.

Mori, A., Subramanian, S. S., Ishikawa, T., Komatsu, M. A Case Study of a Cut Slope Failure Influenced by Snowmelt and Rainfall. Procedia Engineering, 189: 533-538, 2017.

Zhou, R. G., Zhong, L. D., Zhao, N. L., Fang, J., Chai, H., Jian, Z., Wei, L., Li. B.: The Development and Practice of China Highway Capacity Research. Transportation Research Procedia, 15: 14-25, 2016.

Kateb, H. E., Zhang, H. F., Zhang, P. C., Mosandl, R. Soil erosion and surface runoff on different vegetation covers and slope gradients: A field experiment in Southern Shaanxi Province, China. Catena, 105(5): 1-10, 2013.

Comment 7: Line 62. 50 - 70 thousand should be changed to 50,000-70,000 m^2.

Response 7: Thank you for your patience and careful work. We are grateful to the reviewer for pointing out this comment, we have made correction according to your comments. Details are in following paragraph and MS.

For every kilometer of a highway, the corresponding bare slope area formed measures 50,000–70,000 m^2.

Comment 8: General-please ensure numeric units are described consistently and using SI units.

Response 8: Thank you for your careful work. We have carefully corrected these mistakes according to your comment. Details are in the MS.

Comment 9: General-please only use author's last name for citations. E.g., line 73 should be Tresch et al. (date), not Tresch S et al (date).

Response 9: Thank you for your comments! We have followed your advise to adjusted it. Details are in following paragraph and MS.

Tresch et al. (1995) believed that the topographical factor *LS* is one of the main factors for soil erosion modeling within the RUSLE environment.

Comment 10: Line 80 and 81, please ensure variables such as *LS* and *S* are defined.

Response 10: Thank you for your comments! We have followed your advice to adjust and explained it. Details are in following paragraph and MS.

Explain: *L* is the slope length factor. *S* is the steepness factor. *LS* is slope length/slope steepness factor (dimensionless).

Tresch et al. (1995) believed that the slope length/slope steepness factor *LS* is one of the main factors for soil erosion modeling within the RUSLE environment. Various steepness factors (*S*) exist for the most used soil erosion modeling environment and significantly influence calculated erosion values.

Comment 11: Line 84. This sentence needs restructuring as when you say “this study”, it sounds as though you are talking about primary research.

Response 11: We greatly appreciate your valuable suggestion concerning improvement to this paper. We have followed your advice to adjust it. Details are in following paragraph and MS.

Eighteen plot measurements on transects along slopes ranging from 20–90% in steepness were used in this study to qualitatively assess the most suitable S factors for steep subalpine slopes.

Comment 12: Paragraph starting on line 73 is very long (in excess of a page), and should be broken down into shorter paragraphs.

Response 12: Thank you for your careful reading of our manuscript and point out this shortcoming, we have followed your advice to adjust it. Details are in following paragraph and MS.

The use of revised universal soil loss equation (RUSLE) models as predictive tools for the quantitative estimation of soil erosion has been maturing for a long time. The range of application of these models involves nearly every aspect of soil erosion. In addition, many scholars have explored the process of using RUSLE models and combined research objects to correct the parameter values in these models, thus improving simulation accuracy:

Tresch et al. (1995) believed that the slope length/slope steepness factor *LS* is one of the main factors for soil erosion modeling within the RUSLE environment. Various steepness factors (*S*) exist for the most used soil erosion modeling environment and significantly influence calculated erosion values. All existing S factors are derived only from gentle slope inclinations of up to 32%. Many cultivated areas, particularly in Switzerland, are steeper than this critical value. Eighteen plot measurements on transects along slopes ranging from 20–90% in steepness were used in this study to qualitatively assess the most suitable S factors for steep subalpine slopes. Results showed that a first selection of an S factor was possible for slopes above the critical 25% steepness. Rick D (2001) found that using universal soil loss equation (USLE) and RUSLE soil erosion models at regional landscape scales is limited by the difficulty of obtaining an *LS* factor grid suitable for use in geographic information system (GIS) applications. Therefore, he described the modifications applied to the previous arc macro language (AML) code to produce a RUSLE-based version of the *LS* factor grid. These alterations included replacing the USLE algorithms with their RUSLE counterparts and redefining assumptions on slope characteristics. Finally, in areas of western USA where the models were tested, the RUSLE-based AML program produced *LS* values that were roughly comparable to those listed in the RUSLE handbook guidelines. Silburn's (2011) research showed that estimating *K* from soil properties (derived from cultivated soils) provided a reasonable estimate of *K* for the main duplex soils at the study site as long as the correction for the undisturbed soil was used to derive *K* from the measured data and to apply the USLE model.

