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Comment

Interactive comment on “Flash flood occurrence and relation to the rainfall hazard in a highly urbanized area” by K. Papagiannaki et al.

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ANSWERS TO REFEREE COMMENTS We would like to sincerely thank Martin Mergili and the anonymous referee for the constructive comments that helped us to improve the presentation and the overall argumentation and quality of our paper. Following the reviewers' comments and suggestions we proceeded to a careful revision of the article. In more detail, the following changes have been made in accordance with the respective comments:

Reviewer 1

General comments

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1. 'The term vulnerability is frequently used in the paper. However, this term may reflect various concepts. Somewhere in the beginning it should be clearly defined how the term is used in the context of the article'

The term vulnerability may indeed be used in various ways, thus we agree that more clarification is required. At the beginning of the present paper's introduction, 'vulnerability' is mentioned in the context of the literature review followed by the interpretation given by the respective authors. In what concerns the last part of the introduction that presents the article's main ideas, it has been revised according to the suggestion. More specifically, we added an explanation how the article addresses the regional vulnerability to the flash flood hazard, involving the rainfall thresholds for flood triggering and vulnerability-related factors to partly justify the frequency of events and the response of each place to the rain intensity in various time intervals. Relevant clarifications/corrections have been made where needed in the rest of the text.

2. 'Language and style are largely o.k., but need some polishing'

We tried to "polish" the text as much as a non-native English writer can do. However the journal itself also provides "English language copy-editing for final revised papers".

Specific comments

1. 'Data collection: I suggest to put the paragraphs from 3124:22 to 3125:16 to the front of the section. This would result in a more logical order, starting from the general description of the study area, and continuing with meteorological data, the event database and finally the records of the fire brigade'

Revision has been made according to the suggestion. The section has also been enriched with the addition of an informative comment regarding the new user-friendly website of the National Observatory of Athens designed by the authors, which provides a geographical presentation of the high-impact weather events in Greece, including the flash flood events analyzed in the present article

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(<http://www.meteo.gr/meteoplus/weatherevents.cfm>).

2. 'How did you determine the most relevant rain gauges for an event? Are they just the gauges closest to the affected area, or those in the catchment upstream, ...?'

The methodology developed requires an optimum exploitation of the existing rain gauges with the aim to match gauges with areas and then with the flash flood events. There are several reasons why catchments are not strictly followed. Firstly, NOA meteorological stations have not been established with the purpose to monitor hydrological catchments. Their distribution follows mostly geographical criteria, in order to cover most of the Attica basin area. Moreover, the limited number of gauges along with the non-uniform density of the network in the target area do not allow for a sufficient and uniform representation of the basin's catchments and sub-catchments. As explained in the text, an important criterion for the determination of each area is the presence of rain gauges located within the perimeter of the area (each area is then covered by 3 to 5 gauges). Therefore each event is represented by the gauges that are closest to the affected areas.

3. '3130, 22ff: As I understand it, it is assumed that all recorded flood-related fire brigade operations during those events really took place in the city of Athens (and not in surrounding areas which might also have been affected, but where the precipitation parameters used might not be valid). This is acceptable in my opinion, but it should at least shortly be mentioned'

Indeed, some of the events incorporated in the analysis of the city of Athens have also affected surrounding areas, thus there might be an overestimation of the assigned number of operations. This comment has been added, according to the suggestion, in the last paragraph of Section 4.1.

4. 'Figs. 1–3 need a scale bar (alternatively, you may mention the grid spacing)'

Figures have been revised according to the suggestion.

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5. 'As the article concerns both natural and socio-economic issues, it would be good if you could add the most important towns (if possible, as areal signatures) to Fig. 1. Further, the green and red symbols should be shown also in the legend (even though it is clear what they mean)'

Green and red symbols have been added in the legend as suggested. In what concerns the towns, we believe that a greater size of the picture would be required for a clear printing of the respective names. The legend of Fig.1 lists the meteorological stations, which are named by the municipality in which they are located. Therefore, we added in the caption an explanation about the origin of the stations' names. Main municipalities are also shown in Fig.2, in which, as explained in section 3 'Methodological issues': 'The name of each area derives from the respective municipality that covers the major part of it.'

6. 'Fig. 4: I think that the y axis label of the right pane should be replaced by "R10"? In fact, the two figures look very similar, probably the right one has to be replaced by another one at all ... Further, you should write in the caption that the fraction of data relates to the fire brigade reports'

The reviewer correctly observed that the Fig.4b is the wrong one. We replaced it by the correct one. The caption has been also revised according to the suggestion.

7. 'Fig. 5: Be careful, the x axis tick mark labelling is incorrect. E.g., R24 of 30 mm is actually assigned to two classes, this is not allowed. 30 – <60 mm, 60 – <90 mm etc. would be correct'

The figures have been corrected according to the suggestion.

