Response Letter to Reviewers Comments on [nhess-2019-166]

Many thanks for the quick response from the editor and the reviewers. The manuscript has been improved substantially based on the constructive comments of the reviewers.

(The highlighted parts are added to the revised paper)

Response to Comments of Reviewer #2

Major comments

Comment #1: In large parts of their methodology the authors jump to simplistic approaches. This may in some cases be necessary because no better knowledge is available. However, the authors do not provide any arguments / literature references in this direction and also don't use data analysis to reason for their approach. I included details below.

Response: The basin is located north of Tehran and it is very important as described in the case study part. There are several rain gage and hydrometric stations in the basin and several synoptic station around the basin. Therefore, monthly meteorological and hydrologic data and information are sufficient; although there is lack of exact information about the spatial value of properties in the basin. Therefore, the simplistic approach we mentioned in the paper relates to the damage cost analysis and there is no shortage of meteorological and hydrological data in the study basin.

P6L1-13: "In fact, the simplistic approach that is used in this article is about damage estimation. The main reason for this is the lack of precise land use information and accurate spatial value of each property in the basin. At the basin level, for example, there is a lot of gardens along the river, some with less than one-year-old trees and some with more than 20 years old trees that have different economic values and various vulnerability to the flood. In this article, all such gardens are seen in the same way. Moreover, it is supposed that all the agricultural land is used for apple and cherry because other fruit gardens include of very low area in the basin. Furthermore, in the basin there are buildings of one to three floors with different areas, some of them are new and some are old; therefore, they are not of equal value and same vulnerability to flood. While in this article all buildings are considered similar and the damage cost to them was estimated by total area of buildings in the inundation area".

Comment #2. The documentation is incomplete in some parts and it is not always clear what data were used.

Response: In the revised paper, we explained the material and data everywhere it is required and where you mentioned in the comments.

a) Hydrologic model: The main input to the HEC-HMS model is rainfall. We used historical rainfalls but those recorded events that the corresponding runoff events in the hydrometric stations are available. CN and Tc values in all the sub-basins were chosen for calibration of the model. The objective function in the calibration step was to predict the exact peak discharge and time to peak of the hydrograph in the hydrometric stations by minimizing the mean squared error (MSE) between predicts and observations.

P5L5-10: "For calibration of the HEC-HMS model, hourly historical storms which had been recorded in 3 rain gage stations in the basin and the related runoffs at the hydrometric stations (Fig. 1) are used". Noted that for calculation of rainfall specified to every sub-basin, the gage weight method is used where the weights were determined from Thiessen method. The curve numbers (CN) and time of concentrations (Tc) are calibrated within the 10 sub-basins. For calibration and verification of the hydrologic model four largest storm events were extracted from 15 years available data (2000-2014): 1) the storm of 15–18 April 2003 in which a flood of maximum 38.22 m3/s was recorded at Gage3; 2) the storm of 16–19 April 2002 where the peak discharge rate of 32.3 m3/s was recorded at 10 Gage3, 3) ; and 4) ."

P7L4-8: "The main objective is to predict the exact peak discharge and time to peak of the hydrograph in the hydrometric stations by minimizing the mean squared error (MSE) between predicts and observations (Fig. 4a in the manuscript). In Table 1, the calibration result of the hydrologic model is presented. Then the hydrologic model is verified with the storm event in April 2002 (Fig. 4b in the manuscript) and finally used for modelling the design storms in the three scenarios to calculate the flood hydrographs at the sub-basins".

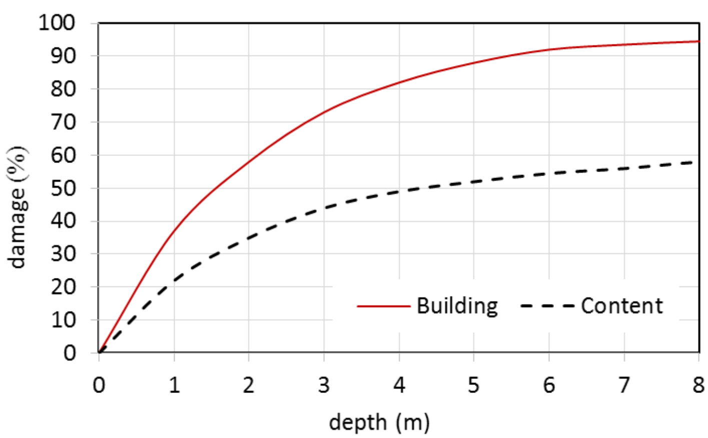
b) Hydraulic model: for starting the hydraulic modelling, HEC-RAS requires cross sections of the river in different points. In this study the cross sections were extracted from Digital Elevation Model. The boundary layers were defined as peak discharges at upstream reaches (output of the HEC-HMS) and the normal depth at downstream outlet.

P7L10-14: "For starting the hydraulic modelling, HEC-RAS requires cross sections of the river in different points. In this study the cross sections were extracted from Digital Elevation Model. For the model's calibration, the peak discharges produced in the hydrologic model's calibration step (flood 15–18 April 2003) are input into the hydraulic model as the boundary conditions at the upstream reaches and the flood depth and velocity at Sulaghan station are compared with the observed ones. The calibration parameters are Manning roughness coefficients that are calibrated manually. Noted that, for downstream boundary condition the flow depth at the outlet point was determined as the normal depth. For the model verification, flood in 16–19 April 2002 and the upstream peak discharges generated in the hydrologic model are used".

c) Damage analysis: for damage analysis we needed to have the land use and the inundation maps. The later was output of HEC-RAS model. Land use maps including residential buildings, restaurants, and agricultural areas were available from local municipality. Applying the inundation map on the land use maps the average depth of inundation and area of inundation for every land use were calculated. Then from the damage-elevation curve percentile of damage to the land uses could be estimated. Finally, the damage cost to each land uses was calculated by the average economic value of one unit of that land use (available from a field survey and interviews with the local authorities and inhabitants).

P7L21-28: Damage Analysis: "In this section, with the help of GIS tool and the land use maps which were obtained from the local municipality, a simple analysis of damages to the buildings, their contents, and agricultural areas is carried out. In this step just five Sub-basins of Imamzadeh Davood, Rendan, Sangan, Sulaghan and Keshar are considered; because of lack of land use maps, low population, and low development in the other sub-basins. For this regard, applying the inundation map on the land use maps, the average depth of inundation and area of inundation for every land use are calculated. Then from the damage-elevation curves percentile of damage to the land uses can be estimated. Finally, the damage cost to each of land uses is calculated by the average economic value of one unit of that land use. It should be noted that for agricultural physical damages analysis in every sub-basin, two dominant products of cherry and apple were identified and based on the percentage of each of them, average crop number per unit area and value of each crop, the damage analysis was performed. Percentages of crops, number of them per unit area and their economic value as well as values of different assets in the flood plain are obtained by several field survey, interviews with the local authorities and local inhabitants, and engineering judgment.