However, methods used to fit the parameters affected the results, and minimizing the sum of the squares of errors in the soil losses provided better results than fitting an exponential equation did. Yang (2014) found that the *C* factor value can be determined as a function of fractional bare soil and ground cover derived from MODIS data at regional or catchment scales. The method offers a meaningful estimate of the *C* factor, thus indicating ground cover impact on soil loss and erosion hazard areas. The method is better than the commonly used techniques, which are based only on green vegetation (e.g., normalized difference vegetation index, NDVI). Thus, the study provided an appropriate approach to estimating the *C* factor in hillslope erosion modeling in New South Wales, Australia, using emerging fractional vegetation cover products. This approach simply and effectively mapped the spatial and temporal distribution of the RUSLE cover factor and hillslope erosion hazard in a large area. The methods and results described in this article are valuable for understanding the spatial and temporal dynamics of hillslope erosion and ground cover. According to a study by Kinnell PIA (2014), runoff production, which is spatially uniform, is often inappropriate under natural conditions, where infiltration is spatially variable. The use of an upslope slope length that varies with the ratio of the upslope runoff coefficient to the runoff coefficient for the area down to the downslope boundary of the segment in modifications of the RUSLE approach produces only minor variations in soil loss compared with those predicted using the standard RUSLE approach when the runoff is spatially variable and the number of segments increases. On the contrary, the USLE-M approach provides predictions of soil loss that are influenced strongly by runoff when runoff varies in space and time. Therefore, an increase in the runoff through a segment causes an increase in soil loss, whereas a decrease in the runoff through a segment or cell results in a decrease in soil loss.

Comment 13: Line 96. Please state what "*K*" is.

Response 13: Thank you for your comments! According to your comments, we explained it. Details are in following paragraph and MS.

Explain: *K* is soil erodibility factor.

Silburn's (2011) research showed that estimating soil erodiblity factor (*K*) from soil properties (derived from cultivated soils) provided a reasonable estimate of *K* for the main duplex soils at the study site as long as the correction for the undisturbed soil was used to derive *K* from the measured data and to apply the USLE model.

Comment 14: Line 101. Please state what "*C*" is.

Response 14: Thank you for your comments! According to your comments, we explained it. Details are in following paragraph and MS.

Explain: *C* is cover-management factor (dimensionless)

Yang (2014) found that the cover-management factor (*C*) value can be determined as a function of fractional bare soil and ground cover derived from MODIS data at regional or catchment scales.

Comment 15: Paragraph on line 122 needs more citations to existing literature. E.g., the sentence on line 125 should have a citation.

Response 15: We greatly appreciate your valuable suggestion concerning improvement to this paper. We have followed your advice to adjust it. Details are in following paragraph and MS.

In general, these studies are mainly limited to sloping fields (Tresch S and others 1995; Rick D and others 2001; Silburn 2011; Yang 2014; Kinnell 2014).

However, the accumulation degree of soil and water loss in highways cannot satisfy the requirements of model development (Xu et al., 2009; Bakr et al., 2012).

References:

Xu, X. L., Liu, W., Kong, Y. P., Zhang, K. L., Yu, B. F., Chen, J. D.: Runoff and water erosion on road side-slopes: Effects of rainfall characteristics and slope length. Transportation Research Part D: Transport and Environment, 14(7): 497-501, 2009.

Bakr, N., Weindorf, D. C., Zhu, Y. D., Arceneaux, A. E., Selim, H. M.: Evaluation of compost/mulch as highway embankment erosion control in louisiana at the plotscale. Journal of Hydrology, s 468-469(6): 257-267, 2012.