8. 'Figs. 5 and 6: It might be good to show a graph relating the number of events and the number of the fire brigade operations (e.g., building a ratio between the two). However, it is the decision of the authors whether they would like to try doing so.'

The ratios operation/event for various ranges of 24-h (R24) and 10-min (R10) accumu-

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lated rainfall is discussed in the text, section 4.1. Figures 5a,b have been revised to include the respective data, according to the suggestion.

9. 'Fig. 7 is very informative and calls for a bit more explanation in the caption: I guess that the red dots represent the events which led to reported flooding, and the blue dots those which did not – but this has to be explained.'

It is correct that flash flood occurrence is highlighted with red colour. The caption has been revised according to the suggestion.

Reviewer 2

General comments

1. 'In the Data Base section it would be useful to clarify the final criteria to select the flash flood events and the final number of analysed events: in line 15 (p. 3125) you say that 48 flash flood events affected the selected area, but in line 29, you say that all the events with more than 10 daily operations have been selected.'

The sentence that refers to the number of the Fire Service operations has been rephrased to make it clear that the events with more than 10 operations are all included in the NOA Database and thus considered in the present analysis.

2. 'The section relative to Methodological issues should be improved, mainly the explanation concerning the division into sub-regions (why do you not use the different catchments as sub-regions?) and some readjustments in the last two paragraphs of the section.'

The methodology developed requires an optimum exploitation of the existing rain gauges with the aim to match gauges with areas and then with the flash flood events. There are several reasons why catchments are not strictly followed. Firstly, NOA meteorological stations have not been established with the purpose to monitor hydrological catchments. Their distribution follows mostly geographical criteria, in order to cover most of the Attica basin area. Moreover, the limited number of gauges along with the

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non-uniform density of the network in the target area do not allow for a sufficient and uniform representation of the basin's catchments and sub-catchments. As explained in the text, an important criterion for the determination of each area is the presence of rain gauges located within the perimeter of the area (each area is then covered by 3 to 5 gauges). Therefore each event is represented by the gauges that are closest to the affected areas.

3. 'Section 4.1 could take into account that Fire Service operations are related not only with the rainfall intensity but also with the exposure and vulnerability of each sub-area: it would be interesting to see how these facts affect the correlation.'

This was also our intention when we searched for the operations time-series data. However, the Fire Service provided us with just the number of the operations per event for the entire Attica prefecture, due to their statistical procedure that does not provide results by local department. This is explained in Section 3 (Methodological issues), as well as in 4.1, last paragraph, where the relation between the number of operations and local vulnerability is addressed. The specific paragraph has been revised to become clearer in what concerns the assumptions made to estimate the effect of the volume of rainfall to the magnitude of impact at a more local level. In fact, a comment has been added to make it clear that when the analysis focuses on the most frequently affected areas (around the city of Athens) some of the events may have also affected surrounding areas, thus there might be an overestimation of the assigned number of operations. However, when focusing on these neighbouring areas together, the number of operations is strongly correlated with all the durations of accumulated precipitation.

Specific comments

1. 'P. 3120, l.12-14. I would recommend a little modification of the sentence "It is shown that the quality of the produced thresholds depends on the distribution and of the rain gauges that cover each specified geographical area of the Attica region." Rainfall thresholds can depend on the previous wet conditions of the soil, or the changes in

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the catchment, but they cannot depend on the observation system. You could say the “estimated thresholds”, and justify this dependence’

We rephrased the last sentence of the Abstract according to the suggestion.

2. ‘P. 3121, l.18-19. You can substitute the sentence “The study of Barberia et al” by “This study”’

The sentence is revised as suggested.

3. ‘P. 3123, l.17. I wouldn’t consider topographic features as a part of the vulnerability. Attending the different criteria to define vulnerability I would recommend you to introduce the definition that you have decided to use.’

The last paragraph of the Introduction has been revised following the suggestions of both referees in order to clarify how vulnerability is addressed in the article.

[4-5]. ‘P. 3123, l.23. Two paragraphs before it appears the same sentence “The target area of this study is the most urbanized and densely populated department of the prefecture of Attica”. I would remove one of them. P. 3125, l.15. You say here that 48 flash flood events affected the target area, but in the previous page you say that 91 FF affected Attica. In order to avoid any confusion I suggest to show in Figure 1, the limits of the Attica Region and the target area.’

Section 2 has been revised based on both referees’ suggestions. The section has also been enriched with the addition of an informative comment regarding the new user-friendly website of the National Observatory of Athens designed by the authors, which provides a geographical presentation of the high-impact weather events in Greece, including the flash flood events analyzed in the present article (<http://www.meteo.gr/meteoplus/weatherevents.cfm>). In what concerns Figure 1, when the size of the target area is decreased then the location and labeling of stations becomes very small. Figure 1 is however revised following the 11th specific comment of the referee.