P5L26: "Damage-Elevation curves that are prepared for different land uses of Kan River Basin are presented in Fig 1"



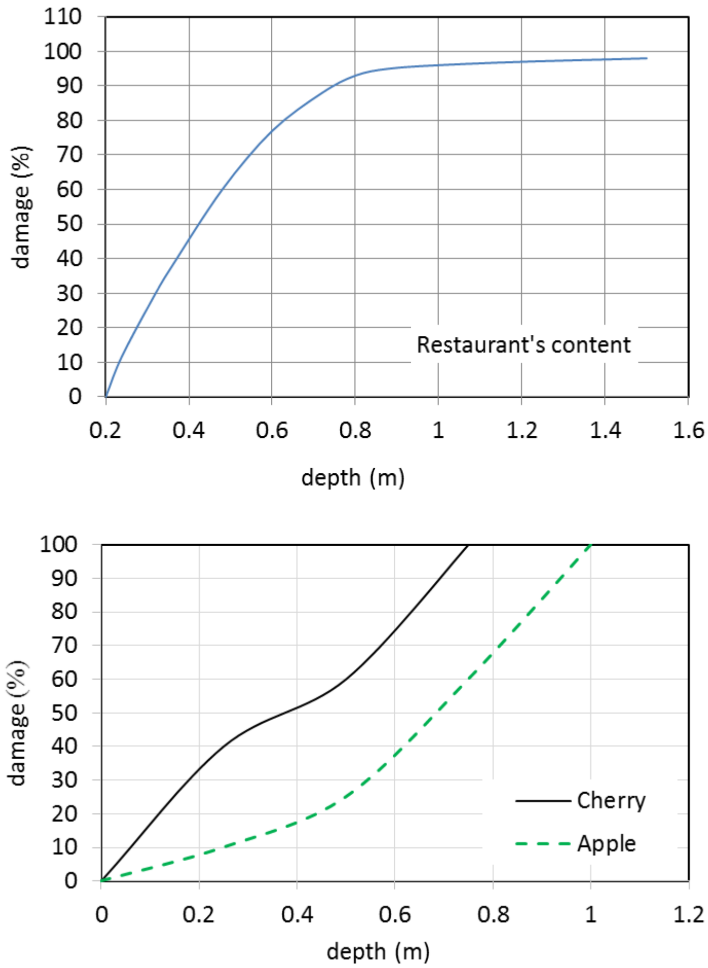


FIG 1 ***DAMAGE-ELEVATION CURVES FOR DIFFERENT LAND USES OF A) BUILDING AND ITS CONTENTS, B) RESTAURANT'S CONTENT, AND C) AGRICULTURE IN KAN RIVER BASIN*.**

Comment #3: In addition to the above, I have some difficulty understanding the motivation for this work. Clearly, atmospheric circulation patterns must be expected to impact extreme rain intensities. However, considering sufficiently long rainfall time series, these oscillations should not affect the probability distribution of extreme rainfall and thus also not our estimates of expected flood damages? Why then do we need to know exactly how much damages vary over time?

Response: We agree that high-intensity rainfalls are available in a long hydrologic time series and any high-intensity rainfall does not change the probability of its occurrence much. However, as the reviewer mentioned, rainfall events during El Nino are raised in intensity and amount. Therefore, even El-Nino event in a year does not expect to change the general probability distribution of extreme rainfall and the estimates of the flood damages, we could expect to have higher flood events and thus more estimates of flood damages in that year. This paper is looking to have an estimates of flood damages in such conditions in comparison with the normal years. In other words, we want to calculate the peak values in the long time series of flood damages because we think that it is related to the El Nino.

Methodological issues

Comment #4: Linking rainfall series and SOI - The references I found describe the AMI as a univariate method and I could not find it in the reference provided by the authors. It is not clear how the joint probabilities are computed from the histograms and the equation for the "optimal number of categories"appears out of the blue". Most importantly, the authors did not provide any evidence that the method gives reasonable results (time series plots of SOI and rainfall indicating the identified lag, scatterplots of lag vs. AMI, cross correlation plots, or similar)

Response: We mentioned in the paper that average mutual information (AMI) is a measure of the "amount of information" obtained about one random variable, through the other random variable. Guiasu (1977) defined the mutual information of two random variables as a measure of the mutual dependence between two variables. Not limited to real-valued random variables and linear dependence like the correlation coefficient, mutual information is more general and determines how different the joint distribution of the pair (X,Y) is to the product of the marginal distributions of X and Y (Guiasu 1977).

Sometimes it is useful to express the mutual information of two random variables conditioned on a third called conditional mutual information. Therefore, mutual information among more than two random variables is also defined. Several generalizations of mutual information to more than two random variables have been proposed (McGill 1954; Hu Kuo Ting 1962). Therefore, AMI is not defined just as a univariate method; although, we have used it as univariate between SOI and precipitation in this paper.

When dealing with large sets of numbers, Sturge's rule (Sturges 1926) can be used to choose the number of categories. Sturge's rule is widely used in the statistical packages like excel for making histograms. According to Sturge's rule the data range should be split into K equally spaced classes where:

$$K = 1 + 3.322 \log_{10}(n)$$

where n is the number of data.

Reference

- Guiasu, S. 1977. Information Theory with Applications. McGraw-Hill, New York. ISBN 978-0-07-025109-0.
- Hu, K.T. 1962. On the Amount of Information. Theory Probab. Appl. 7: 439–447.
- McGill, W. 1954. Multivariate information transmission. Psychometrika. 19(1): 97–116. doi:10.1007/BF02289159
- Sturges, H. 1926. The choice of a class-interval. J. Amer. Statist. Assoc., 21, 65-66.

For verification of the result we can use the linear dependence method of correlation coefficient. Doing so, a scatter plot between monthly SOI and precipitation in Mehrabad synoptic station is prepared. Considering different lag times between SOI and precipitation, Fig 2 represents the correlation coefficient against monthly lag time. This figure is related to the precipitation in the Mehrabad station. Such a trend can be found in the other stations.

