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CORRELATION BETWEEN EXTREME RAINFALL AND INSURANCE CLAIMS DUE TO URBAN FLOODING – CASE STUDY FREDRIKSTAD, NORWAY

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Abstract: During the last decades an increase in extreme rainfall has led to more urban flooding. This study is based on insurance claims of damages caused by heavy rain during 2006−2012 in Fredrikstad, Norway. Data are analysed using Principal Component Analysis. The purpose has been to find characteristics of extreme rainfall and its influence on the extent of urban flooding. The number of claims seems to be peaked in the late summer period. Furthermore, the precipitation depth the week before an extreme rainfall seems to have significantly influence for the pay out from insurers, and thus the changing in runoff factor due to soil wetness is of importance. Compared to 25-year frequency rainfall with 30 min duration, relatively less intensive, but more stable and long-lasting rain seems to lead to more claims. Experiences from previous events may help to determine the level of flood risk when extreme rainfall is forecasted.

Keywords: Insurance claims, flood prevention, Principal Component Analysis

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INTRODUCTION

It is predicted that some of the consequences of climatic change (CC) will be an increase of extreme weather events with larger and more frequent flooding in urban areas. Several studies (e.g. Semadeni-Davies *et al*., 2008a; Tait *et al*., 2008; Willems, 2012) also shows that population growth and increased wealth, in addition to CC, will have major impact on urban flooding

Extreme precipitation and flooding in cities have large social costs such as traffic disruptions, damage to infrastructure and buildings, people experiencing uncertainty for new floods, sick leave due to infectious water, lost sales for businesses, pollution of drinking water and local recipients (Lindholm *et al*., 2008). The insurance company in Norway is of the opinion that these costs could increase by 40% or more over the next ten years (Nyeggen, 2007). Decisions about prioritizing flood preventive and/or mitigating measures in drainage systems are complex. Expertise, time, economy, traffic and development of other infrastructure need to be coordinated. Professionals often experience pressure from governments, local media, developers, local politicians and citizens in general. Given this complexity, it is often easy to lose the holistic perspective needed to take good decisions for efficient solutions.

In Europe, the municipalities often own the sewer systems. Most of the sewer systems in cities were designed and built several decades ago. Before the 1960s, the main technical solution was to collect storm water and sewage from households in one large sewer pipe (combined system). The normal lifetime for these systems are typically being a hundred years or more, accordingly downtown areas in most European cities will have a large ratio of combined systems also in the future. The standard method since the late 1960s has been two-piped systems (separate system), one for sewerage and another for storm water. Increased rainfall will be a new challenge for the transportation system in addition to increased maintenance and malfunctions caused by aging (Carrico *et al*., 2012). In average, 0.44% of Norwegian sewers by pipe length are renewed every year (Lindholm, 2014). At this rate, it will take more than 200 years for a complete renewal of the systems. With a realistic lifespan of 80 to100 years for existing sewers (MEF, 2011) it is obvious that this offers challenges.

For more than 150 years, the dominating concept for urban drainage has been piped network. In recent years, focus has turned from piped networks, to a variety of solutions for storm water drainage including open trenches, ponds and streams etc. This concept has been named SUDS (Sustainable Urban Drainage System) and is considered as a necessary step towards more sustainable solutions to reduce the expected increase in urban runoff (Kennedy & Lewis, 2007; Semadeni-Davies *et al*., 2008b). New concepts of urban drainage management are different from the traditional engineering approach and force cross-disciplinary cooperation (Willems, 2012). The study presented in this paper is based on information from several disciplines; insurance, meteorology and wastewater management, and might be regarded as an example of this new approach.

In this study a comparison is made of registered rainfall and insurance claims in Fredrikstad for the period 2006–2012. The hypothesis is that some characteristics of the fluctuations in short and long term rainfall affect the extent of flooding. If such patterns are known, this can provide great socio-economic benefits, because information regarding where and when to act can be based on forecasted rain events. Events with most rainfall during this period represent the sample in this analysis. Each event is then characterized by several variables related to rainfall and damage. In this study, this sample is used in a multivariate explorative analysis. The results are further utilized to assess connections between rainfall and insurance damage.

ABOUT THE CASE SITE: FREDRIKSTAD

Fredrikstad has 76 932 inhabitants (2013). In recent years, the region has experienced several flood events caused by heavy rainfall. In the early 2000s several insurance companies held the different municipalities responsible for the damages due to limited capacity in the sewers and demanded recourse for their pay outs (Lindholm *et al.,* 2006). The demand was NOK 14.5 million for damage to 300 houses associated with one rainfall event in September 2002.

However, the insurance companies lost the court case versus the municipality since the precipitation was of such an extreme magnitude that it was regarded as a natural peril. A similar trial regarding the rain events 2006−2008 ended in a settlement between the two parties. Fredrikstad is one of the cities in Norway that has been most affected by urban flooding. In 2007 a general plan for storm water management was launched. An intention of the plan was to create awareness among developers regarding sustainable storm water solutions (Fredrikstad Municipality, 2007). Given this objective and the high number of damages in recent years, Fredrikstad is a particularly interesting case for analysing data of damages caused by urban floods.

MATERIALS

Insurance data

Insurance companies are among those that most rapidly experience the consequences of climate change. For water-related damages in Norway between 2008–2011, only 4% of the payments were defined as natural hazards (Ebeltoft, 2012). A national insurance pool called Norwegian Natural Perils Pool covers such damages. However, each individual insurance company must initially cover most claims that are caused by that limited capacity of the sewer system.