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6. 'P.3127, I.8. How do you calculate maximum precipitation? Is it the average of all the raingagues in each sub-region? The absolute maximum? Which time intervals do you use: 5-min, hourly, daily? You say that you correlate it with Fire Service operations, but at which scale do you have and use this information? Daily? For the entire event? Some information about it is in lines 29-33, but it would be better to reorganize the section: a paragraph referred to data and calculation of Maximum Precipitation, another about rainfall thresholds and a third one about the correlations with Fire Service operations and their limitations.'

Maximum precipitation per event is the absolute maximum from the records of the representative rain gauges, while operations are provided in a daily basis and are aggregated to get the event operations (in the quasi-majority of the events, the operations last more than one day to serve all the affected properties). Section 3 has been reorganized according to the suggestion, while clarifications have been made were needed in Sections 2 & 3 regarding the questions posed by the referee.

7. 'P.3129, I. 1-4. You have already said the same in a previous paragraph.'

The paragraph in Section 4 has been revised according to the suggestion.

8. 'P.3131, I. 28.- P.3132, I. 1-3. Probably it would be better if the raingauges were located in the corresponding catchment for which runoff/flash flood is estimated.'

Please see the answer in the referee's 2nd General Comment, which includes the explanation about our methodological approach.

9. 'P.3132, I.22-24. As you say, it is not strange that the rainfall intensity threshold in some very urbanized areas would be above than in other regions with fewer inhabitants. Barrera-Escoda and Llasat (2015) also show how the rainfall threshold associated to flash floods in Barcelona has decreased along the time for the last two centuries due to the improvement of the drainage systems and the creation of pluvial reservoirs.'

We appreciate the information provided by the referee. It is a very interesting article

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and thus added in the references.

10. 'P.3133, I.27. What are the rainfall thresholds for flash flood triggering in the selected areas that you would propose to consider in an early warning system?'

Section 4.2 distinguishes the areas around the Athens city-centre and Hymettus for which the rain intensity-duration graphs have produced the most reliable thresholds that could be used for the needs of an early warning system. Future plans include the evaluation in practice of these thresholds and their improvement by the increase in the precipitation data-series, as well as the expansion of the meteorological network, which is also referred in the concluding remarks.

11. 'Figure 1. You could reduce the region presented in the figure and increase the size of the numbers and the corresponding stations. I am afraid it won't be clear for the readers'

The size of the number has been increased as suggested.

12. 'Figure 3 has not legend explaining the colours meaning.'

The caption of the figure has been revised.

13. 'Figure 7 is so much little and it is not possible to distinguish the legends. You should numerate each graph.'

Figures have been revised to increase resolution and sent separately in the 'supplement' field in the 'reply' form. (Figures 1-6 are submitted separately, therefore you may see the captions of Figures that have a)&b) separately. this will be corrected in the printed version)

Please also note the supplement to this comment:

<http://www.nat-hazards-earth-syst-sci-discuss.net/3/C1110/2015/nhessd-3-C1110-2015-supplement.zip>

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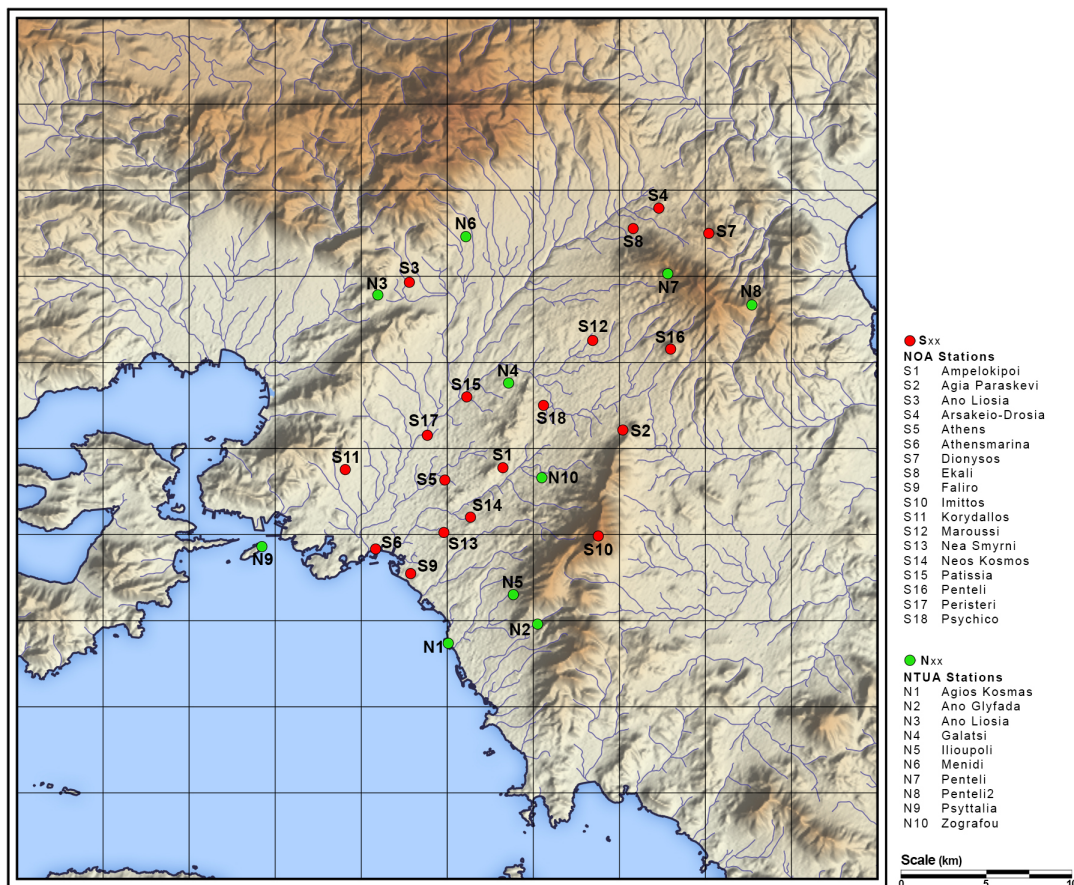