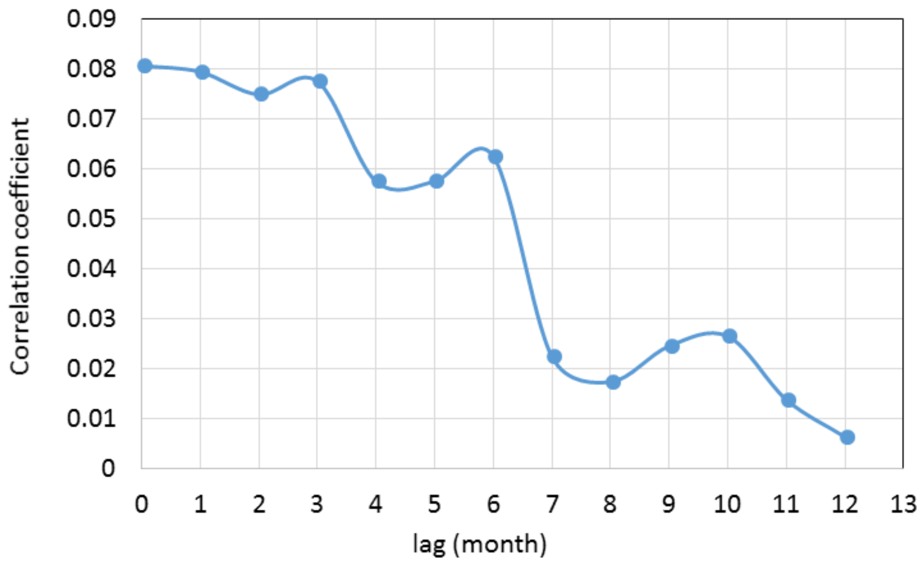


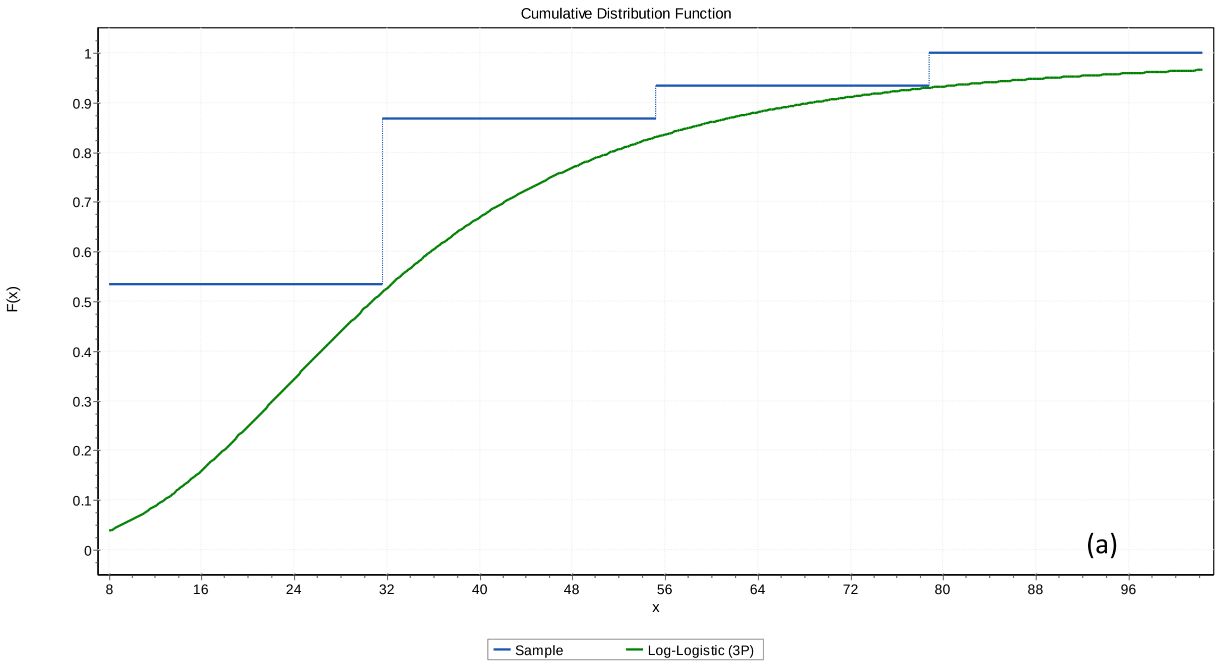
FIG 2. ***CORRELATION COEFFICIENT BETWEEN PRECIPITATION AND MONTHLY LAG TIMES AGAINST DIFFERENT LAG TIME***

Comment #5: Determining increased rainfall during El Nino

(a) There is an obvious problem in using change factors derived for annual rainfall to extreme daily/hourly precipitation. No reasoning is provided for why this is done.

Response: In the present paper a risk base analysis has been performed. On this basis, results of Table 3 mean that for example if a 10-yr return period rainfall is happening while a strong El Nino condition is experiencing, it is expected by 90% probability that the damages cost will be less than 267% of that in the normal condition. Indeed, the rainfall and damage enhancements that are presented in the paper are the expected increase values of yearly rainfall and damages which have been calculated from a long time series of data. Therefore, the %-changes of damages represent the expected annual values for every return period or the values that are probable by the given certainty levels. Fig 3 illustrates the cumulative distributions that are fitted on the %-changes of rainfall in two different months: January and April. Noted that, according to the results El Nino in average increases the rainfall in April and decreases it in April. This figure shows that in 60% certainty the increased rainfall in Tehran is less than 36% in January and in April it follows not only an increased amount but a decreased value less than -28%. However, in the annual time scale which is reported in the paper for the same probability the rainfall increase is less than 8.2. On the other hand, in a year with dominant El

Nino, there are several La Nina events in which it is expected to have less flood damages. Therefore, in average, the annual expected increase in flood damages cannot be calculated by considering the effect of El Nino on a storm event happens in specific time of year and it requires to evaluate all the events during El Nino, La Nina, and neutral episodes. Certainly, it is better to employ a daily rainfall-runoff-damage analysis, but the absence of such data and information, applying the average annual rainfall increase (that is done in the paper), although is relatively simplistic, can provide acceptable results.



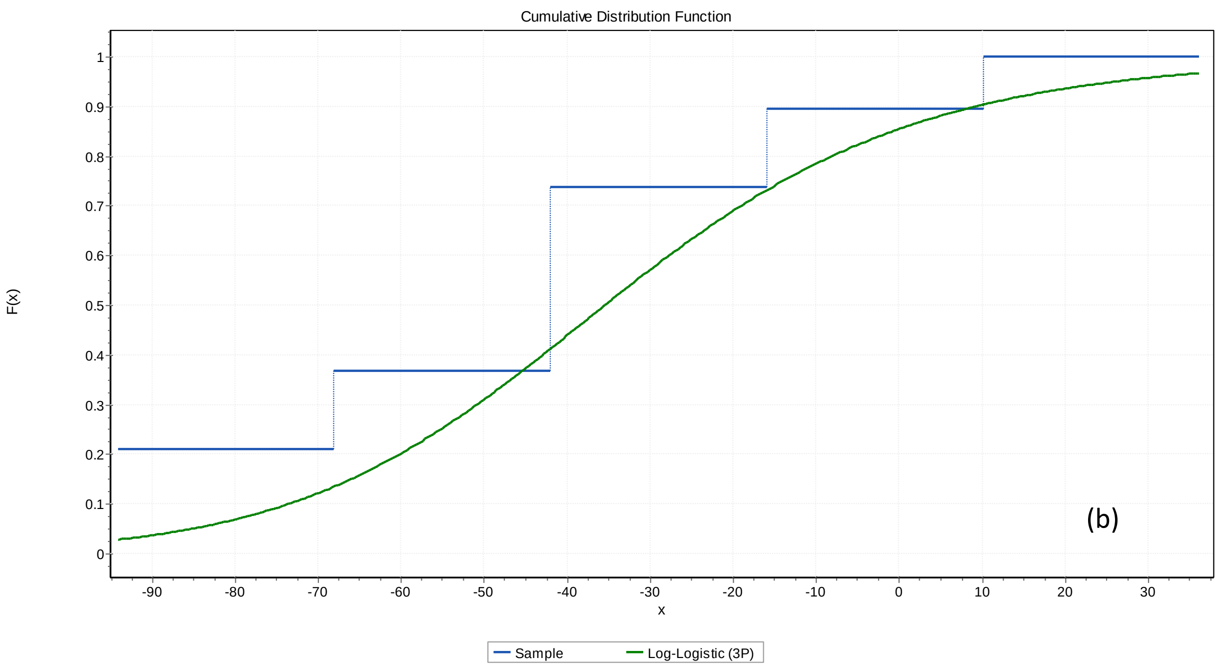


Fig 3. **Cumulative distribution function fitted on the increased percentiles of rainfall in a) January and b) April**

Comment #6: Determining increased rainfall during El Nino

(b) I believe Fig. 3 illustrates the %-changes of rainfall for all years that were identified as "El Nino" in step 1.

i. It is not clear to me why you would pick the 60 and 90% quantiles for the further analysis. The median value, as far as I can see, is 0. My conclusion would be that there is no evidence for an impact of El Nino on annual rainfall? Also the trends identified in Fig.2 look very questionable. Have you tested the significance of parameters?