When a building is flooded, the insurance company is

Table 1. Type of damages and the codes most relevant to flooding

Installation		Source		Cause	
Code	Description	Code	Description	Code	Description
G	Outdoor – water- and sewer system	I	precipitation/snow melt/ground water	9	missing value
H	Water penetration from outside through foundation			E	old age
I	Water penetration from outside above foundation			G	Stop in sewer / sewer back up
				I	Influence from outside
				J	Drainage system

contacted by the owner. An appraiser is sent by the insurance company to assess the damage. The report from the appraiser constitutes the basis for the economic compensation. Details regarding the damage are recorded and stored in a national database, which is administered by Finance Norway, which is the industry organization for the Norwegian finance and insurance companies. Free web-access is provided to an excerpt of this data, collected in a national database named VASK (Finance Norway, 2013).

There has been several court cases in recent years, were insurance companies has claimed that municipalities has not fulfilled their responsibility regarding flood preventions. The court decisions do not provide a clear answer. According to The Ministry of Climate and Environment there is still need for clarifying the responsibility of the municipalities and the responsibility of the individuals, during extreme weather events (Miljøverndepartementet, 2010). Due to the increased number of flood related claims the past few years, insurance companies state that they will hold the municipalities even more responsible for such damages in the future (Nyeggen, 2007).

Municipalities do not have regularly access to Finance Norway’s database for flood events on a detailed level. Hence, they have been forced to make their own records to get an overview of the situation. Information is obtained by own investigations, random contact with residents or from recourse cases. This information has thus become very important when prioritizing flood preventive measures. However, these registrations are believed to be incomplete because detailed information from the insurance companies is missing. As a part of Finance Norway’s dedication to prevent climate-related damages (or any damage that lead to a claim), their database has been made available for specific research purposes.

The data from the insurance companies includes useful information linked to each incident that has led to a claim. The main information in this study has proved to be:

(a) Date of damage
(b) Compensation sum
(c) Type of installation
(d) Source of the damage (e.g. precipitation)
(e) Cause of the damage (e.g. aging)

It is assumed that damages and flooding occur on days where heavy rainfall is recorded. Furthermore, proportionality is expected in that dates with the highest total compensation sum simultaneously have been days with most rainfall. The code system for classifying the damage is further discussed in the section below. From days affected by flooding it was possible to derive a number of numerical variables that was used in the analysis.

Code system of insurance data

The appraisers from most of the insurance companies in Norway are required to code each water related claim as a part of their report describing the actual damage and the related costs. This national reporting system was standardized in 2006, and the market share for the insurance companies using the system in Norway is approximately 90%. In the report, all data concerning the damage should be coded in three categories (Finance Norway 2015):

(a) Installation: This is a rough description of location where the damage has occurred, e.g. water or sewer pipe, inside or outside the building.
(b) Source: This is a more detailed description of the site or the damage itself. There is a separate code that covers precipitation damages, which is used directly in this study.
(c) Cause: This code describes the actual cause for the damage. It might be old age, frost, stop in sewers etc.

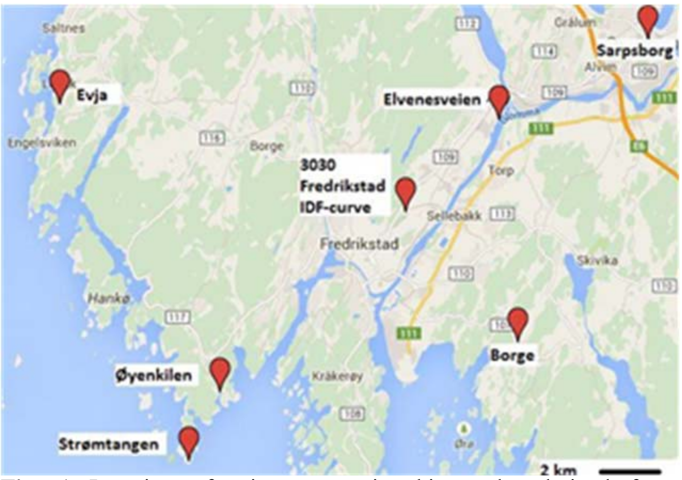

Fig. 1 Location of rain gauges in this study, derived from Meteorologisk institutt (2015).

Precipitation data

Only a few Norwegian cities have more densely distribution of rain gauges than Fredrikstad (Nielsen, 2013). In this analysis, precipitation data is collected from several gauges distributed throughout the district.

Two weather stations in this study, Strømtangen and Sarpsborg, is part of the national meteorological network run by The Norwegian Meteorological Institute (Meteorologisk institutt, 2015), and are included in the analysis for seasonal precipitation. Even though they are at the edges of the case area, they are considered to be relevant due to their continuous recordings of precipitation from all days during 2006–2012.

From 1970−1995, a weather station located in the Centre of the city (3030 Fredrikstad) recorded precipitation. These records defined the basis for the Intensity-Duration- Frequency Curve (IDF-Curve) which is still in use when the purpose is to determine extreme rainfall that statistically can occur in this area.

Furthermore in this study, data from four local rain gauges, Øyenkilen, Evja, Elvenesveien and Borge, owned and operated by Fredrikstad municipality are used. The rain gauges are distributed all around the region as can be seen from **Fig. 1**. The instruments are all Lambrecht 1518 H3, so-called tipping-bucket rain gauges with time resolution of 1 minute. The bucket record each 1 mm rainfall that is further automatically transmitted to a computer server and frequently transmitted to the Norwegian Meteorological Institute (Meteorologisk institutt, 2015). A limitation is that discontinuity in the series of measurement from local rain gauges has occurred, especially in 2006−2007. If a value has been considered as uncertain, the validity has been cross-checked with current recordings from other rain gauges. In some cases values are excluded from the sample.