Fig. 1. Figure 1. Map of target area and locations of surface meteorological stations. Stations are named by the municipalities they are located in.

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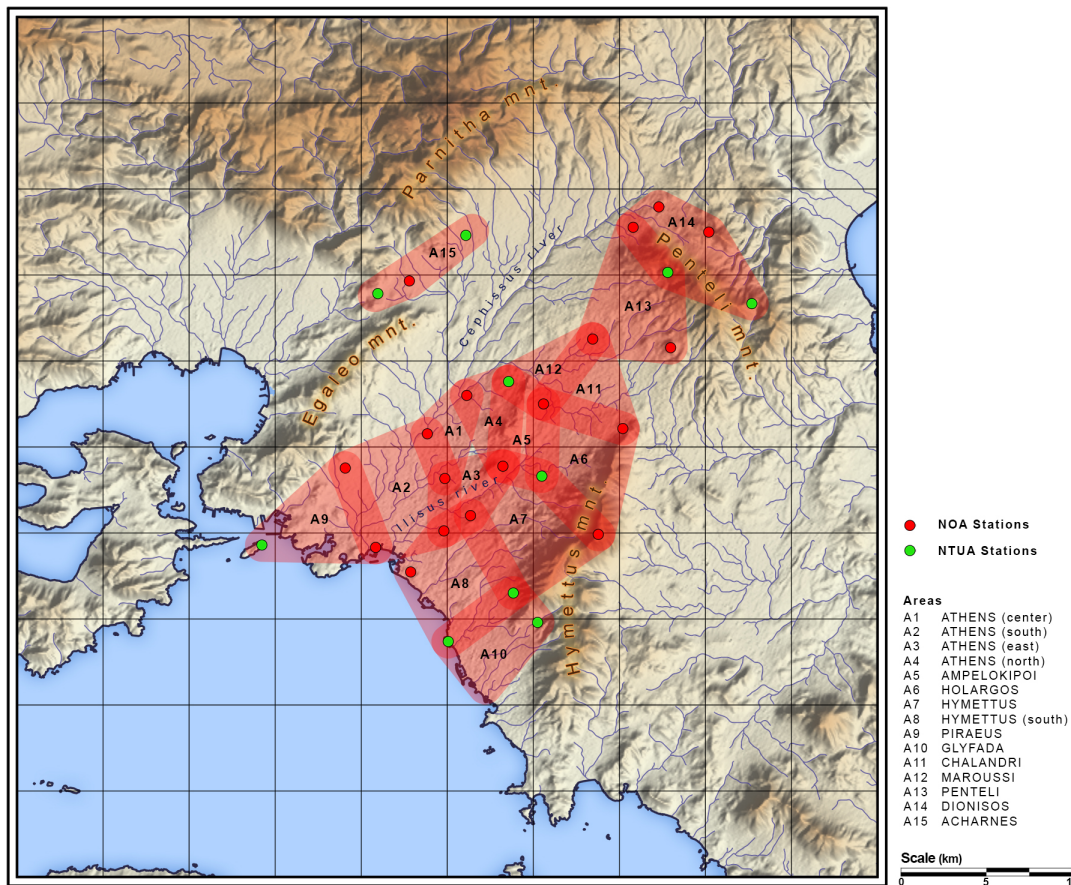


Fig. 2. Figure 2. Division of Athens-Suburbs region in 15 sub-areas. The representative rain gauges in each sub-area are also shown with red (NOA stations) and green (NTUA stations) bullets.

