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)

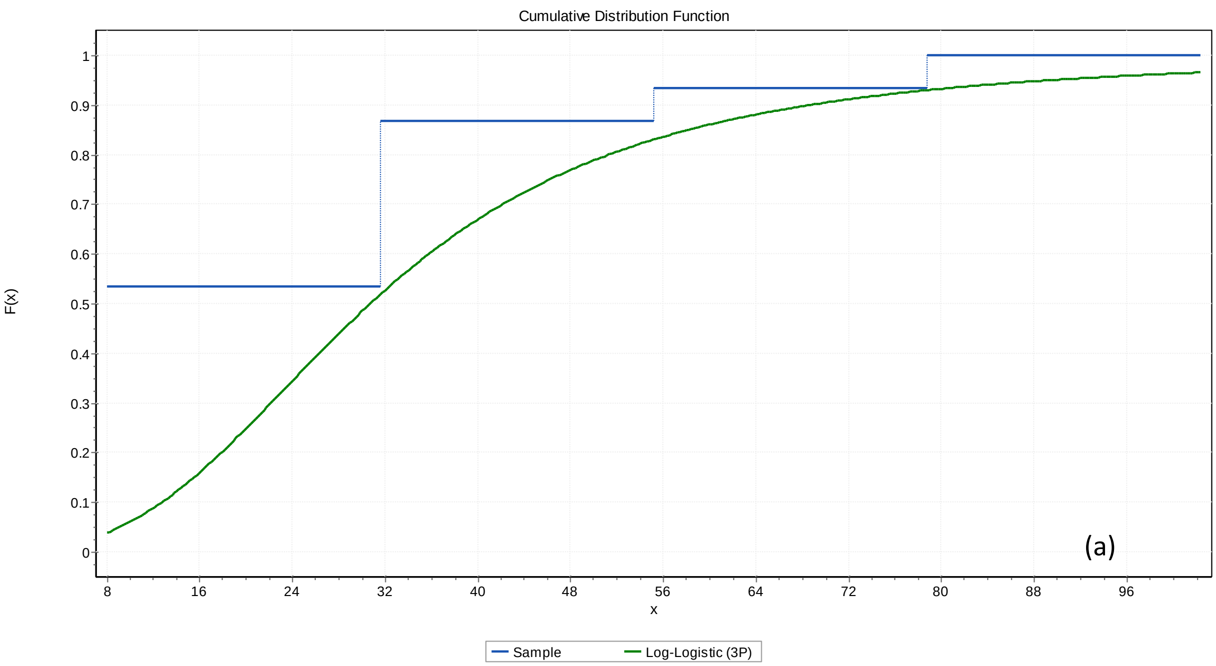
Response to Comments of Reviewer #1

Comment #1: The authors present an investigation of the impact of El Nino on flood damage. The analysis is carried out by (1) establishing the average impact of El-Nino and La-Nina on the precipitation measured in a station within the study area; (2) based on this average impact, different rainfall scenario are run through a hydrologic model to calculate inundation depths for different return periods and (3) a simple loss model is applied to quantify the damage due to the different inundation scenario. I think the topic is important and of broad interest because, as the authors claim, only a few studies have focused on the impact of large-scale climatic phenomena on flood damage and losses. However, I do not believe this analysis, in its current state, is suitable for publication. I found the following major issues with the study:

The impact of El-Nino and La-Nina on precipitation, as measured by equation (3), is an average impact. It is unlikely that rainfall extremes, such as those considered in the study for return periods (RP) of 10, 25, and 50 years, are impacted in the same way. Therefore, it is inaccurate to multiply the 10, 25, and 50 year RP rainfall values by the same, average factor in order to account for the impact of El-Nino and La-Nina. More generally, I do not think it is appropriate to assume that the impact of El-Nino and La-Nina on annual precipitation totals is the same as that on single precipitation events, which is, I believe, what the authors are doing.

Response: In the present paper a risk base analysis has been performed and the increase amounts of damage costs are not deterministic. Indeed, the results of %-damages enhancements that are reported in the paper, do not mean that in every El Nino concurrent with a storm event the flood damages will certainly be increased as those calculated in the paper but it considers a chance for every %-damage increase. 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 be less than 267% compared to the normal condition.

The second issue is that 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. **Figure 1** illustrates the Log-Logistic distribution that is fitted on the %-changes of rainfall in 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%.