The software used in this study will then fill missed values estimated from the non-missing data (CAMO, 2006). An experience from this study which should be paid more attention is the importance of getting continuous observation from outdoor gauges during changing weather conditions. Anyway the data series in this study are considered as representative for the events analyzed in this study.

METHOD

The hazard – a part of the risk triangle

The risk for flooding in urban areas can be viewed in many ways and calculated by different methods. As a basis for this study the Risk triangle described by Crichton (1999) and viewed in **Fig. 2** is used.

This triangle illustrates an interaction between the three elements hazard, exposure and vulnerability. These elements can all be considered as integrated part of risk management to flooding. **Figure 2** is also widely adopted and used in public reports related to CC and more specific articles in urban flooding (e.g. IPCC, 2012; Kaźmierczak and Cavan, 2011; Lindley *et al*., 2006).

If the area of the triangle represents the risk-level, metaphorically the risk can be reduced if the length of one or more of the sides of the triangle is shortened. In relation to risk-reduction, this study only deals with the “hazard-side” of the triangle in **Fig. 2**.

In this context, hazard reflects the frequency and severity rain storms causing flood in urban areas. Flood is often caused by short duration intense rainfall which occurs locally, and this type of rain is often difficult to forecast, warn against and prepare for (Kaźmierczak and Cavan, 2011). As mentioned, CC-predictions indicate an increasing trend of the hazard. For the local society there are limited possibilities to control this, except to providing adequate drainage, pursuing a sustainable flood management practice and maintain a good preparedness (Crichton, 2012).

Both exposure and vulnerability are considered to play an important role as an integrated part for risk reduction at a local level. Exposure describe to which extent the urban communities are located so that they are more or less exposed to flooding. Vulnerability is seen as the individuals’ ability to handle floods.

Fig. 2 The risk triangle (Crichton, 1999).

Principle Component Analysis

The data extracted from the database of the insurance companies are related to the corresponding meteorological data for Fredrikstad and analysed using the method of Principal Component Analysis (PCA). From PCA it is possible to reduce the dimensionality of the dataset, from many variables to fewer latent variables. The latent variables are interpreted in accordance to the original variables in the original data- which reflects new components (principal components) best.

The information carried out by the original variables, is projected onto a smaller number of underlying latent variables, called principal components (PC). The first principal component accounts for the maximum proportion of variance from the original dataset. The remaining variance is described by PC-2, PC-3 etc. which are perpendicular to each other. All principal components will then form a new orthogonal coordinate system that best describes the total variance of the dataset in each principal direction. The explorative analysis process is done by graphic analysis of the PCs and other relations. It is possible to view underlying structures in the data not observed with a univariate tool (Esbensen *et al.*, 2000; Kaźmierczak and Cavan, 2011).

The score plot shows the distribution of samples, and patterns, groupings and similarities among the objects can be viewed. The loading plot reflects the importance for each variable due to the principal components. The score plot and loading plot are interrelated. If sample X is plotted to the far right in the score plot, this sample usually has high value of variable Y, if Y is placed to the far right in the loading plot.

The software Unscrambler® version 10.3 is used for the further PCA-analysis (Camo, 2015). Finally the dataset which is used in this analysis consists of different dates, corresponding compensation sum and recorded precipitation at different rain gauges.

Table 2. Correlation between monthly distributions of claims and registered source = I (S_I) and codes for installation (I_X)

Codes for installation (see table 1)	G	H	I
No. of damages 2006-2012	115	736	495
Corr [S_I,I_x]	**0,995**	**0,973**	**0,965**

Table 3. Correlation between monthly distributions of claims and registered source = I (S_I) and codes for causes (C_X)

Codes for cause (see table 1)	9	E	G	I	J
No. of damages 2006-2012	14	125	232	700	275
Corr [S_I,C_x]	0,290	0,542	0,981	0,998	0,932

EXTRACTION OF DATA FOR THIS ANALYSIS

Identification of relevant insurance registration codes for flood damages

The use and combination of insurance registration codes referred to in this article, has been evaluated by municipal professionals in several Norwegian cities (Vestlandsforskning, 2015). Their main objective of that study was to evaluate the system of coding the type of damages etc. The conclusion was that it is beneficial for municipalities to get access to damage data from insurance companies and this will improve their efforts to prevent water related damages at a local level.

Flooding of a building may have multiple causes and the use of classification codes depends on how they are subjectively ranked. The aim of this analysis is not to point out the responsible part, rather to view this as a multidisciplinary challenge for the community. In this context, the current code system is found to be reasonable.

A flood can theoretically occur in any month of the year. One possible method to detect errors in code-use, is to look at the monthly distribution of damages in relation to source = I (precipitation). If there is a fair correlation between the monthly distribution of these damages and the use of codes for installation and cause related to the type of damage, it is reasonable to assume that the combination of codes is logical and not randomly written down. The calculated correlation coefficients for monthly distribution of claims and source are shown in **Tables 2–3**.

Most of the registered codes in tables 3 and 4 indicate a strong correlation with monthly distribution of claims due to precipitation. The correlation coefficient indicates uncertainties regarding whether claims coded by 9 or E as the cause really are consequences of heavy rain. These claims seem to occur more regularly throughout the year, and have not the temporal fluctuations observed by the other rainfall related claims. This might be a result of miscoding, and these claims are therefore excluded from the sample.