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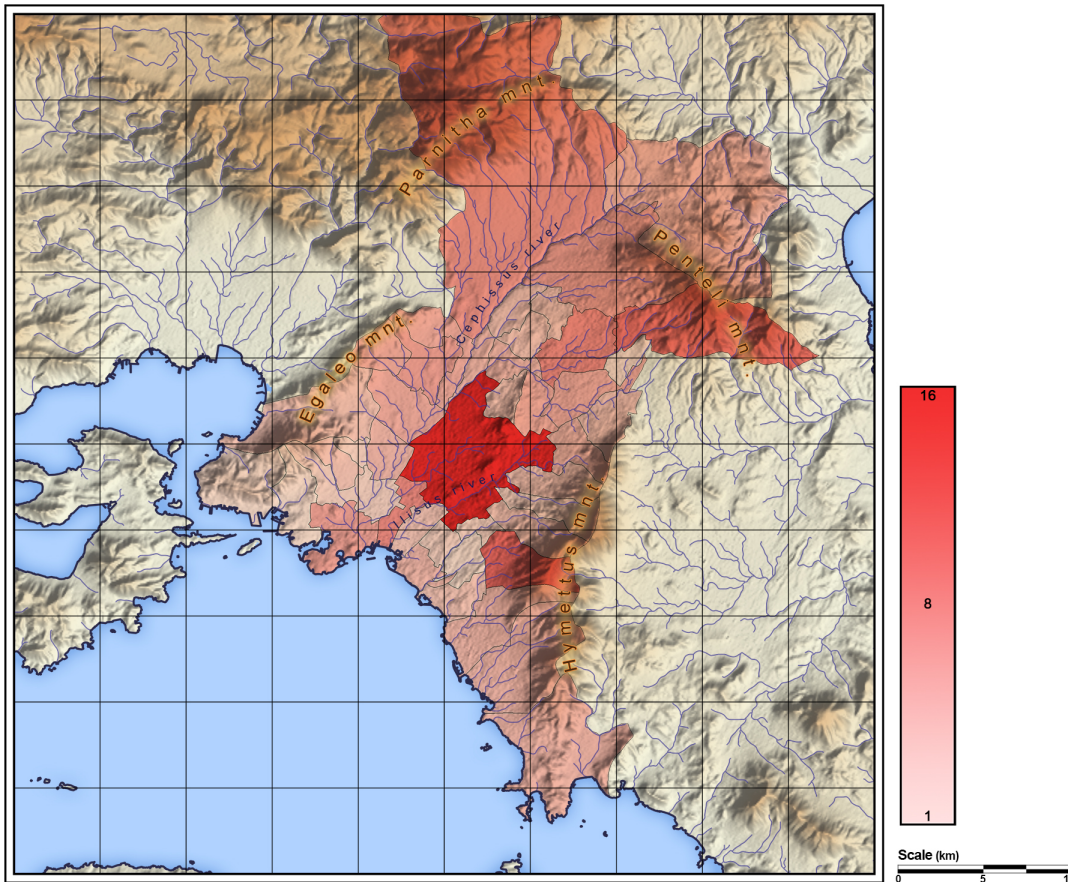


Fig. 3. Figure 3. a) Number of flash flood events per sub-area.