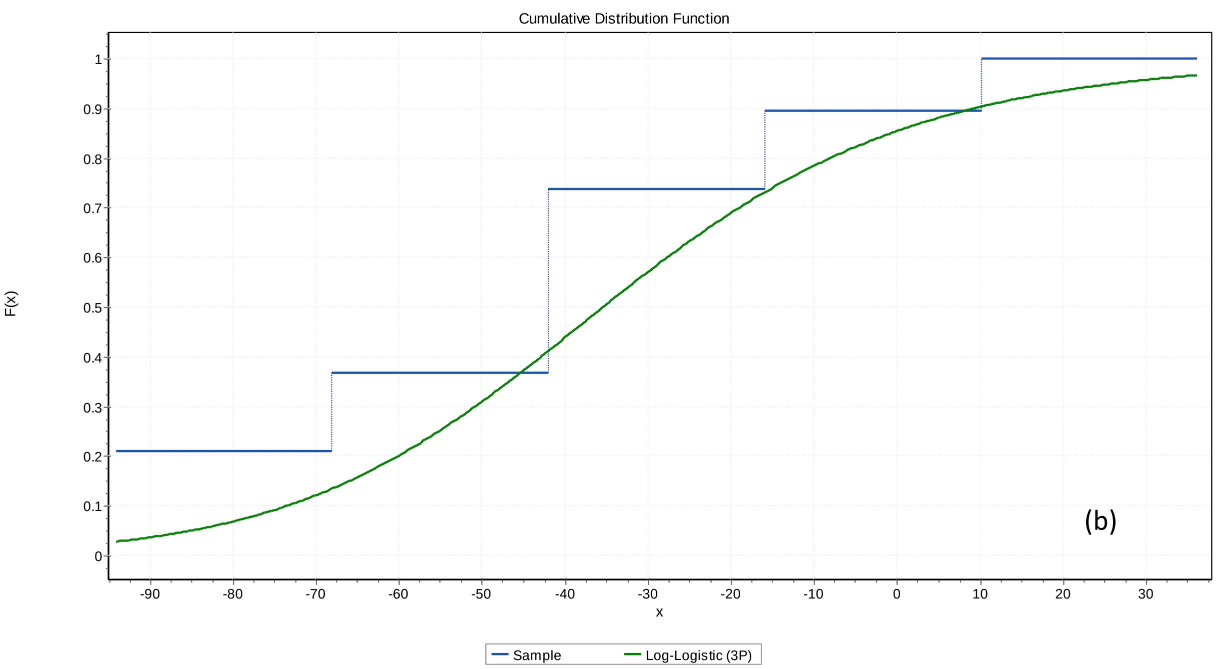


Figure 1: cumulative distribution function fitted on the increased percentiles of rainfall in a) January and b) April

It is obvious that the rainfall increase and the relevant flood damage for a specific month can be higher than that we have calculated in the yearly time scale and vice versa for another month (the yearly change percentile is the monthly averaged for 12 months). Indeed, during a year with El Nino condition, some months experience El Nino, some months experience La

Nina and the others experience neutral episode, but the El Nino months are dominant. Therefore, although in El Nino months it is expected that the flood damages to be increased, in the La Nina and normal months they are expected to be reduced and fixed, respectively. Having an average over the monthly %-changes of damage costs in a year, we could have the annual %-changes of damages which expect to be near to those percentiles that are presented in the paper. The same procedure, but more and more time consuming, can be followed for the time scales less than month if there are appropriate enough data of precipitation and SOI. Unfortunately, there is no long time continues daily data of precipitation in the basin for conducting such analysis. Kan Basin although it is a small basin with limited hydrologic available data, because it is very close to Tehran city with about 10 million population has a great importance regarding to flood management. Kan River Basin provides a busy recreational and pilgrimage place for the citizens from the close cities in the weekends and holydays to spend their time near the river. During past decades, due to flood events many people have died in the basin. The last catastrophic flood disaster returns to June 2015 in which 8 people died, although many other flood events have been recorded, as well. Therefore, in spite of lack of data, the importance of the basin forces the researchers to study the risk of flood and to present the flood mitigation measures.

Comment #2: The impact of ENSO on precipitation varies by season (e.g., Alizadeh-Choobari and Najafi, 2018), so it is a bit simplistic to reduce the impact of ENSO to an annual average, especially when this average impact is then applied to single events.

Response: With great thanks; we read and used the paper: Alizadeh-Choobari and Najafi (2018). Your point is completely correct and as explained in the previous comment we confirm that the seasonal flood damages will be more than that annual ones that we have reported in the paper. However, having an average over the seasons in a year, the annual flood damages can be calculated.

Average impact considering single events: It should be noted that our results show that in total the maximum increase in flood damages would be expected if for example a 10-yr return period rainfall happens while the El Nino condition is experiencing. It is not total annual flood damages or an average of yearly damages. The %-damages could be viewed as the probable values regarding the average annual rainfall increase in the basin during El Nino condition.

Comment #3: The hydrologic model is calibrated using a single event (April 2003). I think the calibration period is too short (only 4 days) to be meaningful, the model should be calibrated for longer periods, to account, for example, for antecedent conditions and seasonality of the hydrologic cycle. I do not see why the authors did not do that as data seem to be available.

Response: This paper aimed at evaluating the flood influence on the societies in term of physical damages while ENSO can affect the precipitation amount, therefore we needed to have a hydrologic model calibrated for flood events to give us acceptable estimates for peak discharges; i.e. we did not need for a continues hydrologic model in a year. On this basis, we looked for the main historical flood events in the available meteorological and hydrological time series. According to the data, most of the floods in the study area have taken place in March to May. In the available time series, we had problem sometimes because of missing precipitation data, sometimes missing runoff data and sometimes the concurrency of rainfall storm with the recorded runoff.

During 2002 to 2016, the basin has experienced several flood events and we have used all the events with observations for the model calibration and verification. In addition to the flood of 15–18 April 2003 and 16–19 April 2002 which have been mentioned in the manuscript, two other events are also have been considered for calibration and verification of the model. Floods of 2009 and 2011 with peak discharges of 34.4 m^3/s and 54.1 m^3/s. These results are added to the paper.

Also two other storm events are also have been considered for verification of the hydrologic model. Floods of 2009 and 2011 with peak discharges of 34.4 m^3/s and 54.1 m^3/s. Comparison between the simulated and observed flood hydrographs are shown in Figure 2 and Figure 3. It is noted that, for the flood of 11-13 March 2011, the peak of 54.1 m^3/s has been estimated by Regional Water Company of Tehran.