Selection of dataset for analysis

The dataset consist of an extraction of correlated dates and variables related to recorded rainfall and compensation sum the current day. To get a representative dataset it is of major importance to select dates with most claims and/or heavy rain. In all analysis claims coded with G, H and I for installation, I for source and G, I, and J for cause as described in table 2 and 3 are included.

In the first analysis for seasonal precipitation, all flooding events during 2006−2012 are included. For the two remaining analysis some selected dates with heavy rainfall and claims with codes as described above are used. For selection of the sample, some criteria are defined:

(a) Events which occurred during 1 November and 31 March is excluded from the sample. Unlike rain, recorded snowfall will not give the immediate response to flooding. By excluding seasons where snowfall may occur, uncertainties with respect to the type of precipitation will be eliminated. As we will see later, there were hardly any flooding events this time period in Fredrikstad.

(b) Only days with ≥ 4 claims were included. Ensuring that selected dates have affected a minimum number of people with some spatial distribution.

(c) If at least three gauges on average recorded more than 25 mm within 24 hours, the dates were included in the dataset. According to Mamen *et al.* (2011) approximately 40 mm rainfall during a 24 hour period represent a 2-year frequency in Fredrikstad, but this 24-hour-limit was only exceeded seven times during 2006−2012.

(d) A single rain gauge which exceeded 2 years-frequency for short-time duration (30, 60, 120 or 360 min) when at least two other rain gauges had recorded rain, was included in the sample set. With this criterion short-duration heavy rain, but less than 25 mm per day were included in the data set too.

From the two last criteria, also days with no claims at all will be included. This was of particular interest, because rainy days with no claims might occur, even though the recorded rainfall was similar to days with flooding. Five days was excluded from the data set though they had more than four claims.

Three of these days had no recorded rain, but were adjacent to days with major damages indicating that these claims were incorrectly dated, probably because the flood occurred late evening or early night. On two other days some claims were registered, but no rain. It is possible that the rain gauges were out of service. If no rainfall was recorded, a flooding situation was unlikely and the flood damages give no sense. Based on the criteria above, the number of samples (dates) used for further analysis are shown in **Table 4**.

Table 4. Number of samples (dates) in the analysis of events

No. of days acc. to “claim-criterion” above	15
No. of days acc. to “rainfall-criterion” above	24
Days covering both criteria	7
Samples (sum of dates)	32

RESULTS AND DISCUSSION

Three different analyses were carried out. Even though there were some differences in the samples, the purpose and the basis for the data are all the same. All events took place between 2006 and 2012 in Fredrikstad. The total number of selected claims during this time period is n=1076 with a total compensation sum of 56.6 mill NOK.

The diagram in **Fig. 3** was used to interpret seasonal fluctuations in precipitation and claims. The plot in **Figs 4a–b** shows how the daily and weekly amount of rain derived from dates selected in table 3 will affect the damage cost. Finally in **Fig. 6** the intensity of the recorded rainfall from 30 to 720 min is assessed in relation to both cost and frequency from 30-year-normal.

Analysis of seasonal precipitation in relation to urban flooding

To locate any patterns in the seasonal distribution, the compensation sum of the claims and rainfalls were plotted, according to the monthly distributing during 2006−2012. For x (precipitation or claims) the relative rate Y_m for each month (m) and each monthly sum $x_{m,y}$ for the years (y) 2006−2012 were calculated using formula 1 and plotted in **Fig. 3**. **Equation 1** is the monthly relative rate Y_m (claims or precipitation). Precipitation was derived from five different time series. Referring to the limitation of the local rain gauges during winter, the recordings from the two weather stations Strømtangen and Sarpsborg are shown in the period 2006−2012. In addition to that a 30-years-normal-curve from the city centre of Fredrikstad 1970−95) exists.

$$Y_m = \frac{\Sigma_y(x_{m,y})}{\Sigma_m \Sigma_y (x_{m,y})} \times 100\% \tag{1}$$

In July, August and September the compensation sum from flooding has a distinct peak. 79% of the compensation for flooding in Fredrikstad during 2006−2012 occurred in these months. However in October the monthly rainfall normally has a peak. Indeed there were some major events these years e.g. 14 August 2008 (218 claims) and 11 September 2011 (117 claims), and during these months the probability for flooding seem to have a significant increase. Winter related flooding such as snowmelt or rain on frozen ground, seem to have almost no impact.

The data from Strømtangen clearly exhibits a peak in August. However for August the years 2010 and 2012 that was most rainy, while hardly any claims were recorded. Accordingly there is no clear correlation between the rainfall peak and the damages that occurred in August 2006−2012.