Response:

Picking the 60 and 90% quantiles: Fig 4 (Fig 3 in the original paper) shows the cumulative distribution of precipitation increases (%) in the El Niño years compared to normal years. Toward a risk-based analysis to the flood damage resulting from El Niño, the probability of any precipitation and its increase percentile occurring in the long-term time series of the study area is important. For this reason Fig 4 has been developed and used to determine the requirements.

In this article it was required to estimate the average amount of damages and the maximum amount of damages that are expected per year. Therefore, a probability level representative of the maximum possible damage and a probability level representative of average damage caused by El Niño were selected. According to Fig 4, if we divide the precipitation increase into two classes of zero to 20% and 20 to 40%, the 60% probability level can represent the mean precipitation increase and the 90% probability level can be considered as the maximum precipitation increase.

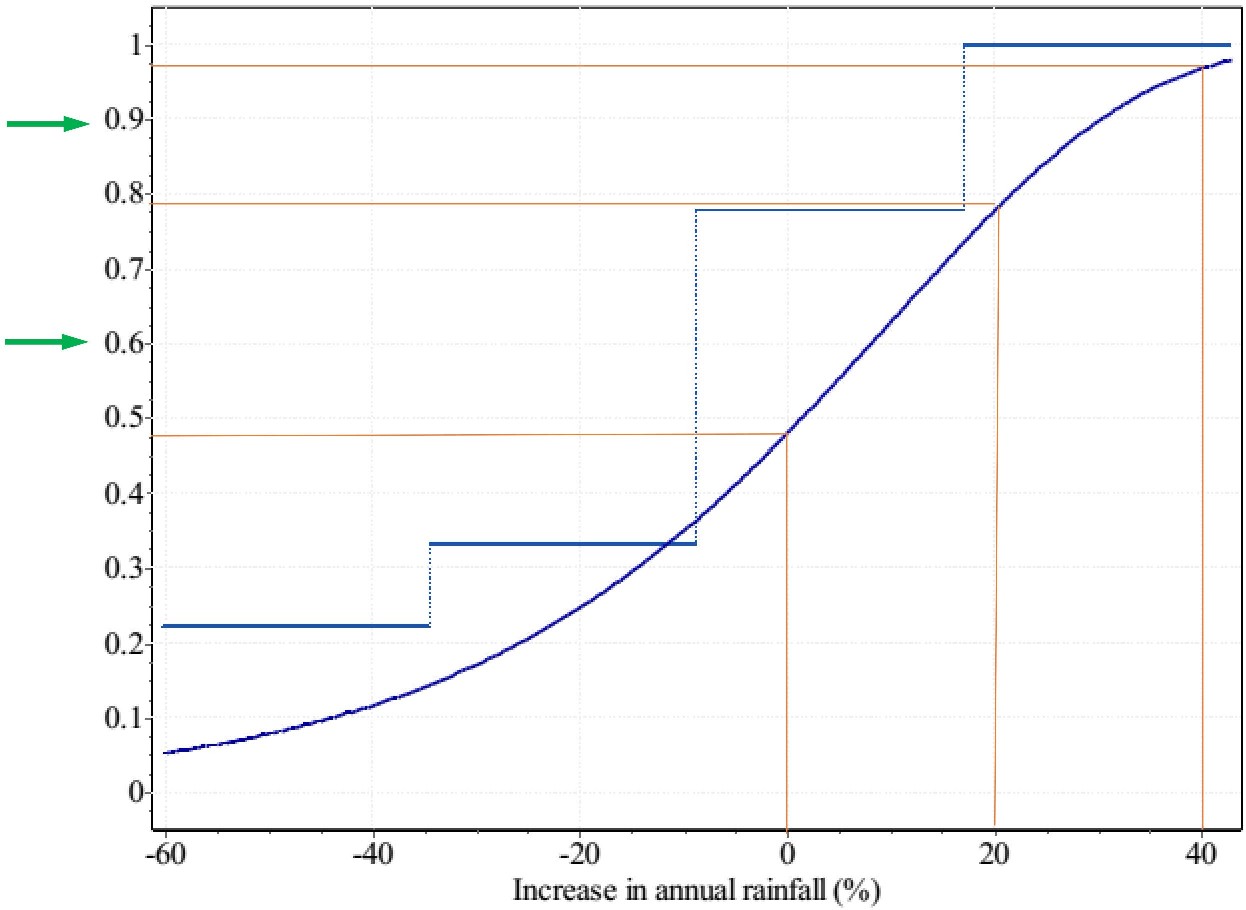


FIG 4: **GUMBEL CUMULATIVE DISTRIBUTION FUNCTION FITTED ON THE ANNUAL INCREASED PERCENTILES OF RAINFALL**

Impact of El Nino on annual rainfall: For evaluating the impact of El Nino on annual rainfall that is better to have a judgment based on the trend analysis instead of CDF plot. According to the yearly SOI time series, 9 El Nino events have been identified from 1951 to 2017. Out of these 9 years, 6 years have experienced increase in the precipitation and 3 years with decrease in the precipitation. Fig 5 provides the annual rainfall against the SOI values during El Nino years. It is clear that the annual rainfall increases as the SOI value decreases (stronger El Nino). In average one unit decrease in the SOI, will enhance 361 mm annual rainfall.

On the other hand, Fig 6 provides the annual rainfall against the SOI values for the total data (1951-2017). This figure illustrates a significant trend in the annual rainfall amount *vs* SOI. It is obvious that by decreasing the SOI value in which the El Nino event got stronger, the annual rainfall increases. Such a trend is also reported in many other papers.