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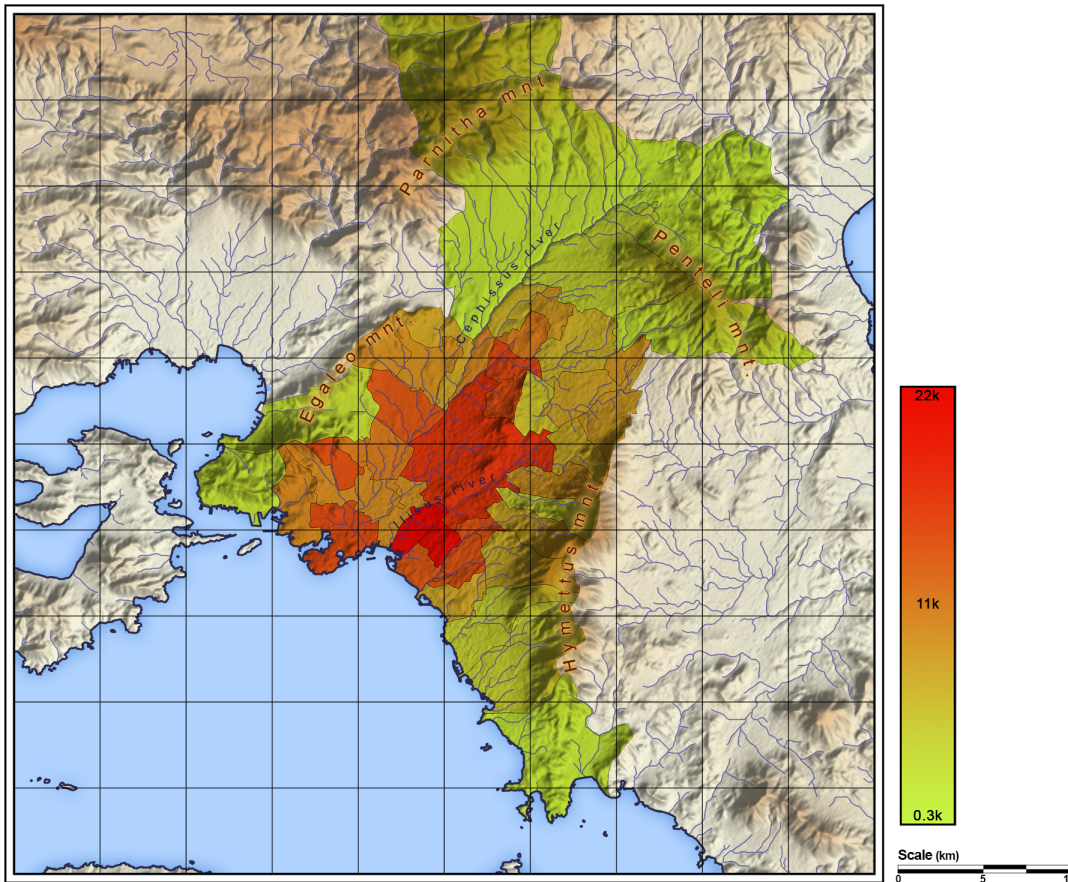


Fig. 4. Figure 3. b) Population density.

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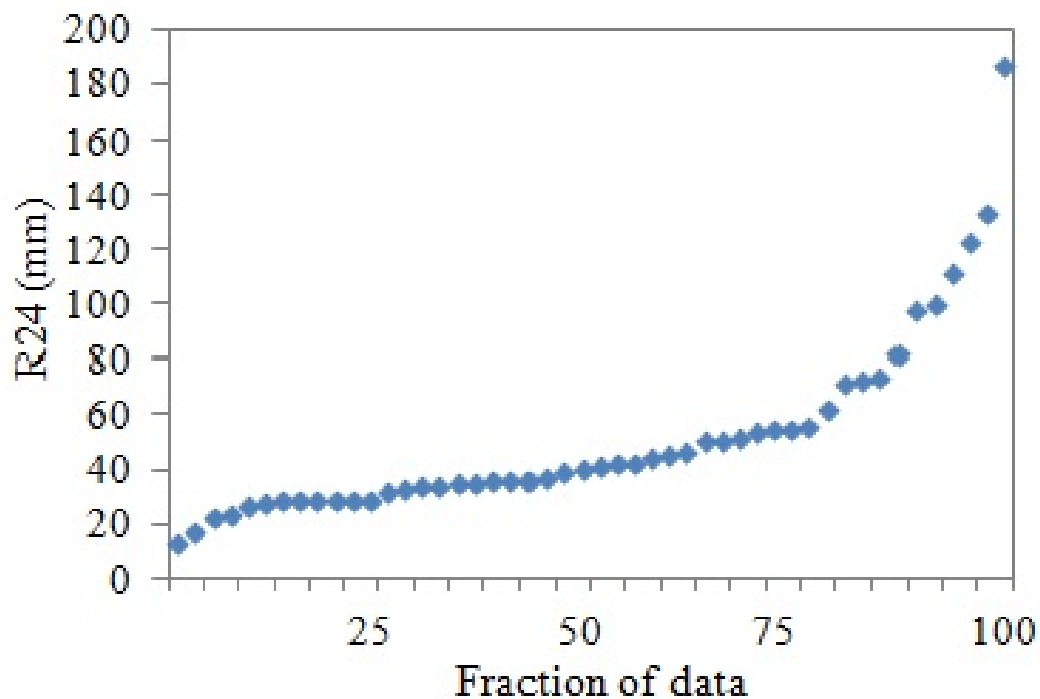
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Fig. 5. Figure 4. Quantile distribution plots for a) R24 and Fraction of data relates to the number of Fire Service operations.