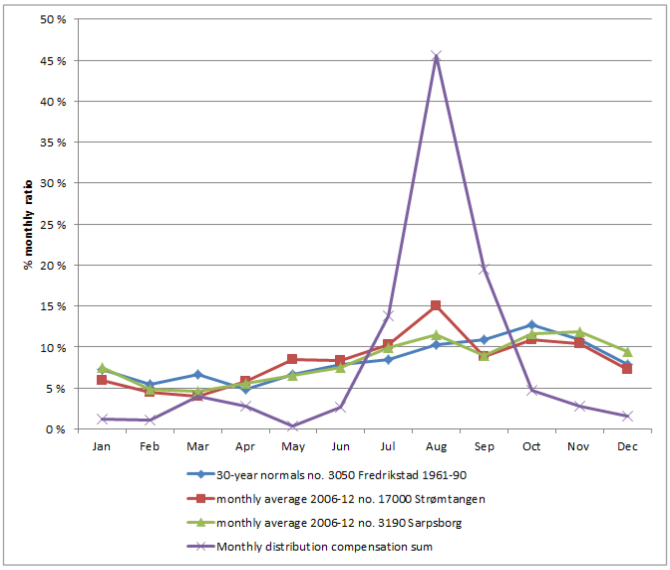

Fig. 3. Monthly distribution of precipitation and claims in Fredrikstad 2006−2012

In south-eastern Norway, the rainfall typically falls in to two main groups: Convective and Stratiform. According to Ødemark (2012) the Stratiform rainfall can dominate all over the year while convective precipitation dominates in the warm season. Thus in the late summer there is a risk of flooding that may occur as a result of rain from both precipitation types, and this may be an explanation for the increased flooding events during this season. Halvorsen (1942) observed that the south- eastern part of Norway received greater amounts of Stratiform rainfall when south-westerly winds blows over the region. This phenomenon has not been confirmed in this study. Although this study is from a limited time-period, the late summer rain in this part of Norway is a well-known phenomenon (Fredrikstad municipality, 2007). The distinct peak of damage cost clearly shows the increased risk for flooding in July, August and September.

Multivariate analysis of daily and weekly precipitation in relation to urban flooding

Long-time rainfall, saturated ground and water courses with a high water level, may affect the risk of flooding. In this section possible correlation between the number of claims and the rainfall the current day, the preceding day and the preceding week (7 days) are investigated.

Measured precipitation from four of the local rain gauges on the particular date, the day before and the accumulated values for the week ahead gave 12 different variables. In Fig. 4a each variable are named “Day”, “Day bef” or “Week bef”, respectively in addition to the first letter of the rain gauges location. Plot in **Fig. 4b** refers to the group of compensation as mentioned above and characterizes a rainfall event from expensive to no claims at all. In the loading plot the different variables are labelled. As category variables in the score plot the total sum of compensation are divided into four groups. For “Expensive dates” (named “exp” in the plot) the total compensation sum for Fredrikstad exceeding 1 mill NOK. Dates marked as “medium” in the plot are in the interval from approximately 400 000 to 1 000 000 NOK and “little” are below 400 000 NOK. As mentioned above, some dates are chosen due to high recorded precipitation and no pay-outs at all. In the score plot they are labelled “no”. PC-1 and PC-2 are 48% and 20%, respectively, which means that 68% of the variance in the dataset is described by the model.

The correlation loading plot is computed for each of the variables in the plot. The correlation loading, is the correlation between the scores (from the PCA) and the actual observed data. Correlation loadings are computed for each variable for the displayed latent variables (PCs or factors). The 2-D plot contains two ellipses that indicate how much variance is taken into account by the model. The outer ellipse is the unit circle and indicates 100% explained variance, while the inner ellipse indicates only 50% (Camo, 2015). The daily precipitation of Elvenesveien (“Day-Elv”) and Evja (“Day Evj”) are within the inner ellipse which means that this variable are more poorly described in the model and seem to be of less importance than the other variables.

From the loading plot PC-1 clearly describes the amount of precipitation the week and the day before the events. Values from all variables are clustered at the far right along the axis. The PC-2 shows the daily precipitation from different variables. The variables describing rainfall during one week from the different rain gauges are more clustered than those showing daily precipitation. It seems that the relative differences between the measurements are less for weekly rainfall than rainfall pr. days. In the score plot each sample is labelled and coloured uniquely from expensive (“exp”) to “no” claims according to the predefined groups. Dates with no claims are clustered at the left side of the score plot, while the most of the expensive dates seem to have higher value of PC-1 and PC-2. It is reasonable that the two samples at the upper part of the score-plot (highest PC-2 value) both were days with high precipitation and a large number of floods. The clusters along the PC-1 axis indicate the importance of the rainfall the day and week before a flooding occurs. The red marks at the lower left side of the score plot are dates were only one rain gauge recorded heavy rain.

Days with no flooding are negatively correlated with the rainfall the prior day and week; this indicates that the nature of the surface is greatly affecting the run-off coefficient. It may not be entirely surprising that variables related to rainfall the prior day and week before an event is correlated. Since the first variable is included in the second, the fluctuations will not be independent. The third principal component (PC-3) describes 13% of the variance. This component seems to describe the day and week rainfall.

From previous studies, among others Holý *et al.* (2013) and Sarikelle (1980), it is showed that the run-off coefficient will increase during the first minutes of a