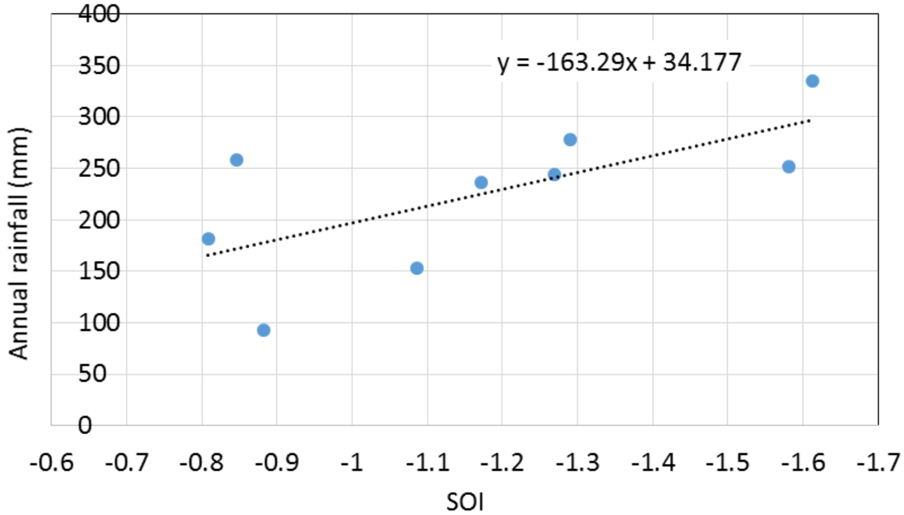


FIG 5. PERCENTILE OF RAINFALL CHANGES AGAINST THE SOI DURING EL-NINO YEARS IN MEHRABAD STATION

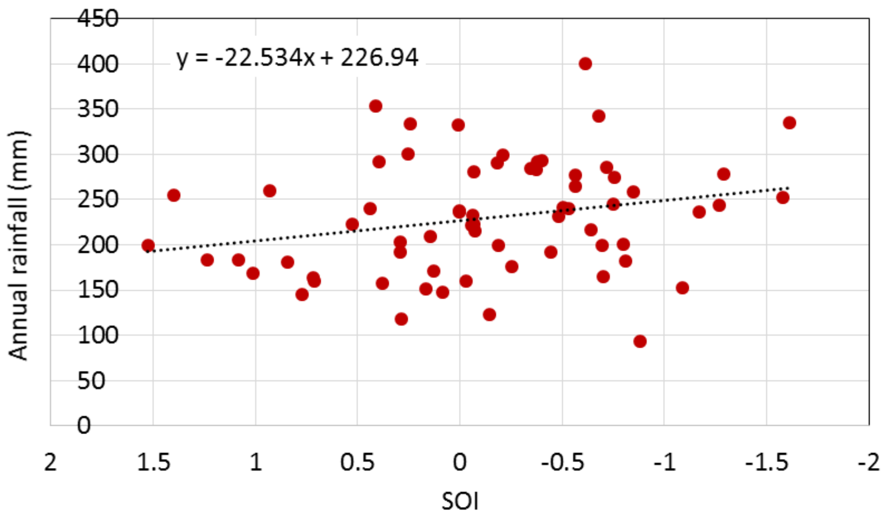


FIG 6. PERCENTILE OF RAINFALL CHANGES AGAINST THE SOI IN MEHRABAD STATION FOR THE TOTAL YEARS

Comment #7: Determining increased rainfall during El Nino

(b) I believe Fig. 3 illustrates the %-changes of rainfall for all years that were identifed as "El Nino" in step 1.

ii. Are the annual rainfall and %-change values correlated? This would certainly impact the trend estimates in Fig. 2 and pose a challenge for distribution fitting in Fig. 3?

Response: Annual rainfall and %-change values of rainfall?!

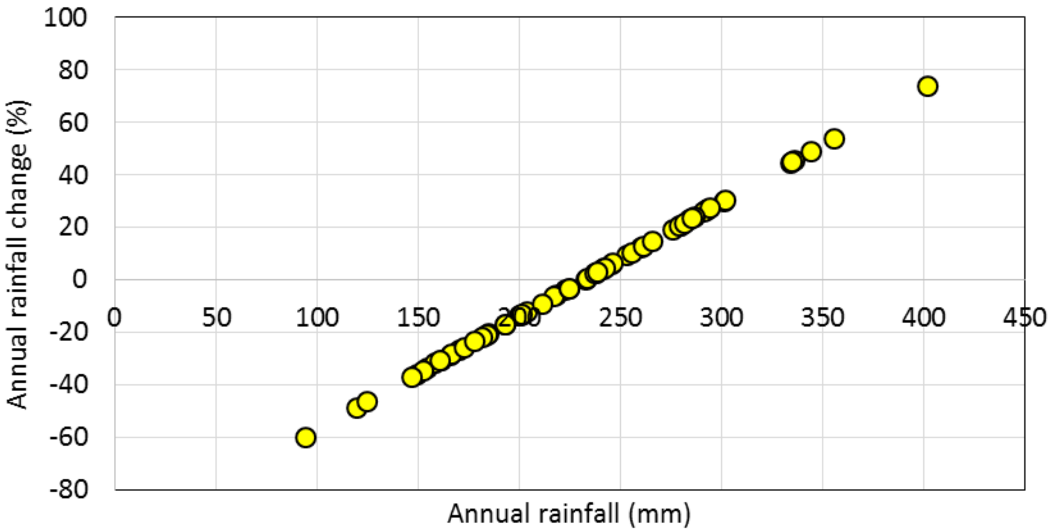


FIG 7- ANNUAL RAINFALL AGAINST THE CHANGE PERCENTILE

About the cumulative distribution, we checked again the result of %-change values and the CDF to ensure the calculations. The data can be provided for further control if required.

Comment #8. Hydrological and hydraulic modelling

(a) The hydrological model was calibrated for a single event only, which is not good practice. Why is only one of the 3 stations used for calibration?

Response: For the flood of 15–18 April 2003 all hydrometric stations have been considered in the model evaluation, although the calibration has been performed on the basis of recorded discharges in station 3. For calibration the automatic calibration of HEC-HMS has been used in which a single discharge station is required for the purpose. For the three other floods, the discharges are not available because of the stations failure or incorrect operation. The results are shown in the following.

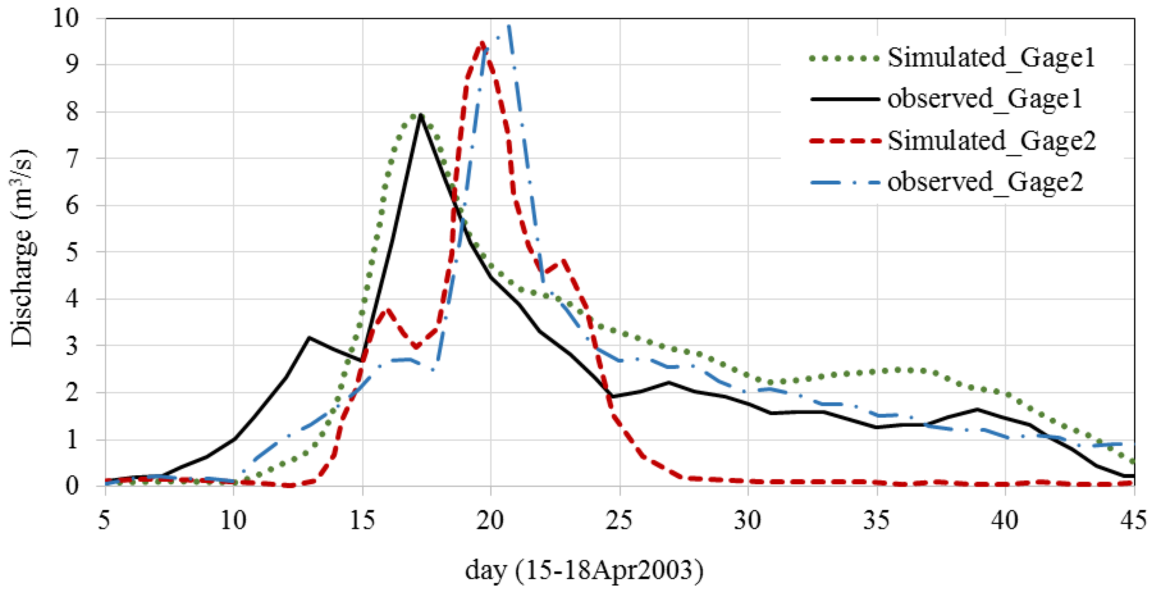


FIG 8. THE OBSERVED AND SIMULATED FLOOD HYDROGRAPHS OF 15–18 APRIL 2003

Also, In addition to the flood events which have been mentioned in the manuscript, two other events are also are considered for calibration and verification of the model. Floods of 2009 and 2011 with peak discharges of 34.4 m3/s and 54.1 m3/s. Noted that hydrographs of these two foods were not available in the Gage 1 and 2. These results are added to the paper.