Comment 16: Line 142, please define what *C* and *P* factors are. This is confusing to talk about multiple parameters in the introduction without describing what they are.

Response 16: Thank you very much! According to your comment, we have followed your advice to adjust it. Details are in following paragraph and MS.

Explain: *C* is cover-management factor (dimensionless); and *P* is the support practice factor (dimensionless).

In using the RUSLE model, most of the research on the cover-management (*C*) and support practice (*P*) factors was conducted by referring to previous research results and data accuracy is often poor.

Comment 17: Section 2 - please add references throughout this paragraph. Many of the statements made should have a citation e.g., about the seasonal regime of the area.

Response 17: We are grateful to the reviewer for pointing out this comment. According to your comment, we have followed your advice to adjust it. Details are in following paragraph and MS.

Xinhe Expressway is in the southern margin of the Yunnan–Guizhou Plateau, which is in southeast Yunnan Province, Honghe Prefecture, and Hekou County. This highway was the first in

Yunnan to cross the border, thereby becoming an important communication channel between China and Vietnam and obtaining important strategic and economic value. The highway is at longitude 103° 33′ 45″–103° 58′ 32″ and latitude 22° 31′ 19″–22° 51′ 48″. The expressway stretches roughly from northwest to southeast, and the total length is 56.30 km. The climate type belongs to subtropical mountain, seasonal monsoon forest, and humid heat climate categories. Between May and the middle of October, the area experiences wet season characterized by abundant rainfall, concentrated precipitation, and increased rain at night (Fei et al., 2017; Zhang et al., 2017).

References:

Fei, X. H., Song, Q. H., Zhang, Y. P., Liu, Y. T., Sha, L. Q., Yu, G. R., Zhang, L. M., Duan, C. Q., Deng, Y., Wu, C. S., Lu, Z. Y., Luo, K., Chen, A. G., Xu, K., Liu, W. W., Huang, H., Jin, Y. Q., Zhou, R. W., Grace, J.: Carbon exchanges and their responses to temperature and precipitation in forest ecosystems in Yunnan, Southwest China. Science of The Total Environment, 616: 824-840, 2017.

Zhang, H., Liao, X. L., Zhai, T. L.: Evaluation of ecosystem service based on scenario simulation of land use in Yunnan Province. Physics and Chemistry of the Earth, Parts A/B/C. 2017.

Comment 18: Section 3 - please use the Harvard reference system to cite each dataset.

Response 18: We greatly appreciate your valuable suggestion concerning improvement to this paper. We have followed your advise to adjusted it. Details are in following paragraph and MS.

2.1.1 Meteorological data

Rainfall data from 2014 were obtained from Hekou Yao Autonomous County, Pingbian Miao Autonomous County, Jinping Miao Yao Autonomous County, and the meteorological department of Mengzi. The rainfall data type was in 5 min format. Meanwhile, two automatic weather stations were established along Xinhe Expressway to gather weather data during the 2014 experiment. Meteorological data was provided by the China Meteorological Data Network covered the period of 1959–2015 (http://data.cma.cn/site/index.html).

2.1.4 Image data

The remote sensing images used in this study were derived from 8m hyperspectral images produced by GF-1 satellite (http://www.rscloudmart.com/).

Comment 19: Section 3.1.2 Is the "S"-shaped sampling method already established in the literature? If so, please cite the literature. If not, please give more detail on this method.

Response 19: Thank you for your comments. We have followed your advise to adjusted it. Details are in following paragraph and MS.

Five mixed soil samples were obtained from one slope using the "S"-shaped sampling method (Shu et al., 2017).

Reference:

Shu, Z. Y., Wang, J. Y., Gong, W., Lv, X. N., Yan, S Y., Cai, Y., Zhao, C. P.: Effects of compound management in citrus orchard on soil micro-aggregate fractal features and soil physical and chemical properties. Journal of Nanjing Forestry University (Natural Sciences Edition), 41(5): 92-98, 2017.

Comment 20: Section 3.1.4 Is the imagery pixel size 8 m x 8m? If so, please state it in this way.