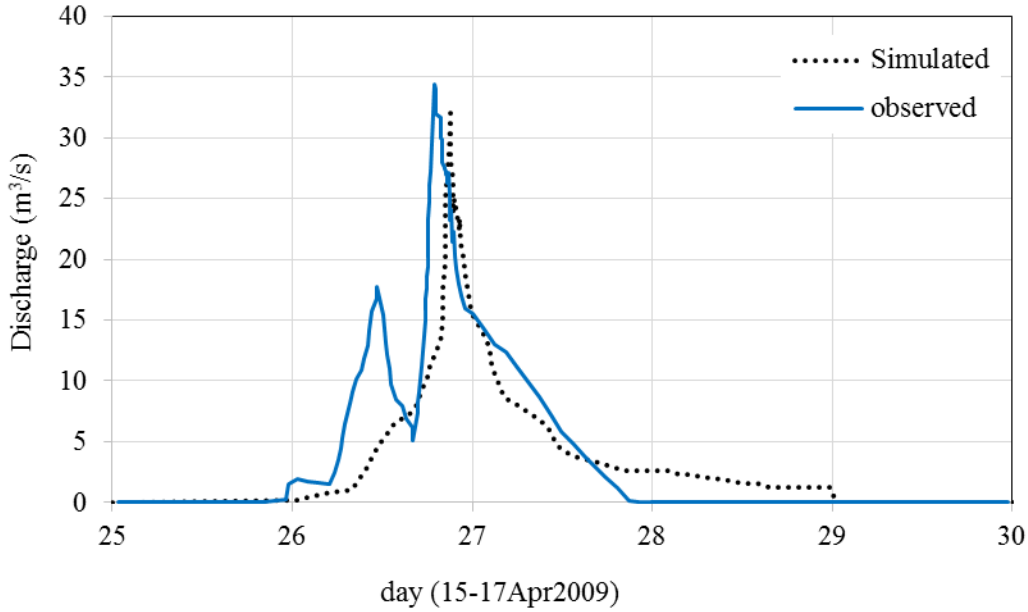


Figure 2: Observed and simulated flood hydrographs at Sulaghan Station in 15–17 April 2009

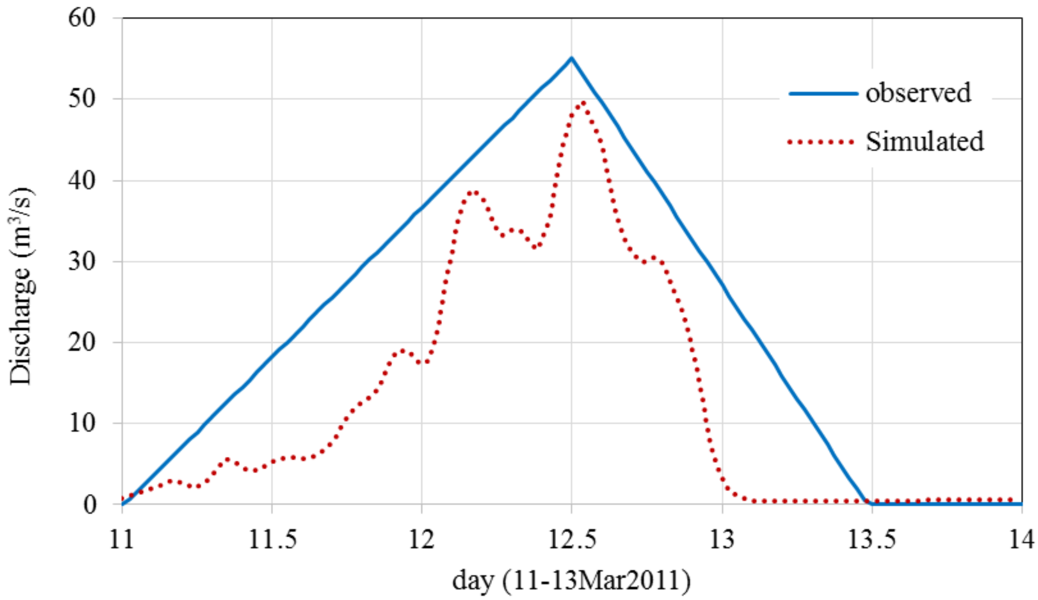


Figure 3: Observed and simulated flood hydrographs at Sulaghan Station in 11–13 March 2011

Comment #4: The manuscript is not well written, and its lack of clarity makes it very difficult to follow and understand. I've reported below many different instances in which sentences are wrong or not clear. I suggest the authors to carefully check the manuscript before re-submission.

Response: Thanks for the comment. The paper is totally checked, revised and all the suggestions are considered carefully in the revised paper.

SPECIFIC COMMENTS

Comment #5: P2L25: Since this is the topic of the paper, it would be good to cite some of these works in which the expected damage under El Nino or La Nina is investigated.

Response: It is done and the introduction part was improved by more relevant papers.

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 examine 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.

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.

Corringham, T.W. and Cayan, D.R. 2019. The Effect of El Niño on Flood Damages in the Western United States, Weather, Climate, and Society, 11(3), 489-504. https://doi.org/10.1175/WCAS-D-18-0071.1.

Null, J. 2014. El Niño and La Niña: Their Relationship to California Flood Damage, Golden Gate Weather Services, August 2014.

Ward, P.J., Jongman, B., Kummu, M., Dettinger, M.D., Sperna Weiland, F.C. and Winsemius, H.C. 2014. Strong influence of El Niño Southern Oscillation on flood risk around the world, Proceeding of National Academy of Sciences of America (PNAS), 111(44), 15659-15664.

Ward P.J. Kummu M., Lall U. 2016. Flood frequencies and durations and their response to El Niño Southern Oscillation: Global analysis, J Hydrology, Volume 539, August 2016, Pages 358-378.