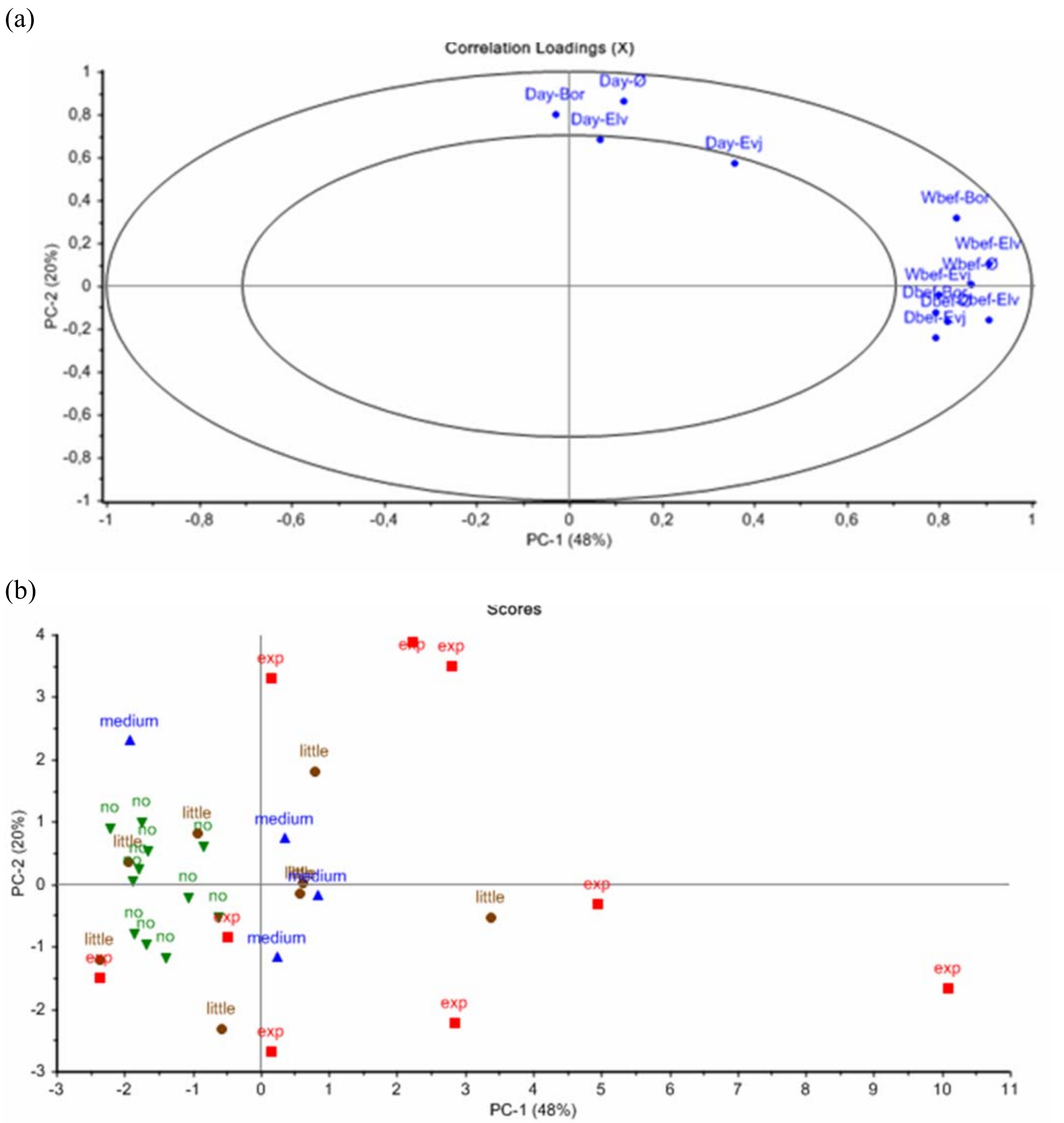

Fig. 4 (a) PCA-loading-plot - Daily and weekly precipitation and water-related claims for selected events, and (b) PCA - score plot - Daily and weekly precipitation and water-related claims for selected events.

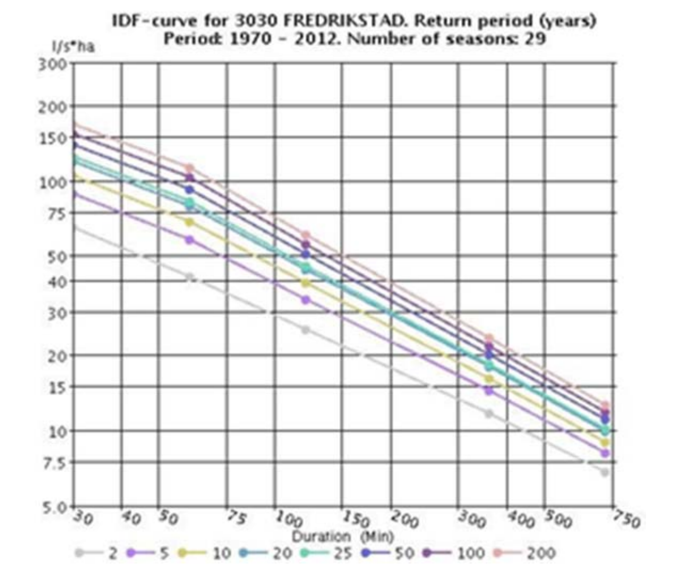

Fig. 5. IDF-curve, station no. 3030 Fredrikstad (Meteorologisk Institutt, 2015)

short-time rainfall independent of type of soil. A study from the US, (Horner *et al*., 2004), stated that the runoff also differs greatly within season and year depending on prior amount of rain. A study of 24 hours precipitation events in a semi-urban area in China (Shi *et al*., 2007) states, that on average runoff under wet soil conditions are two times higher compared to dry soil conditions. Another study in an urban catchment in Baltimore U.S (Brun and Band, 2000) showed that there is a relationship between runoff factor on one hand and the soil saturation and impervious area on the other. The most dramatic increase in runoff ratio for any given percent soil saturation occurs when the fraction of impervious area covers between 20 and 80%. Finally, a study from Germany (Niehoff *et al*., 2002) confirms the impact of the soil moisture conditions and land-use in relation to storm run-off. The fact that **Fig. 4a–b** seems to indicate reduced risk for flooding from rainfall if it occurs after a period with little rain in advance, confirm the findings in these studies.