Response 20: Thank you for your comment! According to your comment, we explained it, details are in following paragraph.

It refers to the image of a multi spectral resolution of 8 meters.

Comment 21: Section 2.2 give a citation for the RULSE equation.

Response 21: Thank you for your comments. We have followed your advise to adjusted it. Details are in following paragraph and MS.

The RUSLE equation (Renard et al., 1997) was used to predict the soil and water loss on the side slopes of Xinhe Expressway. The RUSLE equation considers natural and anthropogenic factors that cause soil erosion to produce comprehensive results. Various parameters are easy to calculate, and the calculation method is relatively mature. The RUSLE model is suitable for soil erosion prediction in areas where the physical model is not needed. See Formula (1).

Comment 22: Section 3 general - the sub-section numbering switches from 3.X.X to 2.X.X - please check the numbering is in order.

Response 22: Thank you for your patience and careful work. We are grateful to the reviewer for pointing out this comment. We have followed your advise to adjusted it. Details are in the MS.

Comment 23: Section 4.1 the sentence referring to ArcGIS software needs further explanation. Why was it necessary to vectorise the data? What does the vectorisation have to do with soil erosion prediction?

Response 23: Thank you for your comment! According to your comment, we explained it, details are in following paragraph.

Vector data is a data organization way to represent the spatial distribution of geographic entities by using Euclidean geometry in points, lines, surfaces, and their combinations. The vector data model of ArcGIS is a layer. The amount of soil erosion is obtained by the superposition operation of the related layers in the ArcGIS.

Comment 24: Section 4.1 sentence starting “The natural and artificial slope catchment watershed…" -the final statement "such as property" needs clarification.

Response 24: Thank you for your comments. We have followed your advise to adjusted it. Details are in following paragraph and MS.

The natural and artificial slope catchment watershed was divided into uniform prediction units on the basis of the extracted graphical units of the artificial and natural slope catchments and according to the differences in aspect, slope, land use, and water conservation measures, such as property.

Explain: such as property refers to aspect, slope, land use, and water conservation measures.

Comment 25: Section 4.1.1 please provide a citation for the ArcGIS tool。

Response 25: Thank you for your comments. We have followed your advice to adjust it. Details are in following paragraph and MS.

The catchment unit of the slope was constructed using the structural plane tools of ArcGIS combined with ridge and valley lines and artificial slope and highway boundaries (Zerihun et al., 2018).

Reference:

Zerihun, M., Mohammedyasin, M. S., Sewnet, D., Adem, A. A., & Lakew, M.: Assessment of soil erosion using RUSLE, GIS and remote sensing in NW Ethiopia. Geoderma Regional,12: 83-90, 2018.

Comment 26: Section 4.1 general - some of this information feels like it belongs in the methodology rather than results。

Response 26: We are grateful to the reviewer for pointing out this comment. According to your comment, we have followed your advice to adjust it. Details are in the MS.

Comment 27: The results section of the paper is highly technical, and currently would be more suited to an engineering type journal. Please consider the title of the journal and the likely audience. Try to tell a more logical story of why certain methods have been used, and think about what information is useful to the reader. Some information could possibly go in supplementary material.

Response 27: Thank you for your valuable and thoughtful comments! We have made a detailed revision of the manuscript and the adjustment of the structure, and we hope that the new manuscript will satisfy you. At the same time, we also explain the meaning of this article to the reader, details are in following paragraph.

We believe that the four new concepts presented in this manuscript may be of considerable interest to the usual readers of this journal.

First, in terms of technical methods: In this study, the revised universal soil loss equation (RUSLE) is used as a prediction model for soil and water loss on slopes, combined with GIS and remote sensing technology. The methods of field survey and runoff observation are used, on the basis of fully considering the differences between the model parameters of the artificial slopes and the natural slopes of the expressway. The catchment area is considered a prediction unit. The prediction units of the artificial and natural slopes are classified, and the soil and water loss of each slope is predicted in real time, thus reflecting the soil and water loss of expressway slope accurately. This study not only provides technical experience and reference for the prediction of soil erosion but also helps promote the study of water and soil loss in mountain highways in the world.