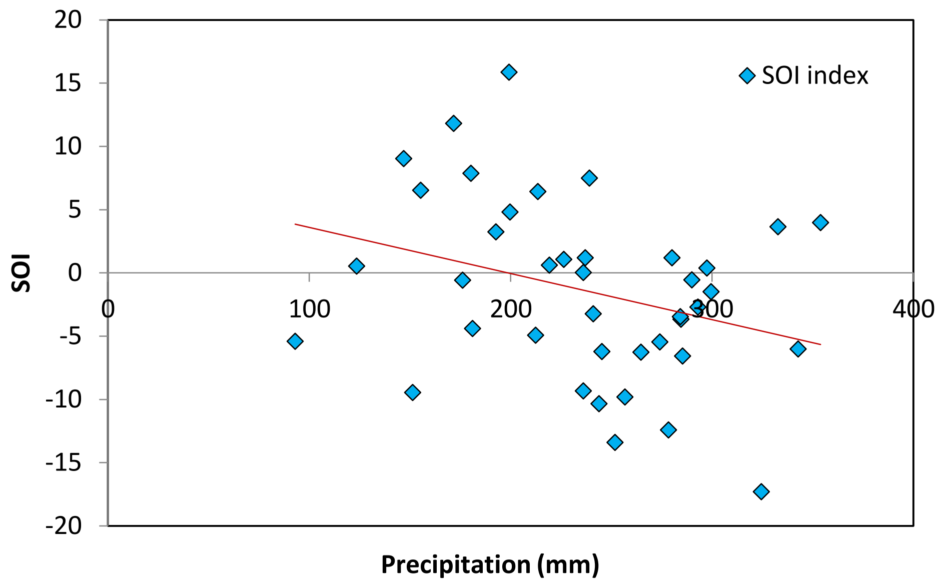
Comment #6: P3L23: SOI is a single variable ENSO index, multivariable ENSO indexes like MEI provide a more complete description of ENSO (e.g. Wolter and Timlin, 2011). Can the authors justify why they are not using a multivariable ENSO index instead?

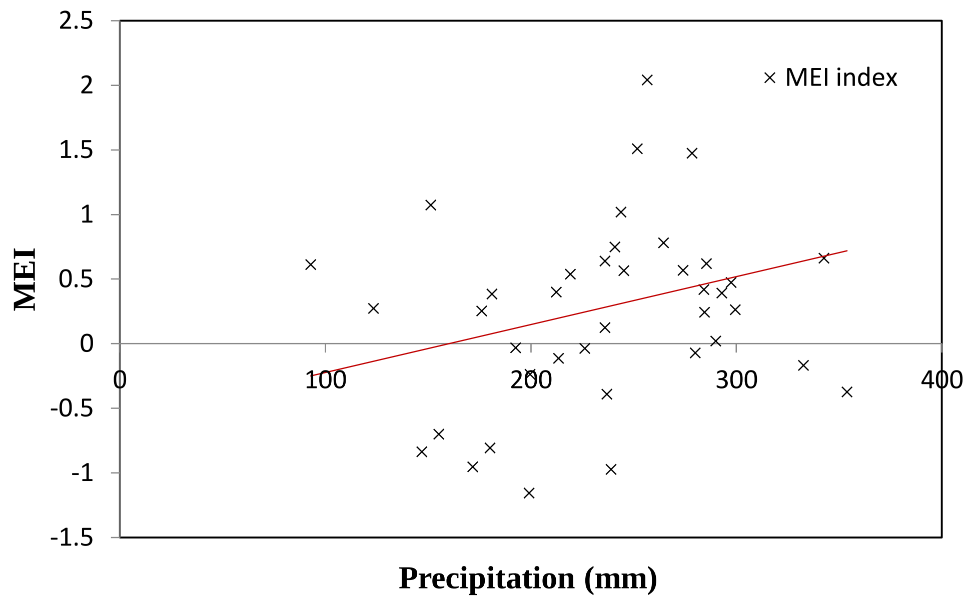
Response: In this study several indices were evaluated to find those that have the highest correlation with the precipitation. Doing so, SOI, MEI, AO, NAO, and MJO were analyzed, finally the results showed that SOI has the highest correlation coefficient with the precipitation in Kan River Basin even a little more than MEI. In Figure 4 you can find the annual precipitation against the aforementioned indices. Based on the highest correlation between the annual precipitation and teleconnection indices, we picked the SOI for further analysis. A summary of these results has been added in the revised paper.

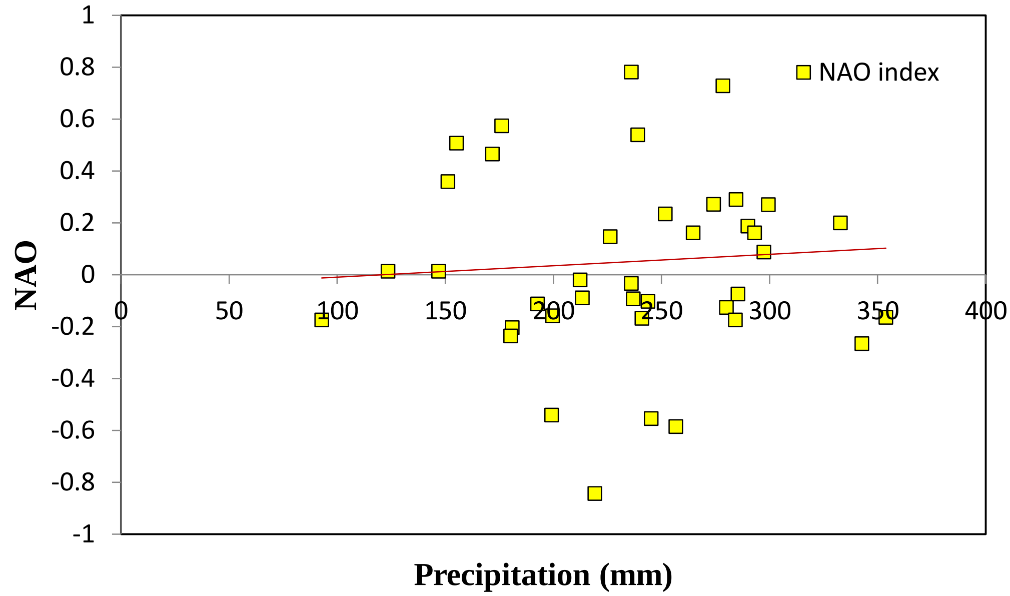
In this study SOI, MEI, AO, NAO, and MJO teleconnection indices were evaluated to select an Index that has the highest correlation with the precipitation in the study area. Results are shown in Table 1. According to the results, there would be a statistically significant association between the SOI (MEI and NAO, as well) and Precipitation. However, SOI has the highest correlation to the Kan Basin precipitation. Therefore. SOI was selected for further analysis.