Comparison between the simulated and observed flood hydrographs are shown in the following:

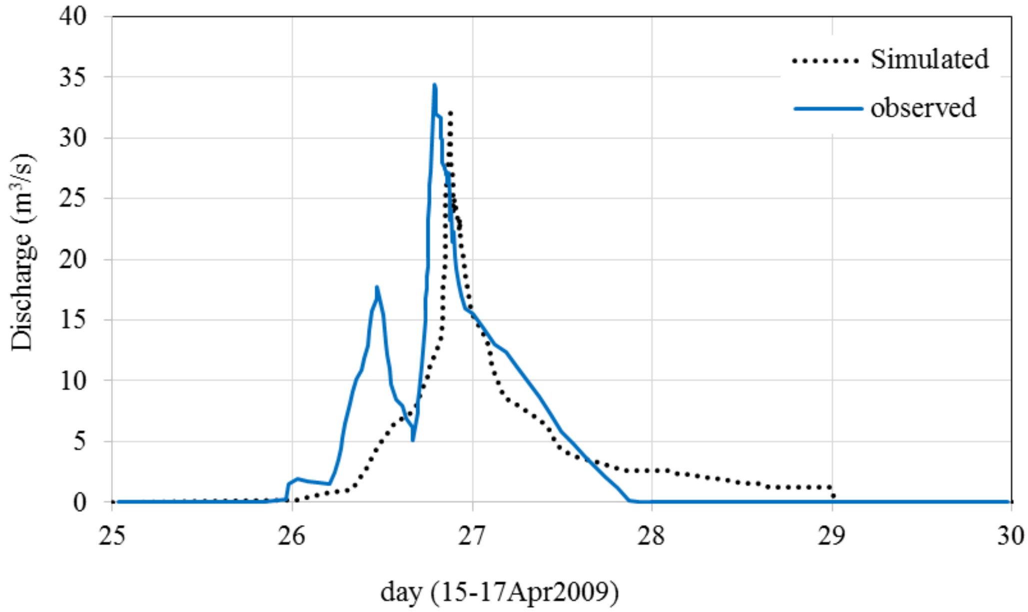


FIG 9. OBSERVED AND SIMULATED FLOOD HYDROGRAPHS AT SULAGHAN STATION IN 15–17 APRIL 2009

For the flood of 11-13 March 2011, a peak of 54.1 m^3/s has been estimated by Regional Water Company of Tehran.

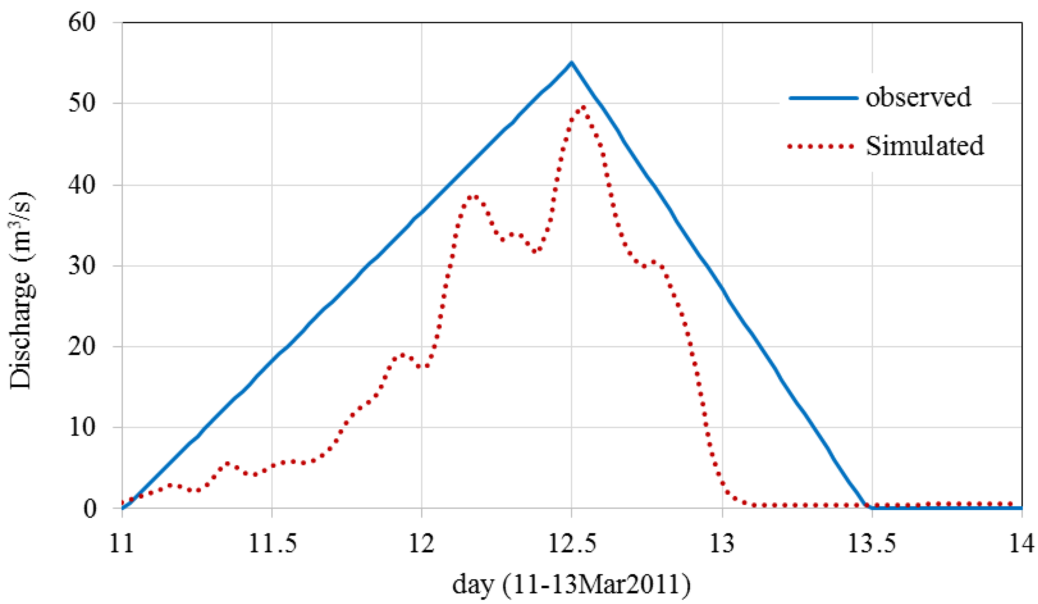


Fig 10. Observed and simulated flood hydrographs at Sulaghan Station in 11–13 March 2011

Comment #9. Hydrological and hydraulic modelling

(b) It is not clear for which areas the HEC-RAS simulation is performed (not highlighted in Fig.1), so I cannot evaluate whether the link between hydrological and hydraulic modelling setup makes sense.

Response: In this study, the hydrodynamic model of HEC-RAS was calibrated using the historical discharges and depths recorded in the hydrometric gauges for flood depth values. Flood hydrographs of the sub-basins with different return periods were simulated by the calibrated rainfall-runoff model (HEC-HMS) and the peak values were used as the boundary conditions for the HEC-RAS model. In this research, all the basin has been model in the HEC-HMS, then the HEC-RAS has been set-up for all the basin integrally. Schematics of the HEC-HMS and HEC-RAS models are provided in Fig 11 and Fig 12, respectively.