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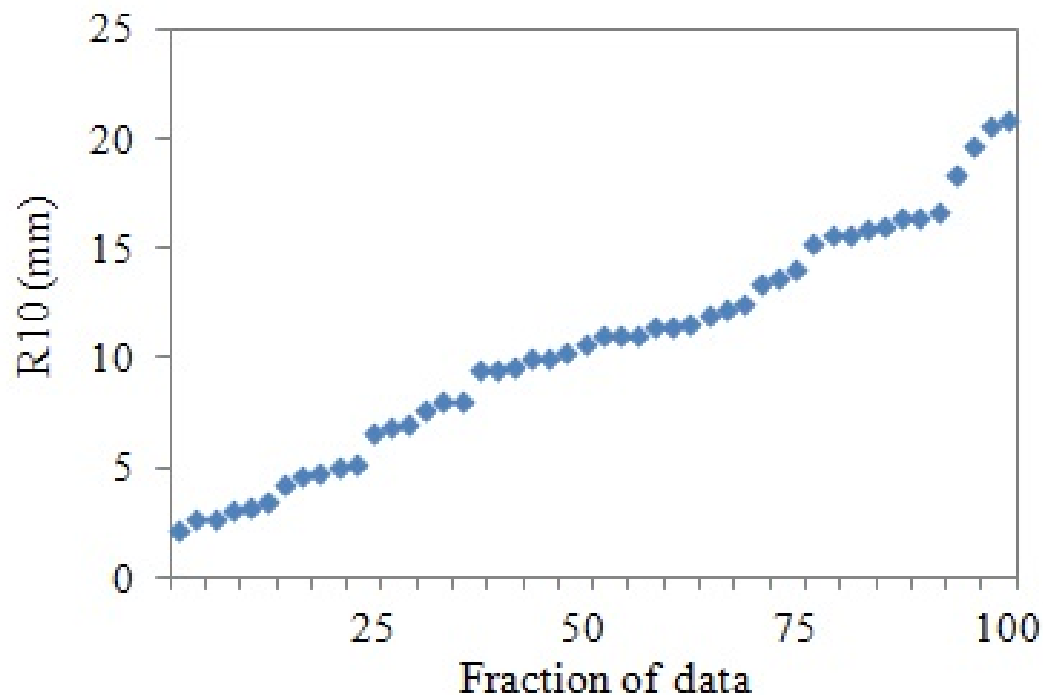
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Fig. 6. Figure 4. Quantile distribution plots for b) R10 observations. Fraction of data relates to the number of Fire Service operations.

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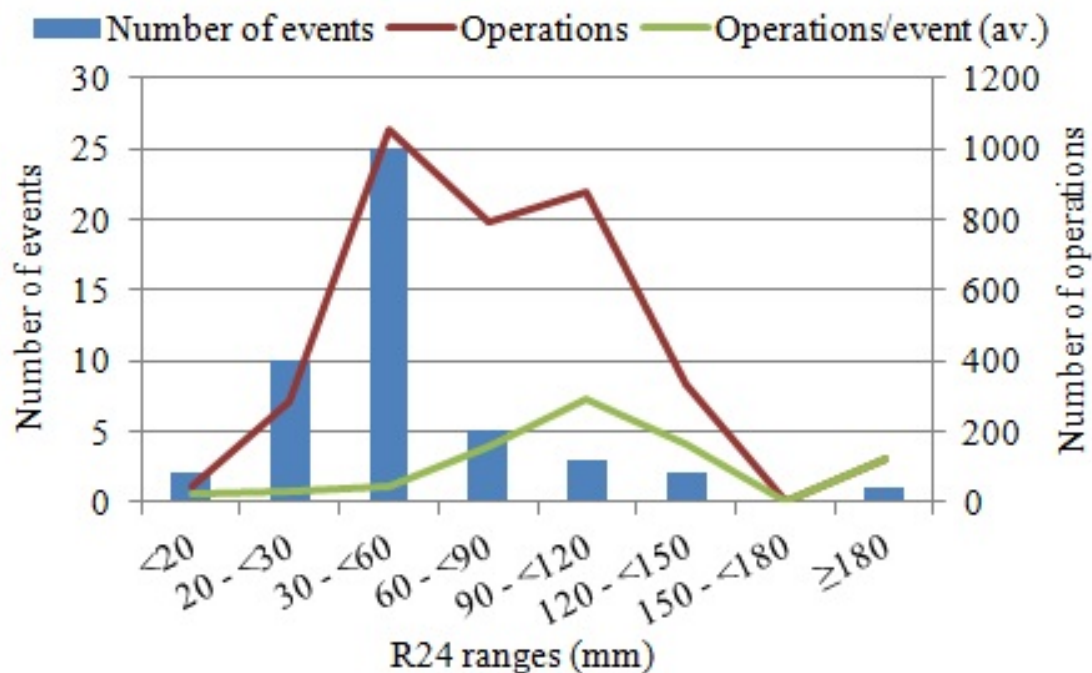


Fig. 7. Figure 5. Number of events, Fire Service operations and average number of operations per event for various ranges of (a) 24-h (R24)