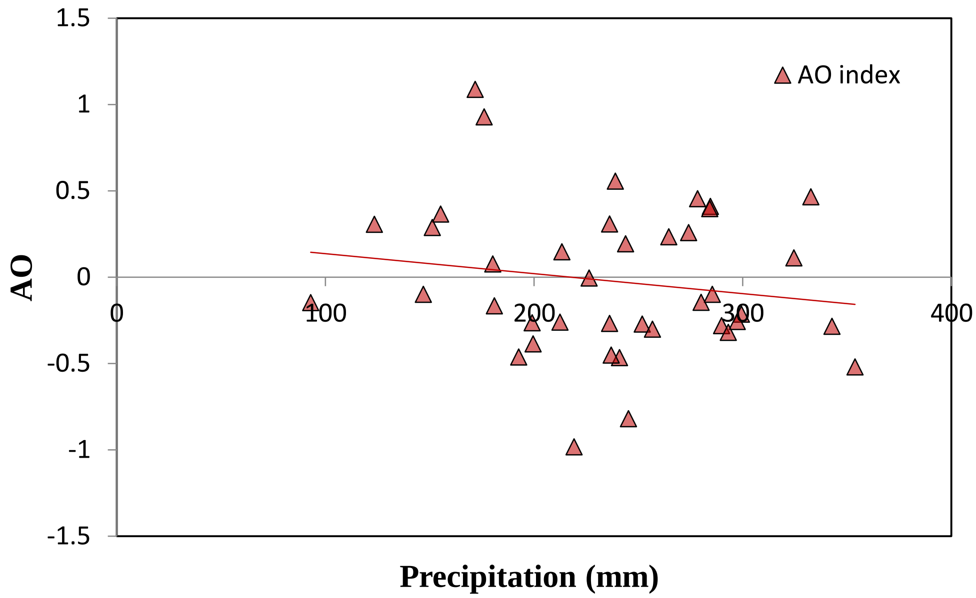
TABLE 1 CORRELATION COEFFICIENT (R) AND P-VALUE BETWEEN PRECIPITATION IN MEHRABAD STATION AND DIFFERENT TELECONNECTION INDICES

Index	SOI	MEI	NAO	AO	MJO
r	0.32	0.29	0.15	0.002	0.1
p-value	0.016	0.02	0.029	0.84	0.9


SOI index
SOI
20
15
10
5
0
-5
-10
-15
-20
0
100
200
300
400
Precipitation (mm)


MEI index
MEI
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
100
200
300
400
Precipitation (mm)


NAO index
NAO
Precipitation (mm)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
50
100
150
200
250
300
350
400


AO index
AO
Precipitation (mm)
1.5
1
0.5
0
-0.5
-1
-1.5
0
100
200
300
400

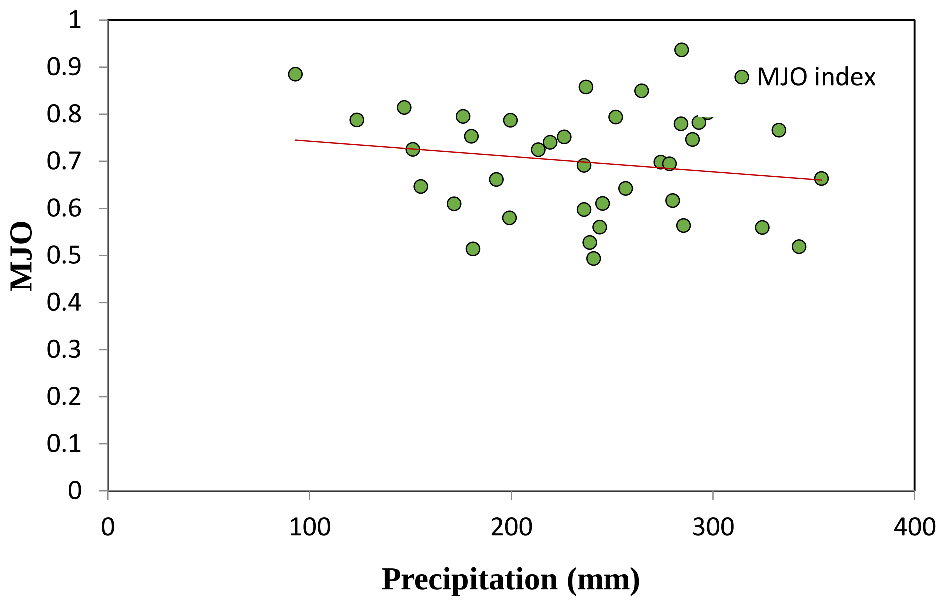


Figure 4. Scatter plot of the annual precipitation in Mehrabad Station against the teleconnection indices

Comment #7: P5L5to10: It is not clear how the calibration has been done. Do the authors calibrate using the storm in 2003 and validated using the storm in 2002? If so it seems like a very small calibration and validation set, especially when 15 years of data seem to be available.