Multivariate analysis of intensity compared with IDF-curves Fredrikstad

An Intensity-Duration-Frequency curve (IDF-curve) shows the probability that average rainfall intensity will occur in a specific region. The calculated probability is based on statistical analysis of recorded rainfall data over a long period, typically 30 years. This curve is required when designing drainage systems.

The purpose of the study presented in this section, is to locate patterns in the short-time duration rainfall and its impact of flooding. The measured progress of rain is characterized as either the long lasting / less intensive or short term/intensive rain, depending on the IDF-curve is intersected from above or below. Furthermore, it is interesting to investigate whether this characteristic is significantly influencing the compensation sum to flooded residents.

IDF-curve (Intensity-Duration-Frequency) for central Fredrikstad (3030 Fredrikstad) has been included in this analysis. The curves shown in Fig. 5 are obtained from the database eklima.no run by the Norwegian Meteorological Institute (Meteorologisk institutt, 2015).

Each plot in the graph illustrates the duration of an extreme rainfall and the corresponding intensity of that rain, derived from observations through several years. The adjacent coloured lines in the IDF-diagram, represents different frequencies, and the lowermost line indicates a rainfall occurring every 2 years (with a probability of 0.5 per year). The lines above this represent even worse but less frequent storms (return period 5 year, 10 year etc.).The data for this analysis are selected using the same criteria as in the section above. In the prior PCA- analysis daily and weekly rainfall were highlighted, and each date consisted a sample defined by multiple rain gauges. Short duration rainfall may occur locally and may not be recorded all over the area. In this analysis a sample consist of recordings from each rain gauge on the selected day. Thus, in this study there will be 125 objects including IDF-values from different frequencies.

There are five variables in this plot, maximum recorded rainfall 30, 60, 120, 360 and 720 minutes, respectively. From **Fig. 6** it is shown that the two first principal components describe almost all variance in the dataset. As seen from the IDF-curve the intensity is inversely proportional with duration for all values. This will obviously make a higher correlation among the data compared to e.g. the data shown in **Fig. 4a–b.**

The loading plot is not shown, but views that all variables are well described by PC-1. When plotting PC-1 and PC-2, the variables for the shortest duration rainfall (30 and 60 min) are slightly below the PC-1 axis (negative PC-2 value). Durations more than 120 min are plotted above the PC-1 axis.

The farther to the right in Fig. 6 the more rainfall is recorded, and PC-1 then describes the extremity of a rainfall. Relative weight to long lasting intensity (more than 120 min) brings the plot to the upper part of the PC-2 axis and vice versa. This can be explained as that negative values of PC-2 indicates short-time torrential rain. If this sample had been plotted in Fig. 5, the slope would have been steeper than the frequency curves.

If a recorded time series had coincided with the frequency of e.g. 5 year-rain in the IDF-curve, the object would have been plotted near the grey marked point "IDF-5" in the score plot. As defined in the previous section Expensive, medium, little and days with no compensation are marked with initial letters and different colours in the score plot.

For objects at the left side of the score plot, little rainfall is recorded. Since the colour code in the plot is making no reference to the spatial distribution of the damages, some red-marked objects are at the far left side of the score plot. This probably means that another part of the region was more affected that particular day.

The more intensive rainfall, the further to the right side of the score plot. As expected, the plots furthest to the right, resulted in higher compensation sums for flood damages. Most of the objects in the score plot are placed above the PC-1 in 1st and 2nd quadrant, and the most expensive dates tend to turn upwards to the right corner in the score plot. This means that the rain intensity has been long lasting relative to the IDF- values. The plot to the far right in the score plot is the time-series for Øyenkilen 14 August 2008 which was the most extreme rainfall event recorded in the district during 2006−2012. This rain had a 30 minute-intensity as a 25-year frequency rain, but the intensity remained relatively high and exceeded a 200-year frequency rain after 120 min.

Except for a few records near the origin, there are only two objects which are located in the 4th quadrant and below the IDF-points. This suggests that both these rainfall started intensively, but declined relatively fast. It is assumed that these rainfalls had little spatial distribution. The plot at the bottom right of the figure was an extreme rainfall event recorded at Elvenesveien 10 July 2012. It began as a 25-year frequency rain after 30 min, but declined soon and had in average a 5-year frequency rain after 720 min. This observation is confirmed by looking at the addresses for the claims; all nine damages that day in Fredrikstad were located near this station.

When designing drainage systems, more attention should be paid to the rainfall over a larger area rather than recordings from one single point. The IDF-curves in Fig. 5 was derived from years with several rainfalls, but only from one single point (only one gauge). The area precipitation tends to be less than point precipitation (e.g. Nielsen, 2013; Willems, 2012). If similar precipitation is recorded from several gauges, the spatial distribution of a