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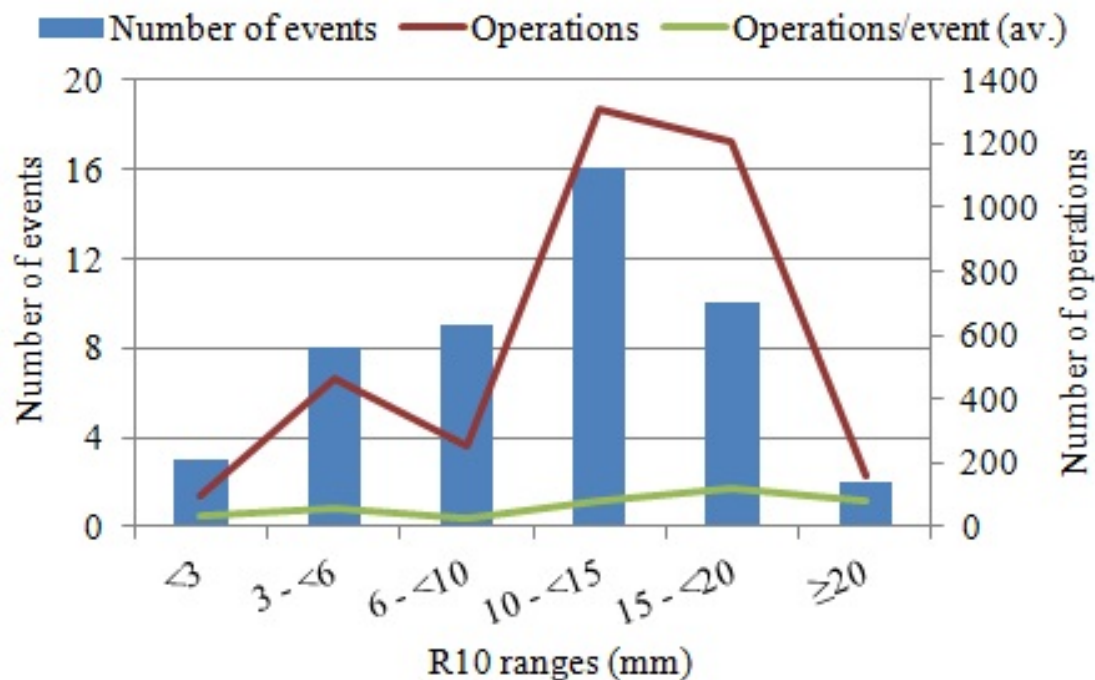


Fig. 8. Figure 5. Number of events, Fire Service operations and average number of operations per event for various ranges of (b) 10-min (R10) accumulated rainfall.

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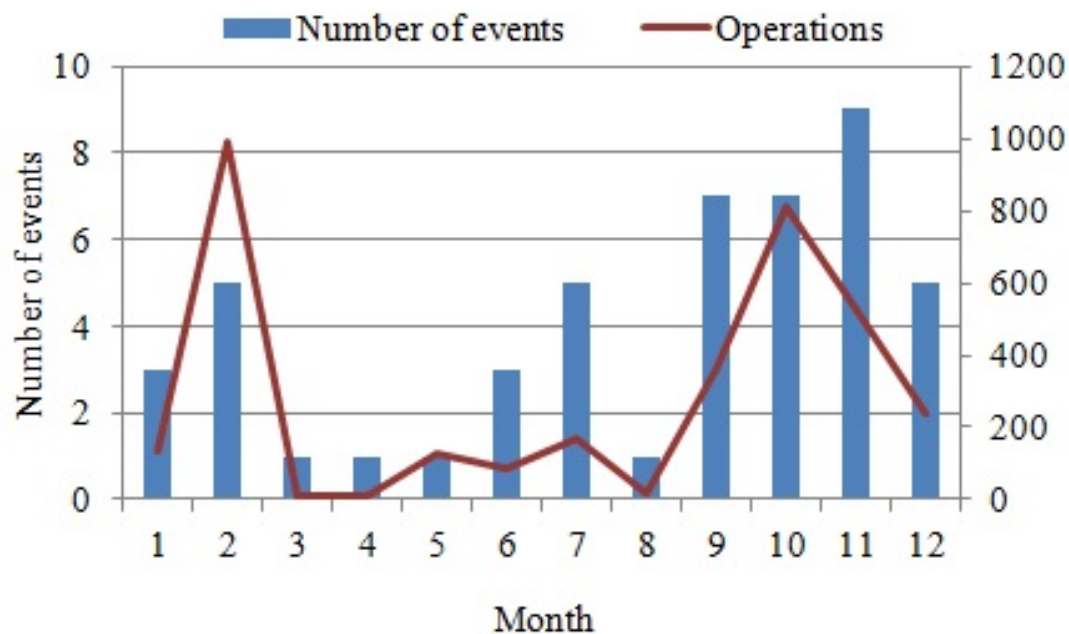
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Fig. 9. Figure 6. Monthly distribution of the number of flood events and Fire Service operations.

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