Response: The validation is limited by the number of flooding events with observations. We have used all the observations available. This comment was also replied in Comment # 3 in detail.

Comment #8: P6L4: It does look like there is a small trend, however I would not say it is “obvious” as there is a lot of data scatter. It would be good to provide a level of significance for the trend.

Response: In this paper Fisher's exact test of independence was used to test the significance of correlation between the teleconnection indices and precipitation in Kan River Basin. In the Fisher's exact test the null hypothesis is that the two variables are independent. In other words, the relative proportions of each teleconnection index are independent of the precipitation:

$$H_0 : \rho = 0$$
$$H_1 : \rho \neq 0$$

Considering the Fisher's exact test, if *p*-value is less than 0.05 the null hypothesis is rejected; i.e. the *p*-value must be less than 0.05. Table 1 summarizes the *p*-value and correlation coefficient values for different indices examined here. According to Table 1, there would be a statistically significant association between the SOI (MEI and NAO, as well) and Precipitation. However, SOI has the highest correlation to the Kan Basin precipitation.

Comment #9: P6L6: "with respectively 334 mm and 252 mm recorded rainfall", are these annual rainfall totals? It sounds like that but in Figure 2 for Mehrabad station I don't see a point for 334mm with SOI>0.8.

Response: These values are the total annual precipitation. El-Niño condition relates to SOI<-0.8 and La-Niña condition relates to SOI>+0.8. The precipitation of 334 mm and 252 mm have been taken place during El-Niño not La-Niña, therefore these precipitation should be looked for in SOI<-0.8 which are shown Figure 5 (Fig 2 in the paper).

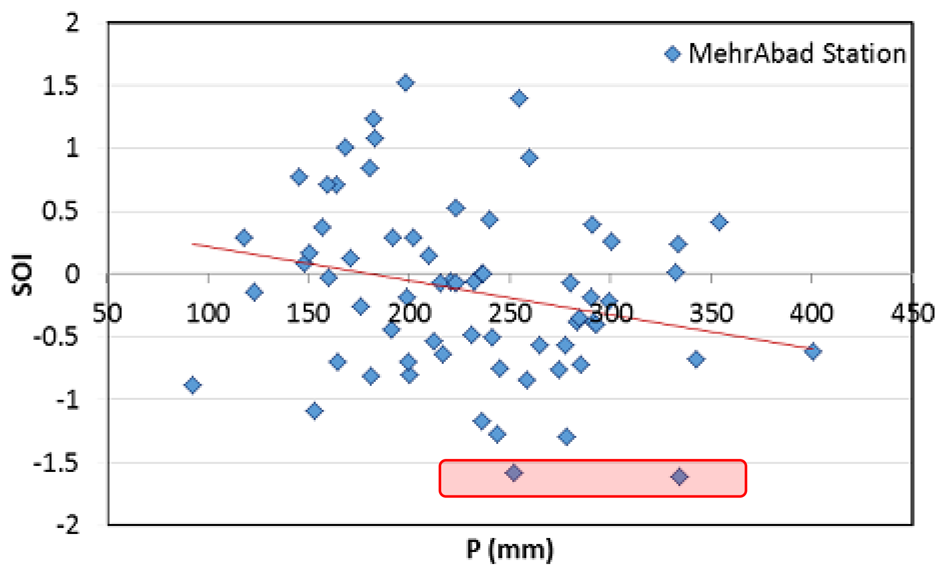


Figure 5. Annual precipitation in Mehrabad station against the SOI

Comment #10: P4L24and26: This is the first time the values 60% and 90% are introduced in the manuscript. The authors should say why they are focusing specifically on these numbers as it is not clear.

Response: Figure 6 (Fig 3 in the 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, Figure 6 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 Figure 6, 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.