Second, in terms of data contribution: In view of the fact that mountain areas have scattered populations, towns, and farmlands, traffic and economy move backward. The topography is complex, and the climate types vary. In addition, the accumulation of highway soil erosion research in the world cannot satisfy the requirements of model development. To date, no mature model of soil erosion for highway is available, thereby resulting in the loss of soil and water in highways in mountain areas. In addition, the relevant data reserves are weak. This study provides a large amount of data on such variables as mountain precipitation and soil erodibility factors. The work provides reference that allows international counterparts to study the ecological environmental problems in mountain areas, recognize and explore the laws of soil and water loss in mountain highways, and alleviate the scarcity of data in mountain areas to a certain extent.

Third, in terms of model parameter improvement: This research aims to characterize soil and water loss in mountain expressways by improving the method of slope element division. In the process of determining the model parameters, the interpolation method is used to obtain rainfall data values. The uneven spatial distribution and heterogeneity problems related to mountain rainfall are solved. The factor of soil and water conservation of artificial slope (P) is corrected by the area ratio method. The soil on the side slope of the expressway is different from the arable soil in the general sense, and the side slope type is also varied. Therefore, the soil erodibility factor (K) is corrected on the basis of the improvement of the slope unit partition and the field investigation. In addition, the other factors are corrected by the experimental data. This study is not only significant in improve the accuracy of the RUSLE model in predicting soil erosion but also provides an updated understanding and inspiration for international counterparts in related fields.

Fourth, in terms of results and understanding: This study fully considers the characteristics of expressways in mountain areas. The catchment area is considered a prediction unit. The method of slope division is improved, and a method of improving the parameters in the model is proposed. Comparison and analysis with actual observation data show that the method of soil and water loss prediction adopted in this paper has less error and higher prediction accuracy than other models and can satisfy prediction requirements. The risk grades of soil and water loss under 20- and one-year rainfall return periods show that the percentage of units with high and extremely high risk of soil erosion is 7.11% and mainly distributed in the K109+500–K110+500 and K133–K139+800 sections. Relevant departments should therefore reinforce the disaster prevention and mitigation efforts and the corresponding soil and water conservation work in these areas.

Comment 28: Section 4.2.1 Please state what the interpolation calculations are

Response 28: Thank you for your comments! According to your comments, we explained it, details are in following paragraph and MS.

On the basis of determining the factors affecting precipitation in different temporal and spatial heterogeneity zones, in the interpolation process, the factors affecting precipitation are introduced, and the cokriging method is selected for interpolated count.

Comment 29: Table 1 and Table 3 Please make clearer what the section of expressway names actually refer to. I.e., how would I find "K83+500~K84+900" on a map?

Response 29: Thank you for your comments! According to your comments, we explained it, details are in following paragraph and MS.

In China, the pile number of the freeway is the meaning of mileage. In general, we can express the position on the road according to the number of the pile. When we enter this section of the highway, we can see the number of piles, but we can't find the corresponding number on the map.

Comment 30: General. When referring to equations, do not refer to the authors by name and then cite. Also, check the spelling of author names is consistent and do not use author first names. For example in section 4.2.3, a sentence reads: If the slope is less than 18, then the formula proposed by McCool et al (Mccol et al., 1987) was used. This should be rewritten as something like: If the slope is less than 18, then the formula of McCool et al. (1987) is used

Response 30: Thank you for your patience and careful work. We have followed your advice to adjust it. Details are in following paragraph and MS.

The *S* factor was calculated as follows. If the slope was less than 18°, then the formula of McCool et al. (1987) was used. If the slope was greater than 18°, then the formula of Liu et al. (1994) was adopted. See Formula (8).

The natural slope catchment slope was divided into less than 1°, 1°–3°, 3°–5°, and greater than or equal to 5° using the Reclassify tool in ArcGIS. The operation formula adopted the *L* factor algorithm of Moore and Burch (1986), as shown by Formulas (5) and (6).

Comment 31: Section 4.2.5 How was NDVI calculated? What data was used?

Response 31: Thank you for your comments! According to your comments, we explained it, details are in following paragraph and MS.