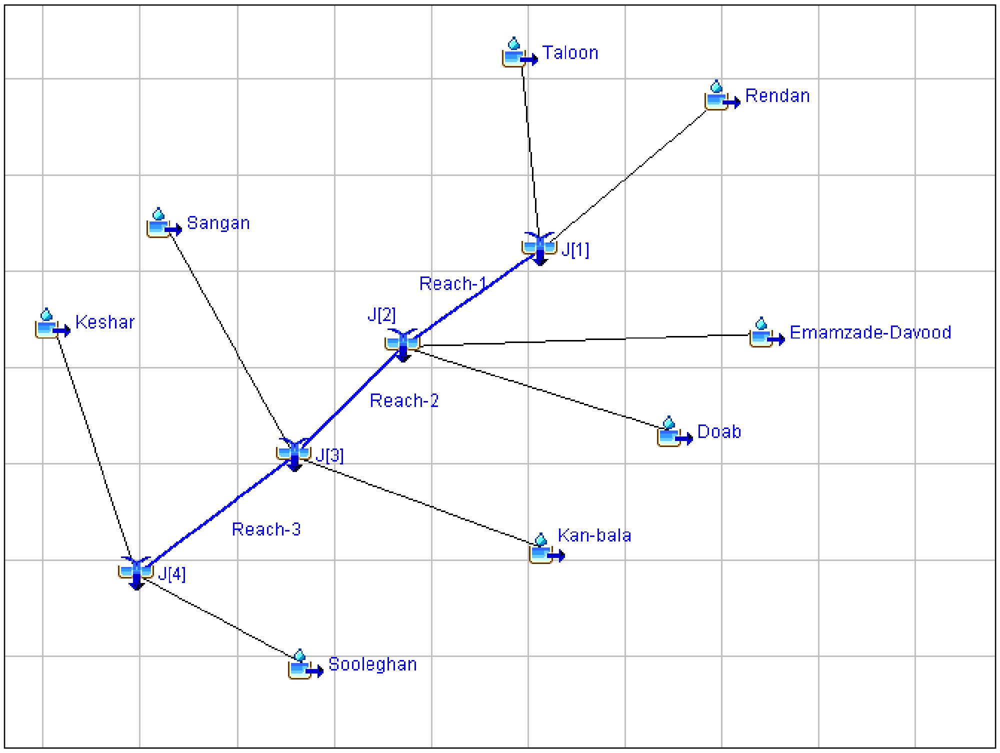


FIG 11. SCHEMATICS OF THE HYDROLOGIC MODEL IN HEC-HMS

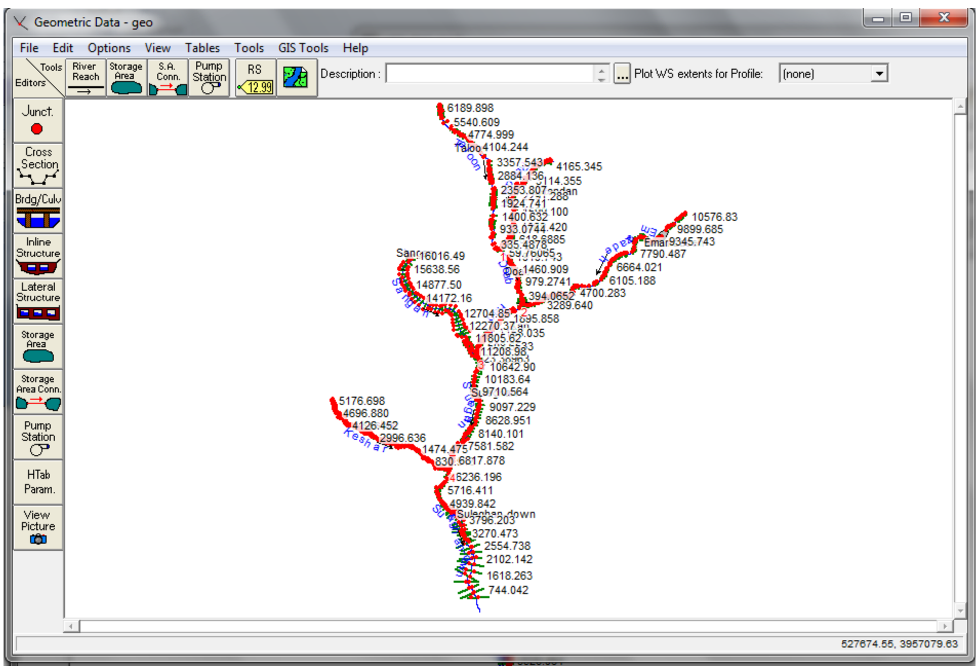


FIG 12. SCHEMATICS OF THE HYDRADYNAMIC MODEL IN HEC-RAS

Comment #10. Damage calculation – It is not clear how the damage calculation was performed. The depth-damage functions are not provided in the paper. In the results section, the authors mention the computation of an "average inundation depth" per landuse class. This seems like a questionable approach, but it is simply not clear what was done here.

Response: Damage analysis part is rephrased and extended to clarify the methodology of damage estimation. Also damage-elevation curves are added to the paper.

P6L1: A comprehensive analysis of physical damages due to flooding requires many information including accurate updated land use map, area and age of buildings, type of the structure, number of floors, exact areas of different agricultural crop in the flood-prone area, crop number per unit area, value of crops, value of buildings (residential and non-residential) and their contents, number of residential, administrative, and commercial buildings in flood prone areas, the area and elevation of buildings, their locations, and spatial distribution of flood depth values in the inundated areas for different return periods. In this paper a simplistic approach is used for this regard. For the building damage analysis, separating residential and commercial ones, the total area of inundated buildings, average inundation depth, and the average economic value of the building and their contents for every buildings type are used. For agricultural damage analysis, considering the dominant crops of cherry and apple, the area of inundation, average inundation depth, crop density, and average price of one single crop the flood damage costs are evaluated.

P7L21-28: Damage Analysis: "In this section, with the help of GIS tool and the land use maps which were obtained from the local municipality, a simple analysis of damages to the buildings and their contents, and the agriculture is carried out. In this step just five Sub-basins of Imamzadeh Davood, Rendan, Sangan, Sulaghan and Keshar are considered; because of lack of land use maps, low population, and low development in the other sub-basins. For this regard, applying the inundation map on the land use maps, the average depth of inundation and area of inundation for every land use category are calculated. Then from the damage-elevation curves, percentile of damage to the land uses can be estimated. Finally, the damage cost to each of land uses is calculated by the average economic value of one unit of that land use. It should be noted that for agricultural damage analysis in every sub-basin, two dominant products of cherry and apple were identified and based on the percentage of each of them, average crop number per unit area and value of each crop, the damage analysis was performed. Percentages of crops, number of them per unit area and their economic value as well as values of different assets in the flood plain are obtained by several field survey, interviews with the local authorities and local inhabitants, and engineering judgment.

P5L26: "Damage-Elevation curves that are prepared for different land uses of Kan River Basin are presented in Fig 13"