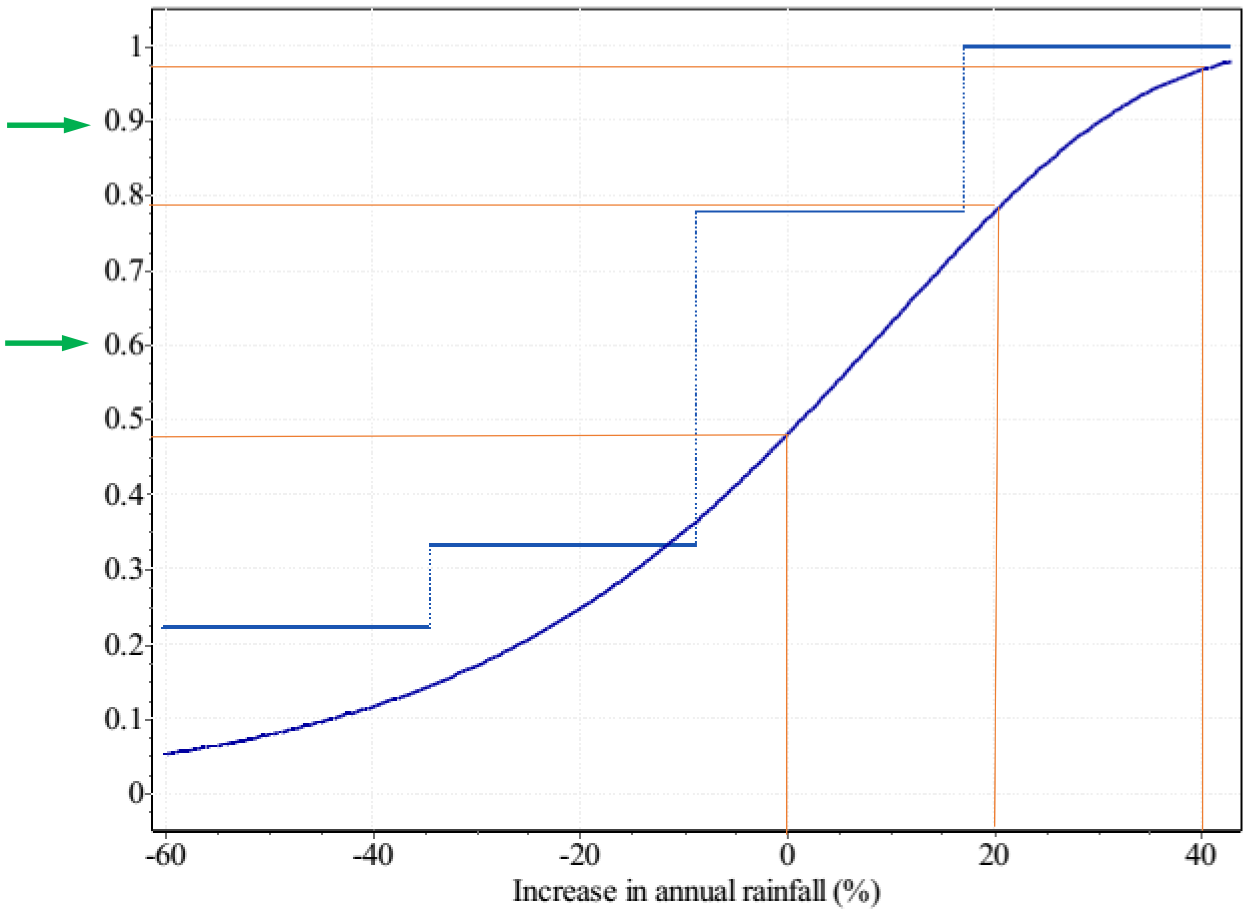


Figure 6: Gumbel Cumulative distribution function fitted on the annual increased percentiles of rainfall

Comment #11: P6L4toL19: time scales (annual or event scale) are a bit unclear in this part.

Response: In this part, annual precipitation has been analyzed. We have made the text clear for time scale in the revised manuscript.

Comment #12: P6L7: "its sufficient data", what makes it sufficient? Perhaps it can be said that Mehrabad station was chosen because it has more data than the other stations.

Response: You are right. It is corrected as follow:

Mehrabad station was chosen for further analyses because it has more data than the other stations.

Comment #13: P6L9: Here the time period is 1952-2017 while before it was 1950-2017.

Response: According to data of the Mehrabad station 1951-2017 is correct (66 year data). So it is corrected in the revised version.

Comment #14: P6L11: "22.2m and 16.96mm" is this average monthly rainfall?

Response: Of course, it is monthly averaged.

Comment #15: P6L13toL19: This part is very unclear and should be significantly expanded: What are the "annual increased percentiles of rainfall"? How are they computed using Eq.3? Why are the increased percentiles of rainfall in Fig.3 only 4 values? Can't the authors use more points to compute the percentiles?

Response: This part was rewritten completely. We used the term "precipitation change" and "average precipitation change" to clarify the methodology instead of "increased percentiles of rainfall".

To evaluate the annual damage costs, under the effect of El-Niño, at first the years with El-Niño condition (SOI<-0.8) were recognized. There are 9 years with El-Niño and 60 normal years among the total of 66 years (1951-2017). Then, using Eq. 3, the "average precipitation change" (ΔP) was calculated according to the annual precipitations in the El-Niño conditions compared to those in the normal conditions. On the other hand, for every year with El-Niño, "precipitation change" (PC) can be calculated. For 9 years with El-Niño condition, the PC ranges from -60.34% to 42.8%. Fitting analytic probability distribution on these percentiles, Gumbel distribution can well be fitted on the basis of Kolmogorov-Smirnov goodness of fit test in 99% confidence interval. Figure 3 illustrates the Gumbel cumulative distribution function (CDF) fitted on the PC values. According to Fig. 3, it can be said that by 90% and 60% certainty the PC values during El-Niño compared to the normal years are less than 31% and 8.2%, respectively.

Comment #16: P6L23: I struggle to understand why 60 and 90 percentiles are considered confidence intervals. Can the authors please explain?

Response: It was explained in the 2 previous comment. Indeed, one of them (60% confidence interval) is representative of average amount of damages (a weak El-Niño condition) and the other (90% confidence interval) is representative of maximum amount of damages (a strong El-Niño condition). Both of them are possible to be happened in different probability levels. We wanted to show the moderate effect of El-Niño and high effect of El-Niño on the annual damage costs of flood. It is clear that the damages due to a moderate El-Niño, are more probable than the strong El-Niño; although the damages cost are lower.

For probabilistic analysis of flood damage costs, two probability level of 60% and 90% were considered. The first (60% confidence interval) is representative of average amount of damages (a weak El-Niño condition) and the other (90% confidence interval) is representative of maximum amount of damages (a strong El-Niño condition). These levels respectively show a moderate effect of El-Niño and a high effect of El-Niño on the annual damage costs of flood. According to Fig. 3, it can be said that by 90% and 60% certainty the increased percentiles of rainfall during El-Niño years is less than 31% and 8.2% respectively compared to the normal years.

Comment #17: P7L1toL14: As before, I don't understand why only two events are used, one for calibration and another for validation when the authors have many more data at their disposal.

Response: This comment was replied in comment #3 in detail.

Comment #18: P721: It would be helpful to know the size of these land use areas. Averaging flood depth and economic values in large areas can give very uncertain results because both flood depth and economic value usually have very large variability in space.