The *C*-factor after topography is an important factor that controls soil loss risk. In the RUSLE model, the *C*-factor has been used to reflect the effects of vegetation cover and management practices on the soil erosion rate ((Vander-Knijff et al., 2000; Prasannakumar et al., 2011;

Alkharabsheh et al., 2013). It is defined as the loss ratio of soils from land cropped under specific conditions to the corresponding loss from clean-tilled and continuous fallow (Wischmeier and Smith, 1978). Due to the variety of land cover patterns with severe spatial and temporal variation, mainly in the watershed scale, data sets from satellite remote sensing were used to assess the C-factor (Vander-Knijff et al., 2000; Li et al., 2010; Chen et al., 2011; Alexakis et al., 2013). The algorithm used in this paper is a method to calculate the C factor proposed by Cai et al. (2000), it is related to vegetation and crop coverage. The formula is shown as (11). Then, the vegetation coverage data were corrected by selecting a sample plot every 2 km along the study area for investigation. The algorithm for calculating f is referred to Tan et al (2005). The formula is shown as (12). Finally, accurate vegetation coverage data were obtained (Figure 9). The *C* factor map of the soil erosion prediction unit in the slope catchment area is shown in Figure 10.

$$C=\begin{cases} 1 & 0\le f<0.1\% \\ 0.6508-0.3436\times lg(f) & 0.1\%\le f<78.3\% \\ 0 & f\ge 78.3\% \end{cases} \tag{11}$$

$$f=\frac{NDVI-NDVI_{min}}{NDVI_{max}-NDVI_{min}} \tag{12}$$

In the formula: f is the vegetation coverage, NDVI is the normalized differential vegetation index, $NDVI_{max}$ and $NDVI_{min}$ are the minimum and maximum value of NDVI in the study region, respectively.