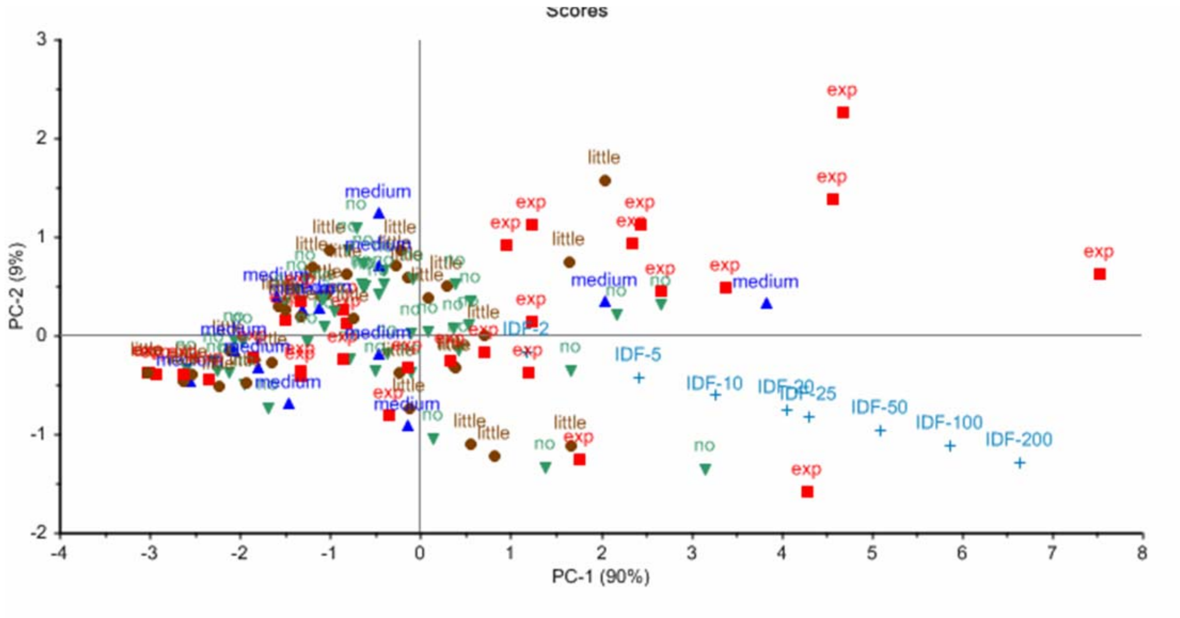

Fig. 6 PCA-score plot - Short time duration rainfall (from 30-720 minutes) at selected dates in relation to claims

rainfall is considered to be better described. IDF-curves for the catchment will appear lower and flatter than IDF-curves derived from one single point (Sivapalan and Blöschl, 1998). This is confirmed by the plot in Fig. 6, and the most extreme recordings would have crossed the IDF-curve from below, since their intensity curves seem to be flatter.

From **Fig. 6**, most of the days with high sums of compensation, the rain starts with relatively low intensity, but the intensity remains higher over longer time relative to the observations included for calculation of IDF-curves. Thus very extreme short duration rainfall with little spatial distribution within a small area of Fredrikstad, do not seem to be the main reason for the claims during 2006–2012.

CONCLUSION

The results from these analyses indicate a correlation between rainfall and the extent of urban flooding in terms of water-related insurance claims.

Regarding the hazard at a local level, obviously the point in time to set an increased emergency situation for flooding is crucial. Specific operation and maintenance measures should be focused when a hazard is forecasted and within seasons with increased probability for flooding. Good preparedness will obviously reduce the risk when a critical situation arises.

Monthly distribution of precipitation and claims in Fredrikstad 2006–2012 shows a distinct peak of damage cost, only a few months a year. This clearly indicates that the emergency measures for flooding in the late summer should be highlighted, while this focus can be lower in other seasons. Limited capacity of the piped drainage and sewer system plays an important role for the damage rates. Natural flood management practices should emphasize the cleaning of drains and ensure adequate drainage paths on the surface. Maintenance of these systems will be more important in certain seasons.

PCA-plot of daily and weekly precipitation of the selected dates in relation to claims indicates a pattern between previous rainfall and increased risk for flooding. Little precipitation the week before is a plausible explanation for why some days with heavy rain results in no claims. Although sealed areas dominate in the urban environment, the risk of flooding is reduced when ground is dry and unsaturated. Thus the runoff factor is an important parameter which should be paid considerable attention when considering a potential emergency situation. Forecasted heavy rain after a wet period should therefore lead to a higher level of emergency for flooding.

The PCA-plot of short time duration rainfall confirms that the most expensive events occur during the most intensive rainfall. The PCA-plot indicates that the most extreme floods during this period were caused by hours of intensive rain, rather than shorter torrential rain.

When utilizing IDF-curves for dimensioning drainage pipes, a CC-factor is often added to take possible future extreme events into account. During 2006−2012 several recordings of rainfall in Fredrikstad had an intensity exceeding the 200 years-frequency limit. The local authorities require using rainfall with a 25-years frequency as input when dimensioning storm sewers (Fredrikstad municipality, 2007). The extent of the largest floods it is not only a matter of undersized pipes. The most extensive rainfall and floods during this period occurred in August 2008 where average rainfall within 60 min at Øyenkilen was recorded to 105 l/s pr. ha. This corresponds to a rain with a frequency between 100 and 200 years from the IDF-curve. However, if the pipes are designed for a 25-year rainfall with 30 min duration, it should be able to tackle an intensity of 124 l/s pr. ha. This illustrate that as in addition to sufficient pipe-dimension, a well-maintained drain system which ensures a rapid run off is of great importance as flood prevention measure.

Scenarios for Norway indicate a future increase in annual precipitation of 0.3−2.7% per decade up to 2050 (Agersten, 2002). As described above there are limited possibilities at a local level to deal with the extent of the hazard. This study has identified some relationships between the characteristics of the precipitation and the number of insurance claims. If some of these patterns pointed at in this study are taken into account, the risk for urban flooding may be reduced.

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