Response: The employed land use map is a vector shape file compose of polygons for different land uses that were generated from maps of 1/25000 scale. In this analysis we have used a simplistic method for damage costs evaluation. Indeed, the damage cost has been calculated having the average flood depth for every land use and the monetary value of one unit area of the inundated land use categories. Although the inundation depth is varied in the floodplain, the economic values are not significantly varied because the case study is a rural area with relatively the same life style in different places. Therefore, the economic value of one unit area of every land use category has been considered the same and the inundation depth has been averaged for each of categories.

Comment #19: P7L24: Are the "flood zoning maps" the flood maps the authors obtained with Hec Ras? It is not clear whether the authors produce flood maps with Hec Ras and then apply the maps on their land use areas or if the flood zoning maps are predefined.

Response: The flood depth is calculated in HEC-RAS and the inundation maps are generated in GIS. The flood map then is applied on the land use map for damage calculation. We ourselves have developed the models in our previous works. The flood zoning maps for 5, 10, and 50-yr return periods considering the increased rainfall intensities were developed specifically in the current paper.

Comment #20: P7L24: How is the "average depth of land uses' inundation" defined? It sounds like the authors calculate an average flood depth for each land use which would make sense to me, but then in Table 2 they seem to have only one average flood depth common to the different land uses which is even more simplistic. Why can't the authors calculate an average flood depth for each land use that would be more accurate we believe.

Response: Certainly, we have calculated the damage cost base upon the average inundation depth for every land use category. The inundation depth in the table is the average of all inundation and as it is misleading we omit it from the table.

Comment #21: P8L3toL4: I think such a big increase in loss warrants a deeper explanation. Why does an 8.2% increase in rainfall produces a 10-fold increase in flood depth?

Response: Due to 8.2% and 32% increase in 5-yr rainfall intensity, the average increase in the average inundation depths are 35.4% and 64.8%, respectively not a 10-fold increase. However, the damage costs have been increased more than 10 times.

About the reason for this %-increases, it is noticeable that although %-increase in damages for the return period of 5 Year (a small return period) is high (1072% in scenario 2) for the bigger return periods the %-increase in flood damages is much smaller (for 10 and 50 return periods respectively 133% and 41% increase in scenario 2). The high %-increase for 5-yr return period may relate to the fact that the initial losses and infiltration amounts are considerable compared to the 5-year rainfall. In such condition, effective rainfall is so reduced that it produces not too much runoff. For higher return periods while the rainfall amount rises but the event duration does not change, infiltration and initial losses increase slightly and, in total, the runoff increases significantly. It is clear that if the increase in precipitation is significant enough, then the runoff increase will also be significant. Therefore, in the cases of large return periods in which the rainfall amounts are large, the infiltration and initial losses are not significant, and so the increase in rainfall intensity will be mainly seen in the increase in the effective precipitation and direct runoff.

MINOR COMMENTS

Comment #22: P1L25: have increased or have been increasing.

Response: changed to "Have been increasing".

Comment #23: P1L27: reached to doesn't make sense.

Response: ... from 12 cases in 1951 increased to 54 cases in 1991

Comment #24: P2L8: ". . .by predicting the necessary measures", it is not clear what you mean by "measures".

Response: ... Prediction of teleconnection indicators helps to reduce the flood damages by implementing the necessary practical measures

Comment #25: P3L2: rain spouted 6 times of the annual precipitation is not clear.

Response: In June 1968 a heavy rain as 6 times as the annual precipitation happened in 2 days had caused 31 losses of life in Tehran central area and huge damage to the properties

Comment #26: P3L4: "events" not "evens" and I think they mean "that resulted", not just "resulted".

Response: In general, during a period of 60-year (from 1954 to 2015) at least 8 flood events that resulted in loss of life (in total 2200 people) have been reported in Kan and 5 central Tehran areas.

Comment #27: P3L14: It should be: "According to previous studies" or "according to Hooshyaripor et al. (2018)".

Response: According to Hooshyaripor et al. (2018) ENSO is the most important large-scale atmospheric signal that affects Iran's climate.

Comment #28: P4L3: Perhaps you should specify that in Eq. 2 log is the logarithm to the base 10.

Response: Of course yes. It is corrected

$$K = 1 + 3.332 \log_{10}(n)$$

Comment #29: P4L9,10: Sentence should be rephrased.

Response: It has been rephrased as:

La-Niña and El-Niño are characterized respectively by SOI>+0.8 and SOI<-0.8 (Australia Bureau of Meteorology 2012).

Comment #30: P4L23: If I understood correctly it should be "for a duration equal to Tc" not "in Tc min duration".

Response: Yes. We have now corrected it as: "for a duration equal to Tc"

Comment #31: P4L25: "Affected by".

Response: We have now corrected it as: "Affected by"

Comment #32: P4L24and26: These sentences are very difficult to understand. Do you mean that the rainfall intensity with Tc duration is increased by 60% and 90%? If so, why are you talking about probability? If not, could you please rephrase the sentences in a more understandable way?

Response: We have rephrased as:

- Scenario II (weak El-Niño condition): In the second scenario it is assumed that the rainfall intensity increases at the 60% probability level.
- Scenario III (strong El-Niño condition): In the third scenario it is assumed that the rainfall intensity increases at the 90% probability level.

Comment #33: P5L23: Do you mean duration of the inundation or the time at which the inundation occurred? The former is more likely I believe.

Response: We have now corrected it as: "duration of inundation"

Comment #34: REFERENCES:

Alizadeh-Choobari O., Najafi M.S. 2018. Climate variability in Iran in response to the diversity of the El Niño-Southern Oscillation. Int. J. Climatol. 38(11):4239–4250.

Wolter, K., and Timlin M.S. 2011. El Niño/Southern Oscillation behaviour since 1871 as diagnosed in an extended multivariate ENSO index (MEI.ext), Intl. J. Climatol., 31: 1074–1087.

Response: We have carefully read and use theses references in the paper.