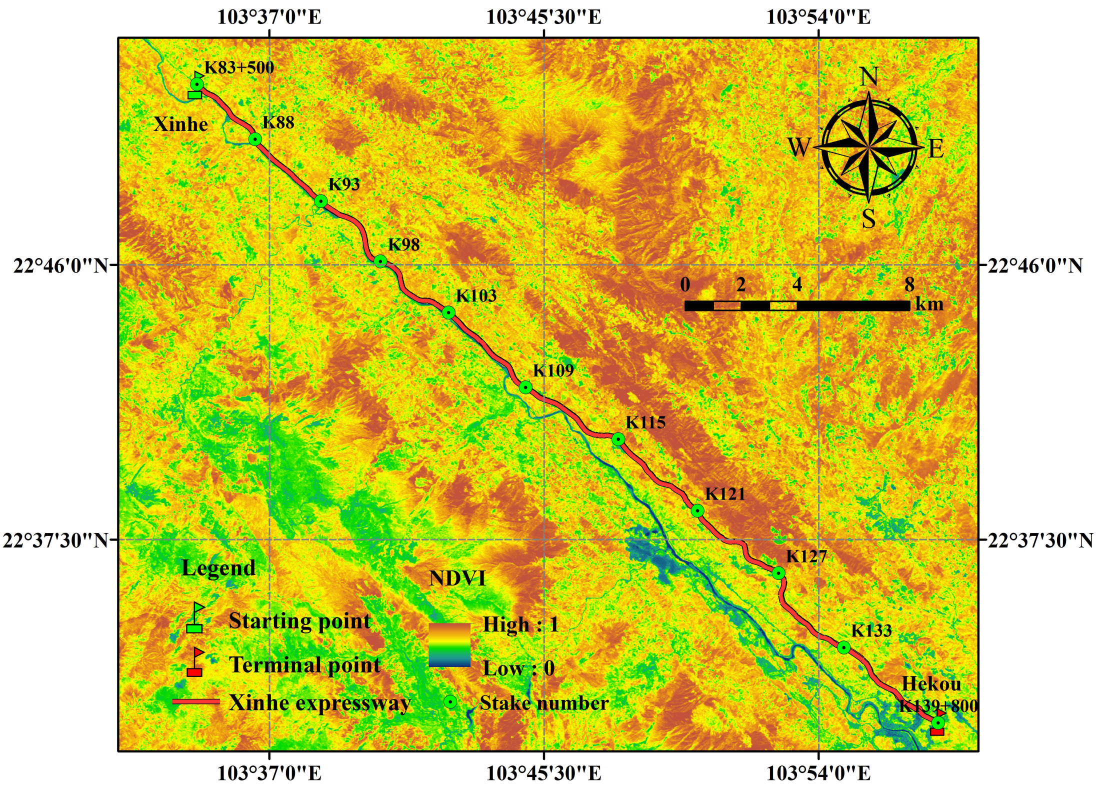

Figure 9 Vegetation coverage along Xinhe Expressway

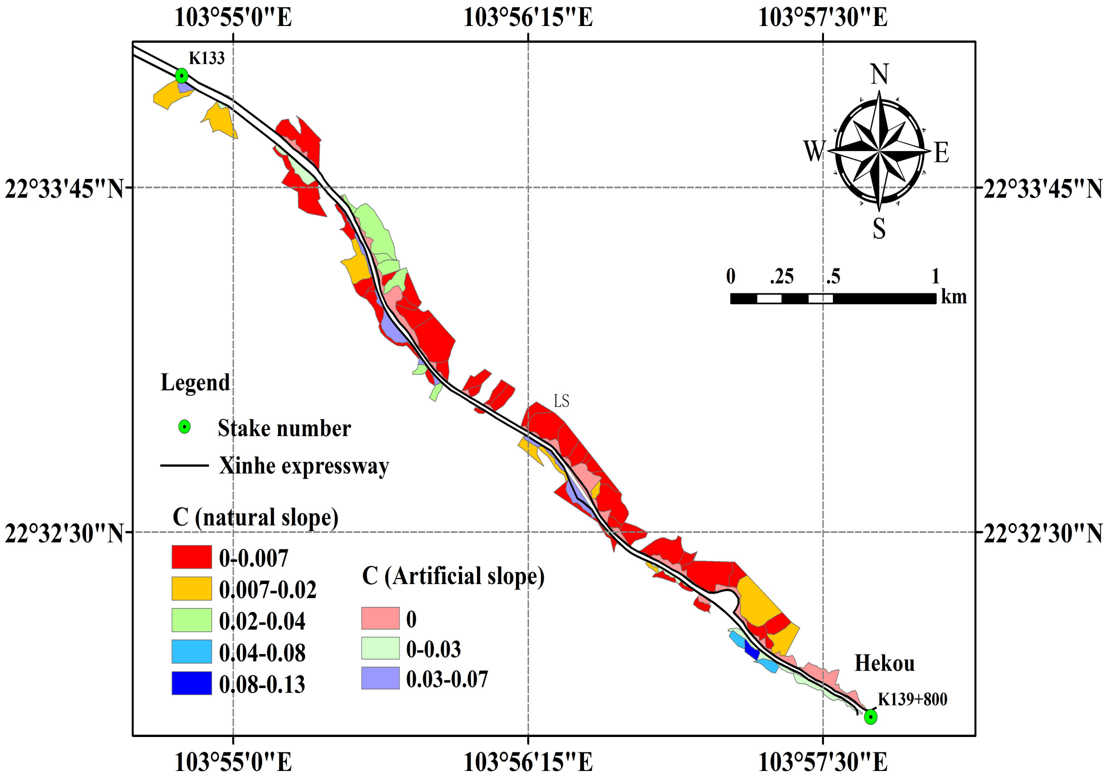

Figure 10 Spatial distribution map of cover and management practice factor

References:

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Comment 32: Section 4.3 How were the field measurements taken in 2014?

Response 32: Thank you for your comments! According to your comments, we explained it, details are in following paragraph and MS.

Runoff plots play an important role in soil erosion monitoring. In general, we need to observe the situation of precipitation (precipitation, precipitation intensity), and through artificial sampling method to obtain the volume of runoff and sediment.

Comment 33: Section 4.3 Please state why the RMSE is within an acceptable range.

Response 33: Thank you for your comments! According to your comments, we explained it, details are in following paragraph and MS.