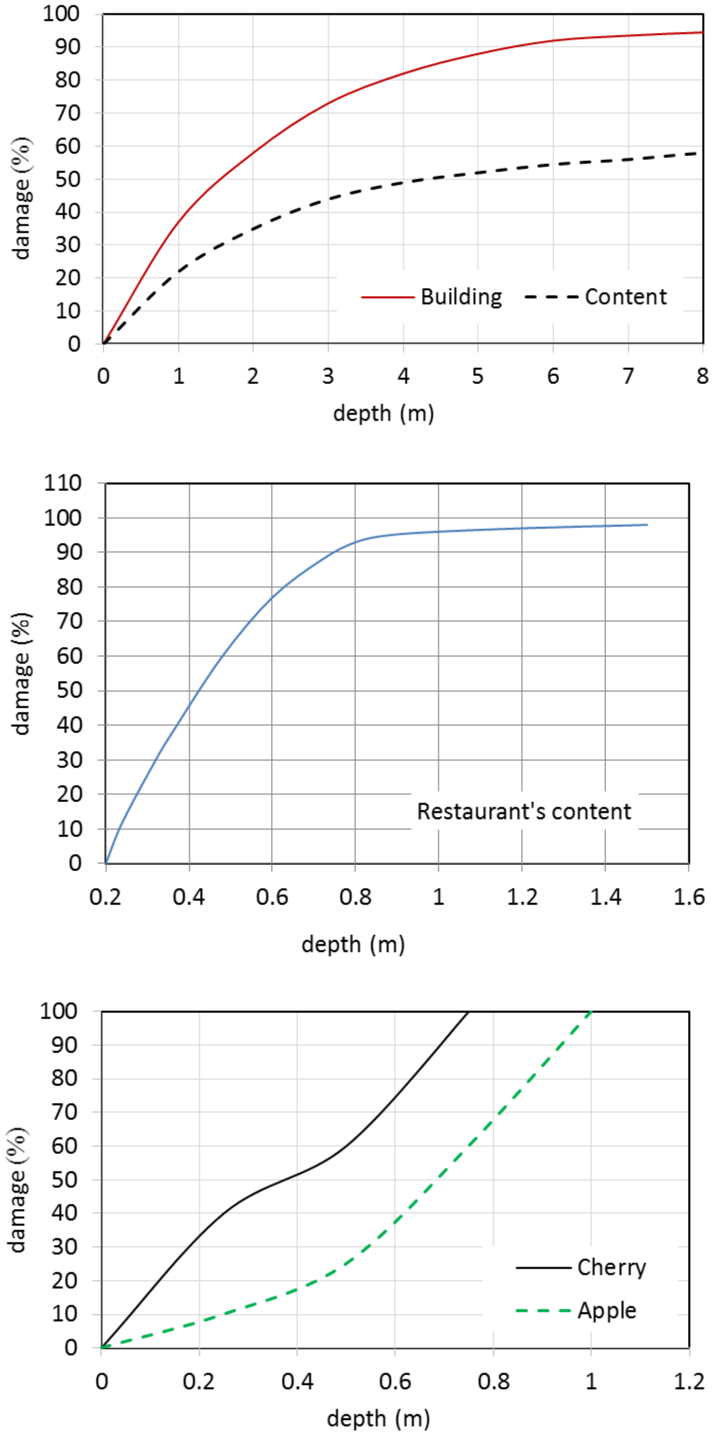


FIG 13. ***DAMAGE-ELEVATION CURVES FOR DIFFERENT LAND USES OF A) BUILDING AND ITS CONTENTS, B) RESTAURANT'S CONTENT, AND C) AGRICULTURE IN KAN RIVER BASIN.***

Minor comments

Comment #11: P1L27: How do you define a flood event? Is it correctly understood that Tehran experienced flooding 12 times in 1951 and 54 times in 1991?

Response: Tehran metropolis is the Iran's capital located below Alborz Mountains where several steep rivers flow through the city from the north to the south, named Kan River (the biggest), Farahzad River, Darband River, Darakeh River, Dar-Abad River and etc. Although they are not very big rivers, flooding is a major problem of them because of their steep basin, potential of snow melt, mountainous valleys that has forced people to live near the river beds and low flood management practices. These rivers have provided some populated rural areas and attracted many tourists for spending their times in the vacations. Todays, the population areas near the rivers have been expanding and the economic activities in the flood plains is being grown up. All of these factors have caused the flooding being increased. Due to flooding of a river/rivers, some parts of the city (areas close to the flooding river and along the river) may experience flooding. Therefore, in the mentioned sentence we do not mean that all the Tehran regions experience flooding in a flood event. To prevent misleading the readers, we rephrased the sentence as follow:

> "According to the available reports, the number of flooding events that happened in any parts of Tehran over four decades from 12 cases in 1951 had grown up to 54 cases in 1991"

Comment #12: P2L1-23: This part of the introduction cites a lot of studies that measured impacts of atmospheric circulation patterns. However, most of these refer to completely different parts of the world, so I had difficulty seeing the relevance.

Response: Many studies have shown the effect of ENSO on the climate variability of Iran. Nazemosadat and Ghasemi (2004) indicated that El Niño is associated with wet periods over most regions of Iran during autumn and winter while the risk of droughts is high during La Niña. Their study revealed that El Niño has the least influence over the southeastern and northwestern regions of the country during winter. Alizadeh-Choobari et al. (2018) indicated that the ENSO cycle contributes to the interannual climate variability over Iran. According to their results, about 26% of the variance in annual precipitation over Iran is related to the El Niño. Based on their achievements, In spite of the seasonality of the ENSO signal and its interevent variability,Iran is anomalously wet during the EP El Niño and dry during La Niña and the impacts of La Niña and the EP El Niño are generally stronger over the warm and arid regions of Iran.

Although, the effect of ENSO on the precipitation has been frequently studied in Iran (Nazemosadat and Ghasemi 2004; Saghafian et al. 2017; Alizadeh-Choobari et al. 2018; Hooshyaripor et al. 2018), there are few studies about ENSO influence on the socioeconomic impacts of floods even around the world (Ward et al. 2014). The main reason for the limited research on the economic impacts of climate and hydrologic variability is said to be the lack of economic data on flood damages (Changnon 2003). Analyzing the National Flood Insurance Program daily claims and losses and Multivariate ENSO Index (MEI), Corringham and Cayan (2019) quantified insured flood losses across the western United States from 1978 to 2017. They showed that in coastal Southern California and across the Southwest of the United States, El Niño has had a strong effect in producing more frequent and higher magnitudes of insured losses, while in the Pacific Northwest, the opposite pattern with weaker and less spatially coherent has been reported. Changnon (2003) revealed that the strong El Niño events of 1982/83 and 1997/98 have caused significant flood damages over $2.8 billion in Southern California. Null (2014) demonstrated that from 1949 until 1997 out of the six seasons that flood damages costs exceeded $1 billion in California three cases had been El Niño years; one very strong (1982), one moderate (1994) and one weak (1968). Ward et al. (2014) showed that ENSO exerts strong and widespread influences on both flood hazard and risk. They assessed ENSO's influence in terms of affected population, gross domestic product and economic damages on the flood risk at the global scale and showed that climate variability, especially from ENSO, should be incorporated into disaster-risk analyses and policies. They revealed that, if the frequency and/or magnitude of ENSO events were to change in the future due to climate change, change in flood-risk variations across almost half of the world's terrestrial regions is happened. Ward et al. (2016) provided a global modelling exercise to examin the relationships between flood duration and frequency and ENSO. They indicated that the duration of flooding compared to flood frequency is more sensitive to ENSO.

Alizadeh-Choobari O., Adibi, P. and Irannejad, P. 2018. Impact of the El Niño–Southern Oscillation on the climate of Iran using ERA-Interim data. Climate Dynamics. 51(7-8): 2897–2911.

Changnon, S. 2003. Measures of economic impacts of weather extremes. Bull. Amer. Meteor. Soc., 84, 1231–1235, https://doi.org/10.1175/BAMS-84-9-1231.

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Comment #13: P3L10: typo 78.23M cbm/s?

Response: Thank you. It is annual inflow that was measured in Sulaghan station equal to 78.23 Mm^3/yr.

Comment #14: P4L20-25: What is a natural uniform rainfall?

Response: "naturally", we mean the rainfall that has been happened historically in the basin. "Uniform", we mean that the rainfall has the same spatial intensity and duration. This term has been changed in the revised paper as:

Scenario I (normal condition): In the first scenario no El-Niño event is considered. It is assumed that the basin receives a rainfall with the given intensities (T=10, 25, and 50) in *Tc* min duration.