The root mean square error is a commonly used measure of the difference between the measured values. The value of the root mean square error is often the amount of the model predicted or the estimated estimate. The acceptable range of RMSE in this study is to be judged by actual value and practical experience.

Comment 34: End of Section 4.3 The idea that the model may be defective needs further discussion. What might the uncertainties be? Why are the difference between monitoring and analogue spatially variable?

Response 34: Thank you for your comments! According to your comments, we explained it, details are in following paragraph and MS.

① End of Section 4.3 The idea that the model may be defective needs further discussion. What might the uncertainties be?

Response: The main problem of RUSLE is not whether it can be applied, but whether the calculation factors can be properly valued. Through the study of this paper, it is found that it is feasible to apply the modified universal soil loss equation to the prediction of soil erosion of the expressway slope. However, because the observation period is relatively short, and the time series of the sample data is not long enough, there is a certain error in the calculation of some factors, which may lead to some research results may not be accurate enough. This needs to be improved and corrected by long-term observation and more abundant field investigation and experiments, so as to further improve the prediction accuracy.

② Why are the difference between monitoring and analogue spatially variable?

Response: This is mainly due to the spatial variability of rainfall.

Comment 35: Can you provide any recommendations for how soil and water conservation measures could be rationally adjusted?

Response 35: Thank you for your comments! According to your comments, we explained it, details are in following paragraph and MS.

We may consider slowing down the roadbed slope to keep the slope stable, then the ecological slope protection technology can be adopted. Such as the spraying and planting technology of bolt hanging net, it can build a layer of planting matrix which can grow and develop on the weathered rock slope, and can resist the porous and stable structure of the scouring. Finally, it can achieve the purpose of preventing and controlling soil erosion, beautifying the landscape environment of the road area and ensuring the safety of road traffic.

Comment 36: Discussion - please comment on how meaningful these methods and results might be in other locations? Is this a site-specific study or does it have wider relevance elsewhere?

Response 36: Thank you for your comments! According to your comments, we explained it, details are in following paragraph.

First, in terms of technical methods: This study not only provides technical experience and reference for the prediction of soil erosion but also helps promote the study of water and soil loss in mountain highways in the world. **Second, in terms of data contribution:** The work provides reference that allows international counterparts to study the ecological environmental problems in mountain areas, recognize and explore the laws of soil and water loss in mountain highways, and alleviate the scarcity of data in mountain areas to a certain extent. **Third, in terms of model parameter improvement:** This study is not only significant in improve the accuracy of the RUSLE model in predicting soil erosion but also provides an updated understanding and inspiration for international counterparts in related fields.

Comment 37: Conclusion. Please write this in paragraphs, not numbered sections. Please define variables again.

Response 37: We greatly appreciate your valuable suggestion concerning improvement to this paper. We have followed your advice to adjust it. Details are in following paragraph and MS.

4 Conclusions

This study fully considered the differences between the model parameters of the artificial and natural slopes of mountain expressways. Each catchment area was considered a unit. The artificial and natural slope prediction units were then divided, thus producing 422 artificial slope prediction units and 814 natural slope catchment prediction units. The soil and water loss of each slope was predicted in real time, thus making the prediction of soil erosion accurate. The R factor used the space interpolation method and the P factor of the artificial slope was corrected by the area ratio method in determining the parameters of model prediction. The other factors were corrected by the experimental data. Error analysis of the actual observation data revealed that the overall average absolute error of each monitoring area was 38.65 $t \cdot km^{-2} \cdot a^{-1}$, the average relative error was 31.18%, the root mean square error was between 20.95 and 65.64, and the Nash efficiency coefficient was 0.67. The method of soil and water loss prediction adopted in this work generally has less error and higher prediction accuracy than other models and can satisfy prediction requirements. The risk grades of the soil and water loss along the slope of Xinhe Expressway were divided into 20- and 1-year rainfall on the basis of the simulated prediction. The results showed that the percentage of slope areas with high and extremely high risks was 7.11%. These areas were mainly in the K109+500–K110+500 and K133–K139+800 sections. Therefore, relevant departments should strengthen disaster prevention and reduction efforts and corresponding water and soil conservation initiatives in these areas.